ST Solutions Australia

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final report

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LiveCare (Health Bolus) IoT Proof of Concept

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Abstract

This project details the LiveCare (Health Bolus) Proof of Concept trial. Boluses were installed, an operational trial was carried out and upon slaughter of the cattle, the boluses were retrieved at the abattoir.

The project team installed the integrated system on the farm, with relevant third parties attending from overseas, including Japan and Korea.

The main learning from this project was that stable data communication is vital for correct operation of the system. Interference in the unlicensed spectrum was a significant issue and could not adequately be resolved. This finding may be important to the whole red meat industry where IoT based technology is being increasingly deployed.

Executive summary

Livestock production on Australian farms typically covers a much greater land area compared to other global regions, where livestock production is more industrialised and occurs in controlled environments. There are increasingly changing market demands and consumer expectations surrounding the consistency and quality of product, as well as facilitating transparency of provenance, from paddock to plate.

The unique practices and climate variability within the Australian livestock industry correlate to unique challenges for the adaptation and adoption of agricultural technology systems. The industry's capacity to remain competitive is dependent on the creation of technology solutions which can overcome industry challenges. Adoption of such solutions is subject to their ability to improve the Australian Livestock industry's quality, efficiency and commercial viability within a global marketplace.

This final report describes and evaluates the research and development of a *proof-of-concept* prototype of such a technology solution. The 'LiveCare' system is designed to integrate into farming practices to enhance the quality of care farmers can provide to their livestock, while efficiently managing the prioritisation of their human resources and ultimately, streamlining operations.

The 'LiveCare' system has already successfully undergone trials in Korea. In order to evaluate the proposed industry-wide adoption of this system within Australia, the interoperability with existing infrastructure systems that are currently prevalent in the Australian livestock industry were explored. This project was also an opportunity to use 'Design-Led Thinking' methodology and obtain from the primary users, farmers and other station-hands details of their experiences and thoughts as to how the technology can add value, or augment their work tasks.

The system consists of internet of things (IoT) devices, swallowed and embedded internally in the stomach of the cattle. These devices monitor the health and vital statistics, in real time, for each individual animal. The data is sent to a network gateway and from there is available to the farmer via a web dashboard or mobile phone app. ST Solutions recommends diversifying the deployment sites for future trials with various beef livestock producers in order to gain a wider understanding, and expand the range of tasks to which this proposed system can add value. From observing a broader scope of contemporary contexts for livestock production, in situ, identification of any additional potential overlaps or compatibility issues can occur.

Initial findings suggest that the 'LiveCare' system would not only be a technology solution to improving current practices, with continued development 'LiveCare' will also be a commercially viable solution to the problems aforementioned.

Initial Project Objectives	Project Result	Constraints Identified
Install 50 boluses and reading/recording infrastructure at feedlot	6 Boluses installed.	Installation halted due to unsatisfactory data collection.
Install continuous Software monitoring systems (app and web dash board)	Developed and deployed monitoring system.	Obstacles to maintaining continuous connection potentially resolved.
Report on system operation, temperature, animal health status and impact of animal health interventions	Due to network issues, the system yielded data sets that accounted for 50% to 88% of time.	Such data collection levels are insufficient to apply machine learning and statistical inference.

Report on issues and opportunities with the system that may lead to future R&D investments	Milestone 1 & 2 Reports tendered with identified issues and opportunities.	Competing with existing infrastructure for bandwidth and maintaining consistent connection.
Provide MLA with real-time data access throughout the duration of the Project	The real time portal was developed to a functional, commercially deployable level for app and web-based devices.	The development of usable applications is largely a pre-existing component of this project. Ongoing UX evaluations.
Recover boluses at time of slaughter	5 Boluses Retrieved, all located in the same position within the stomach. 1 lost due to undiagnosed death and burial of animal.	Removal process must be compatible with expected operational efficiency standards within meat processing sector.
Informed MLA of the date and location of processing (for MLA to collect additional data)	Processing location was co-attended by MLA and ST Solutions representatives.	Bolus retrieval requires risk management to prevent damage to processing equipment and product quality.
Identified and submitted additional development activity submissions to MLA. This may include extending the life of boluses, automated recovery systems within processing plants, and an ability to change the battery so that a tag is owned and re-used by a producer for 20+ years.	Identified and informed the prioritisation of development activities.	This includes the ongoing network optimisation of (data transmit and receive performance) and development of recovery systems within processing plants.

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1 Background

1.1 Overview of LiveCare system concept

ST Solutions Australia's partner Livestock Technology Services (LTS) (http://www.LiveCare.xyz/new/sub5.asp) has developed a prototype product known as 'LiveCare' (www.LiveCare.xyz/new). LiveCare is a bolus (bio-capsule) which monitors the change of body temperature and pH of cattle in real time. By using LoRaWAN technology equipped within the Bio-Capsule, and interworking with the local LoRaWAN provider's LoRaWAN gateway, it provides extensive coverage within cattle farm through limited number of gateways.
The development has three components as follows:

- Bio-Capsule
  - Orally injected
  - Measures temperature (and optionally pH) in real time
  - Life span of 5-6 years
  - Comprised of non-toxic materials
- Data collection box (LoRa gateway)
- Management application- dashboard
  - Farm management tools displayed via a dashboard on a PC or on a smartphone

A proof of concept pilot has been conducted overseas (South Korea) which was orientated towards the detection of oestrus in suckler cows. A separate proof of concept pilot has commenced on a cattle farm in Hokkaido, Japan.

1.2 Value proposition to the Australian meat industry

This is a pilot study which aims to test the connectivity of e-boluses (Live-Care) and its use. The bolus will monitor the health status (via temperature and pH) of cattle and reproduction management in a feedlot environment. This solution results in labour savings around health checks and reproduction processes.

Labour costs in Australia, are significantly higher than in other developed countries, and are a large proportion of the total operating cost. The productivity of staff directly impacts a farm's total revenue and the international price competitiveness of Australian beef. Furthermore, securing experienced human resources on farms is often difficult. This system solution is designed to increase productivity by early identification of disease and intervention/management.

1.3 Technology Overview for Connectivity

The connectivity specifications follow the global standard, however, some factors would need to be optimised for the Australian environment. Australian farms cover a large land area so the best design for system connectivity would have to be determined.

1.3.1 Specification of LoRa and LoRaWAN

Long Range (LoRa) is the physical layer or the wireless modulation used to create the long-range communication link. LoRa is based on chirp spread spectrum modulation, which is very efficient in achieving low power and has a wide communication range. The biggest advantage of LoRa is in the technology's long-range capability in which a single gateway or base station can cover entire cities or hundreds of square kilometres.

The LoRaWAN specification is developed and maintained by the LoRa Alliance and open association of collaborating members. LoRaWAN is a low power, wide area networking (LPWAN) protocol based on LoRa Technology. It defines the communication protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link. LPWAN offers multi-year battery lifetime and is especially suitable for sensors and applications which are required to transfer small amounts of data over long distances a few times per hour. LoRaWAN network architecture is deployed in a star-of-stars topology in which gateways relay messages between end-devices and a central network server. The gateways are connected to the network server via standard IP connections and act as a transparent bridge, simply converting RF packets to IP packets and vice versa. In a LoRaWAN network, data transmitted by a node is received by multiple gateways and gets forwarded to the cloud-based network server. The network server is responsible for performing a variety of operations including network management, packet filtrations for redundancy and security checks. LoRaWAN utilises two layers of security: one for the network and one for the application. The network security ensures authenticity of the node in the network while the application layer of security ensures the network operator does not have access to the end user's application data.

1.3.2 LoRaWAN Communication Classes

Different device classes are utilised by LoRaWAN and each class differs in battery lifetime and network downlink communication latency. This addresses the different needs reflected by the wide range of applications. End-devices of Class A (also known as basic LoRaWAN) were selected for the trial which allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. Class A communication is always initiated by the end-device and is fully asynchronous. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.

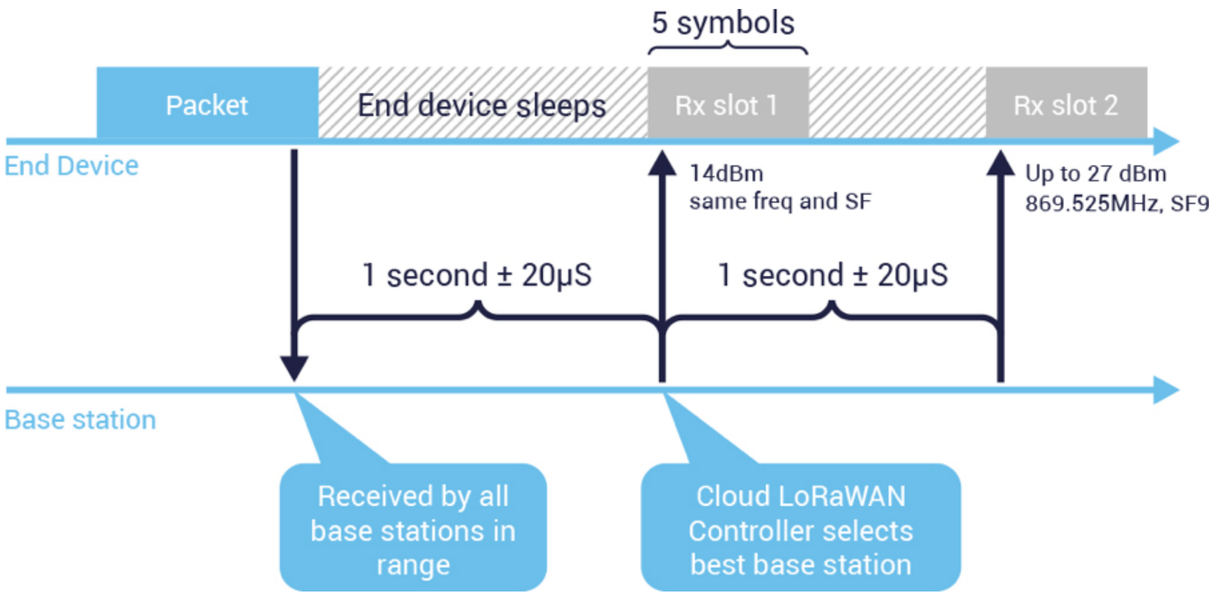


Fig. 1: LoRaWAN Class A communication diagram

1.3.3 Frequency Bands in Australia

LoRaWAN operates in the unlicensed radio spectrum, which allows anyone to use the radio frequencies without having to pay fees for transmission rights. Class licensing is used by the Australian Communications and Media Authority (the ACMA) to manage the spectrum used by services which use a limited set of common frequencies using the equipment under a common set of conditions. Class licences authorise users of designated segments of a spectrum to operate on a shared basis. They do not have to be applied for, and no licence fees are payable. The Low Interference Potential Devices (LIPD) Class Licence authorises user to operate a wide range of low power radio-communications devices in various segments of the radiofrequency spectrum. Between the frequency band of 915 to 928 MHz, the maximum equivalent isotropically radiated power (EIRP) is 1 watt, in which frequency hopping transmitters must use a minimum of 20 hopping frequencies.

In Australia, LoRaWAN operates in the 915-928 MHz frequency band that has dedicated uplink and downlink channels. The frequency used for this trial was 915 MHz. The uplink and downlink frequency used by our LoRaWAN system is provided below:

frhz=922200000 index=4
frhz=922400000 index=5
frhz=922600000 index=6
frhz=922800000 index=7
frhz=923000000 index=8
frhz=923200000 index=1
frhz=923400000 index=2
frhz=922000000 index=3
frhz=925000000 index=127
frhz=925200000 index=128
frhz=925400000 index=129
frhz=925600000 index=130
frhz=925800000 index=131
frhz=926000000 index=132
frhz=926200000 index=133
frhz=926400000 index=134

The uplink frequencies are between index 1 to 8 and the remaining are downlink frequencies used by the gateway to send Mac commands to the devices.

1.3.4 LoRaWAN spectrum parameters

Following the data from GW, it acknowledges quality of spectrum by indicator as received signal strength indicator (RSSI) and signal-to-noise ratio (abbreviated SNR).

Table 1. Link Budget Comparison for Narrowband FSK

Mode	Equivalent bit rate (kb/s)	Sensitivity (dBm)	Δ (dB)
FSK	1.2	-122	-
LoRa SF = 12	0.293	-137	+15
LoRa SF = 11	0.537	-134.5	+12.5
LoRa SF = 10	0.976	-132	+10
LoRa SF = 9	1757	-129	+7
LoRa SF = 8	3125	-126	+4
LoRa SF = 7	5468	-123	+1
LoRa SF = 6	9375	-118	-3

1.3.4.1 Received signal strength indicator (RSSI)

The RSSI (received signal strength indicator) is a numerical value indicating the strength of the received signal entering the receiver input. In the receiver used in the detection system, a value substantially proportional to the logarithmic value (dBμV) of the received receiver input voltage is generated and output as the RSSI value. The numerical range is in the range of -140dBm to -70dBm especially LoRa communication, and a larger numerical value indicates that the input voltage is higher and stable receiving situation. In this verification, RSSI has proportional with a throughput of bit rate. One packet of data would be only 50 bytes including raw data of temperature for cattle in the system thus, 0.293 kb/s (SF12) is enough throughput with transmitting to the gateway.

1.3.4.2 Signal-to-noise ratio (abbreviated SNR)

SNR (Signal to Noise ratio) is the logarithm of S (signal) to N (noise) ratio. It is used as a numerical value expressing the quality of radio signal communication. dB is used as a unit and a larger number indicates less noise. The numerical range is in the range of 10 to -15 especially LoRaWAN communication in this research situation. This factor indicated a success rate of transmitting bolus to the gateway. If SN would be less than -12, it has originated continual pocket retransmission processing upon class A LoRaWAN protocol.

2 Project objectives

2.1 Project Objective

By the 30st of September 2018 the Participant will have:

- Installed 50 boluses and reading/recording infrastructure at the feedlot
- Installed continuous software monitoring systems (mobile apps and web-based dash board on PC)
- Reported on system operation, temperature and pH (pH is out of scope at this PoC), animal health status and impact of animal health interventions
- Reported on issues and opportunities with the system that may lead to future R&D investments
- Provided a real-time access portal for MLA to access (confidentially) throughout the duration of the Project
- Recovered or providing proof of proper disposal of boluses at time of slaughter
- Informed MLA of the date and location of processing (for MLA to collect additional data)
- Identified and submitted (if appropriate) additional development activity submissions to MLA. This may include extending the life of boluses, automated recovery systems within processing plants, and an ability to change the battery so that a tag is owned and re-used by a producer for 20+ years.

3 Methodology

3.1 Field survey

A field survey was conducted to find out the location in the farm where LoRa gateway was to be physically installed. Identifying a gateway installation point was one of the crucial tasks of this project as it would determine the level of connectivity between the gateway and a bolus in a cow's rumen. The conditions of the location that should be carefully considered were as follows:

1. The higher, the better in terms of coverage
2. Sustainable, being capable of supporting the weight of the gateway
3. Good visibility, having few obstacles around (e.g. tall trees, hills etc.)
4. Close to the place where the trial cows were housed or move around, ideally within approximately 3km radius given that some animals will be pastured on the paddocks according to the growth of grass (this number may change according to the farm's size)
5. Power supply through a single socket outlet (SSO) available near the installation point, ideally within approximately 20m of installation
6. Roof, preferable for installing a cable to shelter it from the rain

In light of those factors, the installation point was chosen after inspecting the feedlot based on the following:

Gateway location at the feedlot
On the scaffold at the top of a silo which was, secure, with good visibility, circa 100m away from the nearest pen of the feedlot where all the trial grain-fed cattle would be located and monitored (See below image 1 and 2). Based on the assumption that silos generally need a power supply to be operated, several SSOs were available under the silos. These were available to be connected to the PoE injector, and the one in the power-supply box was selected for this project as it was protected from the outside environment. There was, however, no power supply at that moment, which required the farm to have an electrician to rectify the problem.
There was another prospective location just around the corner of the trial pen with SSOs nearby, however, this idea was dismissed as the installation point on the silo was higher and had better visibility.

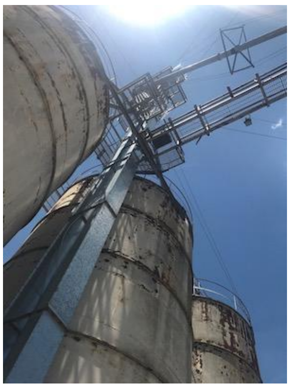


Fig. 2: scaffold at silo

Fig. 3: location of silo and feedlot

In summary, the field survey was successfully completed with a suitable location identified. The project was able to progress to the gateway installation phase. It is worth noting that, on many farms, a power supply and SSO may not be available for gateway deployment for data communication. Hence, further design will be required for LoRa gateway deployment in relation to this matter, possibly including the use of solar panels.

3.2 Site establishment with LoRa established and tested

3.2.1 Lab test

The purpose of the lab test was to ensure that the individual units (i.e. bolus, gateway and network/application server) were correctly integrated and to detect any faults in the interactions between those various components. This integration testing exposed several challenges, which are described with corresponding solutions identified below:

Challenges	Solutions
Unable to register capsules to network server	Registered manually
Unable to join capsules to gateway	Re-entered configuration which was unexpectedly deleted
Unable to send data from network server to application server	Changed data-interchange format which was compatible with network server

As a result, the interaction between all units was successfully verified.

The integration testing shed light on the issues that would likely arise when using different or new units. This suggests that it could require the same effort if a different gateway or network server is to be used. To avoid time-consuming troubleshooting, therefore, it is important to gather all necessary information beforehand in order to understand the requirements and specifications of each new component.

3.2.2 LoRa gateway installation

Following the field survey and lab test, the gateway was physically installed on the selected site. The following materials were obtained for the gateway installation:

- MultiConnect® Conduit™ by MultiTech (gateway)
- Outdoor Antenna (3dBm)
- Outdoor enclosure box to protect gateway from rain
- PoE injector
- PoE Cable
- Plastic conduit (25mm diameter) to protect PoE cable from being chewed by birds
- Vinyl Tape
- Cable ties
- Bolus
- AC cable
- Metal plates gently being bent
- Safety harness and helmet for height safety

MultiConnect Conduit was chosen for this trial as this is one of the LoRa certified gateways, which is compatible with LoRa-equipped modules, and has the approval of Regulatory Compliance Mark (RCM) by Australian Communications and Media Authority (ACMA). This gateway also supports the AS923 channel plan that can be used in Australia and is a standard device for local LoRa providers.

This leads to the conclusion that the MultiTech gateway would be suitable for this trial and eventually make it easier to deploy the service in the Australian market in the future.

There were three stages to the process beginning with securely seating the gateway into the outdoor enclosure box. The box was then attached to the handrail of the scaffold by tightening the bolts on the metal plates. The antenna was also attached to the outside of the box and a cable was run through into the box to the gateway. The cable was protected by twisting vinyl tape aroun the cable where it enters the box. The PoE cable housed by the plastic conduit and connected to the box, ran along the scaffold down to the ground to the PoE injector in the power-supply box. This was secured with cable ties. Finally, the AC cable connected to the PoE injector was plugged into the SSO in the power-supply box to activate the gateway.

Fig. 4: Protected cables

Fig. 5: Box secured to scaffold

Fig. 6: Wire protection with tape

Overall, there were no problems in completing the site establishment. For the future deployment, it should be emphasised that ensuring height safety is important including using a harness and helmet if the installation point is at height. Additionally, a method of protecting cables is essential given that they are exposed to the elements, which may cause a serious damage to the cables, and lead to network downtime.

The completion of gateway installation realised the system architecture as shown in the below image.

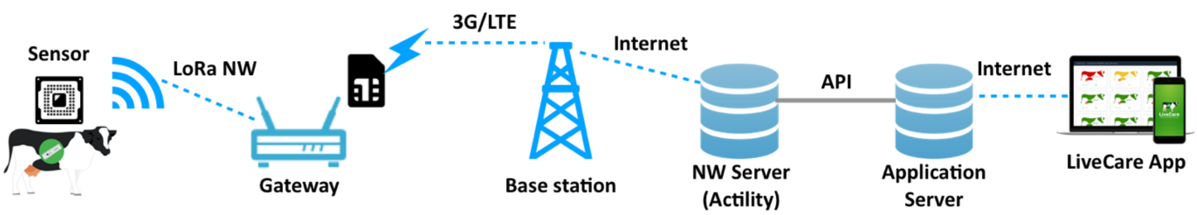


Fig. 7: system architecture

The site establishment, however, is not complete until the connectivity of LoRa network has been empirically demonstrated on the trial site. In the following section the procedure and result of the test will be explained and reviewed.

3.2.3 On air coverage test

Upon the completion of LoRa gateway installation, the coverage test was conducted to see if the gateway was capable of communicating data in the feedlot environment. The coverage was assessed by tracking the signal strength represented as Received Signal Strength Indicator (RSSI) in dBm as well as the ratio of signal power to the background noise power represented as Signal-to-Noise Ratio (SNR) in dB. For the proper performance of LiveCare, the RSSI value should be between -100 and -115 dBm and the SNR value should be positive. These indicators can be affected by the capacity of the antenna, which has to be controlled within 1 Watt in order to comply with the regulation of Australian Communication and Media Authority (ACMA). This test required a LoRa device such as a GPS tracker that tells both indicators at the point where it physically exists. During the test, the device was carried to a number of points around the feedlot as well as approximately 1-2km away from the gateway to measure the RSSI and SNR values.

Below is the coverage map which was created after the test, plotting with coloured markers showing the RSSI level.

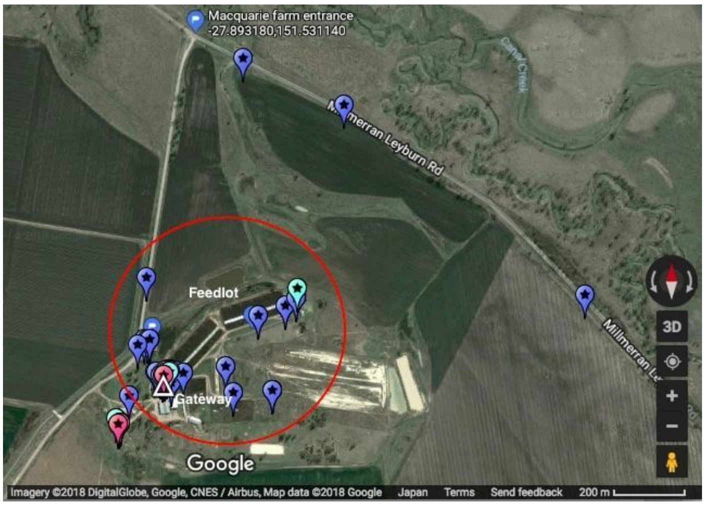


Fig. 8: Indicative coverage map around feedlot

[Color codes]

Pink - Marginal RSSI (between -115 & -137)
Light Blue - Average RSSI (between -100 & -115)
Dark Blue - Good RSSI (above -100)

*the triangle marker indicates the gateway location

As indicated on the map, the LoRa network successfully covered the feedlot environment with the sufficiently good RSSI value of above -100. Moreover, it also reached the points which were circa 1-2km away from the gateway with good RSSI values.

Seeing the above result of the test, it is safe to say that the LoRa network works adequately to implement the bolus insertion into cow's rumen in this feedlot environment. This result, however, cannot guarantee that LoRa will always cover sufficient area meeting all the criteria described in 4.1 as external factors could have an impact on the RSSI value. A coverage test will be required whenever a new gateway is being installed. In addition, this single test does not prove the potential maximum coverage of LoRa network in remote area. Cattle will not always remain within a 2km radius of the gateway such as in a pastured situation.

Another limitation of this coverage test is that it excluded the effect that would be caused by the cow's internal environment or its behaviour. This cannot be assessed until boluses are actually inserted into the cow's body. The sensor implementation was conducted and evaluated in the subsequent section.

3.3 Sensor implemented and tested

With the site successfully established with the adequate LoRa coverage, the sensor insertion was carried out. Two technicians from the sensor developers performed the insertions with the support of feedlot staff. The process of insertion was as follows:

1. Selecting trial animals and making a list (which had been prepared before the implementation day)
2. Turning on the boluses by using magnet-based equipment
3. Moving the animals from the feedlot to the yards where the head bail was available
4. C the animal in the head bail and adjusting the position of its head
5. Recording the bolus number and corresponding cow's ID
6. Inserting the bolus into the rumen by a piston type administrator by one technician while the other held the animal's mouth open
7. Attaching an ear tag to mark that the animal has a bolus in its rumen
8. Attaching a heat detection sticker on the top of the back of the animal
9. Taking a picture of the animal's face to upload on the dashboard
10. Returning the animal to its appropriate feedlot pen

			
Moving the cows through the yards	4. Catching the cow in the head bail	6. Inserting the bolus	7-8. Applying the ear tag and sticker

Fig. 9: Steps of sensor insertion

Inserting the bolus into each trial cow using the process above, the data communications were observed on a dashboard of network server (ThingPark by Actility) to see if the boluses were successfully transmitting bio-data to the gateway.

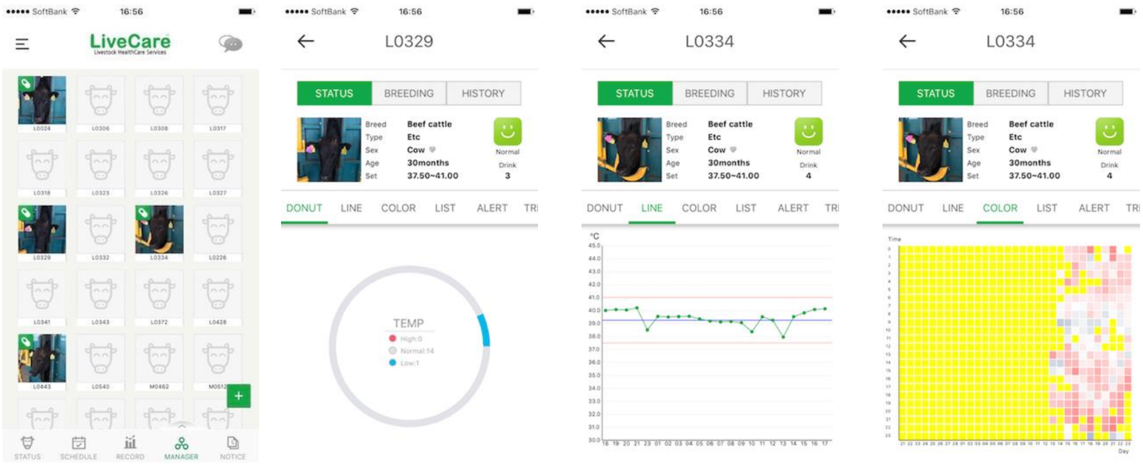
3.4 Real-time portal establishment

After the implementation, body temperature data started to be measured and displayed on the portal (Figure 10). The ID and password of the portal were created and provided to the farm. IDs needed to be created according to the number of people who would be using the portal as the ID links to the device's MAC address (though one ID is available for both web and mobile portal). Both mobile and web App were downloaded via designated URL.

In this trial, thirteen IDs in total were allocated to individuals:

- No. 1-7 for project team members
- No. 8 for general manager of the farm
- No. 9-11 for staff of the farm
- No. 12 for the president of the farm
- No. 13 for MLA

ID and passwords that enable MLA to access the portal were provided to the MLA project manager via a separate email.



List of cattle | Donuts chart | Line chart | Colour chart

Fig. 10: real-time portal (mobile App)

The project team and farm communicated via a chat function embedded in the App so that the team could receive inquiries or feedback from the farm regarding the use of the portal and any issues from its daily operation.

Overall, the portal was successfully established and started to operate after the insertion. This was monitored on a daily basis by the project team and farm and discussed among the parties.

4 Results

4.1 Data collection result

The results were summarised as follows:

<u>Achievements</u>

- Inserted six boluses into six animals
- determined the time it took to complete the insertion: approximately 10 seconds on average for single insertion process; approximately 100 seconds to finish the steps No. 4 to 10 as described in 3.3. (*Fig.10*)
- insertional animals appeared healthy and suffered no ill effects of the bolus insertion

<u>Challenges</u>

- Two out of the six boluses in the rumens did not transmit data to the gateway
- The transmitted data was inconsistent, i.e. some downtime was seen by gaps in the data
- The insertion of the remaining 44 boluses will be suspended until the data transmission conditions improves to an acceptable level

As a whole, the implementation of six boluses was completed successfully except for the preliminary stage where the server had not been switched from 'test environment' to 'production environment' on the day. This led to a delay of a few hours in sensor implementation.

Despite the boluses being inserted correctly and establishing sensor implementation, some critical connectivity issues remained unresolved. The sensors in the animals did not communicate consistently, and two of the sensors did not communicate with the gateway at all. This resulted in some missing data. Based on the hypothesis that the problem would lie in either antenna, gateway or bolus itself, three possible solutions were suggested:

1. Replacing the existing 3 dBi antenna with 8 dBi
2. Considering the option to use a different gateway
3. Reviewing the specification of the bolus to see if any adjustment is required

In regards to the antenna replacement, the 8 dBi antenna would pick up weaker signals at a higher amplitude than the 3 dBi antenna This would reduce interference, such as noise, to obtain a better SNR value. To determine if the data inconsistency was due to the antenna, the replacement was made. Prior to the physical antenna replacement, the transmit power of the existing gateway was reduced down to 22 dBm from 27 dBm in order to comply with the regulation of ACMA, which limits the transmit power to no more than 30 dBm (=1 Watt). Following this, the antenna was physically replaced.
The data inconsistency was still not resolved despite the slight improvement in the RSSI and SNR value.

4.2 Data collection efficacy and connectivity performance.

4.2.1 Success rate of data collection

The success rate of data collection was determined by analysing each layer of data flowing into the system from bolus to the application layer. The success rate of data collection is crucial to ensure the unique data being collected from each animal is accurate and useable. Two of the bolus's failed to communicate successfully.

The radio signal and electric circuits of equipment was checked for issues. Radio signal/spectrum can be affected by environmental factors such as physical obstacles environment factors (rain or moisture in the air).

Cattle flesh is approximately 70%-80% water so could be a contributing factor in the low signal strength (when emitting from bolus to a gateway via the LoRaWAN certified range of the spectrum).

The review of statistics for the 4 cattle with successful bolus transmission is shown in the table below (Table 2). Receiving data every 10 minutes, six times an hour is the normal rate of upload from bolus to gateway. The table shows a success rate of between 50% to 88%. This is not successful or accurate enough to adequately capture each cow's unique data.

Table 2: Table showing data received rate

	Cattle number	L0302				L0443				L0329				L0334			
	Bolus number	702C1FFFFE4A31B3				702C1FFFFE4A31BB				702C1FFFFE4A3067				702C1FFFFE4A303A			
Hour	Category	1-Jun	2-Jun	3-Jun	4-Jun	1-Jun	2-Jun	3-Jun	4-Jun	1-Jun	2-Jun	3-Jun	4-Jun	1-Jun	2-Jun	3-Jun	4-Jun
0	early morning	5	5	4	1	4	5	6	4	6	4	6	4	6	6	2	0
1	early morning	3	3	3	5	6	7	6	4	3	5	6	5	5	8	6	6
2	early morning	6	1	2	3	6	6	5	6	1	3	4	6	6	5	6	6
3	early morning	3	0	1	2	3	2	6	4	2	3	0	6	5	2	6	6
4	early morning	2	1	2	1	2	2	5	6	1	5	2	6	4	3	2	4
5	early morning	0	0	1	0	5	3	1	6	0	6	4	6	6	1	4	1
6	am	6	6	6	6	6	6	6	6	1	6	4	6	6	5	6	5
7	am	6	5	6	6	6	5	6	6	7	6	6	5	5	6	6	6
8	am	6	5	2	2	6	6	5	6	5	6	6	4	6	5	6	6
9	am	4	5	4	4	6	6	6	5	0	1	6	1	6	6	5	6
10	am	2	4	6	4	6	6	6	2	3	0	6	5	6	6	2	6
11	am	6	1	6	5	5	6	6	4	5	1	6	6	6	6	2	6
12	pm	2	5	5	2	7	5	4	5	3	4	3	3	1	6	4	2
13	pm	9	4	1	3	5	5	3	5	6	0	2	1	4	3	3	6
14	pm	3	2	3	6	4	0	5	3	3	3	0	2	6	3	6	6
15	pm	5	5	0	0	4	5	5	6	2	6	3	6	4	3	6	6
16	pm	5	4	6	5	6	6	6	5	4	6	6	6	6	6	5	6
17	pm	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6
18	night	3	6	6	6	6	6	6	6	6	6	5	6	6	6	6	5
19	night	1	1	3	2	6	5	6	6	1	6	5	2	4	6	6	3
20	night	2	1	5	2	6	6	4	5	0	6	1	6	1	5	6	4
21	night	4	0	4	2	6	6	5	5	2	6	3	6	3	5	6	6
22	night	1	0	2	2	6	6	5	5	0	5	4	5	6	6	3	5
23	night	3	2	1	5	5	6	6	3	1	2	4	6	6	1	1	1
Data Received Rate		64.58%	50.00%	59.03%	55.56%	88.89%	84.72%	86.81%	82.64%	47.22%	70.14%	68.06%	79.86%	83.33%	79.86%	77.08%	79.17%

Three of the four cattle that successfully transmitted data were in the same pen so environmental differences in data transmission due to location could not be analysed.

When analysing the data in the table above (Table 2), no patterns of missing data could be determined

The reduced signal strength is hypothesised to be related to physical interference such as infrastructure and other animals located in the signal path. As the LoRa signal direction is a straight pathway from the antenna to bolus, any objects in the pathway could influence the LoRa connection.

4.2.2 LoRaWAN Signal levels

Analysing the receiving signal strength on the gateway to RSSI and SNR, showed a deterioration of the spectrum of the bolus due to environmental changes. The receiving signal was stable when the RSSI was between -100dBm and -120dBm and the SNR was between 15 and -8. As soon as the RSSI went below -135dBm and the SNR went below -15, the gateway instantly stopped receiving the signal. The RSSI and SNR indicators have a proportional relationship that depends on the environmental situation. Physical environmental obstacles may cause noise on the signal spectrum decreasing the SNR value and preventing communication between the bolus and gateway.

The gateway used for the trial was MultiConnect Conduit, which is certified for Australian 915 MHz ISM bands. It is one of the LoRa certified gateways, which is compatible with LoRa-equipped modules, with the approval of RCM by Australian Communications and Media Authority (ACMA) in Australia.

4.2.3 CRC Error

The data log of the Multitech gateway contained a 'CRC error packet' within the data flowing from the bolus to the gateway. The error detection code CRC stands for Cyclic Redundancy Check, which is generally used for detecting accidental errors caused by the transfer of data. Based on the below data log snapshot, it can be assumed that the CRC error was caused by radio interference.

⊟ RF cell modem	
Number of successful initializations of modem	18
Number of modems with failed initialization	0
Number of modems configuration failures	0
Number of times the link with the modem was lost	0
⊟ Uplink	
Number of frames received from RF interface	385378
Number of frames received with a CRC error	74547
Number of frames received with a wrong length	0
Number of responses which missed the R1 slot and were postponed to the R2 receive slot	13993
Number of responses received too late and discarded (no R2 or received after R2)	77

Fig. 11: CRC error for the GW: 004A1C25 – CRC error rate is approximately 20%

⊟ RF cell modem	
Number of successful initializations of modem	39
Number of modems with failed initialization	0
Number of modems configuration failures	0
Number of times the link with the modem was lost	0
⊟ Uplink	
Number of frames received from RF interface	815706
Number of frames received with a CRC error	207686
Number of frames received with a wrong length	0
Number of responses which missed the R1 slot and were postponed to the R2 receive slot	68831
Number of responses received too late and discarded (no R2 or received after R2)	643

Fig. 12: CRC error for the GW: 004A1C2D – CRC error rate is approximately 25%

This shows that 20-25% of all data being transmitted was discarded by the Multitech gateway because of the CRC errors. This is a significant loss of data that was mostly a result of environmental conditions.

4.2.4 Spectrum analysis for CRC error

4.2.4.1 Multitech emit radio signal

The plotted spectrum diagram below shows the downlink sessions to the bolus by separated index-based signals 1-8. The LoRaWAN emitting radio signal range is 922.2MHz to 926.4MHz.

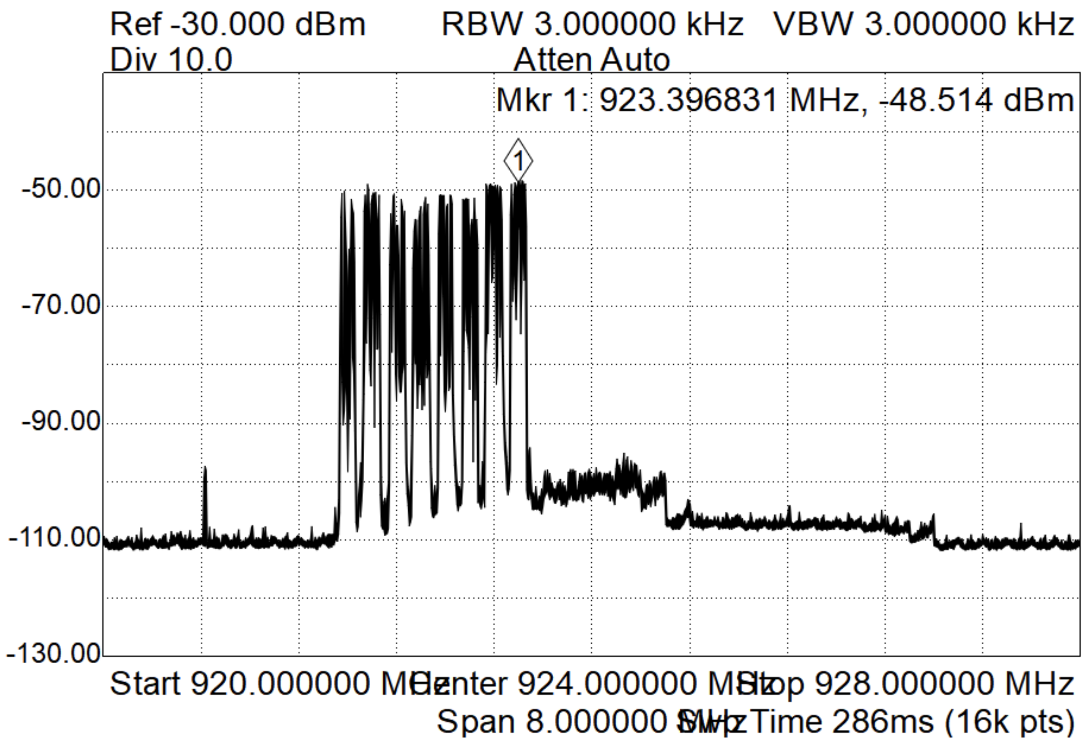


Fig. 13: Downlink Spectrum diagram of LoRaWAN

4.2.4.2 Tractor GPS radio signal interference

The plot below indicates an unknown radio signal at around same range of LoRaWAN spectrum. This is a relativity strong signal of more than -50dBm which would cover an approximately 20 km area. It was difficult to identify the duration of the emitting signal as GPS information for the John Deere tractor. The tractor emits a radio signal of 915-928 MHZ, 1 watt (30dBm). The signal strength 1 watt is the maximum emit-able signal strength under regulation (EIRP) in Australia.

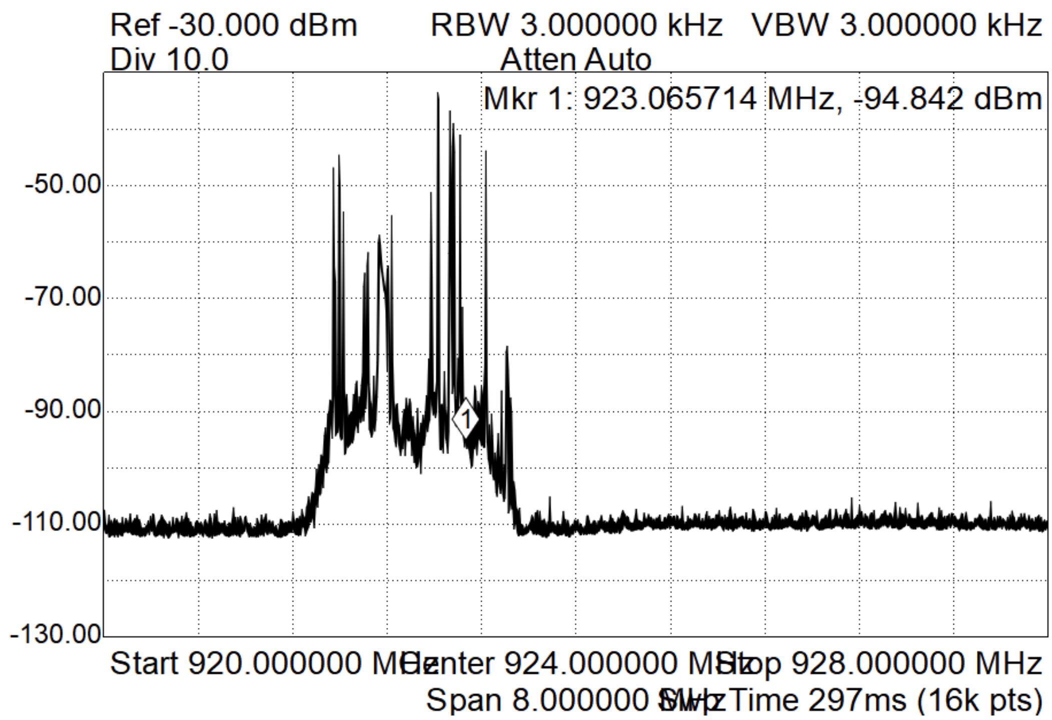


Fig. 14: Spectrum diagram of randomly emitted radio signal

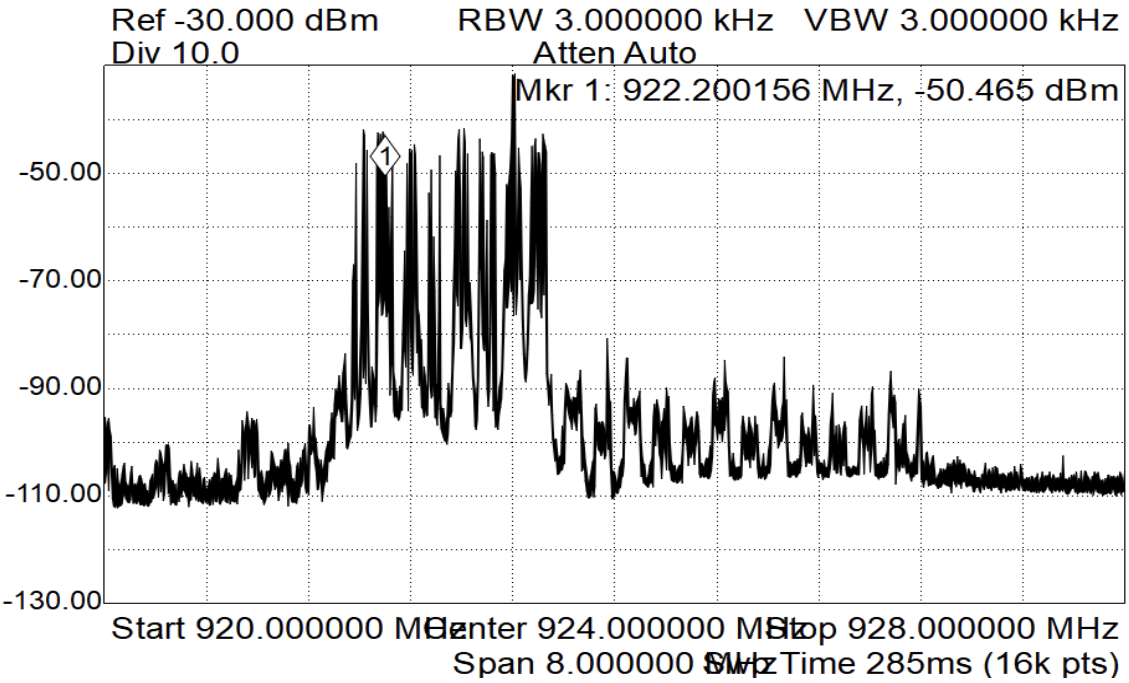


Fig. 15: Spectrum diagram showing radio interference between LoRaWAN and John Deere

The plotted spectrum graphs (Fig 14 and 15), clearly show radio interference between the LoRaWAN and tractor GPS. The 915-928 MHz frequency band is under the unlicensed radio spectrum, which allows anyone to use the radio frequencies without having to pay fees for transmission rights. This interference caused almost 25% of packet data loss which is a critical issue for the cattle management system.

4.3 Processing site visit, observations and physical retrieval of the Boluses

On the morning of the 24th August 2018, the designated processing facility was visited. It was observed that the processing facility functions to a very high standard through sequentially specialised stages in order to maintain line speed and efficiency. Maintenance of this line efficiency is a priority when considering any novel implementations that could add a disruption to their current practices.

Three pathology checkpoints are strategically distributed at different stages of the carcass processing line. These were situated at the head, the gut and final carcass processing stages respectively where specialised equipment is being used.

All five (5) of the Boluses retrieved were located in the same physiological location within the digestive tracts of their hosts. The bolus was located in the rumen, packed within the rumen content just before the reticulum. This was a point of consistency for all hosts, and should be the targeted focus area for future retrieval of Boluses.

After returning from the processing facility, the Boluses were cleaned and sterilised. The boluses were deactivated. It can be seen whether the device is in a powered or unpowered state via red Light emitting diodes (LEDs). These LEDs are internally fitted and are externally visible as they are ambient enough to pass light through the device's plastic housing. The Bolus was designed without a physical switch to ensure the device is streamlined in situ. Following retrieval, it was revealed that two out of the five retrieved Boluses were already in a deactivated state and had therefore not been transmitting data for the duration of the study. This would suggest human error occurred in ensuring the bolus was operational prior to insertion.

Future designs of the bolus would need to consider the retrieval process as the current additional processing time and the potential risk that an un-retrieved bolus poses to processing equipment is considered unacceptable for wide-scale processing. It has been suggested that the use of an electro-magnet during the processing of offal could be an acceptable alternative however it would need to be determined if such a method would do any permanent damage to the bolus.

5 Discussion

5.1 Strategy for further development of applications in the Australian red meat sector with recommendations for further research

Traceability of meat, from farm of origin to plate, is becoming increasingly important to consumers and producers. Traceability systems can be combined with electronic animal identification systems and information portals to provide unprecedented transparency for the red meat sector. Although the value of using electronic boluses for data collection is understood, electronic boluses have typically been seen as a hazard in the processing sector that if undetected, can damage equipment or contaminate consumable product.

A streamlined process for bolus retrieval needs to be developed for the use of electronic boluses to be successfully implemented in the future. The retrieval method must minimise the risk of equipment damage and carcass contamination and must not be disruptive to the processing method.

Ongoing comparative evaluation of existing competitor solutions is relevant in providing a compare and contrast benchmark for validating the value proposition of the LiveCare system.

6 Conclusions/recommendations

6.1 Enhancement for the future research

This project has shown that the before the boluses can be used in the Australian cattle industry, they will require additional research and modification to ensure that they are successful. The boluses and network system were developed in Korea and the environment and cattle production systems are very different in Australia. The following aspects of the current LiveCare system would need to be considered.

6.1.1 Change of spectrum range

Most of the internet of things (IOT) products would connect by narrow-band telecommunication arrangement to LoRaWAN, Sigfox and NB-IOT. LoRaWAN and Sigfox (Certified RCZ4 (ANATEL 506, AS/NZS 4268)) are similar technology and operate in the same unlicensed spectrum range. NB-IOT is developed under LTE range of spectrum to secure certain bandwidth for narrow-band telecommunication and is a potential alternative to the LoRaWAN system to eliminate the interference issues.

6.1.2 Insert memory capability into the Bolus

The current system design of the Bolus has not included any memory to store data in the situation where the system stops transmitting. Inserting memory capabilities into the Bolus would allow data to be stored when it is unable to be transmitted to the Gateway.

6.1.3 Increase emit spectrum power

20mW (13dBm) spectrum output for the bolus was considered reasonable to allow for adequate battery life. The spectrum output is limited to low EIRP by Radiocommunications Act to less than 25 mW(14 dBm) However, investigating a global standard for LoRa product, 20mW(13dBm) would be a feasible specification for LoRaWAN module including Japan.

6.1.4 Machine learning process improvement

To ensure accuracy, 90% of the data would need to be learned under the machine learning process. A 90% success rate is a high requirement but it would allow for an algorithm to be sensitive enough to detect a calving cow by temperature, a cow in oestrus or certain diseases. One of the challenges to developing to a more efficient algorithm based on less than 90% of data is to use another program to fill-up the missing gap. Temperature data gives a linear trend dataset, not a discrete dataset so there is the capability to research a more flexible algorithm.

6.2 Value for the red meat industry

It can be concluded from this project, at this stage, the LiveCare system is not commercially viable in its current state. However, the system has potential for future use by industry as the datasets that were derived during the functional, operational states of the LiveCare system, as well as the ability for the farmer to access and monitor such data in a real-time would be beneficial. This report has explored the interconnectedness of the livestock industry and identified the requirement for greater transparency of provenance for the product (i.e. Disease records by the system) with accumulated data as it moves throughout this ecosystem network of producers, processors, packagers and distributors.

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8 Appendix

8.1 Equipment Used

8.1.1 Spectrum analysis equipment

To check for radio interference, the spectrum frequency analyser “Signal Hound USB-SA44B”(https://signalhound.com/products/usb-sa44b/) was used. It is a USB-powered, economy spectrum analyser and measuring receiver which covers the frequency range of 1 Hz to 4.4 GHz. It consists of a Software Defined Receiver (SDR) optimised as a narrow-band real-time RF spectrum analyser. Signal Hound’s SPIKE software controls the operation of the hardware and provides the SA44B’s computer screen user interface. It enables the device to function as a real-time spectrum analyser (RTSA), using its real-time mode, for sweeps of 250 kHz and less. The USB-SA44B has a preamplifier for improved sensitivity and reduced LO leakage. There is also a thermometer for temperature corrections, allowing accurate amplitude measurements over the entire operating temperature range.

8.1.2 MultiConnect Conduit LoRaWAN Gateway

In order to make a long-range star network viable, the gateway must have a very high capacity or capability to receive messages from a very high volume of nodes. High network capacity in a LoRaWAN network is achieved by utilising adaptive data rate and by using multichannel multi-modem transceiver in the gateway so that simultaneous messages on multiple channels can be received. MultiConnect Conduit is a programmable cellular communications gateway for industrial Internet of Things applications which considered to be the most configurable, manageable, and scalable. The device was developed by MultiTech, which is a company that designs, develops and manufactures communications equipment for the industrial Internet of things. The Conduit features Wi-Fi/Bluetooth/Bluetooth Low Energy (BT/BLE), GNSS, and two accessory card slots. It also provides both the IBM Node-RED graphical, drag-and-drop interface and mLinux development environments. Below is the specifications table of the device taken from MultiTech website under Product Data Sheets section:

Model	MTCDT-Lxxx			MTCDT-H5
Performance	LTE 3GPP Release 9 (100 Mbps peak downlink/50 Mbps peak uplink)			HSPA+
	AT&T/T-Mobile	Europe	Verizon	
	with HSPA+ 21/GPRS fallback	with HSPA+ 42/GPRS fallback	(No fall back)	
Frequency Bands (MHz)	AT&T/T-Mobile	Europe	Verizon	
	4G: 700(B17)/ 850(B5)/ AWS1700(B4)/ 1900(B2) 3G: 850(B5)/ 1900(B2) 2G: 850/1900	4G: 800(B20)/ 1800(B3)/2600(B7) 3G: 850(B5)/ 900(B8)/2100(B1) 2G: 900/1800	700(B13)/AWS1700(B4)	3G: 850/900/1700 (AWS)/1900/2100 2G: 850/900/1800/1900
Processor & Memory	ARM9 processor with 32-Bit ARM & 16-Bit Thumb instruction sets • 400 MHz • 16K Data Cache • 256 MB Flash Memory • 16K Instruction Cache • 128X16M DDR RAM			
Packet Data	Up to 100 Mbps downlink, Up to 50 Mbps uplink			21 Mbps downlink, 5.76 Mbps uplink
Radio Frequency LoRa	LoRa 868 or 915 MHz – a proprietary Digital Spread Spectrum technique			
Radio Frequency Wi-Fi & BT/BLE	802.11 a/b/n/g 2.4 Ghz and 5 Ghz & BT Classic BLE 4.1			
Storage	Micro SD			
Input Voltage	9V to 32VDC			
Connectors				
Ethernet	1 RJ-45 Ethernet 10/100 port			
USB	2 USB Ports: USB Host (Type-A), USB Device (Micro-B)			
Serial	1 Debug Serial: USB Micro-B			
Antenna	Female SMA, Cell 2dBi (Qty 2) GPS (Qty 1) and WIFI/BT (Qty 1)			
SIM	SIM/USIM (2FF)			
Physical Description				
Dimensions (L x W x H)	6.35" x 4.23" x 1.69" (161.3 mm x 107.4 mm x 42.8 mm)			
Weight	1.0 lbs (0.45 kg) with two accessory cards installed			
Chassis Type	Metal			
Environmental				
Operating Temperature	-30° to +70° C*			
Storage Temperature	-40° to +85° C			
Relative Humidity	20% to 90%, non-condensing			
Certifications				
EMC Compliance	US: FCC Part 15 Class B. EU: EN 55022 Class B, EN 55024. Canada: ICES-003			
Radio Compliance	FCC Part 22,24,27			
Safety	UL 60950-1 2nd Ed., cUL 60950-1 2nd Ed., IEC 60950-1 2nd Ed			
Network Approvals	PTCRB, GCF certified module, AT&T, Verizon and T-Mobile. Pending: Rogers, Bell, Telus & Sprint			
Quality	MIL-STD-810G: High Temp, Low Temp, Random Vibration. SAE J1455: Transit Drop & Handling Drop, Random Vibration, Swept-Sine Vibration. IEC68-2-1: Cold Temp. IEC68-2-2: Dry Heat			

Fig. 17: MultiConnect Conduit specifications