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Review of diagnostic technologies for monitoring feedlot animal health

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Abstract

This review was conducted to identify and examine the remote diagnostic technologies that are commercially available or in development for the diagnosis of ill-health and shy-feeding in feedlot cattle. The benefits of these technologies to feedlot operators was evaluated using information obtained from published literature, manufacturers' websites, interviews with the developers/distributors of technologies, feedlot industry experts, and a survey specifically designed to capture the views of Australian feedlot industry stakeholders (veterinarians and operators included) about current or future technologies of practical benefit to the industry. It was, however, difficult to comprehensively evaluate all the features, benefits and costs of available technologies because of limited available information on reliability (accuracy, sensitivity and specificity), cost-benefit, and the compatibility of these techniques with the current Australian feedlot and NLIS systems. These issues will be essential for the successful implementation of a new technology in a feedlot operation.
The technologies under review include the following:

i) rumen devices for measuring rumen temperature and pH
ii) devices for monitoring animal location and movement - accelerometers, pedometers and GPS
iii) devices for measuring daily feed and water intake and estimating daily weight gain, and
iv) devices for measuring rumination.

A number of rumen devices that measure rumen temperature have extended battery lifetime, but there is limited information on their applications in feedlots. Technologies that measure rumen temperature and pH are superior, because they have the potential to be used for the diagnosis of the diseases that are associated with elevated temperature (e.g. bovine respiratory disease complex; BRD) as well as ruminal disorders (acute and subacute acidosis). However, the sensitivity, specificity, and accuracy of most available devices have not been fully established. Sentinel™, a rumen bolus (i.e. oral administration of drugs to ruminants) with a 4-5 year lifespan, is the only device that can measure both rumen temperature and pH, but its potential capability for diagnosing diseases needs to be established.

The current technologies for monitoring animal location and movement have limited potential for implementation in a feedlot operation. This is due to lack of supporting data on their use in feedlots, high cost, and a short battery life. The GPS technology may have future potential

and its compatibility with NLIS would be more feasible. However, further modifications are needed to address its limitations for use within current feedlot operations.

Measuring daily feed/water intake and estimating daily weight gain is considered by veterinarians, feedlot consultants and feedlot operators as the best indicator of animal health and wellbeing. GrowSafe Beef™ feeding equipment is the only commercially available technology that can accurately estimate daily feed/water intake and daily weight gain based on the residual feed intake concept. The poor correlation between veterinary diagnosis, post-mortem findings, and the data generated by GrowSafe Beef™, plus high establishment costs, are limiting factors for the uptake of this technology in its current form.

Technologies that can measure and monitor rumination activity of cattle have the potential to be used in feedlots, but none of those currently available have been evaluated in a feedlot operation, they all have limited battery life, and there is no information on their capability to accurately identify animals with ill-health.

Overall, the identified technologies in this review all have some useful features with potential practical application for use within feedlot operations. However, based on the findings that one of the most important clinical signs of ill-health in feedlot cattle is reduced feed intake, technologies that enable accurate identification of these cattle is likely to be of most practical use to feedlot managers, staff and their advisors.

Executive summary

The Australian feedlot industry has a production value of approximately AUD $2.7 billion annually, and employs approximately 2000 individuals directly and 7000 individuals indirectly. In a typical feedlot, cattle are monitored daily to identify under-performing animals (e.g. shy-feeders) and animals with ill-health. The high concentration of susceptible livestock in a feedlot and in individual pens provides ideal conditions for the spread of infectious diseases. Health management programs are used to detect illness and injuries, and maintain the health of feedlot cattle. Optimal early detection and transfer of affected cattle to hospital pens for treatment are important components of feedlot health management programs. Over the past 10 years, a number of new technologies have become available to allow animals in pain and animals with abnormal behaviour to be detected earlier without the need for intensive monitoring by highly trained personnel. If these technologies can be applied successfully in an intensive feedlot system, animal welfare and productivity will be improved because sick animals can be identified and treated promptly, and labour costs will be reduced because feedlot staff will no longer be required to carry out intensive daily inspections.

The objective of this review is to conduct a scoping study of current and emerging technologies and systems capable of remotely identifying shy-feeders and cattle with ill-health. It appraises technologies and systems in terms of practical implementation in a feedlot operation, including installation requirements, ability to cope with environmental conditions, proximity to cattle, data storage and processing requirements, relative benefits, and costs associated with their use and implementation. The following three main tasks are identified as important in relation to the implementation of remote diagnostic technologies: i) accurate detection of animals with ill-health, ii) identification (e.g. tag number or electronic ID) of animals with ill-health and iii) transfer of identified animals to the feedlot hospital. Each of these tasks requires different procedures and expertise.

The technologies that are identified in this review have the potential to be used for the diagnosis of under-performing cattle (shy-feeders), cattle with ill-health and cattle with ruminal disorders. These include:

i) **Rumen temperature and pH**: Non-invasive, wireless rumen temperature and pH boluses and sensors are used to monitor cattle health and wellbeing. Remote-monitored rumen temperature boluses have the potential to provide temperature data that are highly correlated with rectal temperatures. Therefore, they have the potential to detect adverse health events (e.g. BRD and acute and subacute acidosis).

Infectious diseases (e.g. BRD) and ruminal disorders (e.g. acute and subacute acidosis) are commonly detected by an increased in body temperature and a drop in rumen pH, respectively. Other clinical signs such as depression, lack of rumen fill, cough, altered gait, ocular or nasal discharge, or general physical weakness are also observed, but often later in the disease process. The largest potential benefit of employing an automatic rumen temperature and pH monitoring system in cattle is for early detection of diseases or disorders that plague the feedlot cattle industry. Limitations of wireless rumen boluses (temperature and pH) include limited information on their reliability for the diagnosis of ill-health in feedlot cattle, and the cost of the devices and their delivery into the rumen. Further, the effectiveness of the rumen temperature and pH boluses are affected by specific facets of the system, including the ability to use remote monitoring technologies in specific environments (interference, geographic distribution), battery lifetime, sensitivity and specificity, and the data collection and management plan.

ii) **Animal movement and positioning**: Technologies that can monitor animal location, positioning, and movement include accelerometers, pedometers and GPS.

Accelerometers are devices that continuously measure gravitational force in multiple axes; these values can be processed to determine activity and postural behaviours of cattle, and are highly discriminatory for static acceleration (posture) activities in cattle following painful stimuli. Accelerometers need more complicated technologies to be operated in commercial feedlots. This makes the technology more expensive and also less user-friendly compared to other technologies. Accelerometers that are used on animals' fetlocks may cause some discomfort and pain and also increase the risk of injuries to legs. The neck collar accelerometers are superior, because these will not interfere with animals walking or resting activities, are more visible and can be removed easily.

Pedometers have been used to quantify the number of steps travelled and total distance travelled by individual cattle. Information on resting behaviour and locomotion of cattle can be used as an indicator of welfare status. An on-board algorithm calculating the number of steps from the raw data is contained within the pedometer. The distance cattle travel may be associated with injuries, lameness, and painful or stressful procedures. Pedometers have limited capability for identifying cattle with infection or nutritional disorders in real-time, and ankle bracelets my cause abrasions and discomfort to the animals.

Global Navigation Satellite System (GNSS) location data allows for assessment of animal behaviour and have the potential to detect ill-health. Variables such as total distance, speed, acceleration and turning angle are calculated, which can allow the users to determine an individual animal's performance. The trade-offs between the battery life and frequency of positional update can limit the potential uses of GPS systems in feedlots, where cattle movement and behaviour needs to be continually monitored for a long period of time. These limitations make the use of current GPS technology difficult to monitor changes in pain or wellness status in cattle.

iii) **Feed/water intake and daily weight gain**: Measuring feed intake in open feeding facilities can seriously challenge measurement accuracy. This has been recognised by scientists, veterinarians and feedlot operators as the best indicator of animal health and wellbeing. Feed conversion ratio (FCR), feed conversion efficiency (FCE) and residual feed intake (RFI) are the indices that are used to estimate the daily feed intake and weight gain. The only commercially available technology that has been developed for feedlot operations is based on the RFI principle. The concept of RFI is used to monitor and identify under-performing cattle (e.g. shy feeders) and also cattle with health issues. This technology is a unique tool for managing cattle in real-time on a daily basis. However, there are some issues with the sensitivity and specificity of this technology; to date, the correlation between veterinary diagnosis, abattoir findings and animals identified using RFI technologies is poor. The excessive costs, requirement for skilled staff to manage the data collection, and lack of compatibility with the current feedlot structure are other significant limitations.

iv) **Monitoring rumination**: Rumination is an important part of the process by which cattle digest food, and is primarily determined by ration size and quality (i.e. composition). Chewing the cud is an innate behavioural need in cattle, regardless of the amount of food ingested. Cattle tend to follow a basic 24-hour rhythm and normally spend about one-third of a day (8-9 hours) ruminating. Rumination activity is critical for every ruminating animal's health and can be an important indicator of animal's health and welfare. A drop in rumination is a clear indicator of health issues before clinical signs become apparent and before productivity is affected. The concept of monitoring rumination appears to be sound and reliable. This technology has been validated against the gold standard (visual observation) and can provide data in real-time to the feedlot operators. However, the sensitivity and specificity of these devices for identifying shy-feeders or cattle with ill-health have not been established. Also, these technologies have not been evaluated in feedlots, and it is therefore difficult to fully assess their efficacy within existing feedlot operations.

The survey results showed that industry experts believed the following:

1. BRD to be the most common disease (49% of cases) in feedlots with the highest treatment cost (~ $45.00/head).
2. Cattle with BRD have a higher probability of being pulled daily by pen riders,
3. The number of sick cattle identified each day by pen riders depends on pen riders' skills and experience.

The feedlot veterinarians and industry experts had mixed views on how remote diagnostic technologies should be used by pen riders for early diagnosis of diseases in feedlots. However, 86% suggested that the current technologies should only be used by pen riders as an aid. Industry experts recognised daily feed/ water intake measurements as the best indicator of animal health and wellbeing for the diagnosis of cattle with ill-health, and this was followed by technologies that are able to monitor cattle movement, rumination activity, rumen pH and rumen temperature. Other technologies, such as rumen pH and temperature and rumination, were ranked poorly by industry experts. This may be indicative of lack of knowledge by the industry about the features and capability of these technologies, and underestimating the potential lag-time between changes in rumen function and the manifestation of clinical symptoms (i.e. a reduction in feed and water intake).

Conclusions on preferred and recommended technologies

It is essential to consider industry's views (veterinarians, feedlot operators and feedlot researchers) on emerging technologies along with technological features, such as accuracy, feasibility, and costs. However, this study showed that the industry is not fully informed about the potential benefits of some of the new remote diagnostic technologies. The main concern of the feedlot industry in Australia appears to be the costs associated with the implementation and use of the technologies in feedlots. The benefits of new technologies are only considered important if they can be cost-effective within current feedlot structures. To demonstrate the benefits of these technologies in the medium to long-term, a detailed financial analysis (e.g. NPV) is needed to evaluate the initial cash outflows and subsequent savings from implementation of new remote diagnostic technologies within a feedlot operation.

There is limited information available to determine the realistic annual cost per head of these technologies. This is primarily due to a lack of data on the savings that can be made by early diagnosis and treatment. One industry expert considered that $10/hd would be a realistic estimate; however, this was based only on his personal experience and expectations of the new technologies. Other experts believed that the savings would vary significantly based on the incidence of BRD within a feedlot operation. Some also believed that it would depend on whether early diagnosis would lead to improved treatment protocols, more effective prevention strategies, and reduction in incidence of disease in the future. Overall, feedlot industry experts viewed low cost, user-friendliness, long-life (energy harvesting), and minimal disturbance to the animals as the most important features to be considered.

The diagnostic devices and feeding equipment that are reviewed in this report have used different technologies and approaches to provide a tool for better management, diagnosis and treatment of animals with ill-health and ruminal disorders. As discussed above, cost was considered by the industry to be the most important factor; however, a realistic cost cannot accurately be determined unless these technologies are evaluated in feedlots so that their financial benefits can be estimated. Therefore, a technology should not necessarily be recommended based solely on the cost. We identified a number of technologies within each category that met the basic selection criteria described in this report. A list of those technologies is provided in Table A. These technologies should be considered for further studies to evaluate their efficacy in the feedlot and identify specific features that are needed for better diagnosis and management. The limitations of these technologies will reduce the probability of their uptake by the industry, unless the developers and manufacturers attempt to address these with modifications to their products. Combinations of a number of technologies with complementary features could also be considered an option, since one single technology may not have all the features to address the needs of feedlot operators. However, the cost of this option would be a limiting factor.

Table A. List of technologies that have the potential for further consideration

Technology	Device/equipment	Cost/hd (US $)	Cost of receivers/stations (US $)	Battery life	Limitations
Rumen temperature boluses	TempTrak® (DVMSystems LLC)	MSRP = $50 Anticipated = $25	MSRP= $4000 Anticipated=$800	4-5 years	Low Se and Sp Can only measure rumen temperature Not measuring rumen pH Need further testing in beef feedlot operations Cannot be used for the diagnosis of rumen acidosis and other nutritional disorders High cost for receivers and stations
	SmartStock™ (SmartStock)	$45-$55	$1696	4-5 years	Can only measure rumen temperature Not measuring rumen pH Cannot be used for the diagnosis of rumen acidosis and other nutritional disorders Limited information on features and size Compatibility with NLIS is not known
Rumen temperature and pH	Sentinel™ (Kahne Ltd)	$100		4-5 years	Se, Sp and accuracy of the device have not been determined Limited data in feedlots Compatibility with NLIS needs to be determined
Animal movement/position	GPS	No costing provided	No costing provided	Not known	GPS has the potential to be as an alternative method in the future High cost is a limiting factor Technical complexity Lack of infrastructure within current feedlot operations Required skilled operators for implementation and daily use Se, Sp and accuracy of the device have not

					been determined
Measuring feed/water intake	GrowSafe beef™ (GrowSafe)	Estimated cost $60 per animal/year	Ranges from $7,500 to $9,500 per unit/per year	Solar	Excessive purchase and maintenance costs Data is stored at GrowSafe™ server Not compatible within current feedlot operations Se and Sp of the device have not been determined
Measuring rumination	SCR	$169 (Activity plus Rumination). Extra $40/Head for long distance	$4,000-8,000 Readers, terminal, software and system (depends on complexity, area to cover and distance)	Tag lifetime 7 years	This is a dairy technology and has not been experimented in feedlot operations No information on Se and Sp Complex technology
	RumiWatch	$220	$150	3 years under laboratory conditions	This is a new technology developed for dairy herds and has not been trialled in feedlots No information on Se and Sp

Abbreviations

AHA	Animal Health Australia
BVDV	Bovine Viral Diarrhoea Virus
BRD	Bovine Respiratory Disease
CA	Control Areas
CBTMS	Core Body Temperature Monitoring System
CFU	Colony Forming Unit
CIS	Clinical Illness Score
CMT	California Mastitis Test
CPU	Central Processing Unit
DA	Displaced abomasum
DF2	Delivery Function 2
DFR	Dual Fixed Reader
EAD	Emergency Animal Disease
EGNOS	European Geostationary Navigation Overlay Service
EST	Electronic stethoscope technology
FDA	Food Drug Association
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMM	Hodden Markov Model
IC	Intelligent Component
ISE	Ion Selective Electrode
LRCpH	Lethbridge Research Centre ruminal pH
LRP	Long Range Pedometer
MEMS	Micro-electromechanical Systems
MH	Mannheimia Haemolytica
MRS	Motion Registration System
MSRP	Manufacturer's Suggested Retail Price
NBS	Noseband Sensor
NLIS	National Livestock Identification System
OHS	Occupation Health Safety
QA	Quality assurance
PA	Pedometric Activity
PI	Persistently Infected
PI	Probability Interval
PLMTs	Precision Livestock Management Technologies

PP	Polypropylene
PTFE	Polytetrafluoroethylene
RA	Restricted Areas
RF	Radio Frequency
RFI	Residual Feed Intake
RFID	Radio Frequency Identification
RIC	Roughage Intake Control
ROI	Return on Investment
SARA	Sub-acute Ruminal Acidosis
SVM	Support Vector Machine
SD	Secure Digital
Se	Sensitivity
Sp	Specificity
TIRIS	Texas Instruments Registration and Identification System
USDA	United States Department of Agriculture
VCR	Videocassette Recorder
VFA	Volatile Fatty Acid
WAAS	Wide Area Augmentation System

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1. Background and introduction

The Australian feedlot industry has a value of production of approximately AUD $2.7 billion annually (2009), and employs approximately 2000 individuals directly and 7000 individuals indirectly (ALFA, 2011). There are approximately 700 accredited feedlots distributed throughout Australia. In 2009, the industry had a capacity of about 1.2 million head of cattle and 700,000 head were on feed. The recent data published by the Australian Lot Feeders' Association (ALFA, 2014) show that feedlot capacity and the number of cattle on feed in Australian feedlots has remained relatively steady, with a capacity of 1.27 million, and 873,000 cattle on feed in June 2013. Capacity utilisation recently increased from 69% in June 2013 to 79% in June 2014 (ALFA, 2014). The majority of feedlots are located in areas with close proximity to cattle and grain supplies: southeast Queensland (accounting for 43% of the total pen capacity), and the northern tablelands and Riverina area of New South Wales (39% of total pen capacity). There are also expanding numbers of feedlots in Victoria, South Australia and Western Australia, where approximately 32 feedlots have a capacity for more than 10,000 head (Animal Health Australia, 2010).

In a typical feedlot, cattle are monitored daily. Pens are usually adjacent, with common water troughs. The high concentration of susceptible livestock in a feedlot and in individual pens provides ideal conditions for the spread of infectious disease. Health management programs are implemented to detect illness and injuries and maintain the health of feedlot cattle. Optimal early detection and transfer of sick cattle to hospital pens for treatment are important components of feedlot health management programs. Daily observation of stock is carried out by feedlot employees who are trained in the early detection of livestock diseases. These people are colloquially called 'pen riders'. Treatments and post-mortem examinations of diseased cattle are commonly performed by feedlot staff under the direction of a veterinarian. Animals showing signs of illness will either be held in a hospital pen until healthy or returned to their original pen after treatment if the identified disorder is minor.

While disease events are likely to be detected early and dealt with promptly using the system outlined above, a down side is that, to be effective, this approach requires a high level of continuous attention to detail. Over the past 10 years a number of new technologies have become available to allow animals in pain and animals with abnormal behaviour to be detected without the need for intensive monitoring by highly trained personnel. If these technologies can be applied successfully in an intensive feedlot system, animal welfare and productivity will be improved because sick animals will be identified and treated promptly, and labour costs will be reduced because feedlot staff will no longer be required to carry out intensive daily inspections.

It has traditionally been the role of pen riders to identify the sick animals and shy feeders within feedlot pens and transfer the cattle with ill-health to hospital pens. However, as the number of experienced stockmen decline, industry has identified the need to develop other technologies that can assist in the identification of these animals. Research has shown that cattle with ill-health can be accurately identified by monitoring the amount of time that they spend at both the feed and water troughs. Therefore, there is a high probability such cattle can be identified several days earlier than they would normally be identified by pen riders, resulting in earlier treatments and better outcomes.

It should be noted that at this stage, while new technologies are evolving, the objective is not to entirely replace the pen riders. However, it is recognised that the use of new technologies can assist pen riders and feedlot managers to identify cattle with ill-health, facilitate early implementation of appropriate interventions, and thus potentially produce better health and welfare outcomes as well as create cost savings opportunities. The feedlot sector is, therefore, eager to pursue the development of monitoring systems that identify sick and underperforming animals at an early stage, and assist pen riders to make better informed and timely decisions on when to pull and treat an animal. To maximise effectiveness, these systems should have application in both production and hospital pens. Successful and cost-effective technologies should be capable of the following:

i) being installed in existing facilities,
ii) operating at a level that can identify an individual animal within a pen, and
iii) utilising the existing NLIS tag as the animal identifier.

The objective of this report is to identify and review the full range of technologies and systems that are commercially available or in development, and are capable of delivering on these requirements. We will also explore modifications to existing infrastructure and associated costs that will be necessary for the industry to best use these technologies.

2. Objectives

The earlier a feedlot manager can obtain critical information on a health problem, the lower the economic and welfare cost of the problem. Early detection of disease events means that animals can be treated before productivity is affected. Early detection reduces the cost of treatment and will likely increase treatment efficacy.

The study objectives were to conduct a well-researched scoping study of current and potential technologies and systems capable of remotely identifying cattle with ill health and shy-feeders (non-eating animals) within a feedlot pen. The objectives of this study are as follows:

- list and describe the full range of technologies that have application in this area;
- list and describe commercially available systems, systems under development and technologies with future potential;
- describe the practical implementation of technologies in a feedlot environment, including installation requirements, ability to cope with environmental conditions (e.g. dust, wet conditions), proximity to cattle, data storage and processing requirements;
- list the relative benefits and costs associated with use and implementation of each of the identified technologies and/or systems; and
- describe the current stage of development of the identified technologies.

These objectives were discussed in a joint meeting between the steering committee of Meat Livestock Australian (Des Rinehart) and the project team from the University of Queensland (Michael McGowan, Tim Olchowy and John Al-Alawneh) and Cow Signals Australia (Ahmad Rabiee). A number of areas were identified by the committee members that required further clarification to enable the research team to evaluate the available technologies and also identifying emerging technologies that may have the potential to address the objectives of this review.

It was recognised that there are three main tasks in relation to the implementation of remote diagnostic technologies:

- Detection of ill-health in animals
- Identification of animals with ill-health
- Transfer of identified animals to the farm hospital

Each of these tasks requires different procedures and expertise to accurately detect, identify and transfer cattle with ill-health for further examination and treatment. Currently, in large feedlot operations experienced pen riders perform all three tasks on daily basis with different levels of accuracy. The emerging technologies can be used as reliable tools to assist the pen riders to perform these tasks more accurately and in a shorter period of time. This can help the feedlot enterprises to be more efficient in the use of their resources.

It was recognised and agreed by the research team and steering committee that the scope of the current project was to identify and evaluate the emerging technologies that can facilitate the detection of cattle with ill-health and shy-feeders. Further studies are needed to identify other technologies that can make the identification (e.g. hand-held scanner by pen riders that can communicate with NLIS) and transfer (i.e. drafting) of the animals easier and quicker. It is anticipated that further progress will be made in the future to develop devices with combinations of different technologies that can perform all these essential tasks. However, it is important to make sure that these technologies will be cost-effective in the long-term and also be user- friendly for the pen riders and feedlot operators. It is important to note that the aim of this review is to investigate the application of technologies that are reliable, feasible and cost-effective, and that can be implemented within current feedlot operational systems without major requirement for more resources and modifications. However, an optimal long-term vision would be to invest in potential new technologies that overcome the challenges that feedlot operations are currently facing.

3. Methodologies

3.1 Literature review on feedlot practice, regulations and diseases

Published papers, abstracts and reports on feedlot operation and structure, feeding systems, farming management and diagnostic procedures were comprehensively reviewed using the following:

i) a number of search engines and electronic databases (e.g. CAB [Commonwealth Agricultural Bureau], Biological Abstracts, PubMed, etc.)
ii) hand searching - extensive library searches of relevant journals for published papers and conference proceedings
iii) checking references, cross-referencing of citations in identified papers
iv) review of citations in identified review papers
v) personal communication.

The primary objective of this review was to review the studies that investigated new and available technologies under experimental or commercial feedlot conditions. Studies that reported information on feedlot and diagnostic methods were included. Since the majority of new technologies have been developed for the dairy industry, these were also included along with recommendations about whether such technologies are likely to be suitable for use in commercial feedlot operations. Areas of study included in this review were as follows:

- rumen temperature and pH as diagnostic tools animal activities, movement and behaviour;
- feed and water intake; and
- rumination and ruminal fermentation

3.2 Technological industries

A comprehensive web search was initially conducted to identify technologies that have been developed, evaluated, or commercialised in both beef and dairy cattle. The new technologies were developed predominantly during the past 10 to15 years; some were initially used for experimental purposes and with subsequent implementation in commercial farms. There are also technologies that were specifically designed for commercial use in dairy and beef (feedlot and grazing) enterprises. Published scientific papers that investigated these technologies were identified and reviewed to evaluate the features of these available technologies. Where the required information on these technologies was not available on a company's website, the company was contacted and asked to provide information about their proposed technologies (Appendices I & 2). We explored and evaluated technologies that monitor:

- rumen temperature and pH as a diagnostic tool;
- physical activity of stock, such as accelerometers, pedometers and GPS devices;
- feed and water intake, and behaviour; and
- rumination and ruminal fermentation.

3.3 Feedlot industry expert opinions

A small survey was conducted to explore the views of the experts working in the feedlot industry: people with sufficient experience to comment on the practicality of new and existing technologies in commercial feedlot operations. Experts were asked to provide recommendations for potential future technologies that should be developed to improve the sensitivity and specificity of diagnostic methods. The results of this survey were used to provide an evaluation of future research directions.

A questionnaire was prepared by The School of Veterinary Science, The University of Queensland, and Cow Signals Australia Pty Ltd, which aimed to collect industry opinions on the following:

- feedlot practice, modifying cattle performance, the role of new technologies and diagnostic techniques to improve cattle performance, and
- the application of new and existing technologies in commercial feedlot operations.

A draft questionnaire was initially developed and evaluated by the investigators to minimise question ambiguity (Appendix 3). In August 2014, the questionnaire was sent to 15 industry experts including feedlot veterinarians, and extension officers working in the feedlot industry. The participants were asked to complete the survey online via the SurveyMonkey website (www.surveymoneky.com). An email follow up was conducted 6 weeks after the initial contact, and a PDF format of the questionnaire was sent to the participants who had not completed the survey online. This was followed up by phone calls to those who did not respond to the survey by email or online. Upon the completion of the survey, and whenever possible, a follow-up phone interview was conducted with a number of participants.

Participants were asked to describe current diagnostic practice and management of feedlot cattle in Australia, and provide information and opinions on feedlot production systems and the application of diagnostic tools to improve the accuracy and sensitivity of detecting animals with ill-health. The questionnaire comprised several sections:

- current methods for diagnosis;
- estimates of under- or over-diagnosis of cattle with BRD, lameness and other common illnesses in feedlot cattle; and
- personal views on the cost of technologies, implementation, benefits, efficacy and adoption rate of new technologies.

4. Background review of current practice in Australian feedlot industry

4.1 Current animal health practices in the Australian feedlot industry, and costs associated with disease monitoring and intervention

Identification of sick cattle in a feedlot is a difficult task to perform. The usual methods of assessing the health of feedlot cattle are subjective, involving visual assessment of behaviour aided by minimal clinical measurements. Several epidemiological studies have indicated that even with increased pharmaceutical use, the incidence of morbidity and mortality in feedlots has increased. The efficacy of antimicrobials for the treatment of bovine respiratory Bovine Respiratory Disease (BRD) depends primarily on early recognition and early treatment. Economic losses due to BRD are cumulative (treatment cost, lost production, death loss), and early detection of BRD is the key to minimising these losses.

The confinement of animals within feeding pens improves control of the environment, allows animals to be monitored on a regular basis, and allows the efficient provision of feed and water. Cattle held within a feedlot are provided with their entire food and water requirements by the feedlot operator, providing a high level of control over production (e.g. daily liveweight gains). Therefore, feedlot operators have a high level of responsibility to ensure the water and nutritional requirements of cattle within their care are met. The daily checks identify animals with signs of diarrhoea, poor performance, droopy condition, rough coat, and lameness. Some of these animals are probably suffering from infectious diseases or ruminal acidosis (subacute or clinical). Once removed from their home pen, these animals are placed into a sick pen. After recovery (usually three to four days) the animals may be restarted in the feeding program, similar to new cattle. Currently, most large feedlots in Australia implement the following practices:

- The health management program focuses on high frequency and constant surveillance from the time cattle first arrive and continues for 3 or 4 weeks, aiming for early detection of health problems and prompt appropriate treatment.
- Sick or injured cattle are removed immediately from the feeding group and placed in appropriate sick bay facilities for treatment in accordance with the established protocol prepared by the consulting veterinarian. The treatment area is usually away from, but adjacent to the main feedlot facility. Stressed cattle are allowed to recover on a high fibre diet, either hay or pasture. When the prognosis for recovery is poor, immediate salvage is undertaken or, where this is not possible, humane destruction is performed immediately. When there is doubt about the prognosis, veterinary advice is sought.
- Detailed animal records are kept to monitor the incidence of disease. A record of mortality, including the necropsy reports, is maintained. Such data can be used for the refinement of health management programs, feed management, and the system of cattle purchasing and processing. Wherever practical, the origin of feeder cattle is recorded.

4.2 Required experienced labour and resources for daily monitoring of animals and identifying the strengths and weakness of the current monitoring system

The typical feedlot complex includes: i) pens, ii) handling yards, iii) drains and ponds, iv) stock lanes and feed alleys, v) manure stockpile and composting pads, vi) feed mill and feed storage facilities, vii) stock and vehicle wash down facilities, and viii) (most importantly) skilled and experience staff.

Feedlots have a significant requirement for labour. Pen riders and cattle handlers have a major role in cattle handling, and livestock diagnosis and treatment. Experienced and trained cattle handlers are responsible for: i) daily livestock handling, including pen riding and stock movements, ii) diagnosing animal health conditions, iii) administering animal health treatments, iv) maintaining accurate animal records including treatments and stock movements, and v) complying with occupational health & safety (OHS), quality assurance (QA) and environmental regulations. In order to perform these tasks, pen riders often need to have horsemanship skills, a. basic understanding of animal physiology and the common diseases of feedlot cattle, and a good working knowledge of animal welfare, health and nutrition.

Our consultation with industry experts demonstrated that there is a lack of consistency in skills and experience among pen riders, both within and between feedlots. This variation can lead to under- or over-diagnosis of feedlot cattle with ill-health. Based on our observations of a number of feedlots and discussions with cattle veterinarians, feedlot managers and industry experts, it is apparent that there is little data to demonstrate under- or over-diagnosis by pen riders and potentially increased associated costs to the enterprise. The field study conducted by industry experts, GrowSafe™ (www.growsafe.com), showed no significant correlation between the animals drafted, diagnosed and treated and the number and severity of lesions observed in the abattoirs (Alison Sunstrun, pers comm; June 2014). Currently, there is no defined gold standard test (with sensitivity and specificity) that would allow the probability of false positive and false negative animals to be evaluated at the herd level. Further studies are required to determine the association between clinical signs used by pen riders for diagnosis and drafting cattle, the clinical examination performed by cattle veterinarians, laboratory blood profiles, and abattoir findings to cross-validate the criteria used by pen riders for the diagnosis of cattle with ill-health.

One of the most common methods to determine ill health or distress of an animal is having trained pen riders monitor cattle for clinical signs of discomfort or disease. Multiple clinical signs and subjective assessments are used to determine an animal's overall health status. The combination of clinical and observational findings have been categorised into a single value, or clinical illness score (CIS), which represents the current state of the animal. The potential benefit of determining a CIS is presumably that it correlates with the need for an intervention or the probability of a specific outcome (Hayes et al., 2010). Scoring systems that assign a value based on degrees of illness are relatively common (Perino and Apley, 1998) and are frequently used in disease research (Hanzlicek et al., 2010; White et al., 2012; Coetzee et al., 2012). Even when quantitative measurements, such as rectal temperature, are combined with subjective assessments, the final disease classification remains subjective (Sanderson, 2006; Wenz et al., 2006). This subjectivity may affect how the results are interpreted if the CIS is used as one of the criteria in a treatment or preventative health program.

Research studies have shown limited agreement among observers (e.g. pen riders and farm staff) using the same CIS to identify animals with respiratory disease (Amrine et al., 2013). Potential sources of variation include differences in the experience and training of observers (pen riders), the cattle type, and the environmental conditions. When a subjective scoring system is applied and interpreted by more than one individual, it should be repeatable among individuals. A number of studies have evaluated agreement among veterinarians assigning body condition scores to cows and determined that even small amounts of training among the observers can increase the overall agreement (Kristensen et al., 2006). A clear case definition and educational program can decrease the variation between observers and make the results more clinically applicable. Although CISs are frequently used, true accuracy relative to disease state is difficult to determine. There is no gold standard diagnostic method for respiratory disease in cattle, but the presence or absence of pulmonary lesions at harvest has been compared with ante mortem diagnoses of clinical respiratory disease (Wittum et al., 1996; Schneider et al., 2009; Thompson et al., 2006, Alison Sunstrum, www.growsafe.com; pers comm, 2014). Results from these studies illustrate low correlations between lung scores and diagnosis of clinical illness. White and Renter (2009) estimated the sensitivity and specificity of using clinical signs of illness combined with rectal temperature to diagnose respiratory disease to be 62% and 63%, respectively. A test with imperfect sensitivity and specificity can underestimate or overestimate morbidity, leading to errors in the interpretation of preventative or therapeutic treatment efficacy (Amrine et al., 2013). One way to improve CIS agreement among observers is the implementation of a refined scoring system with limited categories. The objective of assigning a CIS to cattle is to accurately identify those animals that need an intervention (sensitivity) and those that do not (specificity). Therefore, the system could be condensed to those two categories. If cattle are deemed to require an intervention, the selection of the intervention would be based on the clinician's judgment of the case. For example, an animal that was deemed to have clinical respiratory disease may require an intervention with an antibiotic, whereas euthanasia may be a more appropriate intervention for a severely ill animal that is moribund and nonresponsive to human approach. Dichotomising the results would increase agreement among observers and could potentially increase the accuracy of comparison of CIS among individual observers. As previous research has illustrated, distinguishing illness severity based on CIS is challenging (White et al., 2012; Amrine et al., 2013). Much of the analysis of CIS data is based on the dichotomization of an animal into healthy or sick; therefore, systems that have more than two main levels serve a limited purpose.

Overall, identifying the presence of illness in stock on the basis of visual assessment alone is a common procedure and the specific implementation of the scoring system influences final data interpretation. Although CIS are quantitative, they may not be repeatable between or among observers and do not provide an objective measure of the degree of clinical illness. Care should be taken to limit potential sources of variability among observers through training and selection of the appropriate scoring system for the situation (Theurer et al., 2013).

4.3 Current regulation policies and procedures for tracing the movements of exposed and potentially exposed animals, and identifying all infected animals

The National Livestock Identification System (NLIS) is used by all feedlots in Australia because of its implications for food safety and disease management. The detailed records provided by NLIS would be of considerable assistance in tracing cattle during an emergency animal disease (EAD) outbreak. Some of the other benefits include (www.feedlots.com.au):

- enhanced administration of cattle in individual feedlots and reduced labour costs through more accurate individual animal data;,
- enhanced decision making based on individual animal performance data linked to carcase feedback to fine tune compliance with customer specifications; and,
- increased stock security (movement control and tracking diseases) and improved proof of ownership.

Therefore, technologies that have the potential to be compatible with NLIS and communicate with an electronic ear tag can be of high value to the industry.

Controlling the movement of susceptible livestock is an essential component of livestock disease control. However, such controls have significant potential to affect feedlot operations. For the most serious EADs, a national standstill on the movement of all livestock will be immediately applied for a period of at least 3 to 7 days. This means that no stock may be moved, and stock undergoing transport when the standstill is declared are required to stop moving as soon as possible. Guidelines for stock caught in transit at the time of the declaration will be provided by the response authorities. The stock may need to return to their farm of origin or may be permitted to complete their journey.

A national standstill on livestock movement also gives time for emergency responders to assess the situation. A standstill is likely to be followed by the declaration of restricted areas (RAs) and control areas (CAs). These declared areas are geographic areas of land where the movement of livestock (and other materials) may be restricted for extended periods. A RA is a relatively small area around an infected premises that is subject to the most intense surveillance and movement controls. An initial RA is generally based on a minimum 3-kilometre radius around an infected premises and contains all known infected and suspect properties. Movement of susceptible livestock out of the area is usually prohibited, and movement into it may only be allowed under an official permit. A CA forms a buffer between a RA and areas known to be free from disease. A CA may initially be declared over the whole state or territory. It will usually be reduced in size as knowledge about the extent of the outbreak is gained, but will generally maintain a minimum radius of 10 kilometres, including the RA. Multiple RAs may exist within one CA. Animals and specified products are allowed to be moved out of a CA into the free area only under an official permit. Figure 1 illustrates how controls over the movement of cattle may affect access to declared areas, depending on the disease. Similar principles may apply to people and equipment (www.aha.com.au).

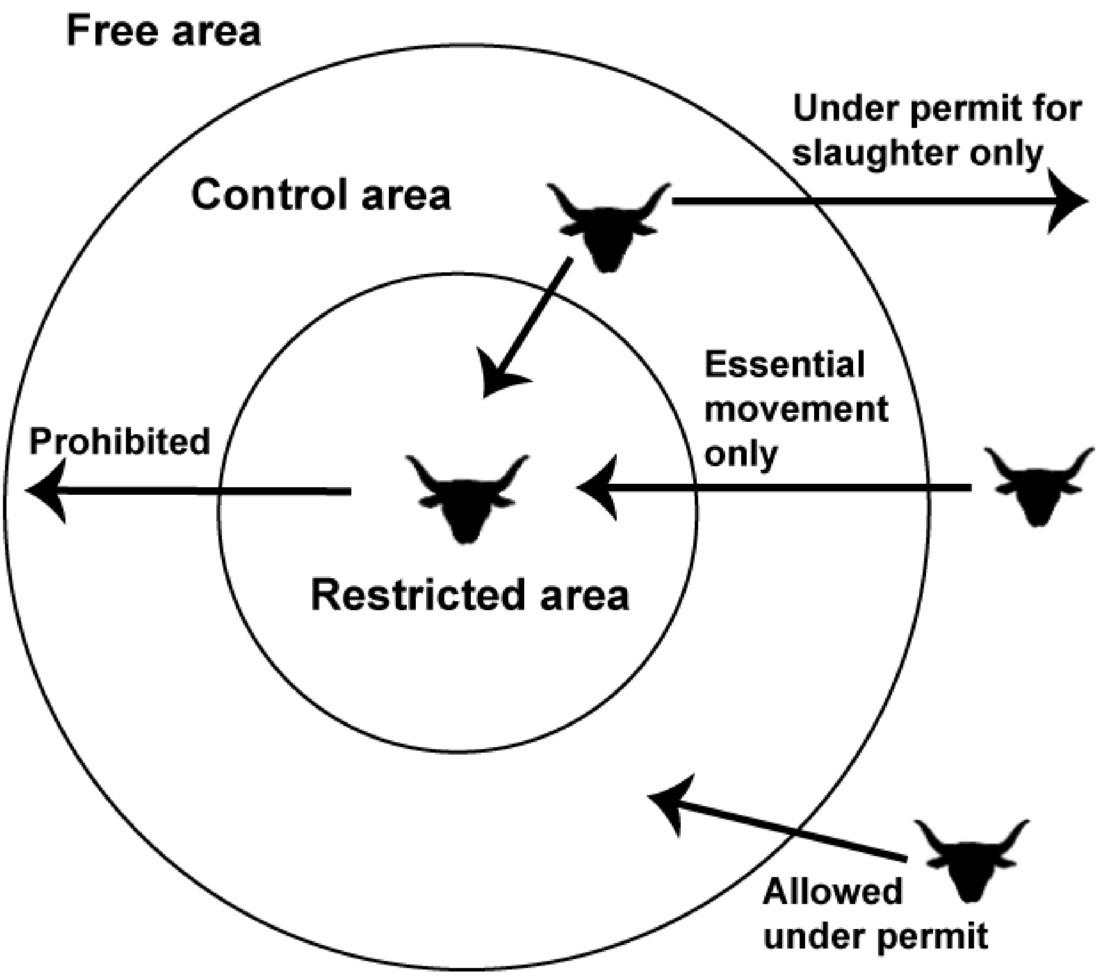

Figure 1. Schematic illustration of standard movement controls (Source: AUSVETPLAN, 2010; http://www.animalhealthaustralia.com.au/wp-content/uploads/2011/04/Feedlot-Manual3_0-10Proof27Apr10.pdf)

4.4 Review of estimated proportion of shy feeders that remain undetected with the current monitoring system

Under current monitoring practice, pen riders and cattle handlers will attempt to identify animals with signs of disease, feed problems (for example, shy feeders), failure to adapt to the diet, and 'poor doers'. Not all cattle will perform well in a feedlot and there will always be a certain number of cattle that will not start and will not grow well. If these animals can be identified early, they can be culled from the yard and fattened on pasture. If left in the feedlot, these animals will reduce profitability by wasting feed. During the time pen riders are observing the cattle in pens, they mainly use clinical signs to identify and draft those animals that are not 'doing well'. However, there is a group of animals, known as 'shy feeders', that don't necessarily exhibit any obvious signs of ill health but are avoiding feed and water. Following a few days of feed and water deprivation, these animals may then exhibit sign that get the attention of pen riders. The lag time between these events can delay the onset of treatment and are costly, because such animals will not grow as much as others and subsequently productivity will decline. In this case, technologies that can monitor daily feed and water intakes can be beneficial tools to facilitate early intervention by feedlot managers, thereby reducing productivity loss and/or mortality. There is no quantitative data on the proportion of shy feeders in a feedlot that are identified by pen riders. Our consultation with industry experts suggest that due to the variation in pen riders' skills and experience, it would be difficult to estimate the proportion of shy feeder cattle correctly identified as such by pen riders.

4.5 Current regulations on diagnosis and reporting of contagious and other notifiable diseases

Controlling an outbreak of an EAD (emergency animal disease) is a complex operation requiring rapid mobilisation and coordination of a diverse team of people and other resources. In addition to animal health issues, an EAD response may need to address financial, social, economic, human, trade, and recovery issues; the response may therefore require input from all tiers of government and from a range of portfolios (www.aha.com.au).

The fundamental aim of the national EAD control policy is to control and eradicate the EAD. The principal option for many EADs is eradication by stamping out (destruction of all infected and exposed animals), where this is applicable to the EAD in question and cost-effective. Stamping out may involve:

- Quarantine of premises and/or movement controls
- Destruction and disposal of infected and exposed susceptible animals
- Decontamination of infected premises
- Surveillance of susceptible animals
- Restriction of the activities of certain enterprises.

Other measures that may be used include:

- Vaccination
- Vector or wild animal control
- Treatment of affected animals.

In some circumstances, a modified stamping-out approach may be used if it is possible to slaughter animals at accredited establishments and produce a saleable product.

4.6 Major diseases in feedlot herds

Feedlots play a significant role in the livestock industry in value adding, optimising carcass finishing, and drought mitigation (www.mla.com.au, 2011). Feedlots and intensive finishing systems require good management to ensure the prevention of disease and the maintenance of good animal health and welfare. Of particular importance are nutritional, infectious, and parasitic diseases.

Nutritional diseases: All ruminants, when confined and fed, have special dietary requirements that must be observed to ensure maximum production while maintaining good animal health. The basis of this management is maintaining good rumen function while maximising production. While the incidence of nutritional diseases in Australian feedlots is very low, diseases of concern include acidosis (clinical and subclinical) and feedlot bloat (www.mla.com.au).

Infectious diseases: Lot-fed cattle are vulnerable to a range of infectious diseases. BRD (Bovine Respiratory Diseases) is the most important and the most common reason for illness and death in Australian feedlot cattle. BRD is associated with 50% and 90% of all sickness and deaths, respectively (www.mla.com.au). Bovine respiratory disease has the most economic impact on Australian feedlot industry, estimated to cost about $40m a year through lost weight gain, reduced feed conversion efficiency, mortality, and treatment and labour costs (Oswin, 2012,http://www.beefcentral.com/lotfeeding/vet-column-what-does-brd-cost-the-feedlot). BRD usually occurs in the first four weeks after entry to the feedlot, and is the result of a combination of stress and disease causing agents, such as viruses and bacteria. The industry experts believe that BRD is the major concern in feedlot operations with more than 5000 cattle, but not as important in small size enterprises. Sackett et al. (2006) reported that BRD accounts for between 60 and 70% of all illness and mortality in feedlot operations. The diseases modelling developed by Sackett et al. (2006) demonstrated that death rates increased by 0.2% in unvaccinated animals and the turn-off weight reduced by 5kg, and 7% of animals were assumed to succumb and be moved to hospital pens for treatment. The extra labour involved in this was also costed. A number of surveys have been conducted in Australia between 1991 and 2013 to estimate the incidence and economic impact of BRD and other infectious diseases in feedlot operations in Australia.

Dunn et al (1993) conducted a survey and studied the incidence of BRD in feedlot operations in Australia in 1991, and showed that up to 64% of mortalities result from the BRD complex, with an estimated national economic impact of $4,194,445. These estimates

(Dunn et al., 1993) were based on 1991 prices, when 275,000 cattle were on feed and the cost per head was $15.25. This study also investigated the effect of vaccination and estimated the potential economic loss at $20.77 per head in feedlots where vaccination is not practised and $12.24 per head where vaccination is practised.

Sergeant (2001) surveyed 72 feedlot operations to investigate the incidence of diseases, including BRD. A more recent survey has also been conducted by Perkin (2013) on 47 feedlot enterprises. The morbidity and mortality due to BRD reported by Sergeant (2001) and Perkins (2013) were compared with those reported by Dunn et al. in 1993 (Table 1).

Table 1. Comparison of survey results on BRD morbidity and mortality between 1991 and 2012 (Sources: Dunn et al., 1993; Sergeant, 2001; Perkins, 2013)

	Dunn et al. (1993)[1]	**Sergeant (2001)**	**Perkins (2013)[3]**
No of responses to the survey	27	72	47
Total Capacity	224,520	275,170	328,878
Total Turnoff	430,715	575,502	710,051
Average rating for BRD	2.8	2.9	3.80
Average annual mortality -BRD (per 1,000 turnoff)	2.7	4.3	7.8
Average annual morbidity - BRD (per 1,000 turnoff)	26.2	46.5	190
% All mortalities due to BRD	40%	64%	53%
% All morbidities due to BRD	44%	64%	84%
Average monthly morbidity rate -BRD (per 1,000 on feed)	11.2	38.6	-

[1] Survey was conducted in 1991, and report published in 1993

[2] Survey was conducted in 2010-12, and report published in 2013

The findings of Sergeant (2001) show that BRD was rated as the most important disease condition affecting feedlot cattle, particularly in medium and large feedlots. The rating for BRD has increased since 1991 (on a scale of 0 – 5). Medium and large feedlots rated it as 5, with a mean rating in these feedlots of 4.9, compared with a mean of 3.6 reported by Dunn et al. in 1991, and 3.8 reported by Perkins in 2012. The rating of BRD also increased for small feedlots, but less dramatically (from a mean of 1.8 to 2.5). The survey conducted by Sergeant (2001) involved a large number of small feedlots, which may have influenced the average rating for BRD in this study. Sergeant (2001) concluded that it was difficult to determine whether the increased rating of BRD was due to an increase in the incidence of BRD, or due to increased awareness and understanding of BRD as a specific disease by feedlot managers. Sergeant also demonstrated that the annual mortality rates from BRD increased since 1991 (Dunn et al., 2003). Again, this may be due to improved diagnosis of

BRD rather than an increase in the incidence. Some evidence of seasonal variation in the incidence of BRD was reported Sergeant (2001), with increased numbers of cases and deaths in late autumn and early winter. However, these observations were not consistent across all feedlots.

Treatment costs associated with the treatment of respiratory diseases in feedlots with different capacities are presented in Table 2 (Data from Perkins (2013).

Table 2: Estimated treatment costs associated with treatment of respiratory disease cases (costs of drugs administered to pulled animals during treatment) (Source: Perkins, 2013)

	Number of feedlots & Costs ($)
Capacity (>10,000)	
Feedlot (n)	12
Average & 95% CI	26.86 (20.75 – 32.96)
Capacity (5000-10,000)	
Feedlot (n)	5
Average & 95% CI	42.00 (21.07 – 62.93)
Capacity (1000-5,000)	
Feedlot (n)	11
Average & 95% CI	17.54 (12.64 – 22.45)
Capacity (<1,000)	
Feedlot (n)	12
Average & 95% CI	24.67 (12.81 – 36.52)

Lameness and foot rot: Lameness and foot rot can be a problem if the feet of feedlot cattle are damaged. Maintenance of the pen surface and good drainage in the pens (especially around water troughs) are essential to ensure feet problems and lameness are minimised. Nutritional disorders such as acidosis, and rations with a high proportion of fermentable carbohydrate (e.g. grain) are also risk factors that contribute to the incidence of lameness/laminitis in feedlot operations.

Parasitic diseases: Most internal and external parasites that can cause disease in feedlot cattle, such as lice and worms, can be effectively controlled during backgrounding and induction.

Feedlot flies: While a large variety of insects and mites can be found around feedlots, only a few of these are of concern. Flies can pose a problem due to their disease carrying potential, high numbers and annoying behaviour, which can result in agitation and reduced feed intake(www.mla.com.au).

5. Review of current and developing remote technologies

The ability to remotely identify cattle that require an intervention due to lower feed intake, sub-optimal productivity, high temperature, pain or disease is important for feedlot managers, veterinarians, cattle health providers, and researchers. Animal behaviour is frequently monitored and used by pen riders and cattle handlers to measure potential changes in animal well-being (Gonyou, 1994). Stress, pain, or high temperature as a result of disease or an undesirable environment such as heat stress, may alter animal behaviour and feed and water intake, which impact on an animal's wellbeing and productivity. Without a clear definition of the expected behavioural response to adverse events in the feedlots, monitoring these changes is challenging (Levitis et al., 2009). Some behavioural definitions are vague and are not specifically tied to one pain or disease response. Improvement in behavioural monitoring techniques is needed for remote monitoring of activity to be useful as diagnostic or research tool.

In recent years a number of methods and technologies have been developed and become available to monitor cattle behaviour. These include subjective visual observation, objective measures of cattle activity, and determination of animal location within the pen area. Subjective measurements of pain and cattle well-being include behavioural, depression, and illness scores based on the pen rider's or observer's impression of the animal's current state. The challenge with these technologies is determining if the behavioural evaluation of the animals is related to and affected by the potential differences between observers and among observers over time. The collection of data using remote sensing technologies can provide the opportunity to more discretely identify potential behavioural changes in feedlot cattle. Continuous monitoring of behaviour using accelerometers and pedometers has been used to assess cattle behaviour in a variety of scenarios (Hanzlicek et al., 2010; Theurer et al., 2013; Pauly et al., 2012; Robert et al., 2009; Theurer et al., 2012; Dockweiler et al., 2013). Monitoring cattle location within a defined environment has also been used in an effort to identify and monitor potential behavioural changes (Theurer et al., 2012; Dockweiler et al., 2013; White et al., 2012).

'Machine learning' studies automatic methods for learning to make accurate predictions or useful decisions based on past observations and experience, and it has become a highly successful discipline with applications in many fields. The term, machine learning, is used when a computer program is applied to a well-posed problem and has a measurable performance that improves with experience. Statistical and computer software tools based on the concept of machine learning can be used on remote diagnostic technologies. In veterinary medicine, machine learning algorithms have been used for applications such as lameness diagnosis in cattle and horses. We believe that the application of machine learning algorithms in remote diagnostic technologies could be beneficial for more accurate assessment of cattle health status and also better decision making by feedlot operators.

In this section the potential benefits and challenges of remotely monitoring cattle behaviours (such as feed and water intake, depression, pain and stress) with available methodologies (including visual monitoring, rumen sensors for temperature and pH, accelerometers, pedometers, feed and water intake, behaviour monitoring and global positioning system (GPS)) will be discussed. It is important to note that not all of these remote monitoring systems are currently directly applicable to a commercial setting. However, the results from research based on these technologies, provide valuable insights to practitioners on the associations between behavioural changes and pain and health status of cattle (Theurer et al., 2013).

5.1 Body temperature

The cattle industry loses millions of dollars annually to health-related performance issues and deaths of newly received cattle (Chirase and Greene, 2001). Bovine respiratory disease (BRD) is the most significant health problem in feedlot operations (Duff and Galyean, 2007) and it continues to have a negative effect on economics, animal well-being, performance, and carcass quality. The organism frequently isolated in cases of fibrinous bronchopneumonia is *Mannheimia haemolytica* (MH). One of the many precursors to respiratory tract disease in feedlot cattle is bovine viral diarrhoea virus (BVDV) (Fulton et al., 2000). Cattle persistently infected (PI) with BVDV are a major beef industry concern. These PI cattle can be the source of the virus for other cattle leading to decreased performance and economic returns while increasing the animal’s susceptibility to other diseases, such as BRD. Diseases such as BVD and BRD are commonly detected by observed depression, lack of rumen fill, cough, altered gait, ocular or nasal discharge, or general physical weakness (Gardner et al., 1999; Berry et al., 2004). After clinical signs are observed, the diagnosis is confirmed by an increased body temperature (usually determined by a rectal thermometer), reaching 40.0 to 42.2 °C (Baker and Merwin, 1985; Gardner et al., 1999; Berry et al., 2004). However, Wittum et al. (1996) observed lung lesions in calves managed from birth and concluded that current methods of detecting clinical BRD are not adequate to prevent production losses and that improved methods are needed. Bucszinski et al. (2014) also showed that thoracic auscultation is of limited value in diagnosis of lung conditions in calves. A Bayesian approach was used by White and Renter (DATE NEEDED) to determine the estimated diagnostic sensitivity (Se) and specificity (Sp) of clinical signs and pulmonary lesions at harvest. Their results showed that the estimated Se and Sp of clinical signs were 61.8% (97.5% probability intervals [PI]: 55.7 to 68.4) and 62.8% (97.5% PI: 60.0 to 65.7), respectively. The use of pulmonary lesions for a BRD was estimated to have a Se of 77.4% (97.5% PI: 66.2 to 87.3) and a Sp of 89.7 (97.5% PI; 86 to 93.8). These results show that neither method was perfect, and both methods were relatively poor at correctly classifying truly diseased cattle. The presence of pulmonary lesions was more accurate than clinical signs for BRD diagnosis

Remote means of detecting increased body temperature related to disease could lead to simple, earlier, and more reliable disease detection. Improved disease detection and earlier treatment may decrease the severity of illnesses and minimise decreased performance and carcass merit. Body temperature is the result of the level of heat produced and sustained by the body processes. Variations and changes in body temperature are major indicators of disease and other abnormalities in cattle. Heat is generated within the body through metabolism of nutrients, and lost from the body surface through radiation, convection, and evaporation of perspiration. Heat production and loss are regulated and controlled in the hypothalamus and brainstem. Significant fever is usually a function of an increase in heat generation related to altered body physiology, although high environmental temperature with high relative humidity can create heat stress related fevers. Environmental conditions are an important consideration for potential remote technologies, because these factors can amplify the proportion of cattle that are falsely identified as having a fever. The developers of new technologies need to account for adverse environmental conditions to be able to accurately interpret body temperature measures.

Normal body temperature varies considerably among cattle (Lefcourt et al., 1999). Daily temperature variation is somewhat random, with a standard deviation around 0.6 °C (Fallon, 1959). Debate exists on how frequently temperature should be measured to detect differences in physiological responses of healthy cattle (Lefcourt et al., 1999). Measuring body temperature continuously would be advantageous to demonstrate the dynamic changes in temperature throughout the day (Mitchell et al., 2001; Brown-Brandl et al., 2003; Green et al., 2005). Most research indicates that body temperature in cattle follows a distinct circadian rhythm, with a range of 0.2 to 0.9 °C (Nakamura et al., 1983; Lefcourt et al., 1999; Al-Haidary et al., 2001; Piccione et al., 2003; Piccione and Refinetti, 2003).

Attempts to measure body temperature of cattle have been made at various anatomical sites, including the rectum, ear (tympanic), vagina, and reticulo-rumen, and in milk. Firk et al. (2002) suggests that the value of a temperature monitor is highly dependent on its location. Rajamahendran et al. (1989) found rectal and vaginal temperatures to be highly correlated (r = 0.95).Tympanic temperature has been suggested to be a superior measure of deep-body temperature because of its proximity to the hypothalamic thermosensitive site and the reduced lag time for any changes (Seawright et al., 1983; Bergen and Kennedy, 2000). However, continuously monitoring tympanic temperature can prove challenging as temperature transmitters may create ear infections, leading to increased local temperatures (Bergen and Kennedy, 2000). In a study by Bergen and Kennedy (2000), the Pearson correlation coefficient between tympanic and vaginal temperatures was 0.77 with vaginal temperatures averaging 0.35 °C higher than tympanic temperatures. Davis et al. (2003a) reported the average tympanic, peritoneal cavity, and rectal temperature of 4 steers during a 24-hour period. Tympanic and peritoneal temperatures were, respectively, 0.1 and 0.2 °C less than the rectal temperature. In a study using 8 steers, Prendiville et al. (2002) reported no significant difference between tympanic and rectal temperatures.

Core temperature is the temperature of structures deep within the body and is the temperature at which an organism is meant to operate. It refers to the temperature of organs and parts of the body that are well insulated (e.g. liver), as opposed to the surface (i.e. skin) or peripheral (e.g. legs, ears) temperature, which fluctuates more. Animals regulate their core temperature with a system of thermoregulatory processes that maintain homeostasis. When the body heats up, reactive physiologic mechanisms cool everything down to ensure the body functions at its best. Similarly, when the external environment becomes colder than the organism, internal processes heat everything up (Bewley and Schutz, 2010).

There are a number of factors that can influence change in body temperature or influence the accuracy of its measurement, including overall health, environment, ambient temperature, activity level, oestrus, pregnancy status, eating and drinking behaviour, excitement and correct placement of the thermometer (Lefcourt et al., 1999). Average body temperature varies by season and reflects ambient temperatures, a phenomena termed “seasonal drift” (Fordham et al., 1988). Feeding may increase body temperatures (Bitman et al., 1984). Metz et al. (1987) found that body temperature increased about 0.2 °C while lactating cows were lying (and decreased after standing up) indoors. The same pattern was not observed in dry cows on pasture or feedlot beef cattle. Pieman et al. (2008) also found that rumen temperatures are higher at night than during the day.

Nakamura et al. (1983) defined body temperature as the “single most useful measurable parameter and a sensitive indicator of the reactions of the animal to physico-environmental factors, disease processes, and physiologic functions such as nutrition, lactation, and reproduction.”

Rectal temperature is most commonly used by herd managers and veterinarians for detecting febrile disease and changes in the health status of cows, although rectal temperature provides only an approximation of core body temperature (Schutz and Bewley, 2009).. However, core body temperature measurements are inherently difficult to obtain. . Moving and manually restraining animals to measure rectal temperatures alter the temperature. A reliable method independent of human intervention is likely to provide a more accurate measure (Prendiville et al., 2002).

Rectal temperature is a key indicator of illness that is often difficult to obtain in many production systems because it requires moving the animal from its pen or pasture to a handling facility for restraint. Despite this restriction, only a limited amount of research has been conducted to investigate alternative methods of temperature measurement for the purpose of health detection. Most of those alternative temperature measurement methods have been used to determine the effects of hot (Lefcourt and Adams, 1996; Hahn, 1999; Davis et al., 2003b) or cold (Lefcourt and Adams, 1998) environmental temperatures, stress-inducing activities (Mader et al., 2005), and growth promotants (Mader and Kreikemeier, 2006) on the animal’s core body temperature.

Rumen temperatures have been demonstrated to be an effective measure of core body temperature (Hicks et al., 2001; Prendiville et al., 2002; Small et al., 2008). Because of the activity of heat-producing rumen microorganisms, ruminal temperatures are generally about 1°C higher than core body temperatures (Bitman et al., 1984). Ruminal or reticular temperatures typically run higher than rectal temperatures (Simmons et al., 1965). Prendiville et al. (2002) compared temperature readings from CowTemp™ rumen boluses (AgriTemp), tympanic telemetry transmitters, and rectal temperatures that were measured hourly. The averages over the 5- day study period were 39.0, 38.4, and 38.2 °C for rumen, tympanic, and rectal temperatures, respectively. While there was no significant difference between tympanic and rectal temperatures, rumen temperature was higher than rectal or tympanic temperature on 3 of the 5 days. Using the CorTemp sensor pill, Hicks et al. (2001) found rumen temperatures to be not statistically different from rectal temperatures. Dramatic decreases in ruminal temperature occur after a cow drinks water (Dracy et al., 1963; Simmons et al., 1965; Kahne Animal Health, per com 2014), and this has been further demonstrated in comparisons of temperatures recorded at a stationary panel for cattle motivated by water versus activity (Small et al., 2008). These authors showed that it takes 60 to 90 minutes for temperatures to return back to their pre-drinking levels (Dracy et al., 1963; Cunningham et al., 1964). The level of temperature depression is related to the amount and temperature of water consumed (Cunningham et al., 1964). While automated reticular temperature recording may allow early detection of disease, oestrus, heat stress, and the onset of calving, one potential limitation to collection of reticular and rumen temperatures is the impact of water temperature and consumption on recorded temperatures.

The results of studies by Bewley et al. (2008a, b) and others using Cattle Temperature Monitoring System (CTMS) bolus residing in the reticulum of dairy cows showed that average differences between rectal and reticular temperatures were quite consistent. The following equations enable producers and veterinarians to estimate rectal temperatures from reticular temperatures:

AM Milking: rectal temperature = 19.23 + 0.496 reticular temperature
PM Milking: rectal temperature = 15.88 + 0.587 reticular temperature

Studies have compared the relationship of alternative temperature measurement devices (Hahn et al., 1990), including intra-ruminal devices (Bhattacharya and Warner, 1968; Hicks et al., 2001; Bewley et al., 2008a), with rectal temperatures. Hicks et al. (2001) showed that temperature readings from a bolus placed via the cannula of a rumen-fistulated Holstein cow had the same average temperature as rectal temperature measurements (38.7°C). The average rumen temperature was similar to the 38.9 °C reported for control calves in a study by Rose-Dye et al. (2011). The rectal and rumen temperature differences observed by Rose-Dye et al. (2011) were similar to other published results that used different methods to determine core body temperature.

Rose-Dye et al. (2011) reported that during a 5-day period, rumen temperatures were significantly greater than rectal and tympanic temperatures, with average temperatures of 39.0 °C (rumen), 38.4 °C (rectal), and 38.2 °C (tympanic). Previous research with rumen temperature boluses indicated that rumen temperature could range from 0 to 0.6 °C higher than rectal temperature, whereas Rose-Dye et al. (2011) found that rumen temperatures averaged 0.13 ± 0.38 °C less than rectal temperature at coinciding time points and the values were highly correlated ($r = 0.89$). It has been demonstrated (Darcy and Kurtenbach, 1968; Beatty et al., 2008) that rumen temperatures generally follow the same pattern as temperatures at other core body locations, with the exception that water consumption will create decreases in rumen temperature that can last up to 3.5 hours, depending on the quantity and temperature of the water consumed (Brod et al., 1982; Bewley et al., 2008b).

Bewley et al. (2008a) compared rumen and reticular temperatures in dairy cows and concluded that the relationship between the two temperature measures was strongly correlated (r = 0.645) and that it varied by season, milking, housing system, and parity. Al-Zahal et al. (2009) compared an *in situ* system that measured temperature and pH with reticular temperature bolus from the same manufacturer as used in the study of Rose-Dye et al. (2011). When dairy cows were fed high concentrate diet, the *in situ* system detected changes in temperature as the concentrate component of the diet increased, but these changes were not detected by the bolus. The authors speculated this was most likely due to the temperature sensor of the bolus being encased within a solid polymer bolus that did not respond to the short-term temperature changes detected by an exposed sensor. However, the relationship between temperature and low rumen pH was similar between temperatures from the *in situ* system and bolus measures. These comparisons of rumen, rectal, and other core temperatures indicate that they tend to respond similarly to influencing factors, although there may be variation in the magnitude of the response.

Rumen temperature boluses are potentially more advantageous to commercial feedlots with a larger number of animals kept for a longer period of time than the tympanic temperature probes and implanted or injected temperature transponders, which are temporary and costly to administer. However, with water and other factors influencing rumen temperature readings, it is unclear if large enough increases in rumen temperature might occur to be detectable during adverse health events. Rose-Dye et al. (2011) showed that rumen temperature boluses detected an immediate response to the MH challenge, whereas exposure to PI BVDV steers caused cyclical temperature increases during and after the exposure period. Response to the MH challenge initially increased daily average and maximum ruminal temperatures by approximately 1.2 °C compared to those of control steers, and by 24 hours daily average temperatures decreased to control temperatures. Rectal temperatures in response to the MH challenge reported by Burciaga-Robles et al. (2010) increased by approximately 2 °C and then returned to control temperatures by 36 hours. Confer et al. (2009) and Corrigan et al. (2007) also reported this change in rectal temperature in response to an MH challenge.

Rose-Dye et al. (2011) demonstrated 2-hour averaged temperature measures were significantly different with BVDV exposure (approximately 0.6 to 0.8 °C). Rectal temperatures in response to BVDV exposure were approximately 0.3 to 0.5 °C greater than those of non-exposed calves during a period from 36 to 72 hours after MH challenge (Burciaga-Robles et al., 2010). In a BVDV intranasal challenge model, Kelling et al. (2007) reported that non-vaccinated animals had higher rectal temperatures on days 9 to 11 after challenge compared with a vaccinated group. Calves challenged with non-cytopathic type-1 BVDV (Ganheim et al., 2005) had a mild fever (>39.5 °C) from day 1 through 5 after inoculation compared with non-challenged controls. These results suggest that rumen temperature measurements are capable of detecting temperature changes in response to both MH and BVDV challenges similar to those that have been reported for rectal temperature (Figures 2 and 3, Table 3).

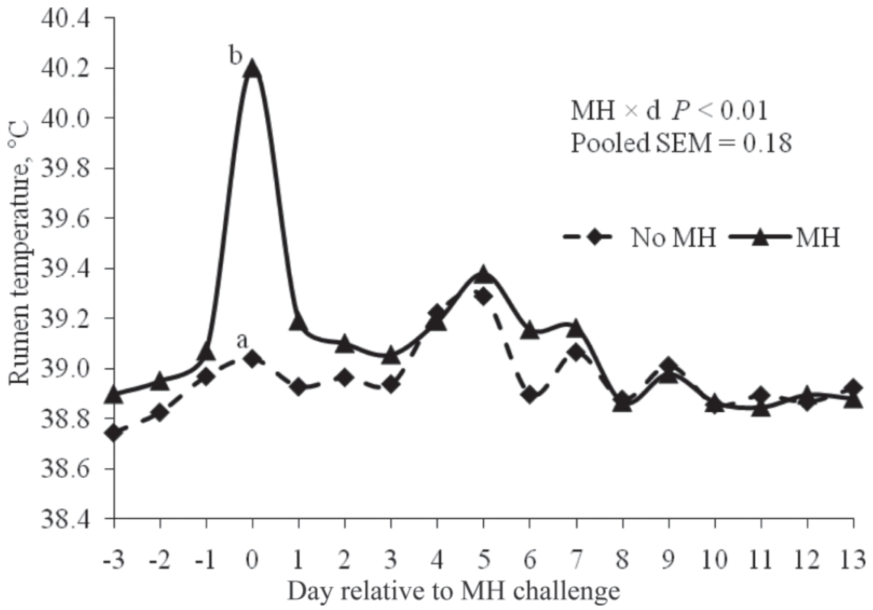

Figure 2. Average daily rumen temperature of calves challenged intra-tracheally with 6 × 10^9 cfu of *Mannheimia haemolytica* serotype 1 (MH) compared with non-MH-challenged calves (No MH). Challenge with MH was conducted at the beginning of day 0. The values plotted represent least squares means of the mean calculated for 12 animals per experimental group on day −1 to 13 and for 9 experimental animals on day −3 and −2. [a,b] Means on the same a day with different letters differ (*P* < 0.01) (Source: Rose-Dye et al., 2011)

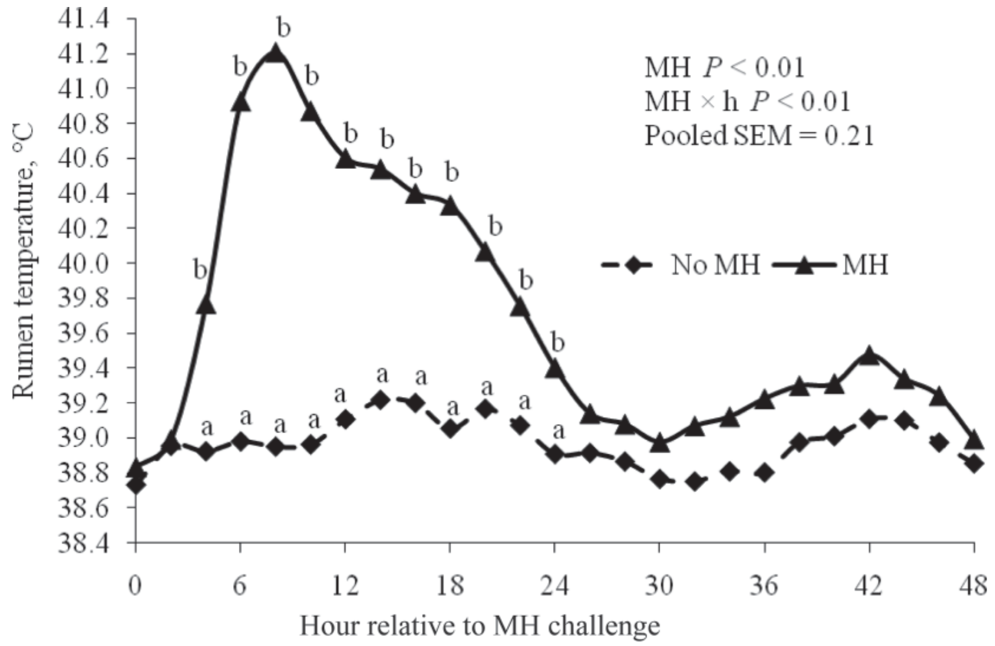

Figure 3. Rumen temperature, averaged every 2 hours, of calves challenged intratracheally with 6 × 10^9 cfu of *Mannheimia haemolytica* serotype 1 (MH) compared with non-MH-challenged calves (No MH). Hour 0 is equal to the MH challenge. The values plotted represent least squares means of the mean calculated for 12 animals per experimental group. [a,b] Means on the same hour with different letters differ ($P < 0.01$). Time points for 50 to 336 hours were not significant ($P > 0.01$) and are not presented (Source: Rose-Dye et al., 2011).

Table 3. Effect of *Mannheimia haemolytica* and bovine viral diarrhoea virus challenge on rumen temperature average, minimum, maximum, and range (°C) 72 h before and 336 h after *M. haemolytica* challenge (Source: Rose-Dye et al., 2011)

Items	Treatments				SEM [2]
	Control	BVDV	MH	BVCV+ MH	
Mean	38.9	39.0	39.0	39.1	0.1
Minimum	34.4	34.2	34.3	34.6	0.5
Maximum	40.3[a]	41.1[b]	41.5[b]	41.6[b]	0.1
Range	6.0	6.9	7.2	7.0	0.5

[a,b] Within row, numbers with different superscripts differ ($P < 0.01$).
[1]Treatments: control = no challenge; BVDV = exposed to bovine viral diarrhoea virus type 1b; MH = challenged intratracheally with 6 × 10^9 cfu of *M. haemolytica* serotype 1; BVDV + MH = exposed to BVDV type 1b and challenged intratracheally with 6 × 10^9 cfu of *M. haemolytica* serotype 1. [2] Pooled SE of the least squares means.

Overall, these studies demonstrated that remote-monitored rumen temperature boluses have the potential to provide temperature results that are highly correlated with rectal temperatures over a normal biological range of temperatures and that they have the potential to be a viable means of detecting adverse health events in cattle. Morbid animals are normally identified by visual signs, supported objectively by rectal temperature results. Remotely obtained rumen temperature measurements have an advantage over rectal temperature measurements in that rumen temperatures are easier therefore more likely to be obtained, and could potentially result in the detection of illness before clinical signs are apparent. Additional research will be necessary to determine if the use of rumen temperature monitoring boluses will allow for detection of naturally occurring disease in commercial production settings. Any improvements in detection will need to be coupled with effective management interventions to decrease treatment costs or decrease disease severity, and create an economic benefit to cattle producers.

5.2 Rumen pH

Grain-based finishing diets contribute to rapid, efficient and economical growth in feedlot cattle. However, some researchers and animal welfare advocates are concerned this may pose a risk to animal welfare. The concern is that grain-based diets increase the risk of ruminal acidosis, the lowering of the pH level in the rumen due to microbial fermentation of dietary starch. Acute ruminal acidosis (grain overload) is a well-known risk when cattle that are not adapted to grain consume too much grain too quickly. This causes the rumen to become too acidic very quickly and can result in severe health problems. To prevent this from happening, feedlots use step-up programs to carefully adapt forage-fed feeder cattle to grain-based finishing diets. Subacute ruminal acidosis “SARA” is a phenomenon in which rumen pH doesn’t increase, but tends to remain relatively low for extended periods of time. SARA is still a potential risk even after cattle have been adapted to grain-based finishing diets. The frequency and consequences of chronic SARA have not been studied extensively, because measuring rumen pH has traditionally required rumen fistulated animals and intensive measurements (Penner et al., 2006 and Penner et al., 2009).

Different methods have been used to measure rumen fluid pH. Among them, rumenocentesis and aspiration via an oral stomach tubing have been practiced at farm level to sample rumen fluid from the intact animal. Rumenocentesis is performed by inserting a needle in the caudoventral region of the rumen to extract ruminal fluid. For stomach tubing, a plastic tube is passed through the oesophagus into the rumen, and rumen fluid is collected. However, for research purposes, rumen fistulated animals are commonly used and samples are generally collected manually. Each of these methods have advantages and disadvantages. For example, samples collected with an oro-ruminal probe may be susceptible to saliva contamination (Nordland et al., 1994) and as a result, show higher pH values and higher bicarbonate concentrations compared with other collection methods (Duffield et al., 2004). Beside this, the method requires considerable restraint and causes discomfort to the animal. Rumenocentesis requires physical restraint of the animal and surgical preparation of the centesis site (Duffield et al., 2004; Nordlund et al., 1994). There is a potential risk of localised abscesses or peritonitis following rumenocentesis (Duffield et al., 2004). A drawback for both techniques is the limited number of animals that can be sampled at any one time and each animal, at least in the case of rumenocentesis, can be sampled only a few times. Furthermore, sampling is unlikely to be successfully and safely performed by a feedlot manager, who is generally an unskilled individual. Rumen cannulation, although suitable for research purposes, cannot be carried out by untrained personnel is neither suitable nor practiced in a commercial setting. A further limitation is the cost, and hazards associated with the surgery. It is also very labour intensive and limited to only a few animals. Moreover, it is difficult to maintain the cannula in growing animals. Thus, a less invasive technique—such as a bolus which can be placed inside the rumen to measure pH continuously and does not interfere with the normal rumen function—is desirable.

Various attempts have been made to continuously measure the pH of ruminal fluid. Smith (1941) was the first to describe the *in vivo* measurement of pH in the rumen and tried to measure pH with the help of a Beckman pH meter assembled in a glass electrode. Later Matcher (1957) and Lampila (1955) made attempts to measure pH continuously in sheep and cattle respectively with the help of a glass electrode. The glass electrode was connected by a wire to a receiver located outside the rumen. Dado and Allen (1993) also tried to set up a system to provide continuous measurement of rumen pH with the help of indwelling pH electrodes. Their system didn't work well due to the difficulties in maintaining sensor calibration. Measurements with the above systems necessitated tethered animals as the indwelling pH probes were connected to instrumentation by cables and hence restricted the animals' mobility.

In recent years, wireless systems able to monitor rumen pH have been developed. The accuracy of wireless measurement systems for continuous monitoring of pH over time has improved with different types of devices (Keunen, 2002; Maekawa, 2002; Cottee, 2004; Beauchemin and Yang, 2005; AlZahal 2007a,b). Wireless stand-alone systems for measuring rumen pH in grazing and unrestrained animal have been developed by Enemark (2003) and Graf (2005). These systems are in limited use and are lacking validation (Penner et al., 2006). Penner et al. (2006) proposed a wireless measurement system, named Lethbridge Research Centre ruminal pH (LRCpH, Dascor, Escondido, CA), for cannulated cows. The limitation of this system was the need for daily recalibrations. Recently, a wireless rumen probe has been promoted commercially by Kahne Limited (New Zealand) to monitor rumen pH, temperature, and rumen pressure in cattle (Kaur et al., 2010). The bulb of this probe was made of an ion sensitive field effect transistor (ISFET) sensor. The probe was evaluated by Kaur (2010) in four rumen fistulated male sheep and the results were compared with the most common method of monitoring pH (glass electrode). The probe was light sensitive, had a time dependent pH drift and performed poorly in comparison with a glass electrode (Kaur et al., 2010). Kahne Limited (www.kahne.co.nz) has subsequently redeveloped their rumen bolus, Sentinel™, to improve the accuracy, sensitivity, life, and cost. Sentinel™ is currently in the final stages of preparation for commercialisation (per com Susanne Clay, Kahne CEO, 2014). There are now several telemetric devices available on the market with boluses that can be placed in intact animals and transmit pH values (e.g. eCow, Dascor, Sentimel Smaxtec, etc.). These systems rely on battery-driven sensors, predominantly based on glass electrodes. The functional life of some of these systems was limited to between 40 and 100 days (Gasteiner et al., 2009; Gasteiner et al., 2012; Phillipps et al., 2010). Only two devices, TempTrak® (for rumen temperature) and Sentinel™ (for rumen temperature and pH), were capable of extended life (4 to 5 years) with different sampling frequencies. Although some of the above devices are marketed for commercial herds, their relatively high price and limited functional life make them more suited for scientific applications.

Kimura et al. (2012) investigated the circadian pH changes in the fluid of the rumen (bottom and middle) and reticulum simultaneously using wireless and wired radio-transmission pH-measurement systems in cows fed a control diet or rumen-acidosis-inducing diet. The pH in the three sites decreased following the morning and evening feeds. In cows fed the control diet, the bottom-rumen and reticular pH reverted to the basal level by the next morning, while the middle-rumen pH did not recover completely, suggesting that active fermentation occurred in the middle of the rumen. The mean pH at 1 hour intervals was higher in the reticulum than at the bottom and in the middle of the rumen. The relatively stable reticular pH may be the result of normal salivation. In cows fed the rumen-acidosis-inducing diet, the bottom-rumen pH fell to approximately 5.2 after the evening feed, but returned to the basal level by the next morning. In contrast, the middle-rumen pH did not return to the basal level (6.5) within 24 hours, presumably owing to continuous, vigorous fermentation. There were positive correlations between the pH at the bottom and in the middle of the rumen and at the bottom of the rumen and in the reticulum. These findings indicate that the radio-transmission pH-measurement system may be a suitable tool for simultaneous measurement of pH in the rumen and reticulum (Figures 4, Table 4).

Table 4. Correlation coefficient in the pH between the rumen and reticulum of cows fed the control diet and rumen-acidosis-inducing diet (Source: Kimura et al. (2012a)

Variable	Control diet	rumen-acidosis-inducing diet
Middle-rumen vs Bottom-rumen	0.409[a]	0.894[a]
Middle-rumen vs Reticulum	0.170	0.764[a]
Bottom-rumen vs Reticulum	0.826[a]	0.797[a]

The bottom-rum and reticulum pH are measured by the wireless pH sensor, and the middle-rumen pH is determined by the wired pH sensor ([a]P<0.01)

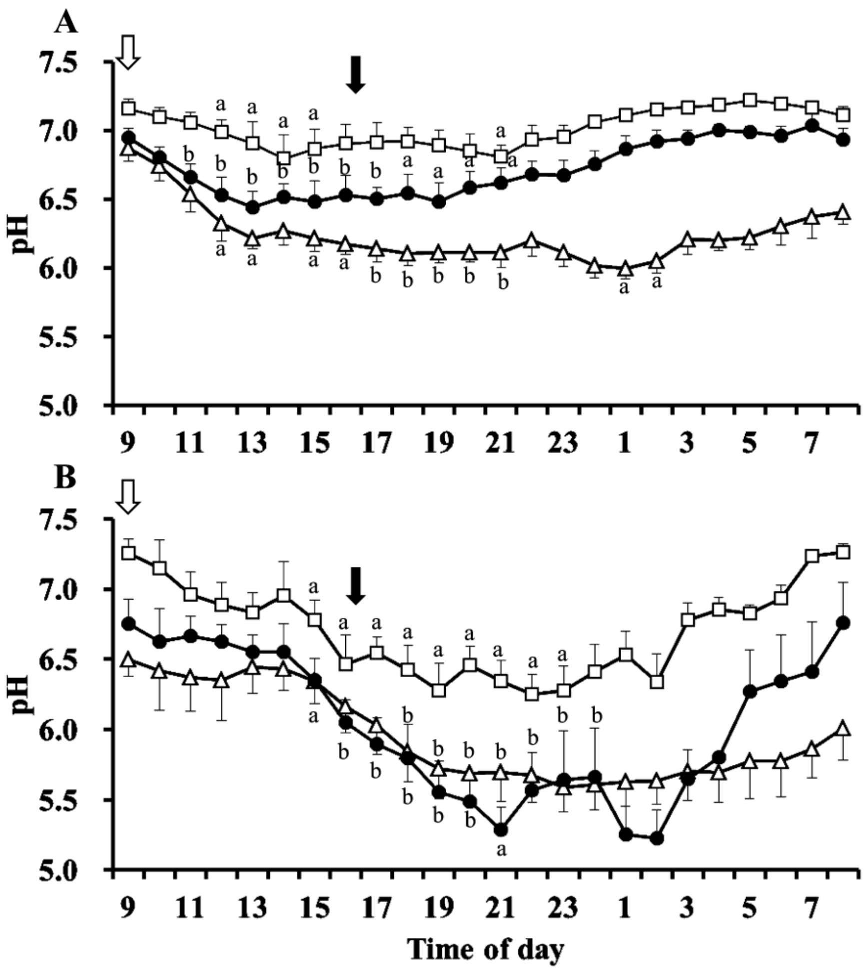

Figure 4. Circadian pH changes at the bottom (closed circles) and in the middle (open triangles) of the rumen and in the reticulum (open squares) of cows fed the C diet (A) or RAI diet (B). Arrows show the times of the morning (open) and evening (closed) feedings. The values are the means ± SEM (n=4).
[a] *P*<0.05, [b] *P*<0.01 (significant difference compared to the corresponding basal pH) (Source: Kimura et al. (2012).

Other studies have examined the pH of reticular fluid (Bryant 1964; Lane et al., 1968). Lane *et al*. (1968) found the highest pH in the reticulum and the lowest pH at the top or middle of the rumen. These differences were still apparent three hours after feeding, although the pH values had all decreased (Lane et al., 1968). The Kimura et al. (2012a) showed a decrease in reticular pH following the morning feed which increased gradually to basal levels by the next morning feed, similar to the change in the rumen. The 24-hr mean, minimum, and maximum pH values were significantly higher in the reticulum than in the rumen (Kimura et al. (2012a), as described previously (Lane et al., 1968). Stratification of the reticulorumen contents likely indicates further spread of the ruminal mat into the ventral rumen (Ahvenjärvi et al., 2001; Hummel et al., 2009; Kovács et al., 1997). These reports suggest that the pH patterns in the rumen and reticulum are similar. Kimura et al. (2012a,b) also observed a significant positive correlation between rumen and reticular pH values, with the pH lower in the middle and bottom of the rumen than in the reticulum. The higher pH in the reticulum in these studies may be caused by the dilution of fluid by salivation and drinking water (Dado and Allen, 1993; Duffield et al., 2004). Further studies are needed to elucidate the reason for the differences between the pH of the rumen and reticulum, and the characteristics of the circadian pH changes in these structures.

Ruminal acidosis is a nutritional disorder generally resulting from ingestion of large amounts of feeds rich in readily fermentable carbohydrates, particularly in those animals not previously conditioned to those feeds. The resulting production of large quantities of volatile fatty acids (VFAs) and lactic acid lowers rumen pH to non-physiological levels. Low rumen pH can result in rumenitis, metabolic acidosis, lameness, hepatic abscessation, pneumonia, and death (Lean et al., 2000). Ruminal acidosis is more appropriately considered a complex of conditions resulting from a similar cause: a failure to maintain effective buffering of the rumen or clearance of fermentation by-products after challenge with rapidly fermentable substrates. Brown et al. (2000) used discriminant analysis to define cows (n = 20) with acute and subacute acidosis in a randomized trial in which acidosis was induced by concentrate feeding. After examining rumen pH cut-points, they found that no single variable measured displayed a consistent response across time that could be used to identify acute or subacute ruminal acidosis. Further, daily fluctuations in rumen pH caused difficulty in using this as the sole measure for diagnosis of acidosis.

Rumen pH fluctuates throughout the day and depends on the diet, time of feeding of concentrates (e.g. TMR with grain content), and supplementation of fibre sources. Because of the fluctuation of rumen pH during the day, diagnosis of acidosis based solely on rumen pH can be difficult. Bramley et al. (2008) showed that low pH was not a sensitive or specific measure for the diagnosis of rumen acidosis, suggesting that other measures of rumen function are important in determining cows at risk for acidosis. The pH cut point at which subclinical acidosis is defined is controversial, with some authors suggesting pH 5.5 for rumenocentesis samples (Garrett et al., 1999). However, *in vitro* fibre digestibility is reduced when pH drops below 6.2 (Grant and Mertens, 1992; Grant, 1994; Calsamiglia et al., 1999). In the study of Bramley et al. (2008), 7.6% of cows had a rumenocentesis pH of less than 5.5, 16.1% of cows had less than 5.8, but 43% of cows had a rumen pH of less than 6.2 (Figure 5).

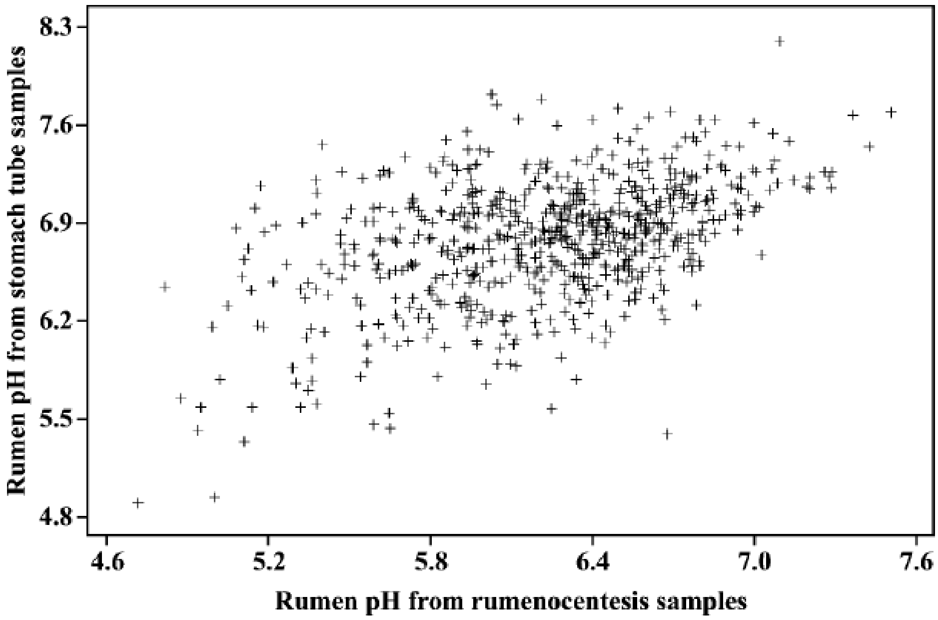

Figure 5. Scatter plot comparing rumen pH measured by rumenocentesis vs. stomach tube (R^2 = 0.20) (Source: Bramley et al., 2008).

5.3 Technologies to monitor body temperature and rumen pH as a diagnostic tool

The largest potential benefit of employing an automatic temperature monitoring system in cattle is likely to be the early detection of cases of disease or disorders that plague the cattle industry (Maatje et al., 1987). For many diseases, an increase in temperature is an early physiological response. In recent years, intensive fresh cow management programs have been established using electronic thermometers to detect fever (Aalseth, 2005).

Non-invasive wireless rumen temperature boluses and sensors have been used to monitor cattle health, and rumen temperatures have also been shown to have a strong correlation (R^2 = 0.80) to rectal temperatures (Rose Dye, 2010; Small et al., 2008). Rumen temperatures increase in calves challenged with *Mannheimia haemolytica*. Bovine respiratory disease (BRD) was diagnosed in 88% of bulls (21/24) based on clinical examination. The use of such reticulorumen boluses had a positive predictive value of 73% for identifying animals infected with BRD when compared with a physical examination (Timsit, 2011). The pyrogenic effect of lipopolysaccharide was shown to only transiently increase rectal temperatures when administered to dairy calves (Theurer et al., 2011). However, rumen temperature increased 2°C when lipopolysaccharide was administered to beef heifers (Small et al., 2008).

Limitations of wireless rumen boluses include the bolus expense and cost administration of the boluses to the animal. Overall effectiveness of the rumen telemetry temperature bolus is affected by specific facets of the system, including ability to use remote monitoring technologies in the specific environment (interference, geographic distribution), data collection, and management plan (Theurer et al., 2013). While the number of proposed experimental techniques for non-disruptive temperature monitoring is large, the number of companies actually marketing telemetric equipment to the livestock industry is small (Tables 5, 4a, b).

Table 5. Available rumen boluses/sensors that are used to measure rumen pH and rumen temperature as a proxy for core body temperature

Developers/ Manufacturers	Country	Name of product/device	Website	Stage of development and usage	Class of cattle experimented
Phase IV Engineering/ DVM Systems LLC	USA	TempTrak®	www.DVMSystems.com	Dairy: Animal health monitoring alerts Commercial Animal calving monitoring and alerts: Under development Animal ovulation prediction and confirmation: Under development Beef: Animal health monitoring alerts Commercial	Dairy Beef software: under development
HQInc	USA	AgriTemp™ (with CorTemp™ component)	www.hqinc.net Australian distributor (www.aesolutions.com.au)	Commercially available for use in the field. A Bluetooth data recorder with iPhone app currently in development	Dairy/Beef (feedlot)
CowTek Inc.		ETD Bolus™	Not available	Not available	
BellaAg	USA	BellaAg Temp® 3.0 Bolus BellaAg Temp® 3.0 Collector	http://bellaag.com	Commercially available for use in the field	Dairy/Beef
TenXsys, In/DHI Provo	USA	Smartbolus®	https://secure.dhiprovo.com/SmartBolus	Commercially available for use in the field	Dairy

Developers/ Manufacturers	Country	Name of product/device	Website	Stage of development and usage	Class of cattle experimented
Smaxtec Animal Care	Austria	Smaxtec	http://www.smaxtec-animalcare.com	Commercially available for use in the field	Dairy
Well Cow Ltd	UK	Well Cow™ bolus	http://wellcow.co.uk	Commercially available for use in the field	Mainly Dairy Applicable in Beef
eCow	UK	FarmBolus™	http://www.ecow.co.uk	Commercially available for use in the field	Dairy Beef (finishing)
		eBolus™		Experimental research only	Dairy
		eCollar		Under development	Dairy
Dascor Inc.	USA	LRCpH	www.dascor.com	Commercially available for experimental research in cannulated cattle and bolus style loggers for non-cannulated animals Remote wireless operation is in development	Dairy Beef (feedlot)
Vital Herd Inc.	USA	e-pill	www.vitalherd.com	Under development	Dairy Beef
Kahne Ltd.	NZ	Sentinel™	www.kahne.co.nz	Commercial/ Under development	Dairy Beef

Developers/ Manufacturers	Country	Name of product/device	Website	Stage of development and usage	Class of cattle experimented
SmartStock	USA	SmartStock™ bolus	www.smartstock-usa.com	Commercial/ Experimental research	Dairy Beef
DKKToa, Yamagata Co	Japan	YCow-S	Not available	Under development, will be commercially available in 2015r	Dairy

Table 6a. Description and functions of wireless rumen temperature and pH boluses

Products	Parameters measured	Location of device	Price/hd (AU$)	Battery life	Recording frequency
TempTrak®	Temperature	Reticulum	MSRP[1]/bolus: US $50 Anticipated/bolus: US $25 MSRP/receiver: US$2000 & Base Station: US$2000 Anticipated/ receiver: US$400 & Base Station: US$400	Estimated life is 3 to 5 years (60 minute bolus) Warranty: 1 year (4 months full warranty, balance prorated).	Standard: 60 minutes. Optional: 15 or 30 minutes
AgriTemp	Temperature	Rumen or implanted	Averages between $41/sensor to $315 depending on how long the farmers want the sensor in the body. Data Recorder: $2600/recorder RF Equipment to transfer data 9.14 line of sight: $2000	Anywhere from 7-10 days to 9 months	Anywhere from 10 seconds to 24 hours
BellaAg bolus	Temperature	Reticulum	Ranging from $45-$55USD depending on volume Collector Gateway software) USD $1178 additional collectors USD $579	5+ years	User defined ranging from 10 minutes to 30 minutes
SmartBolus	Temperature	Reticulum	No information available	No information available	96 readings per day
Smaxtec	Temperature pH	Reticulum	No information available	4 days- depends on the usage	No information available
Well Cow™ bolus	Temperature pH	Rumen	AUS $265/hd (£145) ex works; includes all necessary software, operating instructions and calibration materials Data Receiver linked to smartphones using Bluetooth) AUS $230 (£270) If needed a bolling gun that the Well cow bolus fits into, this will be supplied	~ 1yr provided by developers (100 days based on website)	15 min Data can be stored for 120 days. User can set the required frequency

Table 6a (continued). Description and functions of wireless rumen temperature and pH boluses

Products	Parameters measured	Location of device	Price/hd (AU$)	Battery life	Recording frequency
farmBolus	Temperature Rumen pH Redox	Rumen	£0.06 per cow per day (200 cows, 3 boluses every 4 months, 12 months). £700 for reader with antenna and software	18 months, but sensor life of 5 months	Data collected every minute and averaged over 15 minutes
LRCpH	**Standard/permanent:** Temperature pH (consumable) NH4+ (ammonium ion) (consumable/optional) OPR/Redox **Additional features on request: (Consumable)** Pressure (permanent) Ammonia (NH3) Nitrite (NO2-) Chloride ion Conductivity Dissolved oxygen	Reticulum-rumen	$USD 800-$1500 depending on model & commercial/university and quantity discount. This does not include field replaceable pH or ISE sensors (typically $160 each), or batteries ($15 each) Cost of retrofitable RF/Wireless adapter for cannulated loggers is anticipated ~ $300. Minimal added cost for new production loggers once the application has been field validated.	9-volt battery (batteries should be replaced if drop below 8 volts). Depends on usage, ~6 months to 1 year.	1/sec to 1/18 hours, user settable. Typical 5-min intervals for ~ 75 days of continuous logging of 3 channels.

Table 6a (continued). Description and functions of wireless rumen temperature and pH boluses

Products	Parameters measured	Location of device	Price/hd (AU$)	Battery life	Recording frequency
e-pill	**Initials features** Heart rate Respiratory rate Temperature, pH, VFAs (volatile fatty acids) Rumen contraction Lactic acid **Potential features** Microbial density Methane (CH4) Ammonia (NH3)	Rumen	No information available	No information available	No information available
Sentinel	Temperature pH	Rumen	$100/bolus	4-5 years	5min
SmartStock™	Temperature	Rumen	In quantity of 1,000 cows, the price per head is USD $35.0. One base station is needed per installation at USD $1,696; and as many receivers as required at USD $1,995 each.	Approximately 5 years at 60 minutes frequency	Standard is 60 minutes but it can be at the request of the customer.
YCow-S	pH Temperature	Rumen/Reticulum	Not available yet	~ 3 months whit 10 min sampling intervals.	10min

Note: The information provided in this table obtained either from companies' website or provided by the developer/manufacturer of technologies
[1] Manufacturer's suggested retail price (MSRP)

Table 6b. Sensitivity, specificity, accuracy and other parameters of wireless rumen temperature and pH boluses

Products	Validated externally	Research conducted	Publications	Application claimed
TempTrak	Validation of temperature accuracy, Calibration against rectal temperatures Ultra-sound and blood progesterone for reproductive cycle	Research conducted for illness (i.e., mastitis, metritis, pneumonia and milk fever), calving and breeding at several universities.	Peer-reviewed journals (JDS 96:1549-1555; http://dx.doi.org/10.3168/jds.2012-5822)	Core temperature, diseases, calving prediction, ovulation prediction and confirmation
AgriTemp	Yes	Yes	Thesis Peer-reviewed journals Proceedings abstracts	Oestrus and calving detection
BellaAg bolus	Has been verified against HOBO.	Research under way at University of Minnesota, University of Tennessee, Wageningen and LIC NZ (internal)	A paper to be published in 2014	Core boy temperature
SmartBolus	Limited information available	No information available	No information available	Animal health Feeding/drinking Behaviour Acidosis
Smaxtec	No information available	No information available	No information available	
Well Cow bolus	All pH probes are tested by our supplier in buffer solutions on a test bench	Customers have undertaken research programmes but Cow Well has not conducted internal research.	Proceedings abstracts	Core body Temperature Rumen pH
farmBolus	Yes	Yes	Proceedings abstracts, Peer-reviewed journal) in INRA France, Agroscope, Switzerland	Core body Temperature Ruminal acidosis
LRCpH	Yes pH Calibration is recommended pre- & post-trial to allow correction for sensor drift during the study	Extensive multiple research studies in different feeding systems in cattle (beef & dairy) and other species	Peer-reviewed on ruminal pH by the researchers	Cannulated: pH/temperature/ pressure/ORP/REDOX/ 2 ISE channels (e.g. NH4+, K+) Non-cannulated: pH & temperature or 1 channel ISE or ORP or Pressure & Temperature

Products	Validated externally	Research conducted	Publications	Application claimed
e-pill	No information available	No information available	No information available	No information available
Kahne Ltd.	No information available	Yes- extensive research in dairy herds and one in a feedlot operation	Proceedings abstracts & peer-reviewed papers on earlier generation of device	Performance Health Fertility Herd management
SmartStock	No, active when installed	Yes- extensive research has been conducted using SmartStock bolus- including one at QU	Proceedings abstracts & peer-reviewed papers	BVDV BRD
YCow-S	Yes, in control and acidosis-induced animals	Yes, a number of experimental research has been conducted in control and acidosis-induced dairy cows	Peer-reviewed journals	Ruminal acidosis (SARA)

NLIS: The **National Livestock Identification System** (**NLIS**) is **Australia's** scheme for the identification and tracing of livestock (www.nlis.mla.com.au; www.mla.com.au/Meat-safety-and-traceability/National-Livestock-Identification-System)

5.4 TempTrak®

The TempTrak® device has been developed by Phase IV (DVM Systems LLC) and has undergone experimental testing in dairy cattle. The device comprises a tiny passive RFID (Radio Frequency Identification) temperature sensor IC (Intelligent Component) that enables automatic daily temperature recording and permanent tamper-free animal identification for livestock (Figure 6). The company suggests that this device has the potential to quickly and accurately detect sick animals. The wireless temperature sensor IC is embedded in a specially-designed rumen bolus and requires no batteries. It resides permanently inside the cow and automatically measures a cow's core temperature. DVM Systems LLC claims that providing advance alerts of critical changes in temperatures may allow early detection of sickness, oestrus, heat stress, and the onset of calving.

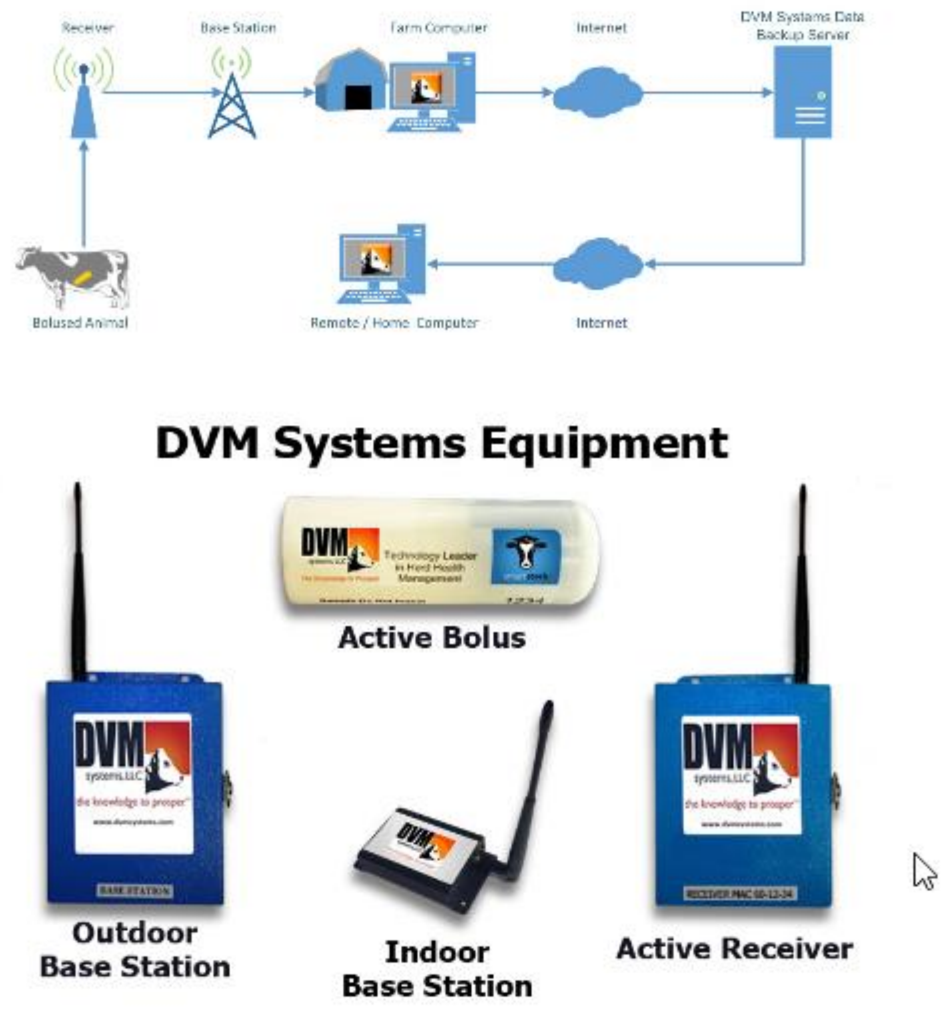

Figure 6. TempTrak® bolus for recording reticulum temperatures (distributed by DVM Systems LLC; www.DVMSystems.com)

The DVM Systems hardware consists of the following items:

- Rumen boluses
  - The bolus logs the last 12 readings and transmits data up to 91.4 meters to a receiver
  - Each bolus has a unique identification that is associated with the animal's ear tag
- Base Station
  - Indoor or outdoor models
  - Obtains information from receivers and forwards information to a computer with TempTrak® software
- Receivers
  - Weather proof enclosure
  - Operates on either AC power (120 or 240 VAC) or solar (12 VDC)

The Phase IV dairy cow monitoring system automatically monitors each cow's temperature and identification as it enters the milking parlour, two to three times per day. The system consists of a bolus, equipped with a passive RFID chip (Phase IV's SensIC™) and an integrated temperature sensor (battery-free), and a Dual Fixed Reader for collecting temperature data from the bolus.

The bolus is read by a Dual Fixed Reader (DFR). The DFR consists of two panels mounted at the entry to the milking parlour. As cows pass the reader, a magnetic field induces a small electrical charge inside the bolus, sufficient to energize the transmitter. The bolus responds to this interrogation signal by transmitting its globally unique identification number and temperature on a coded radio-frequency. Alarms for high-temperature readings can be triggered, enabling early detection and immediate action. Once the DFR collects the information, the information is sent via Ethernet or Wi-Fi to user or third party applications. Alarms for high-temperature readings can be triggered, enabling early detection and immediate action. This application mines this data to identify livestock that are potentially ill and facilitates early intervention in health management. The rumen bolus is encapsulated in FDA and USDA approved materials. It therefore provides tamper-proof identification tracking and temperature sensing for the entire lifespan of the animal.

The information provided by DVM Systems on the impact of feedlot structure and environmental factors indicate that the large pens may need additional receivers. The approximate coverage is estimated to be suitable for pens with 70m x 20m areas. The distance and near or clear line of sight from the receiver to base station and the topography can influence performance measurements. A higher intensity (number of animals) per pen will necessitate additional receivers. Conservative receiver coverage is approximately 70 x 20m with low to medium density of animals per pen. With an extreme density of $9m^2$ per animal, one receiver for every 15m is recommended.

Changes in environmental temperature will not influence the measurements, although extremely high winds could impact the performance of the receivers. There is also a remote possibility that a wireless signal (between the receiver and base station) may not penetrate through a high volume of water (i.e. rainfall of 5 to 7mm in a short time period).

Table 7. Assessment of TempTrak® rumen bolus

<table>
<tr><th>Features</th><th></th><th>Evaluation
(Strengths & Weaknesses)</th></tr>
<tr><td>Feasibility in commercial feedlots</td><td>Trialled in dairy herds and feedlot operations</td><td rowspan="5">Initially developed for dairy cows, and then extended to beef. The software for beef sector is under development

Strengths:

The device has been externally validated
The Se and Sp have been determined
Customised technical support
Supported by research studies published in peer-reviewed journals
Estimate battery lifetime: 3-5 years (with 60min sampling frequency)

Weaknesses:

Low Se and Sp
Rumen pH cannot be measured
Can’t be used for the detection of nutritional disorders such as acidosis
It has not been experimented in commercial feedlots</td></tr>
<tr><td>Sensitivity</td><td>77%
Cows with clinical mastitis had 6.7 times higher odds of having an increase in reticular temperature ($P < 0.001$).
Cows diagnosed with pneumonia had 7.5 times higher odds
of having an increase in reticular temperatures ($P = 0.0047$)</td></tr>
<tr><td>Specificity</td><td>67%</td></tr>
<tr><td>Accuracy</td><td>Accuracy: ±0.28°C,
Repeatability: ±0.1°C,
Resolution: 0.06°C
Optionally, calibrated to finer specification at additional cost</td></tr>
<tr><td>Reliability and durability</td><td>The hardware is</td></tr>
</table>

Features		**Evaluation (Strengths & Weaknesses)**
	durable, water and dust proof and will be operational for many years (i.e., 5 – 10 years). The collected data is securely backed up on DVM Systems server.	
Required skills for implementation and data collection	Data from TempTrack® software can be transferred into Excel (csv) or other statistical software	
Technical support	Dealer provides tier 1 & II (price is dealer dependent). Tier III is provided from DVM Systems to dealer	
Required resources and software programs	Windows 7 or newer, high speed internet is ideal	
Data storage and processing	100 MB storage is minimal, i5 processor or higher (ideally an i7 processor)	
Internet requirement	Ideal minimum of 1.5 Mbps down, 0.500 Mbps up	
Potential compatibility with NLIS	High, will not be an issue	

5.5 AgriTemp™

The CorTemp™ product line is for humans and the AgriTemp™ is a wireless temperature sensor for animals (www.hqinc.net). Most researchers may know the device as CorTemp™. They use the same data recorder, but different size sensors are used for animals. The animal sensors can be swallowed and placed in the rumen or implanted. It depends on the animal and how long the researcher wants to keep the sensor inside the animal (this determines battery size).

AgriTemp™ (www.hqinc.net/agritemp) uses HQI's Core Body Temperature Monitoring System (CBTMS) to record information necessary for the detection and treatment of heat related illness (Figure 7). As animals graze, temperature is recorded and herd managers are alerted when the animal's temperature becomes too high. The AgriTemp™ physiological monitoring system features an ingestible AgriTemp™ thermometer sensor and a CorTemp™ data recorder, which delivers time-correlated core body temperature accurate to ± 0.1 ºC. The AgriTemp™ system consists of an ingestible bolus (the bolus houses a temperature sensor, low-power RF transmitter, and power source capable of providing up to nine months of power) and a receiver unit for monitoring temperature in livestock (Nagl et al., 2003). AgriTemp™ has the potential to be used for monitoring changes in body temperature that may be critical to animal productivity.

5.6 CowTek™

The ETD Bolus™ system (CowTek™ Inc., Brule, NE) consists of a rumen bolus, a desktop or long range exciter, receivers (each monitor up to 91.4m away), and a PDA or computer for data collection and analysis. It provides temperature readings as frequently as every 30 minutes (Schutz and Bewley, 2009). CowTek™ Inc. has also developed the ISO memory tag system for the identification of individual cattle records that can be used in database management systems for the livestock industry. The ETD temperature bolus is used as a measuring tool to monitor cattle for changes in their behaviour. Available information about this technology was limited and prevented a full exploration of the features of this device.

5.7 BellaAg®

The BellaAg® cattle temperature system® allows dairy farmers to monitor cattle temperature wirelessly with automatic alerts for consistent high or low temperatures. BellaAg® claims the BellaAg® bolus can be used to improve overall herd health, detect illnesses three to five days sooner, improve oestrus detection, increase milk production, reduce treatment costs, reduce mortality rates, and improve production efficiency.

The BellaAg® 3.0 system rumen bolus system is 2.5cm in diameter and 9.0cm long. The system contains i) a temperature bolus, ii) data collector and iii) data receiver and iv) temperature software (Figure 8). A wireless gateway is required to transmit the data to the herd manager's computer. The company offers different models allowing the herd manager to choose which gateway works best for his or her operation. The software treats each cow as an individual by gathering all the temperature information collected, identifying each cow's normal range, and then generating an exception list comprised of just those animals that require attention.

Figure 7. AgriTemp™ (CorTemp™) sensor and core data recorder, long range RF remote transmission (Source: www.hqinc.net/agritemp)

Table 8. Assessment of AgriTemp™ rumen bolus

Features	**Description**	**Evaluation (Strengths & Weaknesses**
Feasibility in commercial feedlots	Yes	**Strengths:** Free technical support Potential use of iPhone apps (under development) Supported by peer-reviewed papers and a postgraduate thesis **Weaknesses:** Limited information about the technology The Se and Sp have not been determined Limited battery lifetime It can only be used for rumen temperature Rumen pH cannot be measured Can't be used for rumen acidosis and other nutritional disorders No information if it can be compatible with NLIS
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	± 0.10 °C	
Reliability and durability	Data Recorder has 5-year shelf life	
Required skills for implementation and data collection	Minimal	
Technical support	Available and free	
Required resources and software programs	Software free with data recorder purchase	
Data storage and processing	Data Recorder saves data for later download	
Internet requirement	Internet required for software download	
Potential compatibility with NLIS	To be determined	

The user can configure the sampling frequency (to take as many readings as they wish). At a rate of 96 reads per day, the bolus has a 5 year life. For optimum data collection, the BellaAg® 3.0 system data collector is positioned in a high traffic area (above a holding pen or water source.) The data collector is well sealed to protect it against failure in almost any environment. It is also equipped with a solar power kit. The BellaAg® bolus 3.0 system allows the herd manager to control the amount of data that is received. Using the Bella TempSoft software, the herd manager can set the number of samples taken daily and how often the data is uploaded to the data collectors. For example, the factory default has the bolus take a temperature sample every 15 minutes (96 temp samples in a 24 hour period) and uploading the data to the collector every 8 hours. This can be altered to taking a sample every 20 minutes (72 temp samples in a 24 hour period) and uploading every 12 hours.

5.8 SmartBolus®

TenXsys Inc. technology has been used by DHI-Provo to develop a SmartBolus® which records the internal body temperature in a cow's reticulum as well as motion activity within the reticulum. The data are transmitted from inside the cow to a nearby computer. The TenXsys wireless air temperature sensor gathers air temperature information from a pen or barn, and transmits this data to a computer running the TenXsys bovine health system. The DHI-Plus® temperature and motion software program, developed by DHI-Provo, is then used to analyse the data and provide management alerts for cows with high or low temperature and high or low activity (https://secure.dhiprovo.com/SmartBolus). The SmartBolus® rumen bolus is able to collect temperature (96/day) as well as motion information throughout the day. The data are transmitted wirelessly back to the dairy computer where reports are generated to show exception conditions. The system will monitor the temperatures of cows throughout the day, alerting farmers or veterinarians when a cow's temperature is not normal and also providing heat detection. This device is predominantly used for monitoring, collecting and communicating animal health, temperature, oestrus, motion, eating and drinking patterns and other physiologic information about cattle, such as calving. We approached DHI Provo (https://secure.dhiprovo.com/SmartBolus) to obtain further information on this technology, but were not successful; therefore, our assessment of SmartBolus® is solely based on information provided on their website (Table 10).

Figure 8. BellaAg® rumen bolus and data collector (Source: www.bellaAg.com)

Table 9. Assessment of BellaAg® rumen bolus

Features	Description	Evaluation (Strengths & Weaknesses)
Feasibility in commercial feedlots	Designed for dairy herds	**Strengths:** Battery life time: 5+ years User-defined recording frequency (10-30min) Potential compatibility with NLIS **Weaknesses**: Not validated externally No information on Se and Sp Only measures rumen temperature Rumen pH cannot be measured Cannot be used for the diagnosis of ruminal acidosis and nutritional disorders Minimal technical support Limited research projects There is no published studies in peer-reviewed journals Primarily developed for dairy cows, but can be used for beef feedlots It has not been experimented in feedlots
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	±0.10°C	
Reliability and durability	Very ruggedized	
Required skills for implementation and data collection	Knowledge of administering pill to bovine, Mounting hardware, basic PC skills	
Technical support	Minimal but is always available	
Required resources and software programs	Windows 7 or greater	
Data storage and processing	5Gb of Hard drive space dual core processor and 2 Gigs of RAM (4+ is preferable)	
Internet requirement	No but is helpful when trouble shooting	
Potential compatibility with NLIS	Potentially with some modification	

Table 10. Assessment of SmartBolus® rumen bolus

Features	Description	Evaluation (Strengths & Weaknesses)
Feasibility in commercial feedlots	Developed for dairy herds	The lack of information limited our ability to explore the features of SmartBolus® device **Strengths** **Weaknesses**: Not validated externally No information on Se and Sp Can only be used for measuring rumen temperature Developed for dairy cows No information available if this has been trialled in feedlots No information on price Limited information on technical support, resources required, etc.
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	Not provided	
Reliability and durability	Not provided	
Required skills for implementation and data collection	Not provided	
Technical support	Not provided	
Required resources and software programs	Not provided	
Data storage and processing	Not provided	
Internet requirement	Not provided	
Potential compatibility with NLIS	Not provided	

5.9 SmaXtec®

SmaXtec® pH rumen bolus is able to monitor and record pH and temperature levels in the cow's rumen at 10 minute intervals (Figure 9). SmaXtec® device can also estimate daily water intake. The bolus is 132 x 35 mm (length x diameter) and its measuring range is 0 to 14 pH (values indicated between 4 and 8 pH), 25 °C to 50 °C. Measuring interval is variable (standard is 10 min) and measuring accuracy is ±0.2 pH, ±0.2 °C for a period of 50 days. The material used for manufacturing the bolus is resistant to rumen fluid (www.smaxtec-animalcare.com). The estimated pH measurement correlation coefficient is 0.999. The data generated by SmaXtec® bolus can be received by a SmaXtec® mobile reader (battery life is maximum 4 days- depending on use) or by SmaXtec® USB antenna and transferred to the SmaXtec® base station. The base station should be mounted in the cow shed and constitutes the central device for the system (Figure 9). The measured pH and temperature can be transmitted via internet connection to a SmaXtec® server, which can be accessible at any time.

The SmaXtec® pH bolus needs to be calibrated once, but there is no need for recalibration before each measurement. After insertion, the bolus is retained in the reticulum and is therefore inaccessible. It is important that cows have an empty stomach when the bolus is administered. If the sensor tip becomes filled with food particles immediately after insertion this can cause the sensor tip to become blocked a few days later, thereby disrupting pH measurement. The published data using SmaXtec® are from experimental research. It appears that the device hasn't been fully trialled in commercial herds. The experiments have predominantly focussed on rumen pH, and less effort has been made to establish an association between reticulum temperature and animal health.

Figure 9. Smaxtec® rumen bolus, mobile reader and base station (Source: www.smaxtec.com)

Table 11. Assessment of SmaXtec® rumen bolus.

Features	**Description**	**Evaluation (Strengths & Weaknesses)**
Feasibility in commercial feedlots	Developed for dairy cows	**Strengths**
Sensitivity	Not provided	Can measure both rumen temperature and pH
Specificity	Not provided	
Accuracy	Temp: ±0.2 pH: ±0.2	
Reliability and durability	Not provided	**Weaknesses**
Required skills for implementation and data collection	Not provided	No information on Se and Sp
Technical support	Not provided	Limited or no information on device parameters
Required resources and software programs	Not provided	Developed for dairy cows Limited battery lifetime (50 days)
Data storage and processing	Not provided	No information on prices
Internet requirement	Yes, to transfer the Temp and pH data	No information on supporting research and publication
Potential compatibility with NLIS	Not provided	

5.10 Well Cow™

Well Cow Ltd, a UK based SME company, has developed the world's first automated, long-term measurement device for monitoring pH and temperature in dairy herds (Figure 10). The bolus is inserted orally and remains in the rumen, wirelessly relaying data on the internal temperature and pH at intervals of 15 minutes. The bolus can remain active in the cow's rumen for up to 100 days. (http://wellcow.co.uk). The bolus is 3.2 x 14.5 cm (width and length) and can measure rumen temperature and pH within 4 to 7 pH range (± 0.3) every 15 minutes with a target life of 80-100 days. The device has an allowable manufacturing tolerance of -18mV to +18mV at pH7 (a perfect probe should read 0 millivolts) and pH4 should read between 168mV and 186mV (perfect probe should read 177.8mV). There is currently no compensation built in to the app or server to account for drift over time.

The acquired data is downloaded wirelessly via a 'receiver' to a computer. The reader needs to be within about a metre of the animal, and then the data is transmitted from the bolus into the computer or laptop. If pH levels are not right, an alert will indicate the need for attention. The bolus can store data for 120 days but the manufacturer recommends that data be downloaded every few days, depending on specific requirements (Malcolm Bateman- Well Cow; Per. Com.; June 2014).

Figure 10. Well Cow bolus, calibration materials and the data reader (Source: http://wellcow.co.uk)

Within the current operating instructions; Well Cow suggests that after the calibration process is completed and before insertion, users should perform a 'get status' check with the bolus placed in one or both of the pH buffers supplied. They can then check that the calibrated pH value is close to the buffer value and/or validate the bolus using a pH meter. During the assembly process Well Cow uses an automated test rig which each manufactured bolus is tested on. Tests include radio performance, pH 'sanity' check and temperature value check. They also check the battery strength on each bolus to ensure there has not been any inadvertent battery leakage. The Well Cow pH/temperature bolus should be used to monitor changes over time as a specific reading at any point of time is not in itself an indicator of acidosis. Trends are more useful as pH levels fluctuate continuously during any 24 hour period.

A new communication system has been developed in partnership with Ziconix (www.ziconix.com.au) to automatically collect pH and temperature data from the bolus via a rugged reader and transmit it to a smart device, such as a smartphone or tablet computer, which can be kept away from the animal for security. In turn, this connects to a wide area network and onto the cloud so that the data can be analysed remotely by herd managers, veterinarians, or nutritionists. These new readers will be available commercially in late 2014.Well Cow™ also intends to develop a Reduction-Oxidation (Redox) bolus for automated detection and measurement of other health and disease markers. No further updates on these innovations have been provided.

Table 12. Assessment of Well Cow™ rumen bolus

<table>
<tr><th>Features</th><th>Description</th><th>Evaluation
(Strengths & Weaknesses)</th></tr>
<tr><td>Feasibility in commercial feedlots</td><td>Developed for dairy herds, but can be implemented in feedlot operations</td><td rowspan="11">Developed mainly for dairy cows
Potential application in beef

Strengths

User-defined recording frequency
Can measure both rumen temperature and pH

Weaknesses

Limited battery lifetime (~ 1 year)
Supported by users' research projects
Data have only been published in conference proceedings
No information on Se and Sp
The device has not been externally validated
It has not been experimented in feedlots</td></tr>
<tr><td>Sensitivity</td><td>Not provided</td></tr>
<tr><td>Specificity</td><td>Not provided</td></tr>
<tr><td>Accuracy</td><td>±0.3</td></tr>
<tr><td>Reliability and durability</td><td>Operates reliably for ~ 100 days after which time the user would see the readings starting to drift as the glass sensor within the bolus starts to corrode from being constantly immersed in the rumen liquor.
pH monitors are normally used to sample test liquid not to leave immersed for any length of time hence the corrosion that takes place.</td></tr>
<tr><td>Required skills for implementation and data collection</td><td>Knowledge of smartphone technology and spreadsheets.

Qualified person needed to deploy the bolus into the cow in the same way medicinal boluses and magnets are deployed</td></tr>
<tr><td>Technical support</td><td>Available from the company by telephone and/or email</td></tr>
<tr><td>Required resources and software programs</td><td>Smartphone with Android system.</td></tr>
<tr><td>Data storage and processing</td><td>Data is stored by web server that can be accessed using passwords to access the data from the internet/Cloud</td></tr>
<tr><td>Internet requirement</td><td>Yes
Cellular works fine if no Wi-Fi is available at the farm. It depends on what the cellular connection is like. All bolus data is buffered until such time as the phone comes into range of a decent network connection and</td></tr>
</table>

Features	Description	Evaluation (Strengths & Weaknesses)
	therefore even if cellular coverage was patchy around most of the farm, as long as they could get it to a good position at some point then the data should go through ok.	
Potential compatibility with NLIS	Would not anticipate any problems; the Well Cow system requires the user to identify and reference the cow being bolused with a specific bolus number.	

5.11 farmBolus & eBolus (eCow™)

The eCow Ltd (www.ecow.com) company has developed a number of technologies for dairy cow health monitoring. eCow's products are farmBolus™, eBolus and eCollar. The boluses are used with existing handsets and software to monitor rumen pH and temperature. The eCow package consists of:

- The Samsung Galaxy S2 handset and eCow Hathor software
- Protective exterior casing for the handset
- Antenna matched to bolus frequency

Figure 11. farmBolus and eCow handset (Source: www.ecow.com)

The farmBolus (£700) is eCow's bolus for ruminal pH and temperature monitoring and is designed for use on commercial dairy farms. It gives 5-6 months of continuous pH readings with 28 days of data storage (Figure 11). The farmBolus is designed for herd managers, veterinarians, and nutritionists. The farmBolus sensor is weighted to stand upright in the rumen, which gives the optimum immersion of the pH sensor, which may provide better accuracy. Data is stored on the bolus then downloaded to the eCow handset and uploaded to the server, which can be viewed using the data viewing software. The bolus has auto power off when it is outside of the animal to preserve the battery life.

Smartphone & Software Bundle- The handset, software and antenna enable farmers to download, store and send data via 3G or Wi-Fi. The handset is a Samsung Galaxy S2 with the latest Hathor™ software pre-loaded on to the device. The software enables data downloads, configuring of the bolus device, and graphic visualisation of the data.

The eBolus provides the same features as the farmBolus but it is more suitable for researchers. Two series of eBolus are available: i) 900 GBP models measures rumen pH and temperature, and ii) 1112 GBP model measures rumen pH, temperature and redox (Figure 12). The eBolus is mainly designed and used for experimental research, and has additional features, such as i) redox measurement as well as the pH and temperature measurements, ii) the bolus can be re-calibrated as many times as necessary to lengthen life for as many uses as necessary, iii) software is specifically designed for research allowing parameters such as monitoring intervals for maximum flexibility, iv) data is sent directly to the database, v) auto-off function when bolus is outside of the animal for maximum shelf life, and vi) built in hook for ease of retrieval and storage.

Figure 12. eBolus rumen (Source: www.ecow.com)

eCollar is a new device under development by eCow for monitoring and detecting lameness in dairy cows. No data is currently available.

Table 13. Assessment of farmBolus rumen bolus

Features	Description	Evaluation (Strengths & Weaknesses)
Feasibility in commercial feedlots	Developed for dairy herds	Developed mainly for dairy cows Can be used in finishing feedlots **Strengths** It can measure rumen temperature, pH and redox Supported by published research studies in peer-reviewed journals **Weaknesses** Limited battery life No information on Se and Sp eCow claims that the device has been externally validated, but there is no published report and data to support this claim Limited information about the specific parameters of device It has not been experimented in feedlots
Availability		
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	±0.10	
Reliability and durability	Good	
Required skills for implementation and data collection	Implementation with standard bolus gun. Reading data needs to be shown or video shown but fairly easy once understood	
Technical support	Available directly from the developers	
Required resources and software programs	Client software for PC or laptop and handset comes pre-loaded with software	
Data storage and processing	On company's server	
Internet requirement	Yes, Wi-Fi is required to get data back to eCow's server, but data can be shown on screen of PC or handset	
Potential compatibility with NLIS	Not applicable	

5.12 LRCpH (Dascor™ Inc.)

Dascor™ Inc. has designed and developed Lethbridge Research Centre pH (LRCpH) system, which is an autonomous data logger specifically for use in ruminal pH research. The LRCpH system is a stand-alone, submersible data logger that can be used to record pH, temperature, oxidation-reduction and potentially oxidative-reduction reaction (ORP/Redox) in the rumen of cattle. The system is placed in the rumen through a rumen fistula. The design of this device makes it water tight and impervious to the harsh conditions in the rumen. The system comes with a data logger, a 9-volt battery, and a long-use pH electrode. The capsule is weighted down to keep the sensor positioned in the ventral sac of the rumen. A cable connects the capsule to the rumen plug for easy retrieval (www.dascor.com). Data depth (memory) depends on the model and trial setup, but under typical usage will provide more memory than is utilized during a trial.

All logger designs are driven by the requests and requirements of the end users for form, fit, and function, with a primary requirement for field-replaceable sensor suites and batteries, which would otherwise severely limit the cost-effectiveness of the loggers. The remote wireless monitoring version of LRCpH has been evaluated and is expected to be demonstrated in 2014-15, along with a major new release of software (William "Kelly" Borsum; per com. June 2014).

The accuracy and precision of the LRCpH system, relative to manual sampling, has been evaluated by Penner et al. (2006) and the LRCpH has been used to measure ruminal pH in transition Holstein heifers (Penner et al., 2007). The standard form of Dascor™ LRCpH contains a consumable pH sensor that is manufactured by Sensorex Inc. Other sensors are normally mounted permanently to the logger, including temperature and ORP/Redox sensors. There are four large holes in the electrode shroud to allow free movement of fibrous rumen materials past the sensor. The shroud also keeps the sensor end from pressing against the rumen wall and prevents fibrous materials building up at sensor end. A pre-formatted Excel worksheet is used to record and store LRCpH data. The pH and ORP/Rodex sensors are required to be calibrated using pH 4 and 7 buffers and deionised water, respectively. (Note: the pH sensors are limited by the specifications common to any pH sensor using the KCl/Ag/AgCl electrolyte system. NaCl sensors are available for use with K+/NH4+ ISE sensors to help with K+ cross- sensitivity issues).

LRCpH is considered a reliable and durable rumen pH sensor, which can function for more than 10 years without a major drift. Materials used in the sensor construction are all rated for extended temperature ranges and harsh target environments. Body materials include surgical grade stainless steel and various engineering thermoplastics. All bolus type loggers currently in the field have been factory upgraded to the current standard design and now allow field upgrades to the firmware. Field replaceable pH and ISE sensors include glass and plastic components. The pH sensor lifetime is the single most limiting factor in logger usage. The lifetime can vary widely depending on conditions in the rumen, and proper handling and storage by the user.

LRCpH system has been predominantly used for experimental purposes using fistulated cattle to test the impact of different nutrition on the ruminal environment. There is limited information about the use of this device in commercial feedlot operations. The LRCpH manufacturer intends to develop a wireless and smaller version of the bolus with more features (William "Kelly" Borsum; pers comm, June 2014).

Figure 13. Illustration of the LRCpH measurement system in unassembled (left) and assembled (right) forms (Source: www.dascor.com)

Table 14. Assessment of LRcPH rumen bolus

Features	**Description**	**Evaluation (Strengths & Weaknesses)**
Feasibility in commercial feedlots	The current version of device has been trialled for beef research.	The current version is suitable for experimental research. Note: Dascor™ indicated that they are current developing a smaller and wireless device (under development). **Strengths** The device has externally been tested and validated. It can be collected and reused It can measure a wide range of rumen parameters More suitable for experimental projects User-define sampling frequency A number of peer-reviewed publications by researchers
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	±0.005 Limited only by accuracy of calibrations performed, and consistency in correcting pH for drift.	
Reliability and durability	Highly reliable, Materials used in construction are all rated for extended Temp ranges and usage in harsh target environments. (See text for details)	
Required skills for	All software, setup and	

Features	Description	Evaluation (Strengths & Weaknesses)
implementation and data collection	calibration functions are intended to be intuitively obvious to a reasonably competent individuals.	**Weaknesses** No information on Se and Sp Device is very large and bulky It is only used in fistulated cattle for research The current version of device is not suitable for commercial feedlot operations Limited battery life, depends on the usage It has not been evaluated in commercial feedlots
Technical support	On-line or phone support is available. User's Guides, software manuals, Quick Start Guides, and free download of all software and other upgrades. Users' subscription to the Dascor™ Newsletter is essential for support.	
Required resources and software programs	Microsoft XP-Pro or later, including a USB or RS-232 Serial Com Port. Dell laptops are known to have interface problems and are not recommended. Calibration solutions for pH=4 & 7, an optional water bath are provided.	
Data storage and processing	Data is stored in non-volatile memory, and is overwritten only when a new trial is started.	
Internet requirement	Not for normal operation, but required for remote software installation, training and diagnosis, online support, software downloads.	
Potential compatibility with NLIS	A field is provided (64 characters) for entry of user data and test ID information. This can be increased or modified as needed in future software releases. The required modification of software can be done to comply with NLIS on request.	

5.13 e-pill (Vital Herd)

Vital Herd Inc. (www.vitalherd.com) has developed an e-pill, an electronic rumen bolus, which can capture individual animal information in a non-invasive and practical way. Vital Herd aims to become commercially operational in late 2014, and supply the e-pill device to producers. The Vital Herd alpha prototype of the e-pill is 5 x10 cm (width and length), but the final commercialised product is expected to be smaller. The e-pill rumen bolus is swallowed by a cow and enters its rumen, staying there for the animal's lifetime. While inside the rumen, the e-pill automatically captures real-time vital signs data and transmits the information remotely. The bolus is designed to highlight vital sign issues at an early stage through wireless transmission to a receiver. The technology relies on a proprietary acoustic method for measuring certain vital statistics and the company claims that the device has passed initial tests in a live cow. The unit is able to provide data to a remote computer, to be analysed for diagnostic purposes at an earlier stage than is currently possible.

Information obtained from Vital Herd's developers' statement in the media shows that the e-pill may be able to non-invasively and practically capture individual animals' heart rate, respiratory rate, temperature, pH, individual volatile fatty acids, rumen contraction and lactic acid concentrations. The product also has the potential to capture data relating to microbial density, methane, ammonia levels, and other potentially useful parameters. If Vital Herd can materialise what they describe in their statements, there is currently no other technology that can compete with the range of features that the e-pill offers, while matching the low cost. The price of Vital Herd's e-pill is estimated to be US $40 per head per year for dairy cattle, which is relatively low compared to existing technologies (information obtained in July 2014; www.agra-net.net). To date, there is no published data (journal paper or reports) to support the manufacturer's claims. The developers were unsuccessfully approached to obtained further information; therefore, we will not be able to fully evaluate this technology.

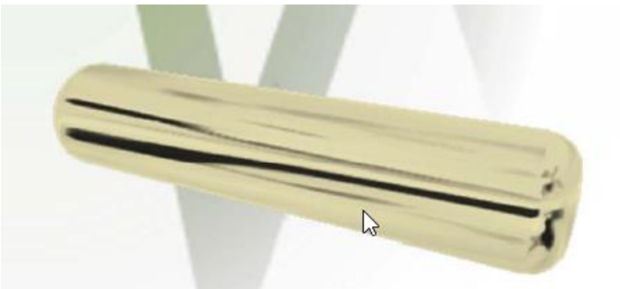

Figure 14. e-Pill rumen bolus (www.vitalherd.com)

5.14 Sentinel™

Kahne Limited is a New Zealand agritech company that has developed, manufactured and distributed a wireless biotelemetry-based intra-rumimal bolus, Sentinel™, for dairy and beef enterprises. Kahne's patented Sentinel™ rumen monitoring system was introduced in 2013 and has successfully completed data collection over an entire season from about 2,000 bolus units. Information and feedback from field use drives ongoing development. The bolus or capsule device resides in the dorsal sac of the rumen. The bolus houses electronics that generate continuous measurements of parameters, including rumen temperature and pH, with a lifetime of up to 5 years. The data are downloaded automatically and wirelessly to the 'Sentinel reader' each time the animal enters the milking shed or approaches a designated area in the pen or paddock, and then transferred automatically to Kahne's servers. The data are then quickly analysed and returned within seconds to the farmer or advisor via in-shed and text alerts. Daily and weekly online farm management reports are available for farmers and their advisors to allow them to continually manage animals based on their rumen function. The key areas of expected benefit from using Kahne's Sentinel™ rumen monitoring system are improved performance, better animal health, more effective reproductive management and simplified herd and system management. The accuracy and precision of the Sentinel™ bolus has been evaluated in a number of scientific institutes. The Sentinel™ rumen bolus has been used for an entire season in the New Zealand dairy industry, and has been trialled on commercial feedlots in New Zealand and the world's third largest cattle feeder in Mexico.

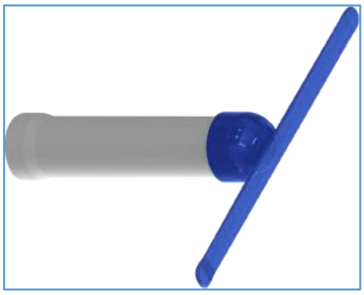

Figure 15. Sentinel™ rumen bolus for monitoring rumen pH and temperature (Source: www.kahne.co.nz)

In order to retrieve information from the Sentinel™ bolus the antenna should be positioned between 5 to 20 metres away from the animals. Depending on the size of the pens, the number of antenna may differ to suit the data capture requirements and animal behaviour. The number of feed and water troughs, age of animals, and number of pens doesn't affect the Sentinel system. The system is designed to cope with all size feedlots regardless of the number of pens.

Sentinel™ rumen bolus will be able to assist feedlot operators to manage rations fed to the animals, and the type of ration or ingredients will not affect the measurement of rumen temperature and pH using Sentinel™ rumen bolus. Kahne Ltd claims that environmental factors (e.g. rain, winds) or the density of cattle will not influence the operation of the Sentinel system; however, no data is provided to support these claims.

Table 15. Assessment of Sentinel™ rumen bolus

Features		**Evaluation (Strengths & Weaknesses)**
Feasibility in commercial feedlots	Yes. The Sentinel system has been adapted for both dairy and beef configurations.	Bolus is designed to reside in the dorsal sac of the rumen. **Strengths** Both rumen temperature and pH can be measured The flexible wing structure is designed to retain the bolus within the rumen Dataset from 2,000 boluses,> 150 million rumen data points, with a number publications in conference proceedings Can be used in both dairy and beef herds. Extended battery life (~ 5 years) **Weaknesses** Se, Sp and accuracy of the device have not been determined. The current version of device has not been tested or validated externally
Sensitivity	Not provided	
Specificity	Not provided	
Accuracy	Not provided	
Reliability and durability	Target lifetime up to 5 years	
Required skills for implementation and data collection	Apps and reporting automatically deliver required actions to the farm / feedlot management.	
Technical support	Provided	
Required resources and software programs	Analysis of data is provided Data is uploaded automatically to Kahne's servers where nutritional and health algorithms are applied. Farm	

Features		Evaluation (Strengths & Weaknesses)
	and feedlot management can retrieve analysis through dedicated apps, the web portal, email and/or SMS.	
Data storage and processing	Data is stored for the life of the animal in the Kahne system; Bolus can store data locally for up to 280 days	
Internet requirement	Connectivity through a dedicated internet connection or GSM.	
Potential compatibility with NLIS	Yes	

5.15 SmartStock™

SmartStock™ has designed a rumen bolus that specifically monitors the health of dairy cows. The bolus is an active RFID transmitter that will transmit an RF based signal up to about 90 m to an integrated database system. The database system links to the owner's herd management program. The rumen temperature is monitored and on a regular basis this data is transmitted to the database along with a unique animal ID. The provided software will ensure the physiological state of all cattle is always known. Animals with values that fall outside of preset value ranges for physiological conditions will immediately trigger an alert to the operator.

Figure 16. SmartStock™ rumen bolus temperature, applicator and base station receiver (Source: www.smarkstock.usa.com)

The base station receiver allows communication to the computer via a serial line from all the field receiver/repeaters that are accepting information from all animals with a bolus. The receiver/repeaters are placed strategically around the dairy, feedlot or grazing pasture, and with peer-to-peer networking are connected to a common database. One system with multiple receiver/repeaters can easily outfit an entire feedlot comprised of over 100,000 cattle.

A pole mount assembly allows for the receiver/repeater to be mounted in a variety of locations and configurations. It can use different antenna configurations. It allows for solar setups. It can be mounted next to a fence or as a stand-alone feature. The pole mount assembly is completely flexible. The solar charging kit will convert power for the TTI00058 receivers when AC line power is not available. The kit includes all mounting brackets, including: antenna mounting hardware, enclosure mounting hardware, battery mounting hardware, power connection cables, 10 mW solar panel and solar charger.

SmartStock™ has a special system in place to send alerts to promote awareness to any illness or adverse health events, and the rumen bolus has the potential to be used to predict oestrus and parturition. Rose-Dye et al. (2011) conducted an experiment in feedlot cattle to monitor and validate the rumen temperature measured using Smartstock™ bolus and rectal temperature in beef cattle exposed to bovine viral diarrhoea virus (BVDV) and challenged with a common BRD pathogen, Monnheimia haemolytica (MH). This research showed that SmartStock™ rumen bolus provided temperature results that were highly correlated with rectal temperature (r^2=0.80), and morbid animals that were identified by visual signs were supported by rectal temperature measurements. This study reported high sensitivity and specificity for SmartStock™ bolus for the diagnosis of BRD in challenged animals (98%).

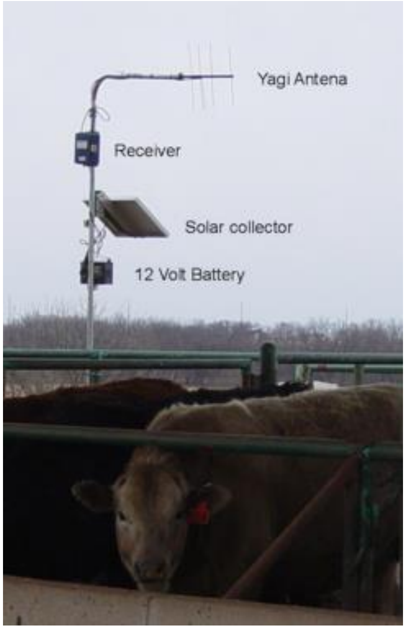

Figure 17. SmartStock™ solar receiver (Source: www.smartstock.usa.com)

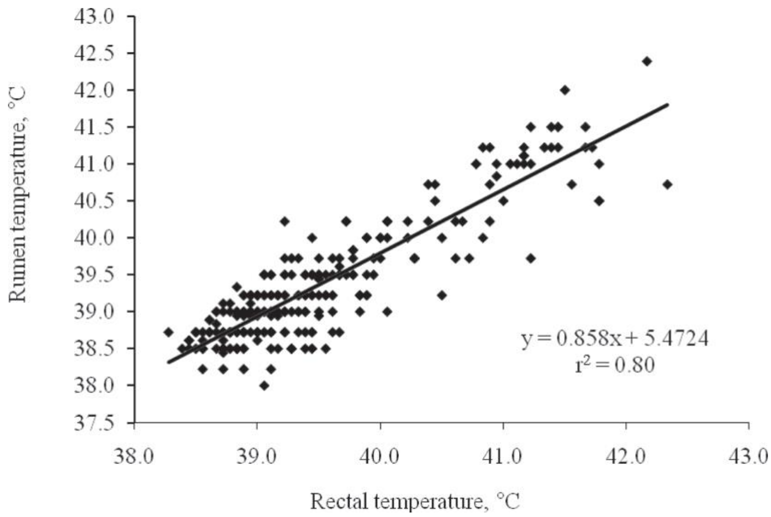

Figure 18. Regression of paired rumen and rectal temperatures taken at 0 and 2, 4, 6, 12, 18, 24, 36, 48, 72, and 96 h following *Mannheimia haemolytica* challenge. Rectal and rumen temperatures were paired for each animal and sampling time by recording the time each rectal temperature was taken and obtaining the single 1-min rumen temperature measure that occurred at the same time (Source: Rose-Dye et al., 2011).

Table 16. Assessment of SmartStock™ (Source: www.smartstock.usa.com)

<table>
<tr><th>Features</th><th>Description</th><th>Evaluation
(Strengths & Weaknesses)</th></tr>
<tr><td>Feasibility in commercial feedlots</td><td>Yes</td><td rowspan="11">Strengths & Weaknesses

Can used be used in both dairy and beef herds
High Se and Sp (based on company's claim)
Suitable for disease diagnosis
Extended lifetime of battery (5 years)
User-defined sampling
Extensive research studies, published papers in conference proceedings and peer-reviewed journals

Weaknesses

Can only measure rumen temperature
It cannot measure rumen pH
Cannot be used for the diagnosis of rumen acidosis and other nutritional disorders
Limited information of bolus's features and size
Compatibility with NLIS is not known</td></tr>
<tr><td>Sensitivity</td><td>>98% for early infection detection (water effects discarded).</td></tr>
<tr><td>Specificity</td><td>>98% for early infection detection (water effects discarded)</td></tr>
<tr><td>Accuracy</td><td>±0.056</td></tr>
<tr><td>Reliability and durability</td><td>High</td></tr>
<tr><td>Required skills for implementation and data collection</td><td>Some computer skills are needed. Pertinent data can be sent to a smart phone.</td></tr>
<tr><td>Technical support</td><td>Phone and email</td></tr>
<tr><td>Required resources and software programs</td><td>Research version of software requires Excel and is available at no cost. Does not have smart phone interface.

Commercial version requires user input, and there is a fee for the software.</td></tr>
<tr><td>Data storage and processing</td><td>Research version stores to Excel and data can be analysed depending on the skill level of the user.

Commercial version has charting & analysis capability.</td></tr>
<tr><td>Internet requirement</td><td>Not needed on the Researcher version of software.
It is helpful for the commercial version as data can be backed up remotely.</td></tr>
<tr><td>Potential compatibility with NLIS</td><td>Not known</td></tr>
</table>

5.16 YCOW-S

YCOW-S is a wireless radio transmission system consisting of a pH sensor, a data receiver, a relay unit and a personal computer (PC) with special software (YCOW-S; DKKToa Yamagata, Japan). The pH sensor is housed in a wireless bullet-shaped bolus, which also encloses a pH amplifier circuit, a central processing unit (CPU) circuit, a radio frequency circuit, and a battery. The housing of the pH sensor is made of stainless steel (SUS316) and polypropylene (PP), which has a low risk of erosion inside the rumen. A glass electrode measures the pH of rumen fluid with a high degree of accuracy using temperature compensation. Polytetrafluoroethylene is utilised in the junction of the electrode in order to reduce clogging caused by the ruminal contents so that the ruminal pH can be reliably measured over a long period of time. It is 184 g in weight, 30 mm in diameter, and 145 mm in length (Figure 19) and can be administered orally via a catheter into the rumen. The glass electrode uses a temperature compensation system, which corrects the electromotive force of the glass electrode to the standard temperature (25 °C) and can detect the rumen fluid pH with high degree of accuracy. The glass electrode has a rugged membrane and is covered with a hardened stainless steel to avoid any breakage. The replaceable lithium ion battery (3.6 V, 1,700 mA; SAFT, UK) supplies a current for a mean life of 3 months when measurements are transmitted continuously every 10 min. The mean variation of the pH measurements was ±0.20 units over a 2 month period of continuous recording (Sato et al., 2012a,b, Kimura et al., 2012).

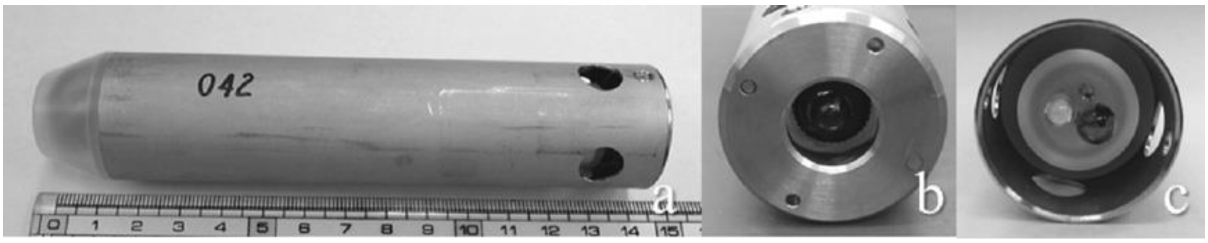

Figure 19. pH sensor of YCOW-S radio transmission pH measurement system. The pH sensor (a), which is 184 g in weight, 30 mm in diameter, and 145 mm in length, was composed of a small-glass electrode (b and c) and antenna (Source: Sato et al., 2012).

The wireless data receiver collects data from the pH sensor and provides operating conditions and corrections for the pH sensor. The mean transmission range from the rumen to the receiver is 32m. The receiver with the CPU and radio frequency circuits is enclosed in a plastic case, and operated through a USB connection using the YCOW-S software installed on the PC. To compensate for attenuation of the radio signal as it passes through the cow's body, the data measurement relay unit is placed in the vicinity of the wireless pH sensor and signal receiver. The software program includes Visual Basic 2005 and runs under Windows XP, Windows Vista, and Windows 7. A specified low-power radio station (429 MHz band) has been used in this system. The main functions of the software are processing data from the wireless pH sensor in order to display on the PC screen, recording measurements to the hard disk drives, and setting operating conditions (measurement interval and calibration) for the wireless pH sensor.

Sato et al., (2012a) estimated the differences between ruminal bottom pH measured using YCOW-S sensor and spot methods (Figure 20). The mean bias was -0.10 (±SD 0.06). The bottom and middle ruminal pH values (6.2–6.8) estimated by YCOW-S method were consistent with previous ruminal pH values (6.4–6.8) measured by an indwelling ruminal pH system (AlZahal et al. 2007). The correlation between continuous recording and spot sampling was high (r = 0.986, Figure 21).

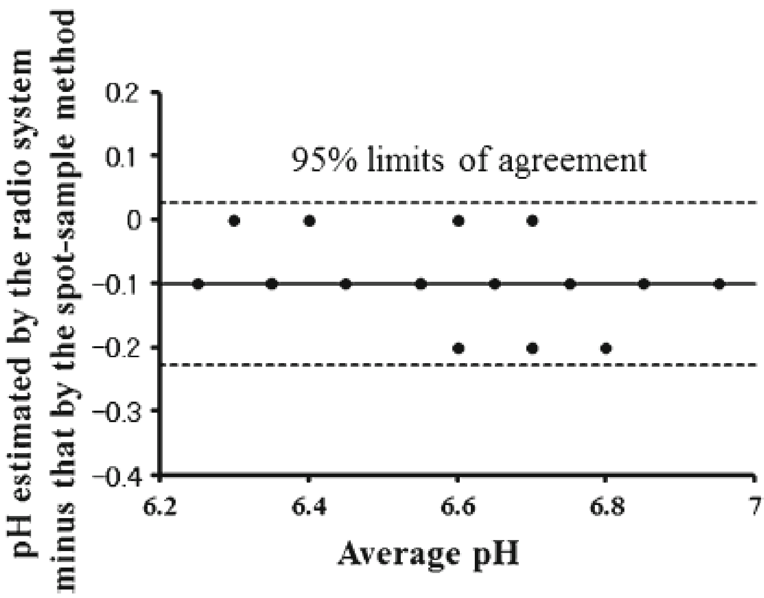

Figure 20. Difference between the pH estimated by YCOW-S wireless radio system and that estimated by the spot-sample method in clinically healthy cattle (n=8, 24 samples). Mean bias (solid line): −0.10. SD bias: 0.06. Confidence limits of the agreement plots are 95% (Source: Sato et al., 2012a)

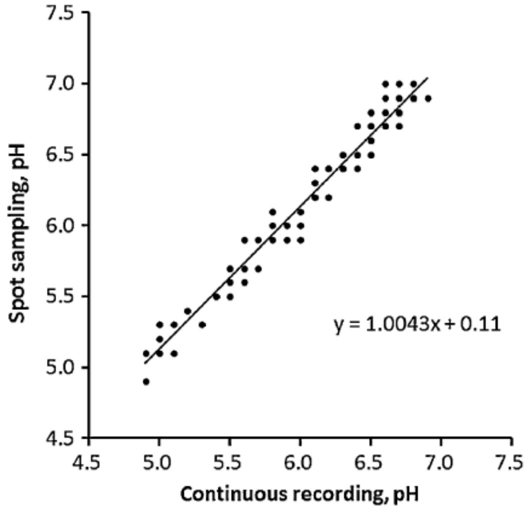

Figure 21. The relationship between the ruminal pH obtained by a continuous recording system and spot sampling. Spot sampling pH (6.36 ± 0.55) was higher than that of the continuous recording system (6.22 ± 0.54), with a correlation of r = 0.986 (Source: Sato et al., 2012b)

Table 17. Assessment of YCOW-S rumen temperature and pH sensor

Features	Description	Evaluation (Strengths & Weaknesses)
Feasibility in commercial feedlots	Yes	**Strengths** Both rumen temperature an pH can be measured Device has be tested and validated externally Publications in peer-reviewed journals Tested in experimental conditions **Weaknesses** No information on Se and SP Claimed high accuracy, but no data provided (SD: ±0.18) The device has not been tested in beef cattle It has not been evaluated in commercial feedlots There is no official website Limited information available on bolus No information on its compatibility with NLIS
Sensitivity	Se has not be quantified. The device can measure ruminal pH in cattle with ruminal acidosis	
Specificity	Sp has not be quantified. The device has designed for the correct and continuous measurement of ruminal pH	
Accuracy	SD: ±0.18	
Reliability and durability	Good reliability, but about 0.2 pH increased after 3 months. Durability is about 3 months	
Required skills for implementation and data collection	Minimal	
Technical support	Not at this stage	
Required resources and software programs	It needs PC installed special software	
Data storage and processing	Long time in PC	
Internet requirement	No information provided	
Potential compatibility with NLIS	No information provided	

Conclusions on rumen boluses

Limitations of rumen remote monitoring systems include the expense, parameters that can be measured, and logistics of bolus administration into a large number of animals. It is essential to conduct a longitudinal study in a commercial feedlot to establish the sensitivity and specificity of available rumen boluses for the diagnosis of health problems in feedlot cattle (infectious and metabolic diseases). A cost-beneficial analysis also needs to be conducted to evaluate and demonstrate the potential long-term financial benefits of these technologies. A number of factors were considered to identify those rumen boluses that have suitable features for implementation in commercial feedlot operations. These include i) development track record of the technology, ii) sensitivity (Se), iii) specificity (Sp), iv) battery life, v) feasibility and vi) overall costs.

Cost and longevity are important issues for commercial operators when they consider implementing any technology for their systems. Until recently, these restrictions have meant that rumen boluses have been only practical for small scale research trials. Now, rumen boluses are being developed with a price point, ease of use, and functional life that satisfies the value proposition required for commercial use.

Rumen temperature

Continued automatic thermal documentation has potential advantages related to remote monitoring of temperature changes. Overall effectiveness of the rumen remote temperature bolus is affected by specific facets of the system, including ability to use remote monitoring systems in the specific environment (interference, geographic distribution), data collection, and management plan. However, these rumen boluses can only be used for health issues associated with high temperatures, and lack the potential for the diagnosis of ruminal disorders such as acidosis. A number of rumen boluses were identified that can be considered for further research trials before being recommended to feedlot producers.

TempTrak® (DVMSystems LLC) and Smartstock™ bolus (SmartStock LLC) are the only rumen boluses that have been validated, with established Se and Sp values and extended battery life (4-5 years). If the features of these boluses are fully functional and have high level of accuracy at the farm level, the anticipated retail prices of TempTrak® would make it the best value proposition for measuring temperature alone.

Rumen temperature & pH

The boluses that can measure both rumen temperature and pH have the advantage of being used for the diagnosis of infectious diseases (e.g. BRD) and nutritional disorders (e.g. subacute and acute ruminal acidosis). As both infectious and metabolic diseases are equally important in feedlot operations with high incidence of respiratory diseases and where diets with high fermentable carbohydrate (e.g. grain) are fed to the cattle, these devices are superior over those rumen technologies that can only measure the rumen temperature.

Optimising nutrition is critical in beef industries to increase the production of muscle mass, while at the same time maintaining the health of cattle. The relationship between rumen function and animal health is well established. It has been suggested by the developers of some of these technologies that because 90% of fermentation happens in the dorsal sac region of the rumen, a bolus residing in this location will provide a better measurement of rumen pH. Although this hypothesis is theoretically sound, there is limited evidence that the location of a bolus in the rumen or reticulum has a significant effect on the diagnostic efficacy of pH or temperature measures. Further studies are needed to examine if these measurements (rumen vs reticulum) have any biological significance, and can improve their value to feedlot operators.

Among the available rumen boluses, Sentinel™ (Kahne, Ltd), Well Cow™ bolus (Well Cow Ltd), farmBolus (eCow) and YCow-S (DKKToa, Ymagata Co) met the selection criteria that were described in this review. All these bolus are placed in the rumen. However, each one of these devices has limitations that make them less ideal to be recommended at this stage without further experimentation. Sentinel™ lifetime (~ 5 years) is ideal for feedlot operations with various feeding periods (e.g. 90 to 400 days), but the Se, Sp and accuracy of the current version of Sentinel™ bolus have not been tested nor validated. Well Cow™ bolus has a shorter life (~ 1 year) and also lacks validated information on Se and Sp, which limits its application in commercial feedlots. The life of farmBolus is also short and its Se and Sp has not been tested. YCow-S bolus has been tested and validated against external pH meters under experimental conditions, but the bolus has not been trialled in commercial farms. The short life of YCow-S bolus (~ 3 months) and lack of information on its Se and Sp make YCow-S rumen bolus unsuitable for use in commercial feedlots in its current form.

Further work will be required in order to link changes in rumen function to a specific disease. The rumen bolus technology has improved dramatically over the years to a level where increased data collection will allow these correlations to become clearer. It is anticipated that more sophisticated algorithms will be developed to link rumen parameters with other data, which will allow feedlot managers to accurately and quickly determine and improve the specific health of individual animals.

5.17 Monitoring physical activities with accelerometers, pedometers and GPS

5.17.1 Accelerometers

Accelerometers are devices that continuously measure gravitational force in multiple axes; these values can be processed to determine activity and postural behaviours of cattle. Figures 23a,b demonstrate a three-dimensional accelerometer attached with the horizontal, vertical, and diagonal axes. Before remote continuous monitoring technology can be used to assess the physiologic and behavioural patterns that cattle display, the technology requires validation (Duff and Galyean, 2007; Weary et al., 2009). Accelerometers have been shown to accurately monitor calves standing, lying, or walking, with 97.7% agreement to video analysis (Robert et al., 2009). This high accuracy makes accelerometers an effective tool for determining posture, compared with labour intensive video footage analysis.

Several studies have illustrated differences in postural behaviour following painful stimuli. Accelerometer analysis has shown that calves increase the percentage of time standing in the hours immediately following castration (White et al., 2088), but over a 5-day period following castration they spend more time lying down and less time walking (Pauly et al. 2012). These studies demonstrate the importance of the monitoring period for detecting time-dependent changes in behaviours. Theurer et al. (2012) demonstrated that calves administered the non-steroidal, anti-inflammatory drug, meloxicam, before cautery dehorning spent more time lying down for 5 days after dehorning compared with control calves that did not receive analgesia, as commonly performed in production practice (Coetzee, 2007). Lying behaviour decreased in calves after being induced with experimental lameness using an amphotericin B synovitis-arthritis induction model (Schulz et al., 2011).

Accelerometers (GP1 SENSR, Reference LLC, Elkader, IA, USA) have also been used to monitor disease and wellness states in cattle. Calves challenged with Mannheimia haemolytica (MH), a common cause of BRD, spent more time lying down compared with unchallenged control calves (Theurer et al., 2012). This agrees with a common assumption that a primary clinical sign of respiratory disease is depression. In another respiratory disease trial, there was no difference in the amount of time morbid calves spent lying down or walking compared with baseline data collected before challenge (Hanzlicek et al., 2010). These findings suggest that the postural activity of cattle may be influenced by disease or pain states, but changes in standing and lying behaviour may not be a specific response to changes in wellness status. Daily environmental conditions, differences among individual calves, and circadian rhythms also affect the amount of time calves spend lying (Robért et al., 2011); therefore, it is important to make comparisons of behavioural activities of calves housed in the same environmental conditions and with appropriate controls to distinguish behavioural changes associated with administering a procedure from daily variation due to environmental conditions (Robért et al., 2011; Fuquay, 1982; Theurer et al., 2011). The placement of the accelerometer on the animal and accelerometer size and weight may transiently alter normal gait and behaviour. A brief acclimation period may be needed for cattle to adjust to having the accelerometer attached to their legs. The behaviours that researchers are predominantly interested in monitoring and recording are listed in Table 18.

Table 18. Ethogram of cow behaviour (Source: Spink et al., 2013)

Behaviour	**Description**
Walking	Movement from one location to another without the head oriented at the ground
Foraging	Grazing or browsing taking frequent bites of forage
Standing	Standing still, no movement to another place
Ruminating	Cow is lying down
Drinking	Drinking at the water supply
Grooming	Cleaning or scratching itself
Social	Interaction with other cows (e.g. grooming, mounting)
Dry forage	Consuming silage left by the farmer

Limitations of using accelerometers to monitor behaviour include hardware cost, data processing, and technological constraints. Accelerometers are relatively expensive compared with hardware required for other behaviour monitoring techniques, such as video analysis. Transforming accelerometer data into useable behavioural measurements can be achieved with validated algorithms; however, validating the algorithms is time consuming. The accelerometers must have sufficient battery life, on-board memory storage (or the ability to wirelessly transmit data), and be small enough to be easily affixed to the animal in some way. A list of available accelerometers are provided in Table 19.

Table 19. Accelerometers that have been trialled in cattle

Developer/ Manufacturer	Country	Name of product	Website	Stage of development and usage	Class of cattle
IceRobotics	UK	IceTage	www.icerobotics.com	Experimental	Dairy
		IceQubic		Commercial/ Experimental	
Reference LLC	USA	Sensr GP1	www.sensr.com	Commercial	Dairy/Beef
Analog devices	USA	ADXL 330 3-axis accelerometer	www.analog.com	Experimental	Dairy
CSIRO	Australia	Fleck2 Fleck3	www.sensornets.csiro.au	Experimental	Beef

5.17.1.1 IceRobotics

IceRobotics supplies behaviour monitoring solutions and tools to livestock researchers for creating and managing objective data sets for studies into dairy cattle health, welfare, and productivity. The devices are designed to record data objectively, and integrate with software that processes the data for statistical analysis. Recording activity data every second can help monitor animal behaviour. IceRobotics technology can meet a wide variety of practical research requirements, from small intensive trials to long-term, multi-site benchmarking projects. Each system consists of three parts:

i) Recording sensor worn on the cow

Two recording sensors have been developed: the IceTag and the IceQube**.** IceTag and IceQube devices have been designed to be compatible with each other, providing flexibility in data collection. The IceTag sensor has been developed to meet the specific needs of livestock researchers to record livestock activity and monitor behaviour. An extensive number of experimental studies in dairy and beef cattle have been conducted using the IceTag sensor (Aharoni et al., 2009; Bewley et al., 2010; Chapinal et al., 2009; Endres and Barberg, 2007; Mcgowan et al. 2007; Nielsen et al., 2010; Ouweltjes et al., 2009; Scaglia et al., 2009; Stanton et al., 2009; Tolkamp et al., 2010; Trénel et al., 2009; Stanton et al., 2010). The IceTag can store the data for 60 days. The data is download wirelessly to an InceReader unit that can facilitate viewing and exporting the data for statistical analysis. The device can be used with an optional neck attachment for recording grazing behaviour (http://www.icerobotics.com).

Figure 22. IceTag (top-left), IceQube (top-right) sensors (Source: www.icerobotics.com)

The IceQube sensor works on the IceTag platform. The IceQube is appropriate for both research use and commercial farm application, as it has a lower cost and long-life sensor. Data is summarised into 15 minute blocks, with 'lying bout' (the frequency of lying events) analysis provided to the second, and storage options are from 3 days or up to 60 days. Data can be downloaded wirelessly to a computer with the IceReader desktop download unit, or via automated farm download system to the CattleGrid online data management system.

The IceTag and IceQube are attached to a rear leg of an animal and provide detailed information on standing, stepping and lying activities, lying bout analysis, and the MotionIndex of the animal. The MotionIndex is a proprietary measure of the overall activity of the animal, as measured in three dimensions.

ii) Wireless data downloading

The automated download system is designed for longer-term, large-scale or comparative research projects with the IceQube. Data is transmitted wirelessly to a local server from the sensor every time the animal passes a trigger point in the barn. The data are then uploaded to the CattleGrid via an internet connection. The CattleGrid is a secure data management and viewing system. Users can log into the CattleGrid via an internet browser to monitor behaviour from anywhere on a near-real-time basis. The automated download system is compatible with the IceQube sensor (http://www.icerobotics.com).

iii) Managing and manipulating the data

IceRobotics has developed various options for managing the data from the IceTag and IceQube sensors to facilitate various types and scales of research projects with different data management requirements.

Data download options:

- ***IceReader Desktop Download System***- the IceReader is a desktop unit, which allows the IceTag or IceQube to communicate wirelessly with the dedicated software installed on the computer via a standard USB connection. By swiping the sensor over the IceReader, the user can activate, query, deactivate and download data. The IceReader is compatible with the IceTag and the IceQube and has a 60 day memory option.

- ***Automated Farm Download System***- the automated download system is designed for longer-term, large-scale or comparative research projects with the IceQube.

With the IceTag, data can be viewed and manipulated down to the per second level of detail. Multiple IceTags can also be queued and left for download. When the IceTag has been attached to the neck of the animal, IceManager provides grazing behaviour analysis. With the IceQube, data is summarised into 15 minute intervals. The lying bout (the frequency of lying events) analysis provides exact timings as for the IceTag. Data download from the IceQube is fast; so no queuing function for devices is required (http://www.icerobotics.com).

The CattleGrid online data management system - the CattleGrid is a unique online data management and viewing system which provides secure remote storage of many years of data, accessible instantly via a web browser. The system provides graphical information and reports at individual animal, group, or herd levels. This makes large-scale comparative research and benchmarking projects viable, providing objective data on an automatic and continuous basis. The CattleGrid can generate highly accurate oestrus alerts to facilitate projects with commercial farms (http://thecattlegrid.com). It is designed for use with the IceQube and automated download, but data downloaded using the desktop system can also be uploaded to the CattleGrid (http://thecattlegrid.com).

5.17.1.2 Sensr GP1 programmable accelerometer

Sensr GP1 programmable accelerometer (Reference LLC., Elkader, IA) is a tri-axial motion recording instrument and capacitive accelerometer that allows the user to monitor, record and evaluate: motions, impacts, shocks, drops, orientation, and temperature. GP1 Sensr measures 10 x 6.5 x 2.85 cm and 234 g, has a battery life of 40 days (2 x AA Alkaline Batteries) and USB connectivity. The programmable accelerometer range is ±2.5 g, ±3.3 g, ±6.7 g, ±10 g and the temperature range is -20 °C to +80 °C.

The GP1 Sensr incorporates a programmable 3-axis MEMS accelerometer. The user can select which range is appropriate for their application. The four acceleration ranges are ±2.5 g, ±3.3 g, ±6.7 g and ± 10 g. It is recommended that the user selects the lowest range reasonable for their application, as this will optimize data. Choosing an acceleration range does not limit the survivability of the accelerometer; the accelerometer is shock rated for more than 1000 gs.

When the GP1 Sensr collects data in the 'Data Recorder Mode' it organizes sampled data into user-specified reporting intervals. A reporting interval is defined by a time segment the user defines; a time segment can be between 1 second and 120 seconds. The reporting interval does not influence the way the GP1 Sensr collects data, it only specifies the time resolution for reporting. If the device's reporting interval is reset to 60 seconds, the GP1 Sensr would still sample at 100 samples per second but report the highest sample that occurred within the 60-second period. Choosing a shorter reporting interval will result in more data records for a given monitoring period. Selecting an appropriate reporting interval is a balance between data resolution, record length, and storage capacity. Once a reporting interval is specified, the software will display the number of days and hours the unit will store data. In general, 60-second epochs are a good reporting interval for most applications and can facilitate reasonable data resolution with an extended monitoring period.

The GP1 Sensr can also be programmed to collect data in the 'Event Recorder Mode'. This mode records each sample (3 axes—100 samples per second) into sequenced data records. Once the 'Event Recorder Mode' is enabled the user can specify when the mode triggers and how long the mode records data. This mode can be used in conjunction with 'Data Recorder Mode'. The GP1 Sensr can be configured to be a real-time data capture device. This mode lets the user see the real-time acceleration influences as they are occurring. For this function, the unit needs to be connected to the user's PC via the USB cable. No other modes can be used while Real-Time mode is enabled. Once enabled, the user can control when the system records/displays data. Recording control can be done on the PC or at the instrument. USB extenders can be used with this mode to increase the cable length if required.

Commercially manufactured GP1 Sensr units, consisting of a tri-axial capacitance type surface-micro-machined (MEMS: Micro-electromechanical systems) ±10 g integrated-circuit accelerometer (Reference LLC, Elkader, IA), have been trialled by Robert et al., (2009). The accelerometers were attached to the lateral aspect of the right rear leg just proximal the fetlock of calves (Figure 23). This mounting site was chosen because of the specific leg orientations associated with the activities of interest; the Y-axis is perpendicular to the ground when the animal is lying, while the X-axis is perpendicular to the ground during standing activity. The accelerometers were placed inside a waterproof case, which was padded and strapped to the leg. The entire apparatus, consisting of case, padding, accelerometer, straps and two AA lithium batteries weighed 0.5 kg.

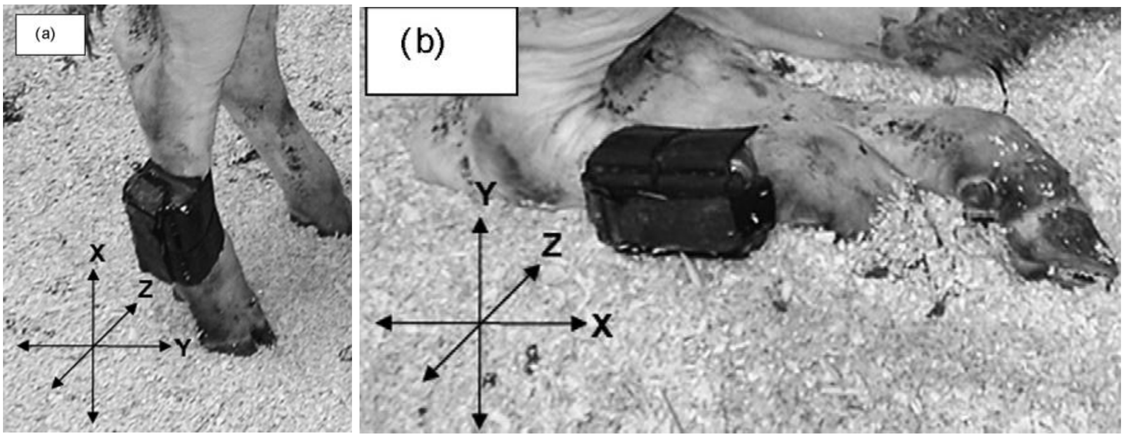

Figure 23. Position of the three-dimensional accelerometer (and illustration of measured X-, Y- and Z-axes) on the lateral aspect of the right rear limb in a standing (a) and lying (b) calf (Source: Robert et al., 2009).

A number of studies of calf behaviour have been carried out using the GP1 Sensr (Bussmann et al., 1998; Aminian et al., 1999; Mathie et al., 2003; White et al., 2008). Calves were fitted with GP1 Sensr devices and video-recorded over a 3-week trial period. A camera was time-synchronized to the computer used to initialise each accelerometer. This time stamp was used to match the video analysis to the accelerometer data for each calf, similar to procedures reported by other researchers (Bussmann et al., 1998; Aminian et al., 1999; Mathie et al., 2003; White et al., 2008). Timing of video taken varied from morning (08:00) to evening (18:00), attempting to get video of each calf involved in all activities (lying, standing, and walking). Efforts were also made to get an equal amount of video of each epoch group, using a check sheet to follow which calves were allocated to each group. Video footage was downloaded onto a computer, and logged by a single individual. Activity (lying, standing, or walking) was determined and recorded for each second for every calf. Properties of the tags feature a dual-radio architecture tag to determine precise location within the pen based on the previously mapped location of the grain bunk, hay feeder, shed, and water using the

Ubisense system (Figure 24). Ubisense is a monitoring system used to evaluate position using a remote triangulation device, tags, and sensors. The tags transmitted ultra-wideband radio pulses which were read by four sensors mounted at each corner of the pen.

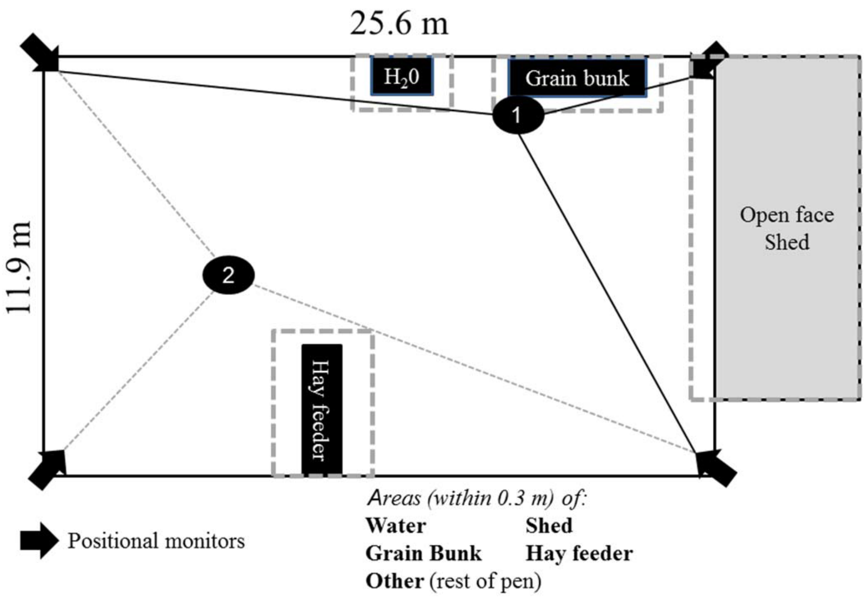

Figure 24. Model illustration of the pen layout and Ubisense sensor location (Source Theurer et al., 2012). A remote triangulation system with positional monitors (arrows) able to triangulate animal position and compare with marked areas of interest including grain bunk, hay feeder, shed, and water. Cattle position is determined by the relative distance between the cattle tag and at least three readers (lines from the readers to the points within the pen). The amount of time at a location is determined by calculating the difference between time of arrival at specific coordinates and previous triangulation time point (Theurer et al., 2012)

5.17.1.3 Analog Devices

The ADXL 330 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The device measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in the tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The device is small (0.4 x 0.4 x 0.15 cm) with low power needs and single supply operation. The technology has not been specifically designed for use in animals (www.analog.com). The device has been used by Martiskainen et al. (2009) to pilot a method for automatically measuring and recognising several behavioural patterns of dairy cows, coupling the ADXL330 accelerometer with a multiclass support vector machine (SVM).

The accelerometer is attached inside a box to each cow's collar and positioned on the top of the neck. A transponder and a battery are used as a counterweight to keep the collar in position. The whole apparatus with the directions of the x-, y-, and z-axes is shown in Figure

25. Since cows are calm animals, a relatively low sampling frequency, 10 Hz, is used with this technology. This reduces the amount of noise, but is still sufficient for registering acceleration (Hämäläinen et al., 2011).

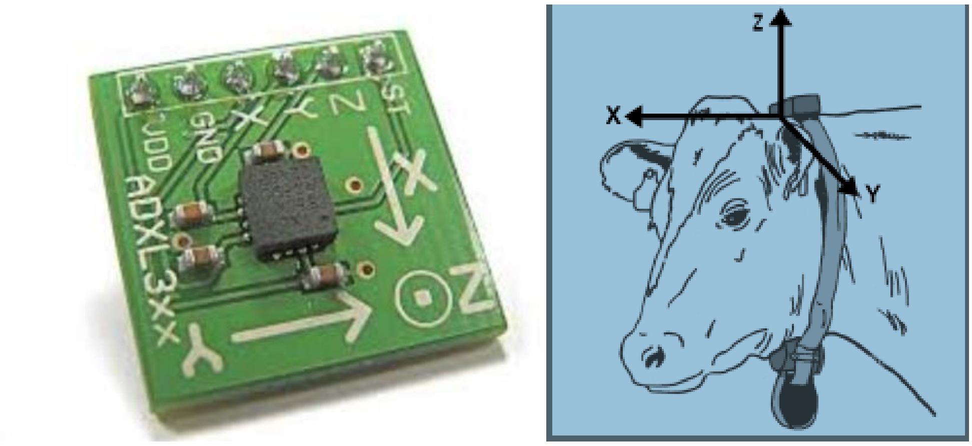

Figure 25. ADXL 330 3-axis accelerometer (Source: www.analog.com)

SVM classification models have been constructed based on nine features. The models have been trained using observations made of the behaviour of 30 cows fitted with the neck collar. Measured behaviour patterns included standing, lying, ruminating, feeding, normal and lame walking, lying down, and standing up. Accuracy, sensitivity, precision, and kappa measures showed that ADXL 330 accelerometer can be used to easily recognise the studied behaviour patterns in dairy cows. However, further work is needed to refine the features used in the classification models in order to gain the best possible classification performance. (Hämäläinen et al., 2011).

5.17.1.4 Fleck2

The Fleck2 was designed by CSIRO in 2003 (Figure 26) for a specific application in animal tracking and control. This device is a compact and low-cost solution with a diverse number of sensors, including GPS, 3-axis acceleration, 3-axis magnetic field and temperature, as well as the ability to hold considerable amounts of data. It provides GPS, 3-dof (3 degrees of freedom, dof) digital compass, 3-dof accelerometer and temperature. (Note: degrees of freedom refer to the movement of a rigid body inside space. It could be explained as "different basic ways in which an object can move" (www.roadtova.com). These allow the user to determine the attitude of the Fleck device on the animal from which the user can determine whether the animal's head is up or down. It may also be possible to determine whether the animal is walking and its gait (i.e. walking or running). The magnetometer, in conjunction with the accelerometers, allows the herd manager to determine which way the animal is oriented with respect to magnetic north. A study by Guo et al., (2009) described the development of a model of animal movement, which explicitly recognised each individual as the central unit of measure. The model was developed by learning from a real dataset that measured and calculated, for individual cows in a herd, their linear and angular positions and directional and angular speeds. The data was collected from a number of sensors, including GPS, 3-axis accelerometer, 3-axis magnetometer, worn on a collar. Animals were able to move freely around a confined area during data collection. The collar number, time (seconds), latitude and longitude were collected and saved in the dataset (Guo et al., 2006; Wark et al., 2007a).

The Fleck3 is the latest member of the CSIRO Fleck platform. The power input stage of the Fleck3 has been simplified and now provides the ability to compute both the energy coming in and the energy being consumed. This makes possible the implementation of sophisticated distributed energy-aware applications. Both rechargeable batteries (with over-charge protection) and super-capacitors can be used as the primary source of power. The Fleck3 incorporates a real-time clock. At the expense of a small current drain, the real-time clock provides several advantages. It allows the Fleck3 to be placed into very deep sleep, reducing the overall energy consumption down to 30 micro-Amps (www.sensornets.csiro.au).

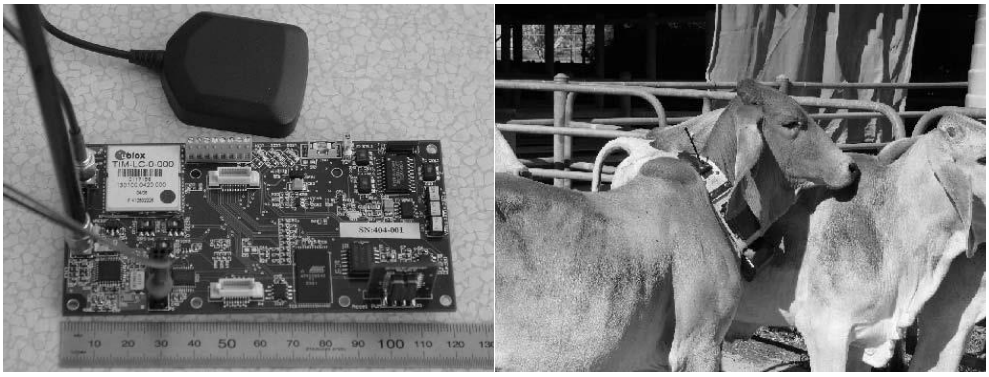

Figure 26. The Fleck2 board (left) and packaged Fleck2 on the cow (right) (Source: Sikka, 2004)

The model parameters developed by Guo et al., (2009) were used to identify hidden behavioural states with real activities, such as relocating, foraging and bedding.

Conclusions on accelerometers

Behaviour or activity has been linked to an animal's wellbeing, and accelerometers have the potential to provide an objective, non-invasive measure of activity that may be linked to specific animal health or performance outcomes. The findings of this review showed that the three-dimensional accelerometers are highly discriminatory for static acceleration (posture) activities in cattle. The 3 and 5-second reporting intervals yield accurate classification of the static activities, but the 5-second epoch would increase the recording time and be most practical for monitoring cattle.

Accelerometers have the potential to provide useful behavioural information, but further research is needed to determine if the measurement of animal behaviour can interpret an animal's wellness status through recognising activities, such as eating, rumination and movement.. The commercially available accelerometers employ similar technologies, but are designed and manufactured in different sizes and shapes for various applications. There are some general features in accelerometer technology that limit its application in feedlot operations.

General features: Limitations of accelerometers in commercial feedlots for monitoring animal behaviour include cost, data processing and technological constraints. Accelerometers are relatively expensive compared with other behaviour monitoring techniques. Transforming the accelerometer into useable behavioural measurements can be achieved with validated algorithms; however, generating the data processing technique is time consuming. The accelerometers must have sufficient battery lifetime, on-board memory storage (or the ability to wirelessly transmit data), and be small enough to be easily affixed to the animals. Objective quantification of cattle postural behaviour, determined by accelerometers, can provide valid data to compare the changes in behavioural patterns associated with pain or wellness status of cattle (Theurer et al., 2013).

Although accelerometers have been extensively used for research projects to optimise their features for use in dairy herds, none of the commercially available accelerometers have been tested for the diagnosis of health related issues in feedlots. There is no data to indicate whether accelerometers can be implemented in a feedlot operation and if the pen riders and feedlot managers can access the data easily in real-time for individual animals.

Accelerometers also need more complicated technologies to be operated in commercial feedlots. This makes the technology more expensive and also less user-friendly compared to other technologies. Since the distance and duration that individual animals may walk on daily basis can vary, a machine learning feature is a necessarily component for this technology to accurately identify cattle with ill-health or locomotion problems. Further, changes in animal behaviour as a consequence of ill health are likely to be delayed, making accelerometers less useful for the purpose of early diagnosis. Currently, the available accelerometers are used for longitudinal studies to monitor behaviour over a period of time and be able to identify the risk factors for poor performance and health status of cattle.

Specific features. Accelerometers that are used on animals' fetlocks may cause some discomfort and pain and also increase the risk of injuries to the legs. The neck collar accelerometers are superior, because these will not interfere with walking or resting activities, are more visible, and can be removed more easily.

5.17.2 Pedometers

Pedometers have been used to quantify the number of steps travelled and total distance travelled by individual cattle (Theurer et al., 2013). An on-board algorithm calculating the number of steps from the raw data is contained within the pedometer. Pedometers are relatively easy to attach and use, but the number of steps taken by cattle varies considerably from day to day and under different environmental conditions. A lower than usual number of steps, and/or too long standing or lying time, can point to lethargy and certain metabolic conditions or lameness, which limit a cow's activity level. Alternatively, a decreased activity level can also indicate an undetected physical injury, which requires veterinary attention. A heightened level of activity can serve to alert the herd manager to nervousness or unease prevalent among the herd. These can stem, among other things, from a lack of food or a shortage of water.

A pedometer is an electronic device that transmits information about the number of steps that the cow takes over a set time. In the literature, there are reports about increased pedometric activity (PA) in cows in oestrus (Koelch, 1992; Schofield, 1988; de Mol, 2000; Lehrer et al., 1992). Significant differences between the PA of sick and healthy cows in the same herd have also been reported (O'Callaghan, 2003). Furthermore, a decline in PA could be detected at least 5 to 6 days prior to the onset of clinical lameness. A number of studies have reported observations on cattle movement using pedometers (Mazrier et al., 2006; Moallem et al., 2002). Measurements of resting behaviour (Vasseur et al., 2012; Mattachini et al., 2013) and locomotion (Nielsen et al. 2010) in cattle can be used as an indicator of welfare status. Commercially available pedometers are listed in Table 20.

Pedometric activity may be associated with painful and stressful procedures. One study demonstrated that calves travelled fewer steps for four days after castration (Devant et al., 2012), whereas another (Currah et al., 2009) was unable to detect a difference in the number of steps travelled after castration. Pedometers have been used to detect early lameness in dairy cattle, but a 15% decrease in activity was needed before the pedometer could accurately identify 92% of lame cattle (Mazrier et al., 2006). The biologic significance of a 15% decrease in activity has not been established, but there may be clinical implications in detecting cattle before a change this large is detected. O'Callaghan et al. (2003) demonstrated that lame dairy cows travelled 22.5 fewer steps per hour compared with cows that were not lame, based on visual locomotion scores throughout most of the lactating period. Stress and libido may also influence pedometric activity; calves have been shown to take more steps for three days after weaning (Haley 2005), and bulls travel more steps per day than steers (Devant et al., 2012).

However, collecting individual behavioural data is labour intensive (Elischer et al., 2013), particularly in large herds. Standing, lying and walking of individual cows can be monitored with devices attached to the leg. These pedometers measure locomotion by three-dimensional acceleration technology (Nielsen et al., 2010) or by a tilt switch (Mattachini et al., 2013) that respond to the position changes of the leg. Devices that measure locomotion have been used, for example, for detection of oestrus (Roelofs et al., 2005) and lameness (Mazrier et al., 2006; Chapinal et al., 2011). Automated devices measuring lying behaviour, i.e. resting time of cows (Ito et al., 2009; Ledgerwood et al., 2010; Vasseur et al., 2012; Mattachini et al., 2013) could be used to assess cow comfort in different management systems.

Table 20. Pedometers used in livestock industry

Developers/ Manufacturr	Country	Pedometer	Website	Applications
Afimilk	Israel	AfiTag	www.afimilk.com	Heat detection Cow identification
		AgriTag Plus	www.afimilk.com	Cow walking activity Rest time Lying down bouts **Health alerts** Supporting indicator for Mastitis Lameness **Environmental indicators** Deterioration in bedding quality Over density in sheds Climate stress **Biological stress** Calving alert 24 hours pre-partum
Fullwood	Uk	Crysta Act+ pedometer	www.fullwood.com	Heat detection Health Discomfort Lameness Calving
Animart Dairy and Livestock Solutions	USA	Track A Cow	www.animart.com	Heat detection Feeding behaviour time Lying time monitoring
ENGS's System	Israel	EcoHeat	www.engs-dairy.com	Heat detection
Insentec BV	The Netherlands	MRS (Motion Registration System)	www.insentec.eu	Heat detection Animal activity
RumiWatch	Switzerland	RumiWatch Pedometer	www.rumiwatch.ch	Lameness Animal activity Heat detection

5.17.2.1 AfiTag pedometers

AfiTag- AfiTag (www.afimilk.com) is the first commercial pedometer marketed worldwide. AfiTag serves two purposes; i) cow identification, and ii) activity measuring. AfiTag incorporates a device that counts the cow's steps and sends this data to the AfiAct oestrus detection module in the computer, where it is analysed to identify cows in heat. AfiTag is an active component (including internal battery) designed for longevity on the cows' legs. AfiTags may be transferred between cows in the farm, making them a cost effective devices for heat detection.

AfiMilk Pedometer-Plus: The AfiMilk Pedometer-Plus Tag provides timely detection of changes in individual and group behaviour, thus alerting the dairy manager to potential health or environmental issues. The AfiMilk Pedometer-Plus system measures behaviour of individual cows as well as groups of cows. Each Pedometer-Plus measures: i) cow walking activity, ii) rest time, and iii) lying down bouts. These parameters are compared against the behaviour history, and alerts for deviations from the norm are generated for individual cattle. AfiMilk is able to identify behaviour irregularities and alerts for individual animals and environmental conditions, such as deterioration in bedding quality, excess stocking density in pens or sheds, and climatic stress.

The AfiMilk Pedometer-Plus system can also be used for health alerts, such as an indicator for mastitis, lameness, and calving.

Figure 27. AfiMilk pedometer (left) and Afimilk pedometer plus (right) (www.afimilk.com)

The Pedometer-Plus can help a herd manager's decision-making capabilities. By early detection of cows in stress, AfiMilk enables timely treatment of cows and/or identification of stressful environmental conditions (i.e. hard climate conditions, low quality bedding and rest area, limited access to feed and/or water, etc.), thus improving overall cow welfare. The Pedometer-Plus—in addition to identifying cows and having all the traditional Afi Pedometer's heat detection capabilities—measures rest time and rest bouts. The AfiFarm herd management software processes this data to give indications of behavioural changes expressing comfort/discomfort. A wide array of data is collected and measured through the AfiMilk sensors and then analysed by the AfiFarm herd management software.

5.17.2.2 Crysta Act+

The Crysta Act+ (www.fullwood.com) uses a pedometer identification tag registering activity to detect oestrus events. It indicates if and when a cow is in heat, enabling determination of the best time for insemination. In addition to heat detection, Fullwood claims that the Crysta Act+ technology can also be used as a tool for lameness detection and reproduction issues such as anoestrus, abortions, cyclic disorders, and early warning of the onset of calving.

Figure 28. Crysta Act+ pedometer (Source: www.fullwood.com)

Fullwood's Crysta Act+ system uses a sensitive accelerometer which provides a complete set of data for each individual cow. By employing an accelerometer to measure rest or lying time as well as the number of rest or lying periods, the new Crysta Act+ system provides an accurate picture of animal behaviour. Crysta Act+ not only monitors activity levels through step counting, but also measures periods of cow inactivity.

5.17.2.3 Track A Cow

The Track A Cow (www.animart.com) heat detection system is a radio-telemetric automated heat detection system that records activities of cows ten times per hour, and transmits high resolution data to the Track a Cow software via a receiver. The Track A Cow heat detection system consists of three main components: i) Track a Cow Pedometers, ii) Receiving System, and iii) Track a Cow Software. The Track A cow pedometer can be used for the following applications:

Figure 29. Track A Cow pedometer (Source: www.animart.com)

Heat detection

- Monitor cows for the presence of heat behaviour;
- Develop an average activity baseline, allowing period of sustained increased activity to be detected; and
- Reporting facilities for cows: i) ready for service, ii) suspected in-heat, iii) with an activity increase.

Feeding behaviour monitoring

- Identify changes in eating behaviour;
- Early detection of disease during cow transition in dairy cows
- Reporting facilities for: i) total feed intake duration, ii) total feed intake visits, iii) average intake duration, and iv) deviation reports.

Lying time monitoring

- Records lying times which are the primary indicator of hoof health and cow comfort;
- Develop a 10-day baseline of lying behaviour; and

- Reporting facilities on: i) lying/standing ratios, ii) lying bouts, iii) average lying duration, iv) position changes, and v) deviation reports.

As limited information and data were provided by AnimalArt (www.animart.com) on the Track A Cow technology, it was difficult to describe and evaluate the capability, features, and cost of this technology. It is not known if this technology has been validated.

5.17.2.4 EcoHerd

ENGS's system (www.engs-dairy.com) has developed as a heat detection device (EcoHeat), to serve in the daily monitoring and managing of a herds' health and wellness issues. By receiving continuous reporting of the cow's activity and posture levels from EcoHeat, herd managers can quickly be alerted to anomalies in a cow's activity and behaviour. ENGS's Long Range Pedometer (LRP) technology delivers detailed reports summarising individual cow's walking and lying/standing periods.

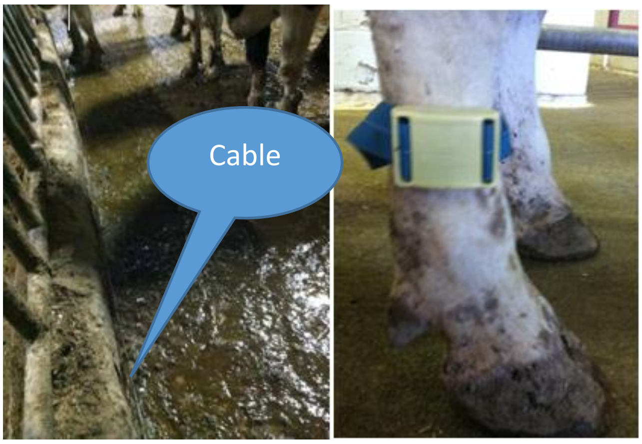

Figure 30. EcoHerd pedometer and cable extended in the feedpad (www.engs-dairy.com)

Daily use of ENGS's EcoHerd System, has the potential to help farm staff to be fully aware and proactive in managing health concerns, as well as many other issues which can affect herd's immediate well-being. Very little information is available on ENGS website (www.engs-dairy.com/animal_welfare.asp), and it was difficult to assess the capability, features, and cost of this technology. It is not known if this technology has been validated.

5.17.2.5 MRS activity measuring

Motion Registration System (MRS) leg transponder has been developed by Insentec BV (http://www.insentec.eu), especially for dairy farms. With the MRS farmers can identify a cow and measure its activity. The MRS transponder is positioned on the front leg of the cow. Lower activity indicates problems with cow health or hoof problems.

Figure 31. Insentec BV motion registration system (Source: www.insentec.eu).

The MRS transponder relies on a step counter with a memory chip. This transponder records every step of the cow. Subsequently these steps are saved in periods. The length of each period is 96 minutes. In total, the MRS can save 15 periods a day. When the transponder from an animal is read at an MRS antenna, the activity details are recorded in the process computer, and these details can be accessed on-line. All activity sessions are saved separately and the data can be visualised graphically to show changes in the number of steps/activity over time. Very limited published information is available on this technology, and it is difficult to ascertain the technology's capability, features, cost and whether it has been validated externally.

5.17.2.6 RumiWatch pedometer

RumiWatch pedometer (ITIN+HOCH GmbH, Switzerland; RW) is another pedometer based system that measures activity related behaviour in cattle. The RumiWatch system also includes a halter that measures a cow's feeding behaviour (see section 8.6) using a pressure sensor. The RumiWatch system (Noseband Sensor + Pedometer) can monitor both feeding and locomotion activities. RumiWatch Pedometers are fixed on the hind limb. The adjustable hook and loop fasteners are used to securely fasten the Pedometer. A PC with Windows XP -SP3/Windows Vista/Windows 7, 32 or 64 bit, 512 MB RAM, 10 Gb memory is required for data recording. RumiWatch Manager and RumiWatch Converter should be installed to be able to record and backup the database.

Figure 32. RumiWatch pedometer fastened on a cow's leg.

The relationships between an animal's lying, standing and walking behaviour (as measured using video recording) and RumiWatch data are presented in Table 21. This shows a high degree of correlation between lying behaviours and RumiWatch interpretations and a high degree of correlation between standing behaviour and RumiWatch interpretations. The correlations for walking behaviours were less satisfactory (Kajava et al., 2014).

Table 21. Behaviour categories used in the continuous behaviour recording: lying, standing, walking and all leg movements (min/h) of the cows were monitored from videos 12-15 hours/cow (Source: Kajava et al., 2014)

Behaviour class	Description	R^2 (VCR & RumiWatch)
Lying	The cow is lying on the sternum head up, or flat on the side head stretched on the ground.	0.999
Standing	The cows' body is supported by all four legs.	0.989
Walking	The cow moves all legs bringing itself to another location within the pen, walking ends when all the legs are still again.	0.687
All leg movements	Other hind leg movements (not leading to a spatial dislocation of the animal) added to WT.	0.888

RumiWatch NBS to monitor jaw movement, eating, rumination and other activities (Source: Kajava et al., 2014)

Descriptive features of the RumiWatch pedometer are presented in Table 22.

Table 22. Features of RumiWatch pedometer

Features	**Description (select the appropriate one) or describe**
Stage of development	Commercially available, with ongoing improvement and enhancement of hardware, software, analysis functions and interfaces
Class of cattle	Current state: commercial application for intensive dairy systems, research application for dairy and beef cattle
Housing condition (eg. grazing vs intensive with TMR)	Suitable for all housing conditions (barn and pasture)
Parameters that can be measured? (eg. rumination, diseases, etc.)	RumiWatch pedometer: ▪ Lying duration ▪ Standing duration ▪ Walking duration ▪ Get up instances count ▪ Lie down instances count ▪ Get up attempts count ▪ Walking steps count ▪ Leg activity change count ▪ Lying, standing and walking index ▪ 3-D motion data of the leg ▪ Pedometer temperature
Price/head ($)	RumiWatch pedometer: USD $500 (August 2014, target price for 2015/2016: USD $60)
Price of accessories (eg. reader, antenna, etc.)	Reader/antenna: USD $150
Technical support provided (Yes/No)- what is the fee?	Technical support is provided (remote support or service on site) – currently free of charge
Recording frequency/rate	10 Hertz (10 signals per second, both for ingestive and motion behaviour)
Battery's life	Up to 3 years under laboratory conditions
Validated externally (Yes/No) (against other methods- gold standard)	Yes, several validation studies by independent research institutions (against direct observation, video observation, and recordings of weighing troughs)
Research conducted?	• Ongoing scientific evaluation of the RumiWatch System in a research and development cooperation of ITIN+HOCH Feeding Technology GmbH and Swiss Federal Research Station Agroscope • Broad application in several international research projects with a focus on animal health, ethology, pasture management
Publications (eg. Proceedings (abstract) Peer-reviewed journal, reports, etc.)	Reports Proceeding abstracts Peer-reviewed journals

Features	**Description (select the appropriate one) or describe**
Feasibility (eg, to be used in commercial farms or research farms)	Current state: main focus on scientific application of the system Goal of the development: application for health and feeding management in commercial farms
Sensitivity of device (eg. detecting the cattle with ill-health)	Currently no automated detection of pathologic behaviours implemented Generation of an automatic alert systems for detection of sick animals is in progress and fundamental part of the RumiWatch research project
Specificity of device (eg. if this has been validated against other methods (gold standard) to identify animals with specific metabolic or infectious diseases, etc.)	Currently no automated detection of pathologic behaviours implemented Validation of the future alert system for detection of pathologic behavioural changes will be part of the ongoing RumiWatch research project
Accuracy of device	Highly correlated with VCR observations of lying, standing and all leg movements Less satisfactory with walking activity monitored using a VCR
Reliability and durability (eg. how reliable is the collected data and how long is the device's life?)	High reliability due to use of high end recording and storage components (e.g. Swissbit SD Memory Cards) with product-specific firmware Prospected lifetime is approx. 5 years (no long-term investigation data available yet)
Required skills for implementation and data collection	Application training (1 day) with practical and theoretical contents offered by the manufacturer is recommended User manual for hardware and software operation should be studied before starting measurements with the RumiWatch System.
Technical support	Offered by ITIN+HOCH Feeding Technology, CH-4410 Liestal, Switzerland (info@fuetterungstechnik.ch) Central warehouse in Switzerland, spare parts will be shipped worldwide
Required resources and software programs	• Windows 7 (32-bit and 64-bit), Windows 8 or 8.1 (32-bit and 64-bit) • 1 GB RAM (2 GB RAM advised) • At least 1 GB free space on the HDD for specific system applications • Additionally a minimum of 10 GB storage for raw data • Minimum 1x USB 2.0 Type A connector
Data storage and processing	• Real-time data analysis on the device and hourly wireless data transmission (Option A: summary transmission) • Recording of 10-Hz measurement data on a SD Memory Card for up to 4 months and serial data transmission via USB (Option B: raw data recording) • Options A and B can be used parallel
Internet requirement	Only when using cloud upload of measurement data (optional)

Features	Description (select the appropriate one) or describe
Potential compatibility with NLIS	Interfaces between RumiWatch software and NLIS application may be possible
Others	see additional information and documents in the Download Centre of www.rumiwatch.com

Conclusions on pedometers

Pedometers can be effective monitoring devices for evaluating pain response and health status of cattle. The relative lower cost of investment and labour intensity compared with other technologies make pedometers an attractive tool to objectively monitor potential behavioural changes.

As pedometers are directly measuring locomotion, they can be a valuable tool for monitoring musculoskeletal pain although individual animal variation in daily walking distance can compromise the accuracy of pedometers for the diagnosis of cattle with locomotion problems. Changes in step counts are not only specific for identifying pain; increased activity levels also indicate the onset of oestrus in cows (Redden et al., 1993; Roelofs et al., 2005). However, similar to accelerometer technology, machine learning component within the pedometers could be beneficial, for the diagnosis of health status of cattle.

Pedometers are extensively used for research studies in dairy herds for monitoring locomotion problems and heat detection. There is limited information on the use of pedometers in commercial feedlots for the diagnosis of animals with ill-health. They have limited capability for early identification of cattle with infection or nutritional disorders because of the lag time between the onset of disease and manifestation of clinical symptoms, such as the decrease in number of steps during the day. Also similar to accelerometers, pedometer ankle bracelets my cause abrasions and discomfort, and their position low on the leg makes them vulnerable to being covered with mud, may interfere with communications.

5.17.3 Global Positioning System (GPS)

An assessment of behaviour of animals from Global Navigation Satellite System (GNSS) location data is very important in terms of behavioural research and to give an idea how deviations in behaviour of individual animals can be detected that might indicate if the animal is carrying a disease. A field trial using 17 Holstein-Friesian cows was conducted by Spink et al. (2013) in a two phases (9 cows in the first phase and 8 cows in the second phase) to demonstrate that individual cow location details recorded over time can provide an overall indication of animal 'fitness'. Variables such as total distance, speed, acceleration and turning angle were calculated, but the software also allowed the users to determine how each individual cow uses the area of confinement (termed a 'field' by Spink and colleagues 2013). In the software, a field can be divided into zones. The software shows for individual cows the frequency of entering that area and the percentage of time spent in it. By including a zone for the place where silage was provided during the experiment and a zone for the watering point, the farmer could deduce how often each individual fed or drank in a specific area (Spink et al., 2013). Also (based on speed) a distinction was made between location data that showed when the cows were foraging or walking. These variables were then related to the age, milk production, duration (days) of milk production and the fat and protein percentages in the milk of the eight cows that were tracked (http://www.etrack-project.eu).

Spink et al. (2013) identified a positive correlation between the amount of time the individual cows spent on foraging and their milk production. Furthermore, a positive significant relationship was found between the fat percentage of the milk and the amount of time that the cows spent in the zone with the silage. Other significant correlations included a relationship between the maximum acceleration and the total distance covered by the animal and the finding that older cows enter the area with the watering point less often and supposedly drink less than younger cows, which was supported by findings on water requirement in livestock.

This study shows that GNSS has the potential to use a variety of parameters to monitor the behaviour and feeding strategies of cattle in relation to their productivity or health. When a cow clearly deviates from these patterns, this could be an indication that the cow is in oestrus or has a disease. This technology can provide the farmer a tool to monitor feeding behaviour and milk production. However, it is suggested that the outlier cattle are of special interest to the herd managers, as these cattle may have health issues (http://www.etrack-project.eu).

Table 23. Global navigation satellite system (GNSS) for the assessment of behaviour of animals

Developer/ Manufacturer	Country	Name of product	Website	Stage of development and usage	Class of cattle
E-Track	UK	TrackLab	www.etrack-project.eu	Experimental	Dairy/Beef

5.17.3.1 E-Trak (TrackLab)

TrackLab is a tool for recognition and analysis of spatial behaviour in farm animals, with 12.5 g weight that can be attached to the animals using glue, neck ring or neck collar (Figure 33, Table 23). The sampling rate can be changed from day, 4 hours or minutes. TrackLab software allows the farmer to import the collected tracking data in real-time or offline. The collected data can be visualised, processed and analysed. Furthermore, it can create interactive systems that respond in real-time to the location or spatial behaviour of animals being tracked. The system will automatically quantify parameters like how much time the cattle spent by the water supply, the average speed of the cattle whilst they were moving, how much time they spent lying down and how often they moved.

Figure 33. TrackLab technology (Source: http://www.noldus.com/innovationworks/products/tracklab/farming).

TrackLab is designed as an open and flexible system, so that the software works with a wide variety of tracking technologies. For outdoor tracking the operator can use GPS data, either real-time or offline and the user can improve the data quality with augmentation services such as EGNOS (European Geostationary Navigation Overlay Service) or WAAS (Wide Area Augmentation System). The indoor tracking can be used in barns or stables. TrackLab supports a wide variety of indoor tracking solutions, including Ubisense™ ultra-wideband sensors and tags, and EagleEye™ stereo camera sensors. E-Track also intends to release a new software for automatically tracking the locations of multiple animals using simple video cameras. TrackLab supports both offline import of track files and real-time live data import (in both cases it is able to handle a wide variety of formats).

The e-Track technology is at the experimental stage, at the time of preparation of this report, and is not commercially available. e-Track data can be visualized and analysed in software programs such as TrackLab. GPS tracking data can also be used to automatically detect a range of behaviours in cattle so long as these can be distinguished by the path of animal in terms of distance moved between samples and the turn angle between samples. However, such analysis is limited when it comes to behaviours which have similar track patterns such as ruminating (lying down) and standing. The preliminary results with combination of GPS and accelerometer data are encouraging, regarding the ability to be able to separate a wider variety of behaviour than with GPS data alone. This technology can provide a wide variety of possible applications for both farmers and agriculture researchers (Figures 34-36; Spink et al., 2013).

Visualisation: Farmers can explore and view the TrackLab data in a variety of ways:

i. Locations show data for each track point (or GPS fix) including position, speed and acceleration. The data can be exported to other programs for further analysis and sort and edit the data in this view to remove outliers.
ii. Maps show the tracks either in OpenStreetMap or on an image of a floor plan of the barns or pens, which the users can import. The maps can be panned, zoomed and drawn to the regions of interest. The operator will be able to plot the tracks as trajectories (in a variety of styles), or show the sample density as a customizable heat map. The tracks can be played back in a variety of ways, so that both short tracks and those acquired over a long time period can be played back conveniently.
iii. Graphs show the value of a measured variable (currently only speed) over time, synchronized with the other views. The data of all the views are synchronized so that the operators can explore the interaction between, for instance, velocity and location (http://www.noldus.com/innovationworks/products/tracklab/farming; Spink et al., 2013) (Figures 34-36).

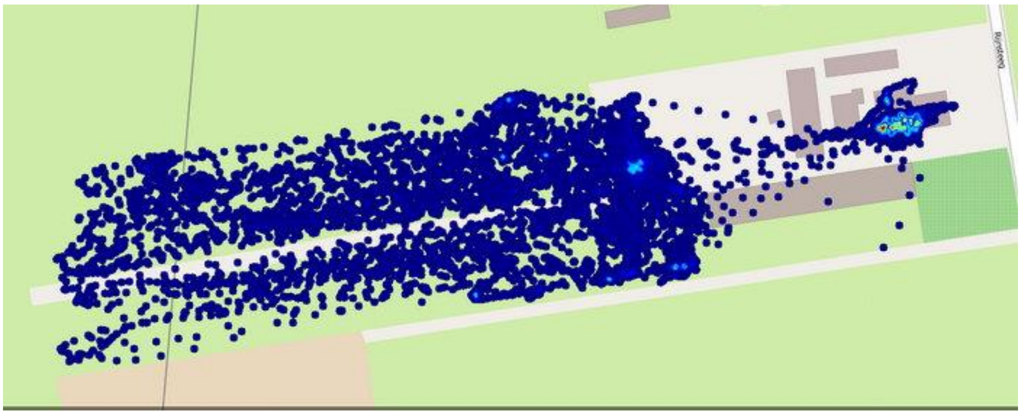

Figure 34. Map of 9 cows in TrackLab from one day. The heat map is generated according to the density of the GPS samples. It can be seen that the cows spent a relatively large amount of time in the stall (on the right), and near the silage and water (in the centre) and that when in the field they spent less time at the far end of the field than nearer to the farm buildings.

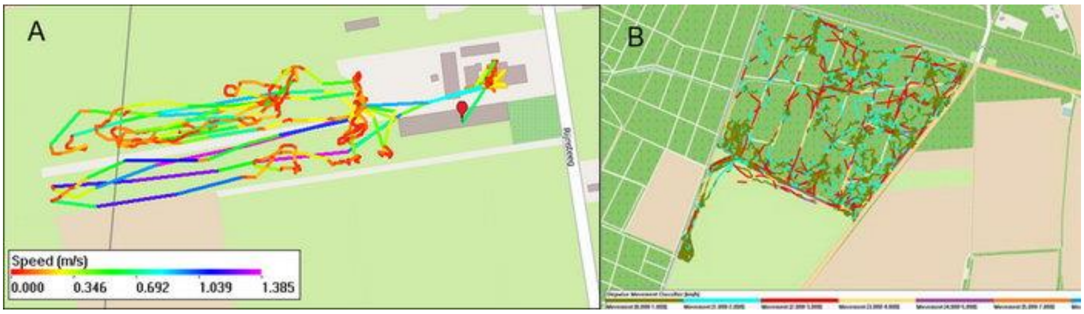

Figure 35. Visualization of a single GPS track of a cow in TrackLab from one day. The colour of the line indicates the speed of the cow at that moment. In a pasture (A), it can be seen that the cow is moving slower in the region next to the farm buildings where the water and silage were available. At a wooded site (B), searching behaviour (long flights, high speed) can be distinguished from foraging behaviour (short flights, low speed) (Spink et al., 2013; http://www.noldus.com/innovationworks/products/tracklab/farming).

Figure 36. Visualization of track of a single cow and its velocity. The hairline on the graph and position maker on the track are synchronized http://www.noldus.com/innovationworks/products/tracklab/farming).

The herd manager will be able to use the location of tracked subjects in relation to zones (feeding troughs, inside/outside) and also whether or not they are moving to generate events. Farm advisors, veterinarians and farmers can create an analysis report showing detailed information about each of these events, and can also make an analysis report showing a wide range of variables for each of your tracks, with statistics such as duration, average speed, maximum acceleration, movement statistics (according to user-defined thresholds), a variety of parameters describing the path shape, and statistics quantifying the zone visits. TrackLab is able to provide its data real-time to other software. For instance, when a cow enters a zone next to a feeding trough, or starts moving, that generates an event, which can be communicated to another program, for instance to open a door to another part of the stall. TrackLab's real-time integration opens up a whole set of possibilities, and Noldus program can help the farmers or veterinarians to configure the technology to their particular needs (http://www.noldus.com/innovationworks/products/tracklab/farming).

Data: As with all measurement systems, location measured using GPS devices has errors associated with it. The size of the error varies according to atmospheric conditions, the location of the subjects (for example, tall buildings can block satellite reception), and movement of the subject. TrackLab incorporates data processing algorithms to remove outliers and smooth the data which specially designed to improve the quality of GPS track data. Furthermore, there is also a powerful function to select and edit individual tracks to improve the quality of collected data (http://www.noldus.com/innovationworks/products/tracklab/farming).

The data can be retrieved using: i) store-on- board system, ii) short range transmission, or iii) network transition via satellite communication. A number of programs can be used to analyse the data, this includes; R (R Core Team, 2014) and AgriGIS http://opensourcegeospatial.icaci.org/tag/agrigis) software packages and Homebrew software. TrackLab data can be used to differentiate the following behaviours in cattle: i) when cows more slower near water and silage, ii) searching behaviour (long segments, high speed), iii) foraging behaviour (short segment, low speed), iv) ruminating and standing don't differ, v) foraging, walking do differ from ruminating and standing, vi) walking has higher velocity than other behaviours, and vii) foraging and walking have lower turn angle than ruminating and standing (http://www.noldus.com/innovationworks/products/tracklab/farming).

Conclusions on GPS technology

The rapid progress in GPS technology is promising and shows that this technology has the potential to be beneficial in farm animal practice, after addressing its limitations for a full implementation within current feedlot operation. The current technology allows for the location of a GPS receiver to be updated every second, this makes the real-time monitoring of cattle more feasible and practical where daily observation of animals are critical to identifying animals with ill-health. However, the intensive recording system may exceeds the power sources available in most feedlot operations. The user-defined real-time updates can overcome the issues associated with battery's lifetime and power sources. Positional accuracy of the systems is also an issue and there has been some discrepancy between visual and tag positions recorded by current GPS technologies.

The trade-offs between the lifetime of battery and frequency of positional update can limit the potential uses of GPS systems in feedlots where cattle movement and behaviour need to be continually monitored for a long period of time. Accuracy of 10m may be sufficient for questions of pasture usage and grazing activities of beef cattle on pasture, but is not sufficient for monitoring feeding and watering behaviours of cattle in a feedlot. These limitations make the use of current GPS technology difficult to monitor changes in pain or wellness status in cattle.

GPS information will also need to be correlated to other information, which requires a common portal for data collection and analysis. Further research is needed to study if GPS can be implemented within current structure of feedlot operation and explore the impact of climatic changes (eg. temperature, rain, winds) on communications between external devices on animals and receivers. The environmental obstacles can also inference with the performance of GPS, for example when animals are under trees or shelters the communication may be interrupted or transferred with delay. Further, a cost-analysis is needed to demonstrate the potential benefits to commercial feedlot operators.

5.18 Monitoring feed and water intake, and behaviour

Residual feed intake (RFI): Residual feed intake or net feed efficiency is defined as the difference between cattle actual feed intake and its expected feed requirements for maintenance and growth. RFI is the variation in feed intake that remains after the requirements for maintenance and growth have been met. Efficient cattle eat less than expected and have a negative or low RFI, while inefficient animals eat more than expected and have a positive or high RFI. Considerable variation in RFI exists among individual animals within breeds or genetic strains. This variation suggests that substantial progress can be made in RFI since the heritability of the trait is about 40%.
(http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10861). Table 24 shows different measures that are used to demonstrate how feed efficiency works. It is also necessary to understand what the concept of RFI in relation to other ratios.

Table 24. Feed conversion ratio, feed conversion efficiency and residual feed intake

Ratios	Estimation method	Interpretation
Feed conversion ratio (FCR)	Intake % daily gain animals	High values are less efficient
Feed conversion efficiency (FCE)	output such as milk yield % by intake animals	High values are more efficient
Residual feed intake (RFI)	The difference between actual intake and expected intake given the animal's level of performance	Negative values imply greater efficiency

In beef cattle, the concept of residual feed intake (RFI) was first used by Koch et al. (1963), who examined a number of indices for calculating efficiency which recognised that differences in both weight maintained and weight gain affect feed requirements in growing cattle. Koch et al. (1963) suggested that feed intake could be adjusted for body weight and weight gain (or any other production trait or energy sink identified), effectively partitioning feed intake into two components: i) the feed intake expected for the given level of production; and ii) a residual portion. The residual portion of feed intake can be used to identify animals which deviate from their expected feed intake, with efficient animals having lower (negative) RFI values. Residual feed intake is therefore defined as the difference between an animal's actual feed intake and its expected feed intake based on its size and growth over a specified period (Kennedy et al., 1993; Arthur et al., 2001b). There are a number of studies that used RFI to assess cattle performance (Kelly et al., 2010: Herd and Arthur, 2009; Herd et al., 2003; Moore et al., 2009: Hill and Azain, 2009; Kelly et al., 2010, Sherman et al., 2009; Nkrumah et al., 2006).

Measuring feed intake in the open feeding facilities can seriously challenge measurement accuracy. A typical feed intake event in a competitive feeding situation is approximately 450 grams, however, severe weather conditions (e.g. strong winds) can create 500 g of weight fluctuation. Therefore, measuring 450 g of feed disappearance while there is 500 g of noise is a considerable analytical challenge. (www.growsafe.com).

To calculate RFI we need the measurement of actual individual animal feed intake. Residual feed intake (RFI) represents the amount of feed consumed, net of the animals' requirements of body weight and production. Efficient animals eat less than expected and have a negative or low RFI, while inefficient animals eat more than expected and have a positive or high RFI (Table 24). There is conclusive scientific evidence that cattle with low RFI consume less feed at the same level of production as high RFI cattle. In addition to reducing feed consumption, cattle with low RFI produce less methane from enteric fermentation and also less manure relative to high RFI cattle, due to the fact they consume less feed. Benefits of selection for lower RFI in beef cattle (Arthur and Herd, 2008; www.growsafe.com) are:

- Reduction in feed intake by 10-12%
- Reduction in liver, stomach and intestinal weights
- 25-30% reduction in methane production
- 15-17% reduction in manure N, P and K production
- Efficient calves become efficient adults
- Progeny of low RFI cattle more efficient (Arthur and Herd, 2008)

It has been observed in North American feedlot farms that by using RFI values in a selection program, overall feed costs can be reduced (Arthur and Herd, 2008; www.growsafe.com), This occurs because cattle with low RFI values consume less feed. It has been demonstrated in numerous studies that "selection for lower RFI will decrease feed intake by young cattle and cows, with no detrimental effects on growth or size of animal" (Herd et al., 2003). Thus, this benefit is twofold. Not only will cattle consume less, but at market time they will still stand up at market conditions and standards. As an example, in contrast to high RFI value steers, low RFI value steers had more lean meat and less fat in their carcasses (Richardson et al., 2001).

Systems are available to measure individual cattle feeding behaviour and intake in group-housed situations. These systems have been used to identifying morbid cattle from healthy cattle based on differences in feeding behaviours (Sowell et al., 1999). Feed and water intake, duration, and frequency are specific behaviours that can be monitored with these systems. Systems that monitor feeding and watering behaviours that are commercially available include GrowSafe (GrowSafe Systems Ltd, Airdrie, AB, Canada) and Insentec (Repelweg, Marknesse, Netherlands). GrowSafe uses radio frequency identification (RFID) ear tags to identify individual animals. Insentec, on the other hand, uses transponder collars to identify when animals are at feeding or watering stations. Both systems have integrated software that allows for real-time monitoring and analysis of animal feeding or watering behaviour.

Radio frequency identification (RFID) technology has been used to document a reduction in the frequency of visits to feeders (Gonzalez et al., 2009). Nkrumah et al. (2004) and Kelly et al. (2010) evaluated residual feed intake and found distinct differences in feeding behaviours among high and low residual feed intake calves using both the GrowSafe and Insentec monitoring systems. Because feed inputs represent one of the largest costs in producing beef, monitoring behaviours that may identify cattle with less than ideal feed efficiencies may be beneficial (Bingham et al., 2009). Monitoring the feeding behaviour of an animal over a period of time allows establishment of a baseline against which deviations in subsequent behavioural patterns can be evaluated. Gonzalez et al. (2008) have used algorithms with 7-day rolling average feeding times as baselines to identify behavioural changes correlated with painful locomotive conditions in dairy cows days before farm staff were able to diagnose lameness. These studies demonstrated that monitoring animal feeding behaviour and intake can provide insight into potential changes in wellness or pain status. However, the costs of setup, maintenance, training and expense of remote cattle monitoring (Tomkiewicz et al., 2010) all are potential disadvantages that must be considered when evaluating remote feed intake and behaviour systems. Nevertheless, the feed intake and frequency of data collection capabilities make these systems attractive monitoring tools to use because feed costs are important to the feedlot producers (Table 25).

Table 25. Technologies measuring RFI and feed intake

Developer/ Manufacturer	Country	Name of product	Website	Stage of development and usage	Class of cattle
GrowSafe	Canada	GSB	www.growsafe.com	Commercial	Beef
Insentec BV	The Netherlands	Insentec feed system	www.insentec.eu	Experimental	Dairy
		Roughage Intake Control (RIC)			Dairy
		Weighing system			

5.18.1 GrowSafe Beef™ (GSB)

The concept of RFI provided a unique potential for GrowSafe to develop a fully automated feed intake measurement system and reliable to be used in a typical livestock production environment on a commercial scale in North America (www.growsafe.com). A GrowSafe system is a feed intake recording system that enables continuous data acquisition. The animal identification tag is read every second when an animal is feeding at the trough, load mechanisms and other sensors are sampled continuously. This built-in redundancy ensures that all activities are correctly assigned to individual animals. The GrowSafe claims that the software continuously audits and calculates the errors which may come from rain, snow, excessive wind and lost transponders. There is no ability for a user to change or amend the raw data collected. Continuous data recording enables advanced behavioural analysis (www.growsafe.com). The data accuracy of GrowSafe tag is nearly 100%, which is due to multiple sampling and extensive system diagnostics. It is stated (www.growsafe.com) that the systems keep track and report themselves when they aren't operating to set tolerances.

Testing procedures: GrowSafe Beef™ has established a conditioning warm up period that cattle are acclimated to the test condition of 70 days. The feed intake is measured for a minimum of 50 days, when cattle are healthy and have a normal feeding pattern within the 70-day test period. Days where bulls are treated for sickness, removed from the pen for any reason (e.g., ultrasound, weights, etc.) are not be counted as a "test day". In the case of sickness, full *ad libitum* intake will have resumed before data collection continues. All cattle within one test are fed the same test diet, and the diet is formulated to provide appropriate levels of energy to ensure expression of animal differences for intake. The ingredient composition of the diet is recorded. Random samples of the diet are sent to a commercial laboratory for complete chemical analysis. All ingredient and chemical compositions of the diet are done on a dry matter basis. Animals entering a test facility have birth and weaning date recorded. From this information and a contemporary group definition, animals within a feeding group share a start of test age that is within a 90-day range. The pen in which an animal is kept forms a component of the test contemporary group. Individual feed intake data is collected on animals within the range of weaning age to not more than 460 days of age. GrowSafe technology and feed intake monitoring system are summarised in Table 26.

Figure 37. GSB system includes; feeding (top left), watering (top right) marking (bottom) cattle with ill-health that need to be drafted for physical examination and treatment (Source: www.growsafe.com)

Table 26. GrowSafe features, functions, capabilities, pricing and maintenance services

Capabilities	Functions
Feed intake and behaviour monitoring system capabilities	• **Proprietary GrowSafe ID reading technology** RFID systems enable unobstructed individual animal behaviour measurement, capable of reading multiple transponders in close proximity • **Accurate feed disappearance measurement and high volume data acquisition** GrowSafe feed intake nodes are sampled up to 8 times per second at a resolution of 10 grams • **Portability** The system has been designed in "plug and play nodes" to enable multiple pen and research configurations. The system can be used in feedlots, dairies and/or on pasture • **Wireless** The data acquisition computer can be located away from the system up to 80km line of sight • **Automatic system auditing** Each day the system automatically audits the total feed supplied to the bunk and the amount of feed assigned to individual animals
Feed intake and behaviour monitoring	• Each animal is tagged with an RFID ear tag. Every tag has a unique number • A RFID antenna is moulded directly in the rim of the feed trough • The RFID equipped trough is suspended on load cells • Every second the animal is present at the feed trough the RFID tag is scanned, and feed trough disappearance is measured at a resolution of 10 grams • The collected data is transferred wirelessly, and then automatically analysed and audited • The system collects data every second
System measurement	**The system measures and/or calculates the following per second:** • Duration and intake for every individual feeding event • Head down and in to out duration during this event • Feed disappearance during events • Feeding frequency over user selected time interval • Automatic calculation of feed supply • Feeding rate throughout feeding event • Animals standing at the bunk not consuming feed • Intervals between events • Number of animals feeding simultaneously, collect and log consumption and behaviour data from each independent station and animal electronic ID • Social hierarchy - "who feeds besides who" and "who feeds first"

Capabilities	Functions
	• Continuous system diagnostic dialogues can be displayed to assist in system performance assessment and troubleshooting hardware, animals feeding and other components • Identify sick animals and poor performers
Accuracy	• Flexible data analysis is, allowing a user to look at the data in many different ways • All events are automatically recorded, and no data is lost • Irregular events can be examined more carefully - micro-observations can be made within an event and interval • Feed supply events, bunk cleaning, wind, rain and maintenance can be identified • Accurate measurement of feed intake during undesirable environmental conditions (eg. strong wind) • Continuously records feed disappearance and appearance at the trough, and audits unassigned feed disappearance • Validated by customers and in-house through independent functional testing
Auditing	Continuous communication error checking and status reporting on: • Weight scale status monitoring • Communication • Weight data integrity audit • Resonant antenna voltage monitoring with alarm capabilities which continuously check the integrity of the ID system • RFID status monitoring • Behaviour data integrity • History of RFID system performance - occupancy at bunks • Error flags appear on screen when the system requires attention • Automatic messaging to telephones, cellular phones, pagers and or alarms by email can be enabled depending on farm requirements
Feed yard program services	The program can provide customers the following services: • Installation, commissioning, and regular service visits • Guaranteed replacement of equipment in case of breakdown • Fixed, predictable monthly cost • Remote monitoring of equipment • Periodic statistical process control • Industry benchmarking • proposes an optimal market date for each individual animal at a time when the cost of gain begins to exceed the value

Capabilities	Functions
	of gain*
Potential diagnostic capability	• Sick animals can be identified by GSB by behavioural changes preceding clinical signs of illness by up to 4 days, often up to 24 hours in advance of body temperature change • Up to 30% of animals in a pen can be identified as poor performers • Up to 30% of animals 'are above' average and performance is penalized when fed beyond optimum market date • Certain implant, feeding and management pen strategies are having detrimental effects on individual performance • Growth of some of the population could be enhanced by alternative implant and finishing strategies
Pricing, maintenance and services	**Pricing** • Demonstration phase into a new territory, the cost ranges from $7,500 to $9,500 per unit/per year. **Pricing is determined on the following** • One 6 position watering unit services one pen with approximately 300 cattle. (Note: This may be spanned across fence lines to service 2 x 150 hd pens) • Amount of customization required • Amount of feed yard commitment • Estimated ROI is $60 per animal/year? • Reduced days on feed carbon offset up to $8 per animal/year? can be achieved • The estimated average cost is $12 per animal/year? (ranges from $6.25 to $14.00 per animal per feedlot stay) **Under a 3-year technology usage agreement** • Technology supply, equipment maintenance, remote troubleshooting • Analytical software and upgrades • Real-time advanced feedlot/ranch analytics - custom decision support software based on site specific production goals • Application programming interfaces between existing feedlot/ranch technology • Continuous training and customer support

Source: www.GrowSafe.com
* **Cost of gain** - yardage and estimated individual animal feed intake; **Value of gain** - market price and discounts for out weight carcasses

5.18.2 Insentec BV

As part of the HokoFarm-Group, Insentec BV has developed mechanics, optics, animal identification, electronics and management systems for agriculture and animals nutrition industries. The Insentec equipment has been designed for dairy and pig farmers. The Insentec equipment includes:

i) Animal station (Insentect's feed)

Insentec's feed system is an electronics feeding station, which can supply a maximum of four different feed types. Liquid additive can also be dispensed. The feed falls into the feed trough at the same time from the synthetic hopper. The shape of the feed trough ensures that the animals can easily consume the feed, which shortens the length of time spent at the feeding station (Figure 37).

Figure 38. Insentec's feed station (Source: www.insentec.eu)

After appropriate quantity of feed is allocated, after it is corrected by the eating speed of the animal, the anti-spill valve automatically closes the auger of the automatic feeder. This prevents any feed falling into the trough not allocated for the particular animal, so avoiding animals 'bumping' against the feeding station. The cows are identified using a TIRIS-collar transponder and an antenna in the feed trough. As an option, the feeding system can be extended with an MRS (Motion Registration System) to register the individual animal activity.

The parlour electronics are mounted in the actual feeding stations. The installation is simple and quick with reliable, low maintenance operation of the feeding station and its electronics. The feeding station can be used with the EcoTec© feeding system. This allows information to be entered and checked via the so-called Portoreader hand terminal. The Portoreader contains a cow calendar, a program to increase or decrease the feed level and a printer connection so various lists can be printed for control purposes. By using the EvoTec© feeding system, the users can enter and check information on their computer. The software package 'Ceres' can be used to modify the feeding strategy and carry out checks.

ii) RIC system

The Roughage Intake Control (RIC) system is suitable for researchers to reduce the cost of labour. The RIC system enables researchers to monitor and influence the individual feed intake behaviour of cattle. The RIC management software offers comprehensive extended potential for analysis and research. The data can be stored in ASCII files to establish a link-up with other software for further processing (Figure 39).

Figure 39. Roughage Intake Control (Source: www.insentec.eu)

The RIC system consists of a feeding gate that identifies the animal, gives or denies it access to the RIC trough and records the visiting time. The RIC feeding trough can be used to record the feed intake after every time cows enter the feeding gate. This enables the users to measure how much an animal has eaten from a certain feed type. Up to four different feed types can be fed at each time. The water intake can also be recorded with the help of a specially designed water trough, which is filled up automatically.

iii) Weight control

The weight of a cow can be used as an indicator in feed intake studies. Insentec weighing system can help to monitor the daily weight of cattle. The RIC system can be combined with a walk-through weighing station or a weighing floor in the concentrate feeding station.

Insentec technologies are designed for experimental research and not suitable nor economical to be used in commercial feedlot farms.

Conclusions on feed and water intake technologies

The concept of RFI that is used by GrowSafe Beef™ technology can be used to monitor and identify under-performed cattle (eg. shy feeders) and also cattle with health issues. This technology allows the feedlot operators to monitor daily feed intake and average daily gain to estimate the production performance of cattle. Animals that fail to eat or drink during the day, are not registered by the system. These animals are then listed and flagged the next day on feedlot monitoring system. This is a very efficient system for early diagnosis of cattle that have not been at the feed or water troughs. Learning machine algorithm is used in GrowSafe Beef™ technology, and enables the software to learn more about animals eating patterns over a period of time and provide a more accurate prediction of animal health and performance.

The published research studies, reports and a webinar presentation by the manufacturers of GrowSafe Beef™ technology demonstrated that high level of accuracy GrowSafe Beef™ make this technology a unique tool for managing cattle in real-time on daily basis. The manufacturers of GrowSafe Beef™ believed that there are some issues with the sensitivity and specificity of this technology, since they observed a poor correlation between veterinary diagnosis, abattoir findings and animals identified by GrowSafe Beef™ as having health issues (e.g. BRD).

The other limitations of GrowSafe Beef™ technology is the high cost, requirement of skilled staff to manage the data collection and lack of compatibility within the current feedlot structure. Major modifications are required within feeding operations of feedlots to be able to implement the current GrowSafe Beef™ and watering equipment, which could be very costly. While, it has been proven that the technology is quite reliable and accurate, these limitations can be prohibitive of being taken up by feedlot operators.

The impact of environmental factors such as temperature, winds and rain on the performance of technology in Australian farming conditions need to be obtained from the two research sites where the GrowSafe Beef™ is currently operating.

5.18.3 Monitoring rumination

Background

The rumination process: Rumination is an important part of the process by which cattle to digest food. It is stimulated by the presence of roughage in the upper part of the rumen.

Once the cud is in the mouth, it is chewed thoroughly, which increases the surface area available for microbial degradation; then the solid matter is swallowed back into the rumen. Thus, one of the primary purposes of rumination is to physically break down course material in order to assist in its transfer from the rumen. An additional function of rumination is to increase the production of saliva, which acts as a buffer to the acids produced during the microbial degradation of carbohydrates.

The need to ruminate: Studies have shown that although the duration of rumination is primarily determined by ration size and quality (i.e. composition), chewing the cud is an innate behavioural need in cattle, regardless of the amount of food ingested (Lindström and Redbo, 2000). This means that a cow needs to ruminate a certain amount each day as part of her natural routine, as well as for the more obvious reasons of good nutrition, health and milk production (Lindgren, 2009). Cattle that are not able to act upon their natural behavioural needs may exhibit typical side-effect behaviours, such as tongue rolling or bar biting.

The importance of rest time: Cattle tend to follow a basic 24-hour rhythm. Normally, cows spend about one-third of a day (8-9 hours) ruminating (Welch, 1982), during which they should ideally be at rest (i.e. lying down). Therefore, most rumination is done at night, with a significant amount of rumination is also taking place during the afternoon rest time. Disruption or decrease in a cow's rest time, which may be due, for example, to additional walking required to reach new housing, elevated activity around oestrus, social agitation or other reasons, can result in a decrease in rumination. Therefore, monitoring both activity and rumination can provide a very accurate indication of a cow's health, welfare and oestrus status.

Nutrition and rumination: Daily rumination time depends mostly on the quality and quantity of feed consumed. In general, cows ruminate for 25-80 minutes for every kilogram of roughage they eat (Sjaastad et al., 2003). Studies have shown that high-producing cows tend to consume more dry matter, eat larger meals in less time, ruminate longer and drink more water compared to lower-producing cows.

Rumination as an indicator of welfare: A cattle's welfare is affected by internal and external factors:

- Internally – cattle nutritional status, any pain cattle may be experiencing, the presence of and the responses to viruses, bacteria and other immunological issues, and

- Externally – cattle's ability to cope with the weather, other cattle in the group, housing and other aspects of environment.

Because cattle can voluntarily control their rumination, they stop ruminating when disturbed. Other events and conditions, such as maternal anxiety, illness or pain, will result in decreased rumination.

Good monitoring is essential to good business: Ideally, cattle monitoring should include monitoring of rumination. However, the opportunity for herd managers to observe rumination is limited, since rumination takes place off and on throughout the day, and most significantly at night. More importantly, because rumination routine is highly individual, rumination needs to be measured per animal, with each animal acting as the reference for itself. Direct observation does not allow farmers to follow rumination on such a granular level.

As outlined earlier in this report, rumination has been shown to be an important indicator of animal's welfare and health. A drop in rumination is a clear indicator for health issues before clinical signs become apparent and before productivity is affected. Likewise, return to normal rumination provides early indication that the intervention, such as medical treatment or nutrition change, is successful. When rumination and activity are both measured, the combination of these two indicators provides a highly sensitive and precise indication of animal status.

Rumination activity is critical for every ruminating animal's health. The chewing activity of a cow produces saliva. Saliva buffers rumen pH. Saliva production will decrease when the rumination of the cow decreases. When a cow eats too much concentrate in relation to effective fibre, the cow's rumination, saliva production and rumen pH will decrease. If either the feed management or feed quality changes, the farmer can follow the cattle's rumination activity and make the necessary adjustments at an early stage. A good example of this practice is the transition of cows from one diet to another. Feedlot herd managers can set and modify the parameters according to the specific requirements of cattle. The electronic systems enables the preparation of feeding programmes according to rumen performance and stage of growth. With the aid of early indication of any illness influencing animal's appetite, a farmer can also reduce the incidence of clinical and sub-clinical metabolic diseases of the entire herd. A number of technologies have been developed to monitor animal rumination in order to detect any abnormalities in animal's eating behaviour (Table 27).

Table 27. Technologies that can monitor rumination activities in cattle

Company/ Distributor	Country	Name of product	Website	Stage of development and usage	Class of cattle developed and validated
Lely	The Netherlands	Qwes-H Qwes-HR	www.lely.com	Commercial	Dairy
CSR	Israel	HR-LD tags 1. Heatime HR 2. Heatime Pro 3. HealthyCow24	www.scrdairy.com	Commercial	Dairy
RumiWatch	Switzerland	NBS (nose-band sensor)	www.rumiwatch.ch	Commercial	Dairy

5.18.3.1 Lely Qwes-H and Qwes-HR systems

SCR Dairy has contributed in the development of 'Lely Qwes-H' and 'Lely Qwes-HR' monitoring system for Lely (www.lely.com), which will identify the cow and measure cow's activity (Figure 40). The additional functionality of the Qwes-HR system is that it also measures cow's ruminating activity, which is an indication of the cow's health. The activity measurement is based on an acceleration sensor instead of the commonly used mercury ones. The system will monitor cow's activity in blocks of 2 hours and thus provide information on the cow's behaviour. The system uses the infrared identification units, which download the information, can be mounted in several places near the feed and water troughs.

This is used to download the information more rapidly on cattle rumination and health. The activity is measured by a unique method. The tag includes an acceleration sensor, microprocessor and memory, which enable the recording of a general activity index. This index quantifies all animal's movements such as: walking, running, lying down, standing up and head movements. The activity index is stored separately in the tag's memory every two hours. This separate recording enables farmers to monitor the cow's activity over time with great accuracy, regardless of the time intervals between the tag readings. The additional information together with the T4C management software, also allows farmers to differentiate abnormal activity associated with oestrus from other activities such as walking to the pasture or any other occasional activities. The tag can store data for up to 24 hours.

Rumination activity: Lely Qwes-HR collars can provide the earliest available information on cow health problems, monitoring the health issues with the Qwes-HR rumination, heat control and cow identification. Changes in rumination are the earliest sign that can be obtained from cattle to warn the farm manager about potential problems. The Lely Qwes-HR measures the rumination of cattle together with their activity. This information combined with animal's identification system using the neck collars. The use of Lely Qwes-HR collars enables the farmers to obtain information about the whole herd as well as individual animals. Qwes-HR collars also indicate the influence of weather on a cow's performance and general herd appetite.

Figure 40. Lely Qwes tags amounted on the neck (Source: www.lely.com)

With the Lely Qwes-HR rumination-time monitoring technology, feedlot producers and veterinarians can obtain some indications of individual animal health. A sudden reduction in rumination activity compared to a cow's normal rumination time perhaps indicates that the animal has lost it appetite, has eaten too much concentrate per kg effective fibre or ill. Continued loss of appetite can be an indicator of sub-clinical ketosis or acidosis. This provides the farmers an early signal to identify cattle who need attention. Together with heat detection, the Lely Qwes-HR collar gives the farmer on-line information about each individual cow's rumination, which serves as an indicator of the cow's health and provides information for feeding and management. Lely Qwes-HR does not interference when working in conjunction with RFID tags (such as TIRIS).

5.18.4 SCR-Heatime® tags

SCR cattle monitoring systems have been designed to collect and analyse data points, from activity to rumination for every individual animal. The SCR Heatime® Series can collect information on health, nutrition, wellbeing and reproduction of status of each animal. This includes rumination, movement and movement intensity and recognizing behaviour patterns (Figure 41). A summary of features of both series are summarised in Table 28.

Figure 41. SCR Heatime HR system (antenna, monitor and tags) and schematic demonstration of monitoring cattle's movement, rumination and heat detection (Source: www.scrdairy.com)

Table 28. Specifications of SCR Heatime HR and Heatime Pro systems

System/Feature	Heatime HR system (Terminal-based)	Heatime Pro system (PC-based)
Maximum no of tags supported at a farm*	400	6000
Tag compatibility	SCR H, H LD, HR and HR LD tags	SCR H, H LD, HR and HR LD tags
Data history	1 year	Lifetime
Herd groups	Herd can be divided in the system into 10 groups (maximum)	Herd can be divided in the system into 10 groups (maximum)
Cow card	Yes	Yes
Sorting gate	Up to 4 sorting gates of 2 or 3 ways	Up to 5 sorting gates of 2 or 3 ways
Sorting manager	Yes	Yes
Reports	Yes	Yes (including editor)
Auto backup	Yes	Yes
SMS alerts	Yes (optional feature)	Yes (optional feature)
Email alerts	Yes (optional feature)	Yes
Long distance coverage	Typical range of SCR RF Base Unit: 500-200 m based on farm audit	Typical range of SCR RF Base Unit: 200-500 m based on farm audit
Clients	One	1 Multiple, customizable dashboards to enable different users access and permissions

* The maximum number of supported tags may be higher or lower depending on the farm layout. An SCR review is required prior to purchase and installation

SCR Heatime® HR system: The SCR Heatime® HR system is a standalone RF real-time tags, long-distance, terminal-based system that provides information on reproduction and health monitoring solution, and no computer is required for monitoring the animals. The muulti-functional neck tags have a proprietary movement sensor and a rumination recorder. The SCR Heatime® HR comprised of the HR tag, readers, and a terminal or computer-based software, constantly monitors individual cows' activity and rumination. The data is collected and analysed by the system and presented in alerts and reports. The SCR Heatime® HR system has been validated by a number of studies (Schirmann, K. et al., 2009), and is able to monitor cattle rumination health, wellbeing and reproductive status in commercial herds on daily basis (Figure 42).

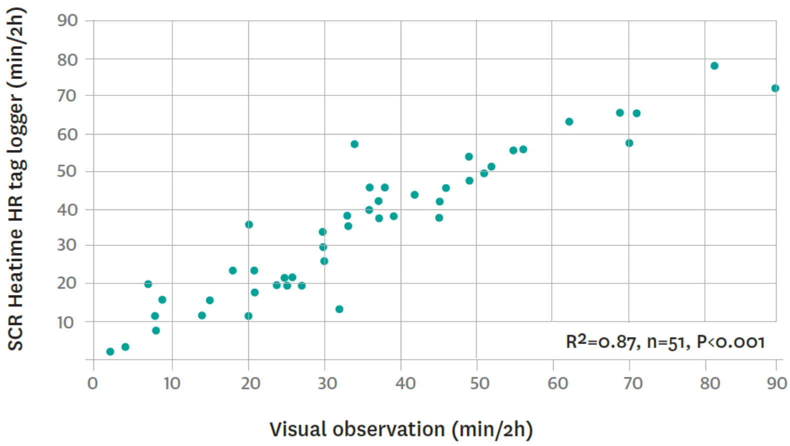

Figure 41. Comparison of logging by the SCR Heatime® HR system with visual observation (Schirmann et al., 2009)

The SCR Heatime HR, with LD tag compatibility, contains a motion sensor, microprocessor, memory and specially-tuned microphone that detect the cow's activity and rumination. Each HR LD tag collects information and transmits it to the SCR system a few times per hour via RF technology, so the information in the system is up-to-date at all times, wherever cattle are housed. The HR LD tag includes a unique sensor that measures each animal's body movements and their intensity. The rumination data that are collected by these RF tags is immediate and actionable, sent wirelessly to the system a few times per hour. This information is used to monitor cattle health, to identify and treat disease earlier. Both activity and rumination data are recorded in the tag and stored in two-hour blocks, therefore farmers can identify the exact behavioural profile of animals.

SCR Heatime® Pro system: This is a real-time monitoring system that enables flexibility in managing individual animal monitoring data. SCR Heatime® Pro system is a PC-based, centralized management system for real-time health monitoring and heat detection in cattle. SCR Heatime® Pro system has the potential to help farmers to evaluate the reproductive, health, nutrition and wellbeing status of each animal and allowing early intervention if needed.

SCR HealthyCow® 24 Solution: SCR Dairy has developed a new system with more features and flexibility, easy to use and can be used remotely. The following is specific features of SCR HealthyCow® 24 Solution:

- Portal and mobile app deliver convenient access to the farm data
- View and edit farm data remotely, from anywhere

- Get real-time alerts and reports on mobile devices
- Control all management systems via a single access point
- Work efficiently, with real-time animal status and the option to update data in the field
- Online backup and restore with remote software upgrades

SCR Dairy system features is provided in Table 29.

Table 29. Features of SCR Dairy technology

Features	Description (select the appropriate one) or describe
Stage of development	Commercial
Class of cattle	Dairy, Beef
Housing condition (eg. grazing vs intensive with TMR)	Suitable for all housing conditions. Normal system collects 24 hours data and transfers when cow passes reader at parlour or over water trough. LD system provides coverage 24/7 with fewer readers (1 reader = 500mx200m+).
Parameters that can be measured? (eg. rumination, diseases, etc.)	SCR Heatime = Standalone Activity & Rumination Application – Health report, Production reports, Cows in heat, Suspected for abortion, Distress calving alert SCR DataFlow (Full system adds milk metering, feeding controls etc. (Raw data = Milk amount, time, flow, Air, blood, conductivity)
Price/head ($)	RRPs from USD $119 (Activity only), $169 (Activity plus Rumination). Extra USD $40/Head for LD (Long distance version of each)
Price of accessories (eg. reader, antenna, etc.)	Extras – Estimates prices: USD $4,000-8,000 Readers, terminal, software and system. Depends on complexity, area to cover and distance. USD $15000 – Optional Auto Sort gate, includes installation/training
Technical support provided (Yes/No)- what is the fee?	Yes – Initial training and first years support included in install. Ongoing update training via web sessions free of charge. Individual training and on-farm support by dealer – generally USD $50-80/hour plus travel time. At dealers discretion.
Recording frequency/rate	Milk – every milk Activity and rumination – every 20 min to logs file and every 2 hours to the DB
Bolus's battery's life	Average Tag life time = 7 years. Warranty 3 years, plus extension available to 5 years, at 7.5% on-cost/ tag.
Validated externally (Yes/No) (against other methods- gold standard)	Yes- see SCR dairy website for publication
Research conducted?	Yes- see SCR dairy website for publication
Publications (eg. Proceedings (abstract) Peer-reviewed journal, reports, etc.)	http://tinyurl.com/ruminationresearch
Feasibility (eg, to be used in commercial farms or research farms)	Used as a commercial solution for more 7 years in more than 15000 farms over the world. Highest usage in UK and Denmark where SCR tags cover more than

Features	**Description (select the appropriate one) or describe**
	50% of the national herd.
Sensitivity of device (eg. detecting the cattle with ill-health)	Health report (post-partum cows) – not applicable, depends on the type of disease and the clinical severity. A few examples: detection of Displaced abomasum cases – 100%, indigestion 100%, ketosis – 92%, mastitis 70%. Heat Report – 85-90%
Specificity of device (eg. if this has been validated against other methods (gold standard) to identify animals with specific metabolic or infectious diseases, etc.)	Health report – detection of diseases was validated against Gold standards such as: BHBA in the blood for detection of ketosis/urine keto-sticks. Mastitis – Lab analysis of milk samples/CMT. DA – diagnosis and surgery of veterinarian. Metritis – diagnosed by veterinarian. Heat Report – measurements of progesterone in the blood, Ultrasound, conception rates. Depends on the population in the herd that has tags.
Accuracy of device	Heat - ≥90% Health – depends on the disease.
Reliability and durability (eg. how reliable is the collected data and how long is the device's life?)	Average Tag life cycle – 7 years. Varies by application. Note – Standard Tag Warranty 3 years, plus extension available to 5 years, at 7.5% on-cost/ tag. Warranty for other collar components and other equipment = 2 Years
Required skills for implementation and data collection	None. Training and support provided with installation. No prerequisite knowledge assumed.
Technical support	Yes. Provided by local distributors in first instance, with escalation to SCR personnel in Aus/NZ or Israel.
Required resources and software programs	Heatime HR (standalone terminal) = None. Heatime Pro – (PC version) - According to DF2 requirement spec –attached
Data storage and processing	Heatime HR (standalone terminal) = None. Heatime Pro – (PC version) - According to DF2 requirement spec -attached
Internet requirement	None required. Optional for software support and training. According to DF2 requirement spec – attached
Potential compatibility with **NLIS***	No conflict with readers. Can operate both SCR and NLIS on same cow. Some data linkage and export/import functions established for common dairy farm management software that use NLIS identification. (e.g SCR Heatime tag and reader identifies cow in heat or rumination health alert, sends draft signal to Jantec system, which then drafts cow via auto draft based on NLIS ID). DataFlow can also use NLIS readers in place of SCR readers (ie for Milk recording/feeding/draft only systems with no Activity/Rumination monitors).

5.18.5 RumiWatch Noseband Sensor

RumiWatch technology (www.rumiwatch.ch) is based on Noseband Sensor (NBS) to monitor all jaw movements and recording and storage of data for up to 4 months (Figure 43). The NBS consists of a vegetable oil-filled tube, pressure sensor and accelerometer, and a wireless transmitter. Jaw movements are registered with a frequency of 10 signals per second. Data analysis is conducted in real time via validated algorithms of the RumiWatch electronics. The headstall is adjustable by the neck strap and by the jaw strap and can be customised individually to the animal. It is suggested that NBS will not restrict neither chewing nor swallowing, and animals should be able to move the jaw freely while wearing the strap but simultaneously exert pressure on the pressure hose (www.rumiwatch.ch).

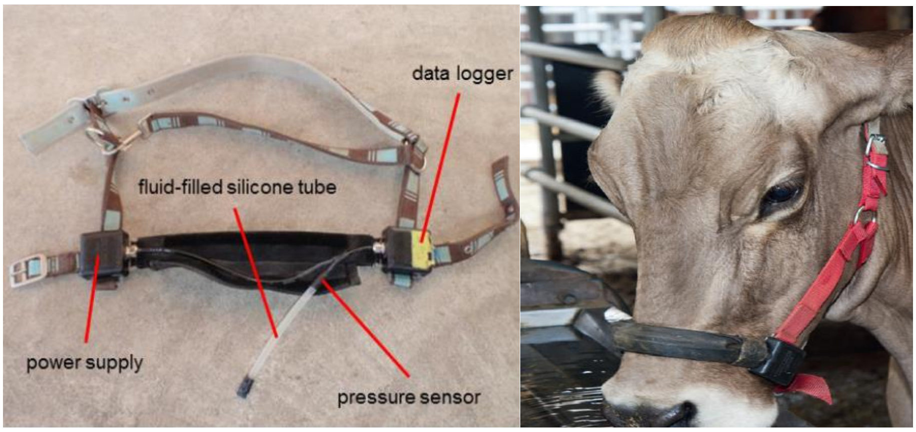

Figure 43. RumiWatch NBS to monitor jaw movement, eating, rumination and other activities (Source: www.rumiwatch.ch)

Cattle with a RumiWatch unit (Noseband Sensor) that are within the range of 5 to 10 meters of a computer can exchange the collected data wirelessly. The raw data recording can be started via USB cable, the USB cable is only used for formatting the micro SD card, which is located in the RumiWatch Unit. The USB cable must be disconnected from RumiWatch Unit to start recording the raw data on the SD card. After connecting the reader to the computer, the raw data recording can be started wirelessly in RumiWatch Manager. To read out the raw data from the SD memory card via USB cable the battery must be connected. The USB cable cannot power the SD card. In case of an interrupted power supply, the SD card can be removed from RumiWatch unit and can be read out by a standard SD card reader. A summary animal's activities is created by RumiWatch unit and pooled on hourly basis. The evaluation is in real-time and created directly during the measurement. The summaries can be transmitted wirelessly and automatically to the computer via RumiWatch Reader.

A unique feature of the RumiWatch NBS is its ability to register and measure every single bolus, jaw movement or drink gulp. Wireless transmission of summaries to the PC enables direct visualization of measurement data to monitor the rumination activity and potentially the animal health. RumiWatch Converter is a software for user-defined analysis, processing and graphical representation of data measured by RumiWatch NBS. For proper data analysis, a logging rate of 10Hz is required. Raw data can be recorded on the internal SD-card of RumiWatch units NBS and can be uploaded later to a computer for analysis in RumiWatch Converter. RumiWatch is also equipped with an alarm function based on validated threshold values for the herd and individual animals. This can help farmers for early diagnosis of diseases and under-performed cattle and reduce the production losses. RumiWatch NBS can monitor and store the following data and information, which is detailed in Table 30.

- Amount of time spent on ruminating
- Amount of time spent on eating
- Amount of time spent on drinking
- Amount of time spent on other activities
- Quantity of chews when eating
- Quantity of gulps when drinking
- Quantity of other chews
- Quantity of regurgitated Boluses
- Quantity of chews per minute
- Quantity of chews per bolus
- Three-dimensional motion data of the head
- Temperature at the Noseband Sensor

Table 30. Parameters that can been measured and recorded by RumiWatch NBS

Parameters	**Functions**
Serial number	Noseband Sensor's serial Numbers
Send time	Timestamp when the summary was sent from Noseband Sensor to the computer
Receive time	Timestamp when the summary was received by the computer
Watch start	Start of 1-hour summary's interval
Watch stop	End of 1-hour summary's interval
Other activity time	Amount of time spent on all other activities (in minutes) within the 1-hour interval (neither assigned to ruminating, eating nor drinking)
Ruminate time	Amount of time spent on ruminating (in minutes) within the 1-hour interval
Eat1- time	Amount of time spent on eating (in minutes) within the 1-hour interval
Eat2- time	Not part of this analysis, value 0
Drink time	Amount of time spent on drinking (in minutes) within the 1-hour interval
Other chew quantity	Quantity of all other chews (All chews not assignable to ruminating, eating or drinking)
Ruminate chew	Quantity of chews when ruminating within the 1-hour interval
Eat1chew	Quantity of chews when eating within the 1-hour interval
Eat2chew	Not part of this analysis, value 0
Drink gulp	Quantity of gulps when drinking within the 1-hour interval
Bolus	Quantity of regurgitated boluses within the 1-hour interval

The service life of the batteries is about 2 years without recording raw data on the SD memory card and about 6 months with recording on the SD memory card. It may vary depending on the actual duration of the measurement and on environmental conditions. When not in use, the battery should be removed. The RumiWatch's battery level can be checked wirelessly in RumiWatch Manager. The battery should be replaced if checking its status a power supply of < 2.85V is noticed. If the power is interrupted, the wireless connection between the computer and RumiWatch unit is interrupted, data analysis and hourly summaries are skipped. However, previously recorded raw data remains stored on the SD memory card.

Table 31. RumiWatch Noseband Sensor (NBS) descriptive features

Features	**Description (select the appropriate one) or describe**
Stage of development	Commercially available, with ongoing improvement and enhancement of hardware, software, analysis functions and interfaces
Class of cattle	Current state: commercial application for intensive dairy systems, research application for dairy and beef cattle
Housing condition (eg. grazing vs intensive with TMR)	Suitable for all housing conditions (barn and pasture)
Parameters that can be measured? (eg. rumination, diseases, etc.)	RumiWatch noseband sensor: ▪ Rumination duration ▪ Feed intake duration ▪ Water intake duration ▪ Other activities duration ▪ Ruminate chews count ▪ Eating chews count ▪ Drinking gulps count ▪ Other chews count ▪ Regurgitated boli count ▪ Chews per minute count ▪ Chews per bolus count ▪ Activity changes count ▪ 3-D motion data of the head ▪ Noseband sensor temperature
Price/head ($)	RumiWatch noseband sensor: USD $1000 (August 2014, target price for 2015/2016: USD $220)
Price of accessories (eg. reader, antenna, etc.)	Reader/antenna: USD $150
Technical support provided (Yes/No)- what is the fee?	Technical support is provided (remote support or service on site) – currently free of charge
Recording frequency/rate	10 Hertz (10 signals per second, both for ingestive and motion behaviour)
Battery’s life	Up to 3 years under laboratory conditions
Validated externally (Yes/No) (against other methods- gold standard)	Yes, several validation studies by independent research institutions (against direct observation, video observation, and recordings of weighing troughs)
Research conducted	• Ongoing scientific evaluation of the RumiWatch System in a research and development cooperation of ITIN+HOCH Feeding Technology GmbH and Swiss Federal Research Station Agroscope • Broad application in several international research projects with a focus on animal health, ethology, pasture management
Publications (eg. Proceedings (abstract) Peer-reviewed journal, reports, etc.)	Reports Proceeding abstracts
Feasibility	Current state: main focus on scientific application of the system

Features	**Description (select the appropriate one) or describe**
(eg, to be used in commercial farms or research farms)	Goal of the development: application for health and feeding management in commercial farms
Sensitivity of device (eg. detecting the cattle with ill-health)	Currently no automated detection of pathologic behaviours implemented Generation of an automatic alert systems for detection of sick animals is in progress and fundamental part of the RumiWatch research project
Specificity of device (eg. if this has been validated against other methods (gold standard) to identify animals with specific metabolic or infectious diseases, etc.)	Currently no automated detection of pathologic behaviours implemented Validation of the future alert system for detection of pathologic behavioural changes will be part of the ongoing RumiWatch research project
Accuracy of device	97.2% correct classification of ruminating behaviour, 95.2% correct classification of eating behaviour (validated against direct observation)
Reliability and durability (eg. how reliable is the collected data and how long is the device's life?)	High reliability due to use of high end recording and storage components (e.g. Swissbit SD Memory Cards) with product-specific firmware Prospected lifetime is approx. 5 years (no long-term investigation data available yet)
Required skills for implementation and data collection	Application training (1 day) with practical and theoretical contents offered by the manufacturer is recommended User manual for hardware and software operation should be studied before starting measurements with the RumiWatch System
Technical support	Offered by ITIN+HOCH Feeding Technology, CH-4410 Liestal, Switzerland (info@fuetterungstechnik.ch) Central warehouse in Switzerland, spare parts will be shipped worldwide
Required resources and software programs	• Windows 7 (32-bit and 64-bit), Windows 8 or 8.1 (32-bit and 64-bit) • 1 GB RAM (2 GB RAM advised) • At least 1 GB free space on the HDD for specific system applications • Additionally a minimum of 10 GB storage for raw data • Minimum 1x USB 2.0 Type A connector
Data storage and processing	• Real-time data analysis on the device and hourly wireless data transmission (Option A: summary transmission) • Recording of 10-Hz measurement data on a SD Memory Card for up to 4 months and serial data transmission via USB (Option B: raw data recording) • Options A and B can be used parallel
Internet requirement	Only when using cloud upload of measurement data (optional)

Features	Description (select the appropriate one) or describe
Potential compatibility with NLIS	Interfaces between RumiWatch software and NLIS application may be possible
Others	see additional information and documents in the Download Centre of www.rumiwatch.com

Conclusions on rumination monitoring technologies

Different approaches have been developed over the years for monitoring fermentation and rumination of cattle, which can also be accomplished with rumen boluses that can measure rumen pH and other parameters such as redox and volatile fatty acids (VFAs). Technologies that are listed in this category are based on monitoring rumination activities. Changes in the rumination is a reflection of changes in fermentation in the rumen which can be the result of changes in the proportion of population of bacteria and other micro-organisms in the rumen. The rumination is a reliable indicator of animal eating behaviour that can be used to differentiate healthy cattle from those with ill-health or nutritional disorders. The first symptoms that are observed in cattle with ill-health (e.g. BRD and subacute acidosis) are the lack of appetite and a reduction in rumination.

The features of Leyly device have been based on the technologies that were developed by SCR. The frequent recording of sound of rumination can be a useful tool to identify animals that need attention. These two devices (Leyly and SCR) are widely used in commercial dairy herds. The Leyly technology, in particular, is used in a number of dairy farms with robotic milking system in Australia. The SCR device has the advantage of recording rumination and movement activities, which are used to identify animals with high level of activities, heat detection and reproductive management. RumiWatch device is a multi-tasking device that is used to monitor jaw movement and rumination and a number of other activities such as measuring number of steps taken by cattle which can be an indicative of animal's wellbeing.

The concept of these technologies appears to be sound and reliable, and the published research studies have supported their implications in commercial dairy farms. These devices have been tested and validated against the gold stranded (visual observation) and can provide the data in real-time to the feedlot operators. However, the sensitivity and specificity of these devices have not been established, to be able to predict the probability of identifying cattle with ill-health or shy-feeders. These technologies have not been experimented in feedlots, and it is difficult to fully assess their implications within existing feedlot structure.

This technology has a high potential to be used in commercial feedlots, but mores studies need to be conducted to explore its application, reliability and costs before this can be recommended to the feedlot industry.

5.19 Other monitoring technologies

There are a number of devices and software programs that have used different or mix of technologies that have been described in previous sections. These technologies are predominantly under development or designed for experimental purposes. These are briefly described here, as there is limited information on the application of these technologies, and reviewed solely for the completeness of this review. Further information on the progress of these can be found on their websites (Table 32).

Table 32. Devices and programs that have used different or mix technologies with diverse applications

Developer/ Manufacturer	Country	Name of product	Website	Stage of development and usage	Class of cattle
Agis Automatisering	The Netherlands	CowManager SensOor	www.cowmanager.com	Experimental	Dairy
Bitsz Engineering	German	Smardwatch	www.bitsz-engineering.de/smardwatch	Experimental	Dairy
Alanya Animal Health Monitoring	Irland	Alanya	www.animalhealthmonitoring.com	Experimental	Dairy

5.19.1 CowManager SensOor

The SensOor (www.cowmanager.com) is a product developed by Agis Automatisering. It comprises a moulded chip that can be clicked into the ear tag of a cow for monitoring cow welfare. The CowManager SensOor system contains 3 modules: fertility, health (temperature and activity) and nutrition (rumination and feeding time). The SensOor saves labour and ensures a sustainable herd management. The CowManager SensOor System comprises the following (Figure 44):

- SensOor: clicks into the ear tag of the cow
- Coordinator: connects to the computer and receives all data from the SensOor or router(s).

- Router: serves as an extra antenna when the distance between the SensOor and the coordinator is greater than 100 metres
- CowManager: software program in which the data is processed and displayed

Figure 44. CowManager SensOor ear tag and antenna (Source: www.cowmanager.com)

The SensOor transmits the data (via a router, if necessary) to the coordinator. If the cow is outside of reach of the coordinator, when it is grazing for example, the data is stored for two days. The data is transmitted as soon as the cow is within reach of the router or coordinator. This ensures that no valuable data is lost. The SensOor enables the farmers to monitor the entire herd on a continuous basis. Farmers would be able to monitor the herd in real-time during grazing by installing an extra router (antenna).

The SensOor is attached to a Supertag ear tag that has been specifically designed for Agis. Automatisering, which is called the coordinator and is connected to the computer for the transmission of data. If the distance to the computer is long, a router (signal booster) is installed. The CowManager software program immediately displays oestrus or illness detection on the computer, tablet or mobile. The CowManger SensOor claims that this technology can measure fertility, health and feeding parameters. Research conducted in cooperation with the laboratory of the Wageningen University has shown that farmers using the SensOor chip have an oestrus detection success rate of 98% (www.cowmanager.com).

CowManger SensOor also claims that the SensOor has the potential to identify cattle with illness two days earlier than detection by the farmer by other means. The SensOor can measure cow's ear temperature. The SensOor indicates whether there is a rise or drop in temperature, before the clinical symptoms exhibit and recognises health problems among the cows at an early stage by alarming the farmer for animal's abnormal behaviour. Monitoring eating behaviour, rumination and dietary change can also be measured by SensOor. Rumination and the cow's eating behaviour are monitored for measuring ruminal health and therefore the welfare of the cow. The SensOor registers the amount of time that cows spend on rumination 24 hours a day. The farmer will receive an alert when abnormal rumination behaviour is detected.

5.19.2 smardwatch System

The smardwatch (www.bitsz-engineering.de/smardwatch/EN/?description) technology offers two versions of smardwatch systems; this includes necklace and bracelet (Figure 45). Earmark is also a new device developed by smardwatch, which is still under development.

Figure 45. smardwatch sensor and bracelet (Source: www.bitsz-engineering.de/smardwatch)

The system consists of one or more smardwatch sensors, the smardwatch base station and the software smardwatch life monitor (Figure 46). A sensor captures information on vegetative functions, muscular reactions, temperature regulation processes, and movement patterns of individual animals in detail the following items are recorded:

- Temperature of skin and environment
- Skin resistance
- Skin potential
- Muscle potential (electromyogram)
- 3D movement activity

Figure 46. smardwatch sensors, base station and software (www.bitsz-engineering.de/smardwatch)

Once the sensors have been activated, the data acquired per animal are transferred to the smardwatch base station in real-time and via radio signal; via wire transfer and then continuously copied to the computer. The respective evaluation software performs the required analyses. For this purpose, the calculated values are stored in a database and represented both graphically and in tables. Subsequently, a complex chronobiological data analysis for all parameters takes place in order to determine their states. This allows to detect behavioural changes and health related attributes such as ‘normal’, ‘noticeable’ or ‘deviating’. A full description of smardwatch’s parameters is summarised in Table 33.

Table 33. Description of parameters that smardwatch monitors and measures in cattle (Source: www.bitsz-engineering.de/smardwatch/EN/?description)

Monitor	**Parameter measured**
3D acceleration/movement	Behaviour
Electromyogram	Muscle activity
Skin potential	Vegetative-nervous reaction
Skin resistance	Vegetative-emotional reaction
Skin temperature/Environment temperature	Thermoregulation

smardwatch offers intensive educational training for smardwatch users and also provides continuous support to the farmers. They will provide individualised quotation to the farmers with various situations.

5.19.3 Alanya Animal Health Monitoring

Alanya Animal Health Monitoring (www.animalhealthmonitoring.com) is an Irish technology company that has developed a new health monitoring system for the dairy industry. Alanya’s solution claims that their technology can improve the existing solutions in the marketplace for the following parameters:

- Behavioural changes
- Temperature
- Lying/Standing time

- Grazing time
- Lameness
- Oestrus detection (multiple metrics)
- Locomotion Scoring

No information has been provided on the type of technology, methods, costs, etc.

Figure 47. Alanya health and oestrus solution (Source: www.animalhealthmonitoring.com)

6. Innovative proposal

A team of scientists at the University of Queensland, Veterinary Faculty, proposed to develop a remote monitoring system that has similar characteristics of the available technologies with extended application and benefits.

Smart Dust (or wireless sensors networks) is a MicroEletroMechanical system (MEMS) sensor that can perform a variety of functions (e.g. GPS tracking, data acquisition, processing and transmission). A single smart dust sensor typically contains a semiconductor laser diode and MEMS beam-steering mirror for active optical transmission; a MEMS corner cube retro reflector for passive optical transmission; an optical receiver, signal processing and control circuitry; and a power source based on thick-film batteries and solar cells. Advances in digital circuitry have enabled the creation of a sensor this small which still has a battery, a nominal amount of system memory (RAM) and a wireless transmitter capable of transmitting information up to 30 meters. In addition to this advance, the use of drones is becoming more acceptable in the agriculture industry. Part of this research program will focus on the use of an off-the-shelf aerial drone model in combination with a multi-spectrum camera system to collect real-time animal and pasture data. Data collected by the MEMS and drone system will be automatically analysed and linked to a network capable device through which the end user can access and receive alerts in either real-time or on-demand.

The efficiency of the presently available radio frequency identification systems used to collect animal- and pasture-level data is limited by their power source requirements. This limitation reduces the ability of these systems to operate in an active mode and to transfer data between the various system components: sensors, antenna, data storage and the data processing base station or hub. Technological advances made possible the fabrication of complete electronic and micro-mechanical systems on a small scale in the order of only a few hundred microns which are suitable for use in this project. This project will test and implement a novel 'low-cost' design for a communication system that uses either the stand-alone 'Smart Dust' system, or the 'Smart Dust' system augmented with an aerial as a communicate tool.

The system will benefit the end users (livestock producers) in many ways. The ease of deployment, ease of use, and the real-time monitoring of pasture and animal health of this system will fit well with livestock producers' daily and longer term management needs. In contrast to existing systems, this system is capable of collecting high quality animal and pasture level data from multiple sources, performing automated data analysis, and real-time presentation of user-friendly information which enhances the producer's decision making ability. The system's real-time monitoring of animal health and reproductive (e.g. oestrus detection) status will have positive effects on animal welfare and productivity.

The envisaged outcome of this project is a low-cost fully functional remote, autonomous pasture and animal health management model. Evaluate the strengths and weaknesses of available remote monitoring systems.

7. Consulting technological industries and feedlot consultants/advisors

Technological industries: A questionnaire was prepared to obtain and collate the required information on each technology (Appendix I & II). This included a description of methodology, accuracy, cost and other parameters that are needed to evaluate the performance of these technologies (Appendix I & II). The developers, manufacturers, university academics and industry experts, who have trialled or evaluated these technologies, under experimental or field conditions, were contacted to collate the required information. We also interviewed a number of developers of technologies, where possible, to obtain further information for the evaluation and assessment of these systems. The information that we were able to obtain from the developers and manufacturers were embedded in the relevant sections for each technology.

Feedlot consultants/advisors: Industry experts in this field were consulted to explore their views on the application of these technologies in the field. A short questionnaire was developed using SurveyMonkey (www.surveymonkey.com), with a series of selection criteria on each technology, and then the industry experts were asked to provide their opinions on whether the available remote diagnostic systems or those that are in the developmental stage have the potential to address the needs of the feedlot industry (Appendix III). They were also asked to comment on the accuracy and cost-effectiveness of the available technologies compared to the traditional methods that are used to identify the animals with health and welfare issues. Descriptive information obtained from the industry experts who responded to the survey is provided in Table 34. A total of 7 industry experts (7 out of 15; 47%) responded to the survey. The participants were veterinarians and feedlot consultants (n=7) who provide services to multiple regions within different states, including northern NSW, central NSW, southern NSW, central QLD, southern QLD, Victoria, South Australia and Western Australia.

Survey results on the estimated incidence of different diseases, the proportions of cattle being pulled by pen riders on daily basis, and treatment costs are presented in Table 34. Most participants believed that BRD is the most common disease (49% of responses) in feedlots with the highest cost (~ $45.0/hd). This also shows that cattle with BRD have a higher probability of being pulled by pen riders (Table 34).

Table 34. The incidence of common diseases and nutritional disorders, percentage of cattle pulled by pen riders on daily basis and estimated cost of treatment per head

	Average & range		
	Incidence (%)	Pulled by pen riders (% per day)	Estimated cost of treatment ($/hd)
Nutritional disorders (e.g. acute and subacute acidosis, bloat, etc.)	3.41 (0.25 – 10)	6.27 (0.1 – 20)	20.25 (2 – 60)
Infectious disease (e.g. BRD)	49.29 (3 – 95)	42.51 (2.57 – 95)	44.60 (18 – 100)
Lameness and footrot	9.40 (3 – 25)	14.91 (0.54 – 50)	15.63 (3.50 – 40)
Parasitic disease	22.50 (5 – 40)		
Others*	4.60 (1 – 10)	5.17 (0.34 – 10)	14.0 -

* One participant included calving problems and reproductive disease in this category

Approximately 86% (6/7) of participants believed the number of cattle diagnosed with ill-health by pen riders on daily basis depends on pen riders’ skills and experience, and 14% believed that the pen riders may over- and under-estimate the number of cases on daily basis. The results of this survey also show that feedlot veterinarians and consultants have mixed views on how the new remote diagnostic technologies should be used by pen riders for early diagnosis of diseases in feedlots (Table 35). However, the majority (86%) believed that the current technologies should only be used by pen riders as an aid to diagnosis.

The majority of industry experts (72%) believed that the uptake of remote diagnostic technologies in feedlot operations within the next 5 to 10 years will depend on the annual cost of technology per head and implementation/ongoing expenses. The accuracy, Se, Sp and required technical skills were also considered by some to be essential for the uptake.

The results of this survey showed that industry experts ranked technologies for measuring daily feed/water intake very highly (1), followed by technologies to monitor cattle movement (2), rumination activity (3), rumen pH (4) and rumen temperature (5). Daily feed/ water intake is recognised as the best indicator of animal health and wellbeing (Table 36). The low ranking of other technologies such as rumen pH and temperature, activities, and rumination suggests that the industry experts are not fully informed about the benefits of other technologies. This also implies that feedlot operators and veterinarians may consider clinical symptoms as the optimal tool for the diagnosis of diseases, underestimating the lag-time between the changes in rumen function and subsequent manifestation of clinical symptoms (i.e. a reduction in feed and water intake and lower activity). If the feedlot operators (pen riders and managers) can monitor the rumen parameters (pH and temperature) and rumination activity in real-time on daily basis, this may result in more cost-effective early diagnosis/treatment and prevention.

Table 35. Industry expert views on the implication and function of available remote diagnostic technologies in feedlots

Function of technologies in feedlots	**(%)**
As a standalone diagnostic tool (replacement for pen riders)	
As an aid for pen riders (as a diagnostic tool)	0.86
Can't rely on available remote diagnostic technologies	
Not enough information available on the accuracy, sensitivity and specificity of new technologies	0.43
Commercially available technologies are too complex	0.14
Farm staff do not have the skills to handle the new technologies	0.14
Further development should be performed to make the technologies more reliable and user friendly	0.57
Costs and ongoing expenses could be a prohibitive factor for the uptake	0.29

Table 36. Ranking of remote diagnostic technologies by industry expert for early diagnosis of diseases in feedlot operations

	Ranks (1=highest, 5=lowest
Measuring daily feed/water intake	1
Monitoring cattle movement, activities and behaviour	2
Monitoring rumination activity	3
Measuring rumen pH	4
Measuring rumen temperature	5

Overall, both veterinarians and farm mangers identified a number of parameters or factors that can impact animal productivity:

- Identifying animals with ill-health with high level of accuracy
- Over- and under-diagnosis of cattle with infectious diseases (eg. BRD) and metabolic disorders (eg. subacute acidosis and bloat)
- Pen-riders' skills and experience to identify animals with health issues
- Cost associated with identifying, drafting and treating sick cattle on daily basis
- Environmental factors that can impact the incidence of diseases and probability of positively identifying cattle with ill-health and welfare issues.

Farm managers had more conservative and cautious views towards the new technologies. They preferred technologies that are more tactile and visible, and require less technical skills so that farm staff can use them with minimal technical skills. They believed the available technologies (known to them to date e.g., rumen boluses and methods measuring feed intake) have not produced convincing results for use as a reliable diagnostic tool for pen riders and farm personnel who are involved in daily diagnosis and drafting cattle with health or welfare issues. However, it appears that they are willing to trial some of the technologies identified as preferred methods in this report as potential diagnostic tools for the pen riders, if the economic cost (eg. costs of device, implementation and maintenance) and required technical skills are not excessive.

The feedlot veterinarians wanted to know more about the methodologies' sensitivity, specificity, feasibility, maintenance, and the technical expertise required to collect data and information on a daily basis. There were different views among cattle veterinarians on over- or under-estimation of animals with ill-health that are diagnosed by pen riders on daily basis. Some were more concerned about the under-diagnosis rather than over-diagnosis, because of the potential loss of productivity from miss-classification of sick animals. However, both groups believed there is around 5% to 10% over-diagnosis by pen riders in most feedlot operations. The feedlot veterinarians were more concerned about animal health and productivity than the cost of diagnosis and treatment. A number of feedlot veterinarians believed that a high number of false negatives and false positives resulted from using subjective measures, such as visual appraisal. They indicated that in a feedlot environment, the use of laboratory veterinary tests are impractical and costly and also require technical training. Currently, monitoring rectal temperature with other subtle clinical symptoms (such as depression and nasal discharge) are the common practice for confirming BRD in a feedlot. Some veterinarians believed that other new technologies (e.g. electronic stethoscope technology, EST) will provide the industry with better, more accurate diagnostic tools but the sensitivity and specificity of EST is yet to be determined.

8. Assessing factors that influence the success of remote monitoring systems

The success of available and potential remote monitoring systems may be influenced by other factors, which are not directly related to the reliability of the technology. Due to limited information on these risk factors, these are briefly reviewed in this report with an attempt to estimate the magnitude of their impacts. This includes, but is not limited to, the following:

a. Farm structure in different regions
b. Feeding systems
c. Environmental factors (e.g., temp, rainfall, etc.)
d. Number of pens and animals per pen (intensity)
e. Number of experienced farm staff (e.g. pen riders)

Environmental and farm factors may influence the success of different technologies. The developers and manufacturers of the technologies that were reviewed in this report were asked for this information to assess the impact of these factors on the performance of commercially available technologies (see Appendix II).

9. General conclusions and recommendations

Along with geographic compression of the industry, consolidation and changes in scale of individual feedlot operations have occurred at a rapid pace in recent years. In all livestock sectors, farms have become larger and more specialized. This has certainly been the case in the cattle feeding sector, which is exemplified by the change in the size (capacity) of feedlots. In addition to increased size of individual feedlots, ownership of feedlots is moving to corporations or large privately held companies that own several feedlots vs. ownership of single feedlots by individuals or partners. The shift to larger-scale feeding operations presumably reflects economy-of-scale advantages in cattle procurement and marketing, as well as in commodity purchase and risk management opportunities that would be more difficult to achieve in smaller and individual feedlots.

Feeding practice: As demographics and size of feedlots has increased over the years, feeding and health management practices have changed significantly. Providing roughage poses problems in handling and product consistency, and is generally expensive relative to grain, which has led to the decreased use of roughage in feedlot diets. In conjunction with less roughage, extensive processing of grain has become the norm in the industry. Rapid application of technology has been a characteristic of the feedlot industry, where ionophores are fed to virtually all feedlot cattle as they produce greater returns on investment than any other technology applied to feedlot cattle. Although the in-feed use of antibiotics has been limited in recent years, antimicrobial drugs have continued to become available, with most approvals focused on therapeutic use and requiring a veterinary prescription. The cost of therapeutic intervention continues to increase, resulting in significant price tags for current practices in the feedlot industry.

Remote technologies: Remote technology is a challenge, but over the past decade a growing number of technologies have become commercially available to the Australian beef industry. The uptake of remote technologies in the feedlot beef sector has been slow and many producers have been left wondering just how these technologies could benefit their beef operations. This is mainly due to a lack of information on application, costs, benefits, and required technical skills to handle the complexity of these technologies in a feedlot enterprise.

Swain et al. (2013) investigated the application of Precision Livestock Management Technologies (PLMTs) to increase the efficiency of production in extensive beef production systems. They found while these technologies have the potential to improve profits, there is a lack of knowledge on how this may be achieved. Swain et al., 2013 explored and surveyed five properties located across northern Australia to examine how the emerging technologies might provide an economic benefit. The following technologies were included i) e-Preg, ii) Walk-over-weighing and auto-drafting, iii) Coarse-resolution location cattle tracking, iv) Fine-location cattle behaviour and tracking, and v) Automated pasture assessment.

Prior to recommending new technologies for the feedlot industry, it is essential to conduct similar studies to identify opportunities and challenges with the available technologies, as well as identify those that can provide the greatest potential economic benefit to feedlot enterprises. Feedlot beef producers are predominantly supportive of the concept of remote technology, but they believe in many cases the systems are too complex, requiring a high level of technical expertise, and they are not confident in the technology’s accuracy and sensitivity for identifying animals with ill-health. However, feedlot producers also recognise that the available technologies have the potential to provide critical information on cattle performance, health, welfare, and behaviour on daily basis throughout the entire year.

A number of technologies currently available that were reviewed in this report have the potential to be adopted within a feedlot operation and can be compatible with the Australian NLIS program. Technologies designed to measure daily feed intake and identify an animal's electronic tag can alert the farm manger if the animal has not been near the feed or water troughs for several days. The rumen bolus technologies have the potential to detect an animal's temperature or rumen pH and alert the farm manager about animals that need urgent attention.

Determinants of technology adoption encompass characteristics of the technology, features of the feedlot/feeding system, reliability, real-time features, market and policy environments, as well as socio-economic characteristics of the decision-making unit. The objective of study was to identify and determine the technologies that are practical, cost-effective, and easy to use, and can be implemented within current feedlot farming systems with minimal modification to the enterprise's structure, and where technology diffusion and extension strategies could be implemented.

Factors contributing to the success of new remote technologies

The probability of greater uptake and success of new technologies in the feedlot industry can be impacted by a number of factors. Failure of some of these technologies to gain a sustainable market penetration could be due to product (device) features, market environment (type of industry), associated cost, and return on investment (ROI). There is limited information in the literature to quantify which of these factors are more important to obtain greater market penetration in the short-term. However, the industry experts are optimistic because the technologies are improving and becoming more user-friendly for the farm staff. It is envisaged that a greater uptake will be likely in the medium to long-term. The following are some of the risk factors that may contribute to the success of available technologies:

- Availability of information and familiarity of feedlot producers/operators and industry experts with the technologies. If the industry is not familiar with the commercially available technologies, it will be difficult to successfully gain their trust for the implementation of new technologies.
- The associated cost and return on investment (ROI) are critical for the decision makers in the industry to promote a particular technology that can be cost-effective and beneficial to the producers. Undesirable cost to benefit ratio is the main obstacle for the technologies that have the potential to be beneficial.

- Accurate and accessible information that is supported by scientific research and industry experts is important to promote the technologies that are practical at the farm level and proven effective. Currently, too much irrelevant information is provided to feedlot producers without practical information on implementation at the farm level.
- The success and uptake of a new technology is also dependent on the history of the technology and the track record of institute/company that developed the technology. This review demonstrated products that have been introduced to the market without adequate investigation into the internal and external validly of the technology.
- Feedlot producers need to perceive economic value in the new technology. There is a need for a financial analysis on the available technologies (eg. net present value (NPV)) to demonstrate that the application of a viable technology is cost-effective in the medium to long-term.
- A major problem with most of the available technologies is that they are often too difficult or complex to implement and use. The market needs technology that can easily be used by the farm staff in a feedlot enterprise with minimal technical expertise.
- Manufacturers, developers and marketing agents need to provide technical support and training to feedlot producers, farm advisors, and veterinarians. Without this, the technology may be perceived as too difficult, not efficient, or not beneficial in the long-term.
- Feedlot producers and farm advisors are the decision makers for the uptake of a particular technology. It is critical that they are convinced that the technologies offer a superior alternative to daily monitoring and manual recording by pen riders and feedlot operators.
- Compatibility of new technologies with the current practice in the feedlot industry is the most important factor that can contribute to the success and uptake of the technology in Australia. The new technologies need to be practical and able to be implemented within existing farm structures.
- Reliability, accuracy, high levels of internal and external validity, and flexibility are also important for the technologies to be successful.

Recommendations

It is essential to consider industry’s views (veterinarians, feedlot operators and feedlot researchers) on emerging technologies along with the technology’s features, such as accuracy, feasibility and costs. However, this study shows that the industry is not fully informed about the potential benefits of some of the new remote diagnostic technologies. The main concern of the feedlot industry in Australia appears to be the cost associated with the implementation and use of the technologies in feedlots, and the benefits of new technologies are only considered important if it can be cost-effective within the current feedlot structure. A detailed financial analysis (e.g. NPV) is needed to consider the initial cash outflows and also subsequent savings as the result of implementation of new remote diagnostic technologies within a feedlot operation, to accurately demonstrate the benefits of these technologies in the medium to long-term.

There is limited information to determine a realistic annual cost per head for the consideration of these technologies. This is primarily due a lack of data on the cost-savings of early diagnosis and treatment. One industry expert considered that $10/hd would be a realistic figure; however, this was based on personal experience and expectations of new technologies. Other experts believed that cost savings will vary significantly depending on the incidence of BRD within a feedlot operation. Some also believed that it will depend on whether early diagnosis using these technologies can lead to improved treatment protocols, more effective prevention strategies, and reduction in the incidence of disease in the future. Overall, in the feedlot industry experts considered the most important considerations for technology adoption to be low cost, user-friendliness, long life (energy harvesting), and minimal disturbance to the animals.

The diagnostic devices and feeding equipment that are reviewed in this report have used different technologies and approaches to provide a tool for a better management, diagnosis and treatment of feedlot animals with ill-health, poor performance, and ruminal disorders. As discussed above, cost was considered the most important factor by the industry, but a realistic cost cannot accurately be determined unless these technologies are evaluated in feedlots and their financial benefits estimated. Other considerations, although secondary to cost are also important. We identified a number of technologies within each category that met the basic selection criteria that we described in this report. These are provided in Table 37. These technologies should be considered for further research studies. The current limitations of these technologies will need to be addressed by developers and manufacturers before significant uptake by the feedlot industry can be anticipated. Although combinations of different technologies with complementary features could also be considered an option, the cost of this would likely be prohibitive.

Table 37. List of technologies that have the potential for further consideration

Technology	Device/equipment	Cost/hd (US $)	Cost of receivers/stations (US $)	Battery lifetime	Limitations
Rumen temperature boluses	TempTrak® (DVMSystems LLC)	MSRP =$50 Anticipated=$25	MSRP= $4000 Anticipated=$800	4-5 years	Low Se and Sp Can only measure rumen temperature Not measuring rumen pH Need further testing in beef feedlot operations Cannot be used for the diagnosis of rumen acidosis and other nutritional disorders High cost for receivers and stations
	SmartStock™ (SmartStock)	$45-$55	$1696	4-5 years	Can only measure rumen temperature Not measuring rumen pH Cannot be used for the diagnosis of rumen acidosis and other nutritional disorders Limited information on features and size Compatibility with NLIS is not known
Rumen temperature and pH	Sentinel™ (Kahne Ltd)	$100		4-5 years	Se, Sp and accuracy of the device have not been determined Limited data in feedlots Compatibility with NLIS needs to be determined
Animal movement/position	GPS	No costing provided	No costing provided	Not known	GPS has the potential to be as an alternative method in the future High cost is a limiting factor Technical complexity Lack of infrastructure within current feedlot operations Required skilled operators for implementation and daily use Se, Sp and accuracy of the device have not been determined
Measuring feed/water intake	GrowSafe beef (GrowSafe)	Estimated cost $60 per animal/year?	Ranges from $7,500 to $9,500 per unit/per year	Solar	Excessive purchase and maintenance costs Data is stored at GrowSafe server

					Not compatible within current feedlot operations Se and Sp of the device have not been determined
Measuring rumination	SCR	$169 (Activity plus Rumination). Extra $40/Head for long distance	$4,000-8,000 Readers, terminal, software and system (depends on complexity, area to cover and distance)	Tag lifetime 7 years	This is a dairy technology and has not been validated in feedlot operations No information on Se and Sp Complex technology
	RumiWatch	$220	$150	3 years under laboratory conditions	This is a new technology developed for dairy herds and has not been trialled in feedlots No information on Se and Sp

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11. Appendix 1

Table 1. Information on features on available remote technologies

Features	Description (select the appropriate one) or describe
Website	
Stage of development (eg. under development, commercial, etc.)	
Class of cattle (eg. dairy, beef)	
Housing condition (eg. grazing vs intensive with TMR)	
Parameters that can be measured? (eg. rumination, diseases, etc.)	
Price/head ($)	
Price of accessories (eg. reader, antenna, etc.)	
Technical support provided (Yes/No)- what is the fee?	
Recording frequency/rate	
Bolus's battery's life	
Validated externally (Yes/No) (against other methods- gold standard)	
Research conducted?	
Publications (eg. Proceedings (abstract) Peer-reviewed journal, reports, etc.)	
Feasibility (eg, to be used in commercial farms or research farms)	
Availability	
Sensitivity of device	

Features	**Description (select the appropriate one) or describe**
(eg. detecting the cattle with ill-health)	
Specificity of device (eg. if this has been validated against other methods (gold standard) to identify animals with specific metabolic or infectious diseases, etc.)	
Accuracy of device	
Reliability and durability (eg. how reliable is the collected data and how long is the device's life?)	
Required skills for implementation and data collection	
Technical support	
Required resources and software programs	
Data storage and processing	
Internet requirement	
Potential compatibility with **NLIS***	
Others	

NLIS= The *National Livestock Identification System* (*NLIS*) is *Australia's* scheme for the identification and tracing of livestock (https://www.nlis.mla.com.au; /www.mla.com.au/Meat-safety-and-traceability/National-Livestock-Identification-System)

12. Appendix 2

Table 1. Factors that may influence the success of technologies in feedlot herds

Description of factors	Comments
Farm structure • No of pens • No of feed troughs per pen • No of water troughs per pen • Size (area) of pen • Age of animals • Distance of antenna/receiver from animals • Others	
Feeding systems • Type of ration, • Ration ingredients	
Environmental factors • Temp, • Rainfall • Wind	
Intensity • Number of animals per pen • No of pen rider per pen	
Number of experienced farm staff (e.g. pen riders and other personnel)	

13. Appendix 3

Feedlot industry experts survey questionnaire

University of Queensland Survey on remote diagnostic technologies in Australian feedlots

1. What state(s) and region(s) do you service?

- ☐ Northern NSW
- ☐ Central NSW
- ☐ Southern NSW
- ☐ Central QLD
- ☐ Southern QLD
- ☐ VIC
- ☐ SA
- ☐ WA

Other (please specify)

***2. Estimated incidence of following diseases in the feedlots that you provide service to?**

Nutritional diseases (ruminal acidosis (clinical and subacute), bloat)	
Infectious diseases (BRD)	
Lameness and Foot Rot	
Parasitic diseases	
Others	

3. What is your view on the number of cattle diagnosed with ill-health by pen riders on daily basis?

- ◯ Over-diagnosed
- ◯ Under-diagnosed
- ◯ Just about right
- ◯ Depends on pen riders skills and experience
- ◯ Not sure
- ◯ There is limited data on this
- ◯ No comment
- ◯ Other (please provide an estimate on under- or over-diagnosed cattle)

Other (please specify)

***4. Estimated percentage of cattle pulled by pen riders on daily basis to receive treatment and/or hospitalised?**

Nutritional diseases (ruminal acidosis (clinical and subacute), bloat)	
Infectious diseases (BRD)	
Lameness and Foot Rot	
Parasitic diseases	
Others	

* 5. Estimated cost of diagnosis and treatment per animal?

Nutritional diseases (ruminal acidosis (clinical and subacute), bloat)	
Infectious diseases (BRD)	
Lameness and Foot Rot	
Parasitic diseases	
Others	

6. Do you believe the new remote diagnostic technologies can help pen riders with early diagnosis of diseases in feedlot cattle?

- [ ] Yes- as a standalone diagnostic tool (replacement for pen riders)
- [ ] Yes - as an aid for pen riders (as a diagnostic tool)
- [ ] No - can't rely on available remote diagnostic technologies
- [ ] Not enough information available on the accuracy, sensitivity and specificity of new technologies
- [ ] Commercially available technologies are too complex
- [ ] Farm staff do not have the skills to handle the new technologies
- [ ] Further development should be performed to make the technologies more reliable and user friendly
- [ ] Costs and ongoing expenses could be a prohibitive factor for the uptake
- [ ] Others

Other (please specify)

7. If suitable remote diagnostic technologies are identified, what level of uptake by feedlot producers would you predict within the next 5 to 10 years?

- [ ] <10% with available technologies
- [ ] 10% to 30% with available technologies
- [ ] 30% to 60% with improved technologies
- [ ] > 60% with improved and user-friendly technologies
- [ ] Current technologies are not very reliable
- [ ] Depends on the accuracy, sensitivity and specificity of technologies
- [ ] Depends of the cost of technology and implementation/ongoing expenses
- [ ] Depends on the technical skills required
- [ ] Not sure
- [ ] Other

Other (please specify)

8. In your view, which of the following technologies would be beneficial for early diagnosis of diseases in feedlot operations (1=highest, 6=lowest ranking)?

Measuring rumen pH	
Measuring rumen temperature	
Monitoring cattle movement, activities and behaviour	
Measuring daily feed/water intake	
Monitoring rumination activity	
Others (please specify)	

9. In your view, what would be a realistic cost ($/head/year) a feedlot operation may be willing to pay for a reliable technology that can monitor animal health and performance?

*** 10. Please describe in your view, what would be the ideal technology that should be developed for feedlot enterprises?**