Final report

EmbediVet implantable device

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Executive summary

The EmbediVet implantable project was brought about by Livestock Labs to develop a device that would addresses a gap in the agriculture technology (agtech) sector. Agtech has mainly focused on developing crop related technology and left animal production ready for new technology solutions. Livestock Labs saw one addressable area where farmers need to know the well-being of each animal in the herd. This kind of precision management in livestock has become more complex over time due to increasing herd sizes, new technologies and regulations. Animal producers across the food chain would benefit from having information about the health and welfare of their animals regularly collected and provided to them throughout the animal's lifecycle.

The EmbediVet device was designed to be implanted under the skin of livestock and collect biometric markers of animal health and well-being. The markers were identified early on in the research process and included heart rate, temperature, blood pressure, and activity level. The data would be collected by a set of physical sensors that were encapsulated in biocompatible material. This data is then processed and provided to producers regarding the animal's health and welfare.

The specific objectives of the project were to engineer an implantable device to measure temperature, movement and heart rate. The device would be tested in the field with livestock to ensure the accuracy of measurements and to develop a good customer experience model. A second device would be developed to allow the implant to be inserted into a cow by a farmer with little assistance by a veterinarian.

Livestock Labs used an iterative lifecycle development process during the EmbediVet implantable project to develop the implant and its supporting technologies. The implant underwent intense engineering phases that resulted in two versions that were field tested and used in trials. The supporting technologies were also designed, developed, and tested to ensure the implant data would be collected, processed, and provided to the producers.

At the conclusion of the project, the implantable device was in the testing and refinement stage for the version that will be used to move forward mass manufacture and deployment to market.

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1 Background

1.1 Livestock Labs Technology

Livestock Labs started with the idea that an implant collecting biometric data from livestock would be valuable to farmers. The EmbediVet implantable project was proposed to take the initial prototype through a development phase which could lead to an implant that could be brought to the public.

1.1.1 Initial Design

The initial design was a circuit board with several sensors and communications components. It was prototyped to prove out the circuit design and demonstrate that the sensors collect data.

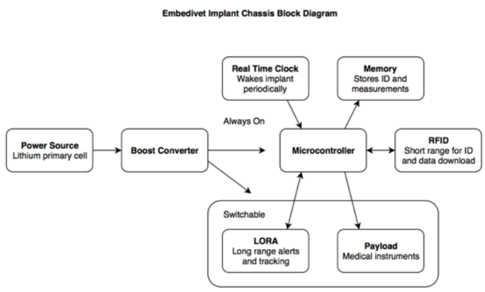

Fig. 1 Circuit Block Diagram

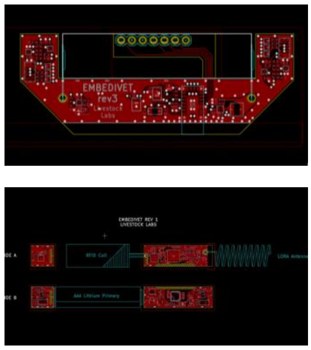

Fig. 2 Prototype Implant Circuit Designs

1.2 Market Opportunity

While the biometric implant design was intended to work with all mammals, Livestock Labs saw an opportunity to bring it to market in the livestock sector. One factor was the lack of tech being developed for animal agriculture, most companies in the agriculture technology (ag tech) space were focused on crops.

1.2.1 Beef Cattle

Initial market research helped narrow the market to beef cattle production and identify a selection of sensors and metrics that could be valuable to producers.

Beef producers need to stay competitive by increasing productivity and decreasing inefficiencies. Farmers and feedlots have had to scale up the size of their herds while reducing the costs of raising them. This produces greater inefficiencies as they are unable to closely monitor each animal in bigger herds. We have identified almost $200M per year in addressable loss from disease, deaths, and calving in our target market. We also see an additional $270M in missed opportunity in Australia for things like labor costs due to manually inspecting for fertility.

The EmbediVet implantable project was structured to take this initial market understanding and develop a deeper understanding of the market and what needs the implant could meet.

1.3 Australian Beef Industry

The EmbediVet implantable project objectives and supporting milestones were designed to bring about the maturation of the technology and help the company develop a deeper understanding of the value the implant can bring to beef cattle industry.

Food requirements over the next 30 years are expected to exponentially increase. Using the EmbediVet system, beef producers will have greater output with less effort. They will have data on individual animals in a way they have never have before. This precision cattle management will allow them to put their time, money and resources to best use.

Adoption of the EmbediVet system into the Australian beef cattle market will improve productivity and efficiency generating larger profits along the supply chain and help make Australia more competitive in the worldwide beef market. It will also bring a level of asset assurance and traceability that the banking, insurance, live exports, and government sectors can use to better assist food producers.

2 Project objectives

The agreed upon EmbediVet implantable project objectives focused on core biometrics, testing and an insertion device.

2.1 Temperature

- Engineering a device that will measure and track the temperature of cow

2.2 Heart Rate

- Engineer a device that will identify and communicate heart rate, which may be indicative of distress and movement

2.3 Activity Level

- Engineering a device that will determine and communicate movement

2.4 Field Test

- Test device in the field with animals to ensure that measurements are accurate and that there is a good customer experience

2.5 Insertion Device

- Engineer a device that can be inserted into a cow by a farmer with little assistance by a veterinarian

3 Methodology

MLA is committed to investing in top quality scientific research, performed by suitably qualified, experienced and registered researchers and organisations. In experiments that involve livestock, MLA acknowledges that such research needs to be done under the auspices of a recognised Animal Care and Ethics Committee (AEC). The responsibility for obtaining AEC approval lies with the researcher. MLA has in the past not specifically asked for evidence that such AEC approval had indeed been obtained.

The EmbediVet implantable project used an iterative lifecycle development process to create the hardware and software of the implant and its supporting technologies: a data collection device, data services, and the implantation tool. Testing was conducted in the lab, field, and with trials.

3.1 Implant (Sensor) Development

The implant, called the EmbediVet Sensor, was developed to be placed subcutaneously in an animal and detect heart rate, temperature, and activity levels at regular intervals. A second device, the EmbediVet Basestation, was then developed to collect the measurements. The implant was also designed to send a distress call over long-range radio to the Basestation if it detects abnormal metrics.

3.1.1 Version 4

The prototype circuit board was re-designed as version 4 and new components were selected for the device that would deliver the best temperature, heart rate, and movement data. A significant change was the shape of the board which moved to a more ergonomic shape for implanting.

3.1.1.1 Hardware

- Circuit boards were printed and assembled with necessary components and instruments including the accelerometer, thermometer, and LED sensor array.
- After testing, boards were attached to batteries, which had a new form factor as it was a better fit with the new board.
- The final assembly was done in-house including adding the coating using a three-stage process that encased the EmbediVet boards in the biocompatible resin.

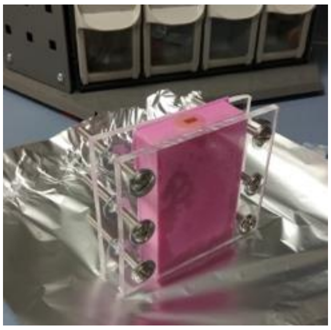

Fig. 3 Sensor Coating Jig

Fig. 4 Sensor Coating Shells

Fig. 5 Coated Sensor

3.1.1.2 Software

- The device firmware was developed to handle the component level requests, take sensor readings, and transmit collected data over Bluetooth.

3.1.1.3 Lab Testing

- Components. The board and each component were examined and then tested for pass/fail quality control. Testing resulted in adding a magnetic switch to handle power cycling and possible power savings.
- Instruments. Each instrument was examined and then tested to confirm that output was being achieved.
- Device. The assembled device was tested for hardware and firmware functionality, focused on heart rate, temperature, and activity level detection.

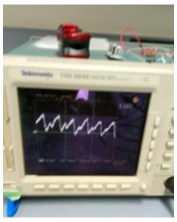

Fig. 6 Oscilloscope Test of Sensor

- Coating. The coating was tested by itself as the barrier around the fully assembled device.
    - The coated EmbediVet implant was tested for cytotoxicity according to ISO 10993-5 (2009) by a local laboratory. The results showed the device coating to be non-cytotoxic.
    - The coated implant and resin shell were tested in a high salinity and strong pH solution to stress test integrity. The resin showed no initial deterioration but after a month some discoloration of the coating and pitting was observed. The solution was well out of the bounds of mammalian viability and impact to the device was expected.

Fig. 7 Test of Coating Shell

Fig. 8 Test of Coated Sensor

3.1.1.4 Trial – Utah State

Livestock Labs trial to prove out the implant and pylon was conducted at Utah State University. Dr. Kerry Rood surgically implanted three EmbediVet devices into three cows. Livestock Labs employees installed two pylons in the barn structure to capture the EmbediVet implant data. Data collection took place for a month. All animal research was done in compliance and under IACUC oversight at Utah State University, Logan, UT. USA. (IACUC Approval Number: 2830). The goals of the trial:

- Animal Welfare – confirm that implant does not "bother" cows or otherwise interfere with their day-to-day activities
- Implant Placement – collect information on different placements of implant
- Coating Integrity – determine if there is any impact to the coating
- Data Transmission – collect data and information on data transmission of the cows

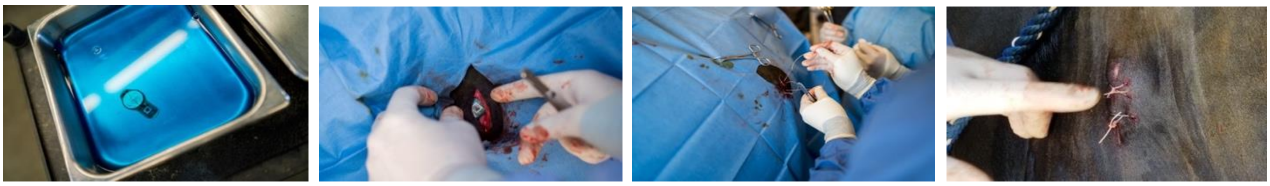

Fig. 9 Sensor implantation

3.1.2 Version 5

Livestock Labs used the feedback and observations from the testing and Utah trial to better inform the design of the implant and pylon.

3.1.2.1 Hardware

The shorter board shape had a pronounced rounded edge that feedback indicated would make it easier to implant under the cow's skin. The board size was reduced by 10% and included the new components such as the long-range radio and antenna.

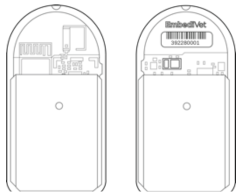

Fig. 10 Sensor version 5 drawing

- Circuit boards were printed and assembled with necessary components and instruments.
- After testing, boards were attached to batteries, which had a model selected for better performance and better fit with the new device shape.
- As the last process of the in-house final assembly, the device was placed in a thermoplastic case and then filled with resin. The new coating was identified as a cheaper and less labor-intensive solution.

Fig. 11 Sensor version 5 case and device

Fig. 12 Sensor version 5 final assembly

3.1.2.2 Software

- The device firmware was further developed to incorporate the new components and improve overall device handling. It included a custom network protocol that was developed for long-range transmissions.
- Data processing and storage requirements were identified and implemented.
- Alerts requirements were determined by market feedback and focused on distress alerts, estrus alerts, and calving alerts. The distress alerts were prioritized first as a simple check for out-of-bounds data. The fertility alerts (estrus, pregnancy, and calving) involved more sophisticated alert calculations.
- Alerts are delivered via email, in the customer account, and SMS.

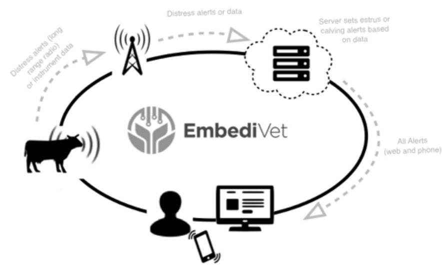

Fig. 13 EmbediVet data flow

Subject: Alert Recieved from BeefStew! (undefined)
From: Beef Stew <beefstew@livestocklabs.com>
To: <jes@livestocklabs.com>
Time: Today at 16:24
Message-ID: <51e9e68f-e28f-7652-546d-eb0621553efb@livestocklabs.com>

HTML Plaintext

{"name":"notification","length":297,"processId":32723,"channel":"beefstew_oob","payload":"{\"id\":719,\"serial\":\"696971\",\"recordedat\":\"2019-01-22T07:05:28.573\",\"hr\":107,\"spo2\":78,\"temperature_min\":0,\"temperature_max\":36,\"temperature_avg\":28,\"max_g\":null,\"activity_min\":48059,\"activity_max\":474,\"activity_avg\":26,\"source_id\":null,\"savedat\":\"2019-01-22T04:05:28.576786\"}"}

Send help! or BBQ sauce!

Fig. 14 Example of email alert

3.1.2.3 Testing

- Backwards compatibility testing was done to ensure revision 5 had all the functionality of revision 4.
- The coated EmbediVet implant was tested for cytotoxicity according to ISO 10993-5 (2009) by a local laboratory. The results showed the device coating to be non-cytotoxic.
- The coated was tested in "near cow" conditions (heat, pH, salinity) and tested over a period of time with no negative impact to the device.
- Physical testing was conducted to determine battery safety and impact resistance.

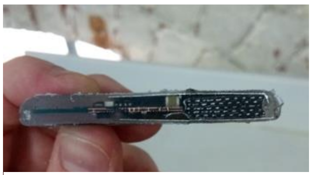

Fig. 15 Physical testing - bandsaw results

3.1.2.4 Trial – Field Test

The EmbediVet Sensor version 5 and pylon 2 was tested in the lab and then underwent a field test. In particular the EmbediVet Sensor long-range transmission was tested and while it was not expected to match the performance of the evaluation module, which is equivalent to 7 kilometers, it was expected would be more than 1km in range.

The implant (Sensor) and pylon (Basestation) were taken to a farm and tested. The pylon successfully collected data records and then the implant was triggered to send a long-range alert. The pylon was midway through uploading 306 collected data records when the alert came in. The alert was successfully detected and sent to the server, the server returned a "200" success message. The band signal strength by the EmbediVet long-range radio system was tracked on a second computer.

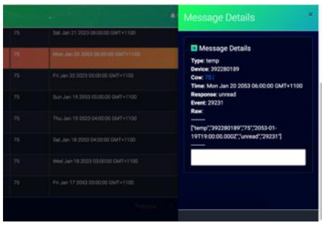

Fig. 16 Screenshot of alert

3.1.2.5 Trial – Beaumah

The Beaumah internal trial (March 2019) provided key insights on the implantation, process in the farm setting, Sensor data, validation of updating software in vivo, and the field testing of Basestations and mounting hardware.

3.1.2.6 Trial – UNE

The internal trial done through University of New England (April 2019). Data was gathered by the UNE team to compare against the EmbediVet Sensor data and the retrieval process was tested when the cattle were sent to the abattoir. The UNE team spent the remaining time working on classifying behaviors for the neural network.

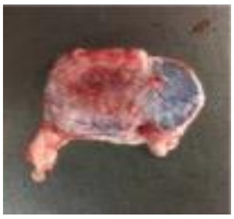

Fig. 17 Tissue encapsulated Sensor after retrieval

During the UNE trials, the Precision Agriculture Research group assessed the body temperature, activity classification and several animal welfare metrics. The temperature was tracked using the EmbediVet Sensor and by taking rectal readings. There was an expected delta between a core temperature reading and a subcutaneous reading. UNE calculated and provided the offset for that delta by constructing a Bland-Altman plot. The behaviour prediction algorithm provided for implementation is a DT using a 19-second epoch. This was provided in their "Testing of 'EmbediVet' multi-sensor" report. (Precision Agriculture Research Group)

3.1.3 Version 6

Livestock Labs used the feedback and observations from the testing, trials and veterinarians to improve the shape to work best with the implantation device and to improve the functionality of the Sensor. This version is in the testing phase and is expected to move to the trial phase next.

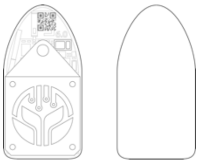

Fig. 18 Sensor version 6 drawing

3.1.3.1 Hardware

The EmbediVet Sensor v6 design reduces the size of the device by 1/3, making the dimensions 50mm x 25mm x 6mm.

- Circuit boards were printed and assembled with necessary components and instruments.
- After testing, the boards were attached to the standardized battery.
- After in-house assembly the device was ready to be placed in a molded thermoplastic case and have it sealed. The sealing method and opacity of the bottom shell are being tested to determine the optimal solution.

3.1.3.2 Software

- The device firmware is being developed to incorporate the new components and improve the maintenance and alerting processes.
- Data processing and storage continue to be built out to accommodate data being sent and to turn it into actionable information.

3.1.3.3 Testing

- Backwards compatibility testing is being done to ensure revision 6 had all the functionality of revision 5.
- Functionality testing is being done to ensure all components and instruments are achieving optimal outputs.
- The coated EmbediVet implant will be tested for cytotoxicity according to ISO 10993-5 (2009) and other biocompatibility concerns by a local laboratory.

3.2 Supporting Technologies

3.2.1 Basestation Development

The EmbediVet Basestation sits near where animals gather and collects the biometric data as the animals pass by. It also receives long-range alerts and sends all data to the servers for storage and analysis.

3.2.1.1 Version 1

For the Beaumah trial, a basic pylon (data collection station) was built using off-the-shelf components and a weatherproof box.

The two pylons were run off wall sockets in key locations in the barn. They were placed within 100 feet of an area which the cows visited daily. Equipped with mobile/3G service, they were to collect data once every 10 mins from each cow, if in range, and transmit to our servers.

Fig. 20 Installation of Pylon version 1

3.2.1.2 Version 2

The second version was built in-house with modules, a microcontroller board and solar recharged battery. This design included the long-range radio module and was tested in the lab. Next it was tested at Beaumah farm and deployed there for the Beaumah trial. The Basestation was placed at a water trough and there was a clear line of site to the Sensor as it was moved. The EmbediVet Sensor was moved incremental distances away from the Basestation and the qualities of the signal, such as strength and noise, were recorded. This continued until the broadcast could not be received or corruption exceeded 50%. The expectation was that the radio broadcast range would not match the performance of the TI evaluation module, which is equivalent to 7 kilometers, but would be more than 1km in range. The radio signal was assessed for strength and quality.

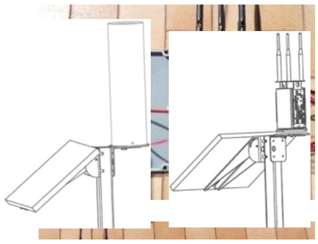

Fig. 19 Pylon version 3 drawing

Fig. 21 Pylon version 2 with solar

3.2.1.3 Version 3

Basestation version 3 was developed in response to the feedback from the testing and trials of version 2. The main internal change was designing a PCB board to replace the microcontroller board and modules and improve the design on the communications systems. The housing was changed from a square box to a round tube.

The pylon tube unit is approximately 40cm x 12.7cm (16” x 5”). It should last for 3 days with no sunlight and fully recharge using the solar panel in less than 1 day.

After passing tests in the lab, the basestations are currently deployed at trial farms. Software development is focused on incorporating new components and improving the maintenance and alerting processes of the Basestation.

3.2.2 Implantation Device (Applicator) Development

The EmbediVet Applicator is the tool intended for use by the customer to insert the EmbediVet Sensor subcutaneously. The implant tool needs to be robust against conditions on farms, ergonomic for multiple uses during an implanting session, and cause the least amount of distress to the animal.

3.2.2.1 Prototyping

The Applicator had two competing styles at the start of the design process: the squeeze gun style and the plunger style. The squeeze trigger was discarded because while it was more ergonomic it was less robust for farm use and had an increased probability of human misuse.

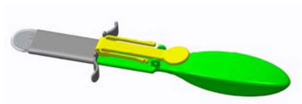

Fig. 22 Applicator Prototype

3.2.2.2 Version 1

The initial plunger style design was refined, and the body and plunger were 3D printed in-house. The blade, pin, and nose flap were custom made.

Fig. 23 Applicator version 1

3.2.2.2.1 Lab Test for Version 1

The Applicator was tested in the lab on a cow head to validate the implantation process and design functionality of the Applicator. It was also provided to two veterinarians for feedback.

Fig. 24 Applicator inserted to base of nose flap

Fig. 25 Prop Sensor placed under skin

Fig. 26 Visible outline of Sensor

3.2.2.2.2 Test for Version 1.1

The feedback from the lab test resulted in critical design changes, including allowing for one-handed use, getting two new blades angles to test, and making a smaller cannula for a smaller EmbediVet Sensor (version 6) which would improve pocket forming, ease of insertion, and reduction of animal discomfort.

- Dr. Kerry Rood was provided with the improved versions and tested the three different blades using the version 1 body.
- Dr. Rood used the Applicator at an abattoir facility to test the blades and provide further design feedback.
- Dr. Rood advised that a different blade angle would need to be tested and gave feedback on Applicator design. It was noted that one-handed use would not be possible with this version.

Fig. 27 Applicator inserted

Fig. 28 Prop Sensor is placed under the skin

3.2.2.3 Version 2

Version 2 had new design for the one-hand grip and changes were made to components to make them easier and more intuitive to use.

3.2.2.3.1 Test for Version 2

Dr. Kerry Rood provided initial feedback for the version 2 body design and the current iteration of the Applicator is with Dr. Kerry Rood for testing.

Fig. 29 Applicator version 2

3.2.3 Data Services Development

The EmbediVet data services were developed to process and display data. The main components are data storage, neural networks, and data display.

3.2.3.1 Data Storage

As the Sensors and Basestations designs iterated, it became necessary to bring servers online to handle data storage and webservices. The next phase was to build out the Database architecture and communications layers. Testing, data sanitization and improved architecture are ongoing work as the software and neural networks continue to grow.

3.2.3.2 Neural Networks

With the maturation of the Sensor and Basestation designs, the machine learning architecture was determined and implemented. The two main services developed to process data were the algorithm management service and the network management service.

3.2.3.3 Data Display

The customer facing data display was developed as a website, the Customer Portal, and as APIs for businesses to pull the data. The Customer Portal architecture was based on feedback from beef producers and others in the industry. UI/UX refinement and customer testing will be the part of the ongoing work to develop the Customer Portal.

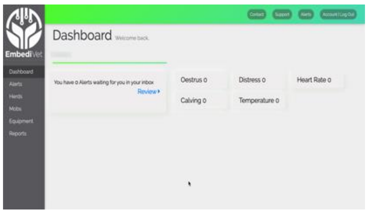

Fig. 30 Website version 1

4 Results

4.1 Objectives Outcomes

4.1.1 Temperature

The EmbediVet Sensor measures and tracks the temperature of a cow. Lab testing and field tests produced data and charts showing this metric.

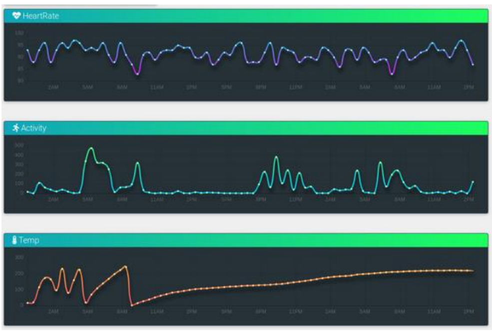

Fig. 31 Beaumah data displayed on website (2019)

4.1.2 Heart rate

The EmbediVet Sensor identifies and communicates the heart rate of a cow. Lab testing and field tests produced data and charts showing this metric.

4.1.3 Activity Level

The EmbediVet Sensor measures and tracks the activity levels of a cow. Lab testing and field tests produced data and charts showing this metric.

Table 1: EmbediVet Sensor Beaumah Data (4/30/19)

Serial	HR	Avg Temp	Min Temp	Max Temp	Avg Act.	Timestamp
x0160	85	38.38	37.7	38.38	263	4/30/19 17:56
x0078	92	38.13	38.01	38.13	200	4/30/19 17:57
x0039	93	37.63	37.57	37.63	252	4/30/19 18:01
x0181	94	38.76	38.51	38.76	192	4/30/19 18:03
x0167	85	38.95	38.63	38.95	241	4/30/19 18:08
x0172	96	39.7	39.45	39.7	278	4/30/19 18:13
x0057	91	38.95	38.51	38.95	227	4/30/19 18:13
x0050	90	38.32	37.63	38.32	322	4/30/19 18:18
x0178	90	38.26	37.82	38.26	160	4/30/19 18:20
x0188	91	39.07	38.57	39.07	147	4/30/19 18:20

4.1.4 Field Test

The Sensor was tested in the field at Beaumah and UNE. The Beaumah trial provided proof of concept for the measurement and tracking of the temperature, heart rate, and activity level metrics of the cows.

The UNE trial conducted by the Precision Agriculture Research group assessed the body temperature, activity classification, and several animal welfare metrics. Their measurements helped determine accuracy and provided suggestions for future refinement. The temperature was tracked using the EmbediVet Sensor and by taking rectal readings. There was an expected delta between a core temperature reading and a subcutaneous reading. UNE calculated and provided the offset for that delta by constructing a Bland-Altman plot. The behaviour prediction algorithm provided for implementation is a DT using a 19-second epoch. This was provided in their “Testing of ‘EmbediVet’ multi-sensor” report. (Precision Agriculture Research Group)

4.1.4.1 Temperature Measurements

UNE found a circadian rhythm in both data from the rectal loggers and the EmbediVet Sensors. “The level of agreement between EmbediVet and rectal temperature was evaluated by constructing a Bland-Altman plot. A Bland-Altman analysis involves plotting the differences between values generated by 2 methods of measurement on the y-axis against the average of the values produced by the 2 methods on the x-axis.” (Precision Agriculture Research Group) This analysis allowed UNE to calculate and provide the offset for the difference between the data sets.

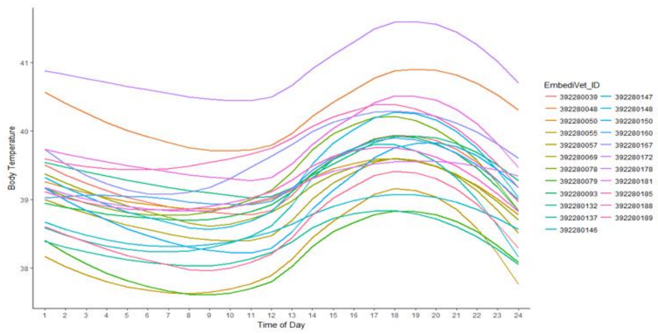

Fig. 32 EmbediVet Sensor data (Temp, °C) over a 24 hour period on 1st May (Precision Agriculture Research Group)

4.1.4.2 Activity Level Measurements

The activity level measurements were tracked and classified as walking, feeding, or standing using a behavior prediction algorithm. Each dimension was tracked, classified, and then scored.

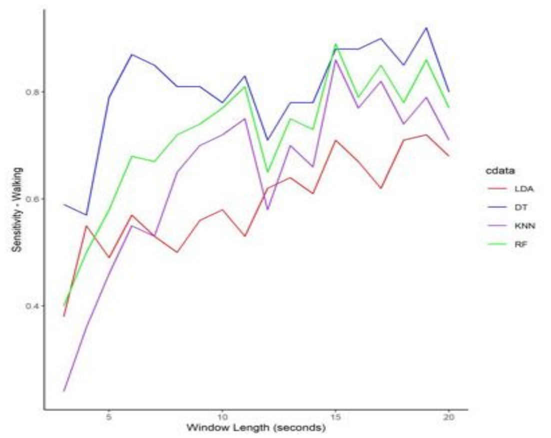

Fig. 33 Sensitivity values of the LDA, DT, kNN and RF algorithms at epoch lengths of 3-20 seconds for walking behaviour.

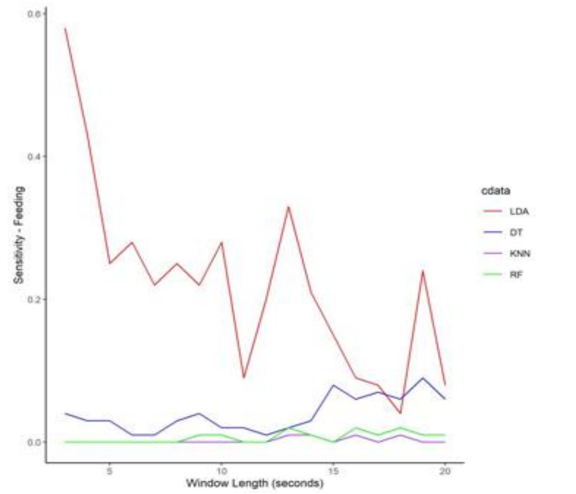

Fig. 34 Sensitivity values of the LDA, DT, kNN and RF algorithms at epoch lengths of 3-20 seconds for feeding behaviour.

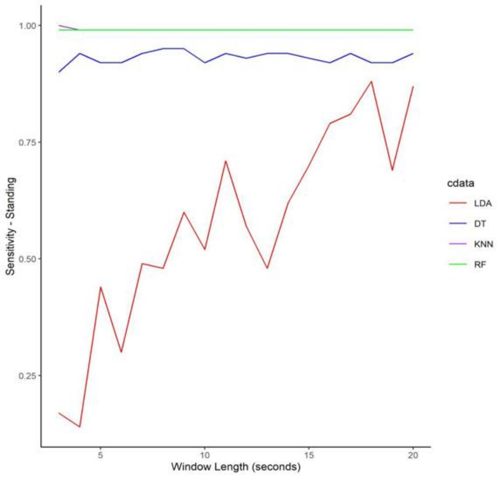

Fig. 35 Sensitivity values of the LDA, DT, kNN and RF algorithms at epoch lengths of 3-20 seconds for standing behaviour.

	Active	Inactive	*Precision*
Active	**62**	9	*87%*
Inactive	128	**1220**	*91%*
Sensitivity	*33%*	*99%*	

Fig. 36 Matrix showing the breakdown of behaviour predictions for the DT

The UNE trial co output provided a valid measure of internal body temperature. The behaviour measurements agreed with visual observations for standing and walking events. Given the similarity in posture between feeding and standing in feedlot cattle, there is little dynamic acceleration experienced resulting in similar acceleration signals between standing and feeding leading to a poor predictive ability of the algorithm.” (Precision Agriculture Research Group) This confirms that the temperature and activity level objectives have been met. UNE offered up possible solutions for improving the behavioural algorithms and confirmed that with research and development the algorithms may “provide an alert detection system of animals displaying abnormal behavioural patterns associated with illness or welfare issues”.

4.1.5 Insertion Device

Applicator version 2 met the objective of creating a device that would allow the Sensor to be inserted into a cow by a farmer with little assistance by a veterinarian. The one-handed design allows for a farmer or farm hand to insert the blade and push the implant under the skin.

5 Discussion

5.1 Project Objectives

Livestock Labs has met each of the project’s objectives and is well-positioned to continue to iterate and expand the design of the Sensor.

5.1.1 Temperature

- Objective: Engineering a device that will measure and track temperature of cow
- Result: The EmbediVet Sensor design was able to meet the objective of a device that measures and tracks the temperature of a cow in version 4. The trials provided confirmation that while thermometer readings have a high precision of accuracy, there are several environmental factors that have to be accounted for. Livestock Labs will need to continue testing and improving the algorithm that processes the temperature data. The offset calculated by UNE is the starting point for this improved data fidelity.

5.1.2 Heart Rate

- Objective: Engineer a device that will identify and communicate heart rate, which may be indicative of distress and movement
- Result: As with temperature the goal of heart rate identification and communication was achieved with the EmbediVet Sensor version 4 design. The heart rate collection and transmission to the database has been steady with each subsequent version. The company learned an important lesson when making a “simple” sensor change when they discovered the new algorithm used with the sensor had a reduced accuracy. The unexpected work hours to refactor the algorithm presented the company with an opportunity to examine and improve the change management process to reduce the likelihood a future occurrence. Going forward the goal is to maintain robust processes, increase the fidelity of the processed data, and test the accuracy in trials.

5.1.3 Activity Level

- Objective: Engineering a device that will determine and communicate movement
- Result: The EmbediVet Sensor design was able to determine and communicate movement of a cow in version 4. Going beyond the communication of the movement, the UNE trial helped classify movements and assess their accuracy. While the accuracy was high, some aspects such as distinguishing standing and feeding behaviour will need further refinement. Livestock Labs will continue testing and improving the algorithm that classifies the activity data.

5.1.4 Field Test

- Objective: Test device in the field with animals to ensure that measurements are accurate and that there is a good customer experience.
- Result: The Beaumah trial provided proof-of-concept for the measurement and tracking of the temperature, heart rate, and activity level metrics of the cows. With the UNE trial, Livestock Labs was able to determine the accuracy of the measurements and begin assessing the requirements for a good customer experience. They determined that the Sensor was collecting valid measurements and good agreement between observed behaviour and the classified behaviour of the data. Future trials will be informed by the feedback and working relationship the company had with the Precision Agriculture Research group at the University of New England.

5.1.5 Insertion Device

- Objective: Engineering a device that can be inserted into a cow by a farmer with little assistance by a veterinarian.
- Result: In some ways this objective was met with version 5 of the EmbediVet Sensor. Its small, ergonomic shape meant that a veterinarian could implant (shave, numb, cut, insert device, and close wound) it in 2-3 minutes. But the objective was really meant for the EmbediVet Applicator which will remove veterinarian assistance and put the implantation in the hands of the farmers. This device is inserted into the animal and the implant is pushed through its channel under the skin of the cow. Version 2 of the Applicator meets with veterinarian approval and is undergoing final testing before going to trials and being used by early adopting customers. Safety, animal welfare, and ergonomics will stay at the forefront of future design considerations.

5.2 Project Delivery

The project objectives centered on the core technical features needed for the EmbediVet implant to progress towards the early commercialization phase. As the project concluded, the trial results had proved out temperature, heart rate and activity levels as individual metrics that provide the ongoing monitoring and insights for distress, estrus, and calving.

What was less understood at the outset of the project was the extent to which the systems that support the implant would need to be built out. In the end several critical back-end components (database, webservices, neural network) and four product lines were developed (Sensor, Basestation, Customer Portal, and Applicator) to provide a good experience getting data from a cow to a farmer. What worked well was having flexibility in the objectives and milestones to allow for the additional systems to work and the feedback for each design iteration. It ensured the project wasn't locked into specific technologies which could have created bottlenecks during the rapidly changing design and iteration phases of the project.

The project encountered slowdowns from a typical amount of design changes based on testing and some tight timing due to organizational delays, funding, and winter holidays. The communications and responsiveness of MLA to resolve timing issues that came up was a great asset to the project delivery.

The project has met its objectives and successfully concluded.

6 Conclusions/recommendations

6.1 Key Insights

The key insights from this project have broad application across the beef industry.

6.1.1 EmbediVet implants increase productivity

Beef producers want to maximize productivity and minimize inefficiencies. The EmbediVet System boosts productivity by providing alerts and metrics on each animal. Farmers of large-scale pasture operations and feedlots of all sizes would benefit from an affordable way to closely supervise cattle in a scalable way.

- Producers are able to respond quickly to alerts on distress and take the appropriate corrective action.
- Early detection of illness prevents the spread of disease, minimizes weight loss and treatment costs.
- Fewer dead and underweight animals means the most animals on optimal feed for the shortest time.
- Larger farms and feedlots may find additional value in having an easy way to share health metrics and insights with their veterinarians.
- Livestock exporters and transporters could use the EmbediVet system on their vehicles and ships to track animal distress, care for them sooner and reduce weight loss and number of deaths.

The EmbediVet System can combine key animal characteristics with their data to let farmers know about estrus, pregnancy, and calving.

- For farmers tracking estrus, the EmbediVet system can provide tracking of animal's cycles and alerts which estrus is detected.
- Early detection of indicators for pregnancy and miscarriage can help a farmer to check on animals in the most need of attention and reduce treatment and feed costs.
- Calving alerts can be set to let a farmer check on potentially prolonged or distressed calving where the cow and calf could be in danger.

6.1.2 EmbediVet implants add transparency to animal welfare

Each group in the beef production chain has an interest in animal welfare from a regulation, reputation, and value perspective.

- Farmers and feedlots can use the EmbediVet system to show a health history and recorded stress events for their animals. This gives them some leverage in the selling process.
- Livestock exporters and transporters could use the EmbediVet data to prove how the animals were cared for. This would bolster their reputation for animal welfare and ensure they had traceability regarding the animal's condition before and after transportation.
- Abattoirs could use the distress events to show how their animals were treated prior to killing and processing.
- Consumers who are known to buy humanely raised beef at a higher price would have greater assurance on how the animals were treated.

6.1.3 EmbediVet implants provide asset assurance

The EmbediVet system provides farmers with an easier way to proof the size and health of the herd.

- Farmers could use their EmbediVet data to obtain better deals with banks and insurance companies.
- Banks and insurance companies would have greater confidence that they were correctly assessing the risk and value of the deals with beef producers.

6.1.4 EmbediVet implants provide traceability

The EmbediVet System incorporates the NLIS identification and has location history of an animal in addition to the health history. In the event of a biosecurity or food safety issue this information could reduce the time needed to identify potential problematic sources. In the case of an issue after a transaction, beef producers, livestock exporters, and others in the production chain would find value in knowing the health and location history of an animal.

6.2 Recommendations

6.2.1 Future R&D

The implant design will continue to be iterated with a focus on a smaller footprint, greater lifespan, and production cost reduction. Some of the early sensors and metric had either high complexity to develop or did not provide enough value to the customer to be pursued in the early version of the implant. As the EmbediVet system matures, new sensors and metrics should be evaluated and pursued if they are aligned with the needs of customer and the vision of the company. Some promising ones include audio detection of illness, determining blood pressure, calculating weight, and measuring key chemical markers in the body. The EmbediVet neural network R&D will ramp up as larger datasets are obtained, resulting in numerous insights around animal health, well-being, and value.

6.2.2 New Markets

The Australian beef industry is in the first market for the EmbediVet system. The US beef production and Australian sheep markets would be the second market. Outside of commercial beef production, the animal sciences community is a market worth exploring. Livestock researchers at universities could make use of the EmbediVet implants to obtain important data on their animals during experiments.

7 Key messages

7.1 Early Intervention

Beef producers using the EmbediVet system will be able to respond sooner to distress and illness. Depending on the distress, it could prevent loss of life. For illness the producers will be able to separate out sick animals sooner to provide treatment, prevent weight loss and reduce the spread of the illness. Knowing which animals to attend to earlier will reduce the work for the producer and could prevent some of the added costs of additional hands and veterinarian visits.

Livestock exporters and transporters could use the EmbediVet system on their vehicles and ships to track animal distress, care for them sooner and reduce weight loss. Having verifiable data to prove animal welfare and traceability would be help maintain the reputation of the companies and value of the animals.

7.2 Fertility optimization

Beef producers using the EmbediVet system will be able to track estrus, pregnancy, and calving. Some farmers will find the estrus detection useful for fertility planning. Earlier detection of pregnancy and miscarriages would allow the producer to optimize the use of feed, attempt another joining, or check the health of the cow to prevent complications.

7.3 Improved Transparency

Beef producers would be able to prove their herd health and size giving them leverage with banks, insurance providers, and buyers. They would get back information on the health and quality of their animals through to processing, allowing them to understand how well the animals are treated past the gate and give them insights to the best producing animals.

Livestock exporters and transporters using the EmbediVet system will have verifiable data on the traceability and welfare of the animals. This would help companies maintain their reputation and give them a way to show the health of the animal before, during, and after transportation.

Beef processors using the EmbediVet system would have a reduction in paperwork and could gain valuable business intelligence about the supply chain from the history and traceability of the animals being processed. They would have data to bolster the labeling (grass-fed, organic, free range) of the meat.

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