final report

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Develop whole of farm integrated sensor monitor

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Abstract

Farmbot identified that there was a lack of easy to use, affordable water and other infrastructure monitoring systems available to producers. We identified a number of new low cost technologies that had potential to produce cost effective ground break solutions.

Farmbot undertook R&D and developed a range of prototypes with associated testbeds with the aim of creating innovative solutions for Water Flow Monitoring, Water Quality Monitoring, Electric Fence Monitoring and the optimisation of Satellite Data transmission.

The project included the sourcing of specialised optics, ultrasonic components, development of specialist electronics as well as the development of advanced control and analytic software. These were integrated into a series of evolving prototypes.

The project resulted in the creation of cost effective and easy to use Water Flow, Water Quality and Electric Fence monitor solutions. These will now be made available to the livestock and other industries. These solutions can provide significant savings, improve certainty of optimum development and welfare of their stock and ultimately improve a farms productivity and ROI.

Executive summary

Objectives

The ability to have a near realtime view of assets and infrastructure such as tank levels, flows and electric fence status from anywhere, anytime will provide substantial cost savings, risk reduction and stock loss minimisation for producers and free up scarce resources for productive tasks.

Distance and limited communications are the common challenge to all of agriculture. They cause substantial costs for producers (labour, vehicle, OH&S and many more). To date there has been a lack of easy to use, affordable water and other infrastructure monitoring systems available for producers. Producers are time poor and typically want an easy to install and use solution for their needs that does not require skilled technicians to maintain. The labour component in installation and support of existing technology by technicans can be a major component in the total cost of ownership.

The Farmbot water level monitor has been very popular with producers due to its low upfront cost, simplicity and ease of use with access to the system anytime from anywhere. Feedback from our clients and industry told us that the following additional services would be of great value:

- Water Flow Monitor
- Electric Fence Monitor
- Water Quality Monitor

In addition they highlighted any measure than can reduce Comms/Satellite Transmission charges would be critical to takeup.

Approach

The Farmbot design philosophy is to use the latest technology in creative ways to provide simple, cost effective solutions for the challenges of agriculture and other remote applications. The Farmbot technical team spoke to a wide range of our users to gain insights into the detailed requirements of the project.

We identified a number of new low cost technologies that had potential to produce cost effective ground breaking solutions. Key to all our solutions are the embedded algorithms and analytics in our monitors to better analyse the data and optimise what is transmitted to deliver rich meaningful data at an acceptable ongoing cost.

Farmbot undertook R&D and developed a range of prototypes with associated testbeds with the aim of creating innovative solutions for:

- Water Flow Monitoring – This utilises off the shelf pulse water meters. Embedded algorthms were developed to accurately handle a broad range of old and new meters
- Electric Fence Monitoring – A specialist RF detector was developed, tuned specifically for electric fence pulses. This required extensive iterative development of hardware and software to produce a device that can be mounted on or near and fence that can detect power levels in a range from 0 to 7.
- Water Quality Monitoring – A number of off the shelf options were investigated but these were all expensive and not suitable for agricultural use.

  Salinity: Our research showed that a Texas Instruments high speed analogue and timer technology could be utilised to produce a highly accurate ultrasonic salinity measure. This also incorporates an off the shelf turbidity sensor. A number of prototypes were developed resulting in a practical version with accuracy of 1gm / litre in the range from 0 - 40 gms.

Blue Green Algae (BGA): A series of prototypes were developed that detect the specific fluorescence of BGA (Phycocyanin) under narrowband light. Specialist narrow band optics were imported for the trial ready version.

- Work was carried to improve the efficiency of the Satellite data transmission to enable the cost-effective transmission of the additional data while minimising usage charges. This involved analysing trends and other characteristics of the data so the most meaningfull summary is sent.

Once the sensing modules were developed to a field testable stage they were integrated into the standard Satellite and 3G/LTE monitor platform. Once local field testing was completed, (within 200km of Sydney) the trial modules were shipped to trialists.

Key Results

The project has delivered the following cost effective monitoring options available on the Farmbot Satellite and 3G/LTE monitor platforms. These are simple to install and use, and provide information easy to use form:

- A practical flow monitoring option supporting up to 3/4 separate lines. This is coupled with water level changes to calculate input volumes
- An Electric Fence monitor that can wirelessly detect the status and power of a fence up to 5 km from the Farmbot monitor. As it is not electrically connected to the fence it is not vulnerable to lightning strikes
- A Salinity and turbidity monitor that can analyse the dissolved salt level in water within 1 gram / litre accuracy. This accuracy is sufficient for most producers and horticulturalists purposes
- A Blue Green Algae and turbidity monitor that can identify medium to high concentrations of Blue Algae in a body of water. This can provide critical early warning of toxic blooms
- Further optimisations to our transmissions algorthms to allow for the maximum useful data to be sent for the lowest practical cost

The above are currently in field testing and will be made available to our all customers over the next 2-3 months. Feedback to date on pricing and functionality has been very encouraging.

Insights

Our requirements discussion with our users highlighted the need for low cost, medium accuracy sensor technology that will give a timely warning of impending issues. Water quality solutions are typically high accuracy, high cost and lab grade. These often require a technician to operate and service. Our devices are designed for the end user, with accuracy appropriate for the application and robust.

Many areas are unlikley to ever be serviced by anything other than Satellite communications. Potentials users in these areas requested that our solutions be effective over Satellite as well as 3G/LTE. With 3G/LTE we provide a more timely and detailed solution.

Our research in developing the electric fence solutions lead us to a greater understanding of the electromagnetic emissions of active fences how best to provide simple solution that can be practically mounted in a simple and animal proof way.

The relative simplicity of an innovative ultrasonic salinity detector has allowed us to produce a low maintenance and relatively robust solution that will be very accessible to producers. Modern high speed, low cost electronics and embedded computing is the key to this. The availability of relatively high quality, low cost narrow band light filters and other specialist optics open up many options for a range of applications, especially in the water quality domain.

Implications for industry

The Livestock industry will now have access to simple to use, cost effective Satellite and 3G solutions that will provide the following benefits:

Flow Monitoring – Producers will have a tool to provide clear quantification of water consumed by stock for each out bound water line. Quantification of tank inflow and hence bore/pump production rates. Diagnostic information on pump/bore issues, leaks and breaks. This provides additional data for stock management and saves time in dealing with infrastructure issues.

Electric Fence – Producers will be able have a near realtime view of electric fence function and receive alerts on failure. This will be a particular value for Cell Grazing operations where electic fences are key to optimum pasture management. It can also provide early warning on issues that are starting to compromise electric fence function.

Water Quality – Salinity and Blue Green algae are of particular concern to producers in certain areas. Early warning of changes allows timely response to minimise any the impact on their stock.

Further Research

Flow monitoring – water meter cost is a significant component of the solution – We plan to investigate non-invasive ultrasonic flow monitoring in a separate R&D project.

Modern ultrasonic tech is very effective and low cost – has potential applications for a range of areas including liquid depth/level metering.

We plan to investigate the use of optics for detection of other forms of algae.

Conclusions

Farmbot is pleased with the outcome of the project and believe that we will get a good return on our significant investment of time, funds and key resources. The project resulted in the creation of cost effective and easy to use Water Flow, Water Quality and Electric Fence monitor solutions. These will now be made available to the livestock and other industries and will provide significant savings, improve certainty in optimum development and welfare of their stock and ultimately improve a farms productivity and ROI.

Recommendation

The project shows that there is significant value in applying recent technical advances to longstanding problems. There is a virtually endless array of technology components and devices available at very accessible cost from China that allow for innovative low cost experimentation on a wide range of applications. We recommend the allocation of further resources and budget to explore potential solutions to many of the challenges faced by agriculture.

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FARMBOT MONITORING SOLUTIONS

1 Background

1.1 Overview

The ability to have a near realtime view assets and infrastructure such as tank levels, flows, electric fence status from anywhere anytime can provide substantial cost savings, risk and stock loss minimisation for producers and free up scarce resources for productive tasks.

The majority of the solutions available today are not Satellite enabled leaving many producers without viable technology options. Farmbot has a Satellite first approach to all solution development. This means that we design all our solutions so that they will perform effectively with Satellite, 3G and potentially other communications methods. When higher bandwidth is available (eg. 3G/LTE/NB-IoT), the service becomes more timely with greater detail in the data.

From the outset Farmbot has developed IP that provided the optimisation of transmitted data, specifically useful for Satellite comms. This project builds on previous work by improving algorithms and use case specific analytics.

Distance and limited communications are the common challenge to all of agriculture. They cause substantial costs for producers (labour, vehicle, OH&S and many more). To date there has been a lack of easy to use, affordable water and other infrastructure monitoring systems available to producers. Producers are time poor and typically want an easy to install and use solutions to their needs that do not require skilled technicians to maintain. The labour component in installation and support of existing technology by technicans can be a major component in the total cost of ownership.

The Farmbot water level monitor has been very popular with producers due to its low upfront cost, simplicity and ease of use with system access anytime from anywhere. Feedback from our clients and industry told us that the following additional services would be of great value:

- Water Flow Monitor
- Electric Fence Monitor
- Water Quality Monitor

In addition they highlighted any measure than can reduce Comms/Satellite Transmission charges would be critical to takeup.

1.2 Industry Benefits

The purpose of the project is provide the livestock industry with a simple to use, cost effective Satellite and 3G solutions that will provide the following benefits:

Flow Monitoring – A service to provide clear quantification of water consumed by stock for each out bound water line, Quantification of tank inflow and hence bore/pump production rates, Diagnostic information on pump/bore issues, leaks and breaks. To provide additional data for stock management and save and effort time in dealing with infrastructure issues.

Electric Fence – A service to enable a near realtime view of electric fence function and receive alerts on failure. This will be of particular value for Cell Grazing operations where electic fences are key to pasture management. It can also provide early warning of issues that are starting to compromise electric fence function.

Water Quality – A service to provide early warning of changing water conditions. Salinity and Blue Green algae are of particular concern to producers in certain areas. Early warning of changes allows timely response to minimise any the impact on their stock.

1.3 Overarching Aims

Farmbot has identified the need of producers for additional monitor services. We identified flow monitoring, electric fence monitoring and water quality monitoring as high priorities. The purpose of the project was to deliver solutions that are:

- Cost effective and accessible to all producers
- Simple to install and use with no need for costly technical support
- To be of suitable accuracy for agricultural purpose – ie. Not paying for unnecessary precision
- Robust in typical agricultural environments
- To work anywhere in Australia / World due to the Satellite communications option
- To provide payback on the cost of the system in less than 12 months

2 Project objectives

2.1 Overview

Develop three different sensors modules, with satellite connectivity, suitable for use by producers, trialled at producer sites and refined for use in the producer environment through their feedback. There is also a need to improve the efficiency of the Satellite data transmission to enable the cost- effective transmission of the additional data while minimising usage charges. The sensors will be integrated into the existing the upgraded base Farmbot Water Level monitor. These sensors will be simply installed by unskilled farm labour hence avoiding the high installation and support costs of other solutions.

Sensors to be included are detailed in the following sub-sections:

2.2 (1) Wireless fence monitor

Electronic circuitry and support software that accurately detects and measures the strength of electric fences without an electrical connection to the fence. Having an ability to incorporate a single monitor unit located on a stock water tank allows multiple tasks that are currently performed manually to be reduced. As it is not connected to the fence, it will not be destroyed by lightning strike (very common) and is trivial to install by farm labour. This will provide real-time electric fence status to the producer and their staff 24x7 via their PC, tablet or phone. They will receive SMS and other forms of warning as soon as a failure is detected. It will also provide detailed electric fence power levels that will provide early warning of problems such as vegetation and other things shorting out the fence and reducing effectiveness. Farmbot have had a large number of enquiries for this solution from producers that are converting to cell grazing. They typically place tanks in the corners of paddocks within 50 metres of electric fences. This facility will reduce the need to do fence checking runs (labour, fuel, wear and tear), will provide early warning of fence issues before they impact operations and support the optimal management of stock especially in the cell grazing configurations. Farmbot plan to charge an upfront figure of about $300 for the electric fence sensor option. The ongoing subscription charge (approx. $40) of the base unit will cover all communications, access and support for this sensor. There is no solution on the market today that provides a wireless system, that is extremely easy to install and use, utilises Satellite and has an acceptable cost of ownership.

2.3 (2) A water quality sensor

Measuring and monitoring water quality is vital for many farmers across Australia. Turbidity measurement is one example. Extract from a paper prepared by the DPI sets out the issues with unhealthy on-farm water can pose for livestock (see additional information).

The cost to farmers of not incorporating water quality sensing can range from livestock becoming sick to livestock fatality.

Farmers are currently moving from surface water (including Dams) as a stock water source to tanks and troughs due to water quality concerns. This has reduced disease propagation but there are still room for considerable water quality issues originating from the water source. Water sources include rivers, dams, bores and pipeline systems. Drought, nutrient run off, water table changes, and releases from mines can impact a water supply and seriously impact stock wellbeing and value. Farmbot are getting an increasing number of enquiries for water quality monitors to be incorporated into their base water level monitor. There are different needs in different areas which will drive the design of this solution. Farmbot propose to initially focus on Turbidity, Algae and Salinity. They will make the platform flexible so they can respond to customers needs as they arise. This solution will give early warning to producers of changes in the water quality providing the opportunity to either move stock or remedy the source of the problem before it effects the bottom line and animal welfare. The information is provided to the producer and their staff 24x7 via their PC, tablet or phone. They will receive SMS and other forms of warning as soon as a issue is detected. Farmbot plan to charge an upfront figure of about $150-400 for water quality option. The price is dependent on the particular attribute of the water we will be testing for. The ongoing subscription charge (approx. $40 per month) of the base unit will cover all communications, access and support for this sensor. The systems available on the market today tend to be laboratory grade and prohibitably expensive. The Farmbot solution, will be suitably accurate, extremely easy to install and use, with a acceptable cost of ownership.

2.4 (3) A water level & flow monitoring system

This will support up to 4 flow sensors per Farmbot water level monitor. Water level and water flow perform very separate and discrete functions. Water flow measurement forms an important function for producers who run tanks with multiple water pipes connecting downstream tanks and troughs. Without water flow measurement and monitoring capability, producers are unable to understand the full water usage of downstream water assets and are unable to determine and analyse issues affecting singular pipes within a multi-tank system.

The base Farmbot Level monitor enables a producer to ensure that their stock tank always has water. A large number of Farmbot customers and propects have requested a flow monitoring option in addition to the base level monitor. This will allow the user to know exactly how much water is being consumed by every branch line from a tank and also the pump flow rates. This provides significant value. This includes, actual water drunk per day per trough, precise determination of leaks, detailed pump behaviour which can provide early warning of pump motor and controller malfunction or failure as well as clear quantification of bore flow rate changes. In the common case of branch lines running for many kilometres from tank to trough, there will be significant time savings when breaks occur and the faulty branch line is highlighted by the system. This means problems solved faster with less stress or losses of the animals. Also, if a trough is blocked (dead animal in it etc.) preventing other animals from drinking, it is clear from the flow rate that there is a problem to attend to immediately. The integrated view of water level and flow information is provided to the producer and their staff 24x7 via their PC, tablet or phone. They will receive SMS and other forms of warning as soon as any issue is detected.

Farmbot plan to charge an upfront figure of about $150-200 for for each flow sensor (up to 4). The ongoing subscription charge of the base unit will cover all communications, access and support for this sensor. The systems available on the market today prohibitably expensive and don’t provide a Satellite option. The Farmbot solution, will be suitably accurate, extremely easy to install and use with a acceptable cost of ownership. Without this system, there is a much higher likelihood of stock losses, especially in hot weather.

2.5 (4) Satellite Data transmission cost reduction

Experimentation has demonstrated that the volume and frequency of data transmission can be reduced by the use of Use Case specific algorithms. Algorithms will need to be developed that do trend analysis, data compression and noise reduction to significantly reduce the volume of satellite data transmission and power consumption. The aim is to provide an effective real-time data feed without constant data transmission hence ensuring acceptable operational costs. The base Farmbot water level monitor utilises existing trend analysis and compression technology to reduce our communications costs & power consumption. This is key to Farmbot’s ability to having a low Total Cost of Ownership and making solutions accessible to all producers.

The additional data that will be required to be transmitted via Satellite from the additional sensors will need specialist algorithms to be developed to minimise the transmission charges.

This will provide accurate and detailed water information and data for analytics (not this project) which will include long term usage trends, supply behaviours, animal and other behaviours.

3 Methodology

3.1 Overview

The project has 4 development modules with varying methodologies depending on the needs of the testing and refinement involved.

3.1.1 Wireless Electric Fence monitor

3.1.1.1 Methodology

Our research has shown that the energy of the fence and hence its effectiveness can be measured by the RF emissions of the fence. This testing phase focused on varying elements of the electronic receiving circuits and the antenna to yield the most effective system.

The Monitor based analysis algorithms were also iteratively developed to optimise how the fence power data is processed and communicated back over Satellite or other means.

Each electric fence manufacturer design energisers with different RF output signatures. The challenge was to produce a detector mechanism that was capable of reliably sensing the major energisers on the market today. We had to sample the RF pulses from a wide range of common energisers to understand the range of possible patterns to be detected.

The frequency of the energiser RF energy spike is typically around 1 MHz so the detector had to clock at high speed to adequately sample the energy pulse and duration. This required successive cycles of hardware and software modifications to increase sensitivity. Significant time was spent to ensure that the system was not sensitive to background radio noise which is more common in urban areas or around machinery sheds.

A series of electric fences energisers were set up in order to test the device's effectiveness with low and high-powered units from a range of vendors. These were initially tested at the Farmbot work areas and subsequently on grazing properties.

3.1.2 Design

The final design uses a compact electric fence detector module that can be mounted about 60cm above a fence on a short pole. This puts the unit out of harm's way and not electrically connected to the fence. This will then communicate wirelessly using LoRa to a Farmbot Monitor within 5 kms. The Farmbot Monitor will then provide the connection back to the Farmbot Servers and through to the customer. As the device's antenna is mounted approximately 70 cm above from the fence there will be no need for calibration of the device. The module has been designed to be compact and installed in a few minutes.

The electronics includes the following features:

- AM Pulse receiver for electric fence pulse detection with Op amplifiers and conditioning circuitry
- ARM microprocessor
- LoRa radio
- CANBus output and Digital pulse encoded outputs
- Antennae for LoRa & Fence reception

3.1.2.1 Field Trial

The Electric Fence detector on a PVC pole attached to an electric fence.

3.1.3 Water Quality Sensing

The purpose of this sub-project was to develop an easy to use set of water quality sensors that connect to the Farmbot Monitor. These must be of sufficient accuracy to suit the needs of the producer whilst being of reasonable cost.

The following water quality sensor units have been developed:

- Salinity
- Turbidity
- Algae (Blue Green)

As a result of the test activities, our understanding of water quality needs have evolved and we are now planning to package the sensors in 2 groups:

- Salinity and Turbidity
- Algae (Blue Green) and Turbidity

This reflects the likely Use Cases for water monitoring. The salinity package needs to be quite compact so that it can be placed inside a water tank where necessary. The Blue/Green Algae package is typically used in larger bodies of water and hence needs to have a form that can be moored in a fixed location and be subject to unkind wind and weather.

3.1.3.1 Methodology

The key driver for our design has been to produce a compact, cost effective and robust water quality sensor package. To meet our objectives, we have had to reconsider the designs produced in Milestone 2 of the project. The following sections detail our revised approaches. As such we have explored unconventional approaches and newly available technologies to produce a device that meets our needs.

In addition, our designs have been simplified as we are using super-hydrophobic coatings to prevent the build-up of organic and crystalline fouling on key surfaces and lenses. This has removed the need for complex mechanical means of keeping key surfaces and lenses clean. These have recently become available at low cost and allow us to use much simpler mechanical designs.

Once our devices passed controlled laboratory type test sets, then we trialled the devices using water samples from rivers and lakes in eastern NSW.

We sourced Blue Green Algae from a range of sources including powdered forms as well as NSW inland waterways (Lake Burrendong). A range of bore water samples have been obtained for Salinity/Conductivity testing.

3.1.3.2 Research

Revised Blue Green Algae Sensor (BGA)

The proof of concept Blue Green Algae (BGA) sensor confirmed the use of low-cost components to detect BGA but revealed issues that would need to be overcome to increase the resolution of detection needed to provide an effective early warning system for potentially toxic algal blooms. The most critical of these issues were:

- Reflected light from excitation source back into the photo-detector
- Crossover from the excitation source spectrum into the emission spectrum.

These two issues resulted in a low limit of detection that was unacceptable.

The revised BGA sensor consisted of:

- Dual excitation LEDs
- A narrow bandpass filter
- Luminosity sensor
- Turbidity Sensor
- Self-contained electronics to perform measurements and provide a wireless link.

The superior performance of the revised system is due to the narrow bandpass filter only transmitting the emission wavelengths from the fluorescence of BGA and the dual LEDs providing high intensity light with narrower spectrum to increase the amount of fluorescence. Additionally, the Luminosity sensor provides a wide dynamic range with the ability to measure light intensity down to 0.1 Lux allowing for the detection of even lower intensity emissions from the BGA. The addition of the turbidity sensor allows for calibration of the sensor to remove the effect of turbid water reflecting additional excitation light back into the Luminosity sensor.

Dissolved Salts Sensing

The first iteration of the Salinity sensor used an electrical conductivity probe. Testing of the salinity sensor yielded a list of complications that ultimately lead to a revised solution. Using a conductivity sensor to infer salinity had issues such as de-calibration and fouling of the electrodes which would limit its usefulness as a long-term field-based sensor.

The cost of high-end commercial sensors would also be prohibitive for many farmers. The conclusion was that conventional salinity probes do not meet the requirements of long-term measurement stability and sensor maintenance.

This necessitated the research and development of an alternative method to measure salinity. After exhausting a range of conventional approaches, the method of using acoustic velocity to infer salinity was selected. Our new approach avoids the issues of the conductivity sensors and we believe we can manufacture more affordable and robust devices using this design.

Science

Salinity is defined as the total concentration of all dissolved salts in water. As the salt concentration increases so too does the density of the water. Since the speed at which sound waves propagate through a medium is dependant on its density it is possible to infer the salinity from the acoustic velocity of the water. To do this, an ultrasonic pulse travels through the water along a known distance and back to the receiver. The ultrasonic pulse time of flight (TOF) and the distance is then used to calculate the acoustic velocity.

There are two other factors that effect the density of water and thus the acoustic velocity. Firstly, depth which for this use case is negligible and secondly, temperature which is a significant factor. Minor temperature changes can lead to major changes in calculated salinity.

The algorithm used to calculate salinity as a function of acoustic velocity, depth and temperature was derived from the velocity model developed by Medwin (1975).

Turbidity Sensing

Cost effective turbidity sensors are readily available as they are used in a range of automotive and commercial mass market applications. We use a turbidity sensor that is commonly used in dishwashers.

3.1.3.3 Design

The suite of water quality sensors modules has been designed to be connected to a Farmbot monitor. There will be 3+ metre cable that attaches the Salinity and Turbidity sensor unit to the monitor. The BGA and Turbidity sensor unit will wirelessly connect to the monitor via a LoRa radio.

The sensor electronics will include the following components:

- Sensors (custom integration)
- Sensor specific power supplies
- Microprocessor to manage and pre-process raw sensor data
- Wired and wireless output to the Farmbot Monitor

3.1.3.3.1 Prototype BGA sensor with integrated light source

BGA underside: The top left is the Turbidity sensor. Bottom right in the BGA sensor. The circular pipe is the buoyancy chamber.

BGA Top: IP67 rate housing with LoRa antenna – includes the BGA sensor. The second shorter cylinder houses the Turbidity sensor.

3.1.3.3.2 Revised Salinity Sensor

The revised salinity sensor consists of:

- Encapsulated ultrasonic transducer and open water chamber
- Turbidity sensor
- Temperature sensor (for MK 1 only)
- Self-contained electronics to generate the ultrasonic pulse and perform the salinity calculation.

The module is designed to float with the sensor head submerged 10- 25 cm beneath the surface of the water. The data is sent via a cable to a standard Farmbot Monitor.
The TOF and temperature data is then sent via the Farmbot Monitor for post processing in our server.

MK 1 Salinity sensor showing the sensing chamber at the bottom left:

MK 2 The salinity sensor with the open sensing chamber at bottom:

(This unit will sit inside a flotation ring – it is IP67 rated)

3.1.4 Water level & flow monitor

3.1.4.1 Background

The flow monitoring functionality is an adjunct to the Farmbot Water level monitor. Water flow & level are directly coupled. The system will calculate the tank inflow based on the net outflow and the water level. This will provide additional flow information without additional hardware cost. The system will provide an aggregate flow total over the period covered by each packet transmission for each monitored outlet. The period between each data transmission (packet) is determined by the water level changes in the tank and the maximum transmission interval period. This solution will use similar analysis and control algorithms to the current water level monitors but will be optimised for flow requirements. This is designed to minimise Satellite transmission charges but provide sufficient flow detail to satisfy the producer's flow monitoring needs.

3.1.4.2 Testing Methodology

- The test setup was designed to ensure that the flow monitoring hardware and software accurately records the water meter flow ticks. The test rig consisted of 3 water meters in series to create scenarios where ticks from each meter often occur concurrently to challenge the tick counting interrupt logic of the monitor.
- Monitor audit logs, meter reading logs and diagnostic equipment were used to accurately measure the system performance and diagnose issues
- Testing focused on validating that the system sends data transmissions when necessary to ensure the forecast water level stays within the set margin of actual value. In addition, it validated that the aggregate flow data was delivered with sufficient detail to alert the user of any unexpected issue in a suitably timely manner.
- The daily data transmission totals were tracked to drive refinement of the transmission algorithms and control parameters.

The testing phase involved iterative testing while varying a range of algorithms and control parameters.

3.1.4.3 Final Design

The testing phase has validated the overall functionality of the originally proposed design. The integrated flow and water level monitoring system supports up to 3 flow sensors per Farmbot water level monitor with an optional rain gauge. A forth flow meter can be attached instead of the rain gauge. The details are outlined below:

- The solution will make use of inline water meters such as a Bermad Multi-Jet Water Meter or B-Meters with connected reed switch. Depending on the device, the ticks typically represent 1, 10, 100 or 1000 litres of metered water.
- The Farmbot Water Level monitor unit will have 4 connectors on the underside that can support a range of sensors including tick counting reed switches (one per flow meters).
- The installation of the inline flow meter, the reed switch and cable is designed so that unskilled farm labour should be able to carry it out reliably.
- The system will calculate the tank inflow based on the water level changes and the total outflows.
- The system will provide an aggregate flow over the period covered by each packet transmission. The period between each data transmission (packet) is determined by the rate of water level changes with optimisations for the flow requirement. See the test result section for details of transmission timings.

- The software implemented a software debounce functions that would handle awide range of new and old reed switches in meters. A parametric system was devised that requires a constant 50ms fall time to identify a pulse. It was implemented in the interrupt framework to ensure concurrent pulses are not missed.

3.1.4.4 Electronic Design

The Flow monitor uses standard reed switch equipped water meters of any brand. As part of this project the Farmbot Monitor has been modified to directly accept input from these reed switches via attached cabling. The digital inputs electronics of the monitor has been designed to handle large EMF pulses that can occur due to electrical storms. No electronic pulse debounce has been implemented. This will be handled in software as it will be less expensive and more capable of handling older electrically noisy meters.

3.1.5 Transmission Algorithms

3.1.5.1 Methodology

This sub-project is not directly visible to the user/producers. Indirectly, the requirements will flow from the other sub-projects and determine aspects of the work in this sub-project. This phase involved iterative testing while varying a range of algorithms and control parameters. This work will be implicitly tested by the testing of all other sub-projects. Trialist input will drive the fine tuning of the transmission control parameters.

3.1.5.2 Research

The use cases for the other 3 sub-projects were analysed in detail to determine the data transmission requirements. Modelling was conducted to determine the optimal data compression/aggregation and transmission patterns for each of the use cases.

4 Results

4.1.1 Wireless Electric Fence monitor

4.1.1.1 Test results

Testing utilised Daken & Gallagher electric fence energisers. Tests were initially conducted in a setup at the Farmbot workshop with subsequent testing on properties in the Oberon region and Queensland. Testing produced the following outcomes:

- The detector worked best at relatively close range to the fence – 30cm - 100cm. This led to the design decision to produce a detector mount that attaches to a fence post or within a metre of the hot wire.
- The power of the signal diminished quite rapidly so that the system was not effective after 2-3 metres from the fence. We believe later development will increase this range
- Mounting a detector directly on the fence post means that there is no requirement for calibration due to the known proximity of the live wire and hence the ability to measure an absolute power value
- Mounting the insulated device antenna at least 60 cm from the live fence wire ensures that it is safe from lightning strike.
- The tests included fences that were shorted out, long, short and with low power energisers. In each case the system showed a useful indication of fence power
- The LoRa radio system reliably allowed the electric fence detector to be mounted up to 5 km away from the Farmbot Monitor. This will allow for a very economical operational costs in remote locations
- The end to end system (Electric fence detector, Farmbot Monitor and the Farmbot Web Application) is with trialists and ready for initial commercial release
- The tests confirm device effectiveness
- The following table details the power levels and practical interpretations:

Power	Fence Status
7	High Power
6	High Power
5	Medium Power
4	Medium Power
3	Partial Short / Low Power
2	Partial Short
1	Major Short
0	Energiser inactive

Every fence is fairly individual in terms of quality of setup, age, rust on connections, and marginal earthing issues. These all impact the overall performance. Once a user is familiar with the fence information on the Farmbot Dashboard it is easy to view status over time to help identify trends and changes.

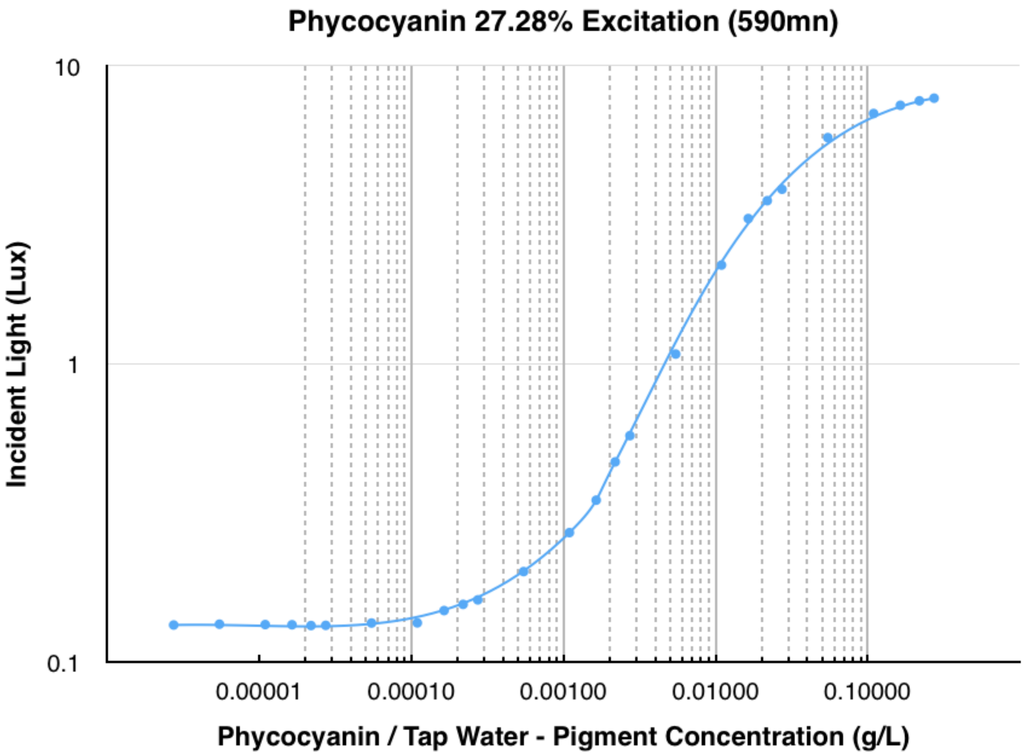
Farmbot will be developing Analytics that will identify fence power trends and issues and highlight them to the user in simple, easy to digest forms.

4.1.2 Water Quality Sensing

4.1.2.1 Test Results

BGA Prototype Testing

Previous experiments on BGA detection indicated that the powdered BGA used was contaminated with green algae. To determine the absolute accuracy of the sensor, lab grade material of known dry mass was imported for the next series of experiments. The selected BGA source was lab extracted Spirulina Powder that contained 27.28% Phycocyanin which is the specific fluorescent pigmentation that we are using for detection. The experimental methodology was identical to the previous tests. The sensor was submerged in a black container of a known volume. The concentration of BGA was increased with multiple measurements performed at each step. The following graph details the results:



The results confirm that the revised design has increased the resolution of BGA detection significantly. The lower limit of Phycocyanin pigment detection is at 0.000164 g/L or 0.0006 g/L of Spirulina.

While grams per litre of fluorescent pigmentation is meaningful to the scientific community there is no real-world way to visualise this data. The method selected to convey this data is by conversion to Biovolume of BGA per L. This is calculated by using the average dry mass per biovolume for 6 cyanobacteria species, 486 fg/um^3 detailed in *(Rapid determination of the dry weight of single living cyanobacterial cells using the Mach Zehnder double beam interference microscope*).

From this we can convert the dry mass per litre of BGA used in measurements to Biovolume of BGA per L (mm^3/L). This unit may seem esoteric but it is the unit used by **waterNSW** to set Algal bloom alert levels. (see below).

From this conversion we see that the minimum concentration of BGA the sensor can detect equates to 1.2346 mm^3/L biovolume of BGA per litre. This corresponds to an **Amber Level** alert.

Future iterations of the sensor will be constructed with better narrow bandpass filters and more intense LEDs which will potentially increase the lower detection level.

WaterNSW provides Algal Bloom alert levels which we can use as a meaningful metric to provide farmers: https://www.waternsw.com.au/water-quality/algae

		Biovolume of all BGA
Alert Levels	Cells/mL	mm3/L
Green	500	0.04
Amber	5000	0.4
Red	50000	4

Red:
Red alert levels represent 'bloom' conditions. The water may appear green and may have strong, musty or organically polluted odours. Blue-green algae may be visible as clumps or as scums. The 'blooms' should be considered to be toxic to humans and animals, and the water should not be used for drinking (without prior treatment), stock watering, or for recreation.

A red level alert is in place when >50,000 cells of Microcystis aeruginosa are present or a biovolume of all toxin producing cyanobacteria exceeds 4 mm3/L. A red alert level is also triggered if the total of all blue-green algae (toxic and non-toxic) exceeds 10 mm3/L or scums are present for long periods. At red alert level a waterbody should not be used for primary recreation. Waterbody managers should notify the public through signage and media avenues. Results should be forwarded to the appropriate Regional Algal Coordinating Committees (RACCs) for further dissemination and assistance in management of blooms

Amber:
At amber alert levels blue-green algae may be multiplying in numbers. The water may have a green tinge and musty or organic odour. The water should be considered as unsuitable for potable use and alternative supplies or prior treatment of raw water for domestic purposes should be considered. The water may also be unsuitable for stock watering. The water remains suitable for recreational use, however algal concentrations can change rapidly. Water users should use caution and avoid water where signs of blue-green algae present.

Amber level alerts are triggered when Microcystis aeruginosa concentrations are between 5000 and 50,000 cells/mL or the biovolume of all blue-green algae is between 0.4 and 4 mm3/L. At this alert level investigations increased sampling of algae is undertaken.

Green:
At green alert levels blue-green algae are present in the water at low densities, possibly signaling the early stages of the development of a bloom, or a period where a bloom is declining. At these densities, the blue-green algae do not pose a threat to recreational, stock or domestic use. A green level alert occurs above 500 cells/mL of Microcystis aeruginosa or >0.04 mm3/L of total blue-green algae biovolume but below the amber alert level. At this level routine sampling for algae should be undertaken.

4.1.2.2 Summary

We will continue trial the BGA monitor on lake and prone waters over the summer months.
Typically a seasonal occurrence.

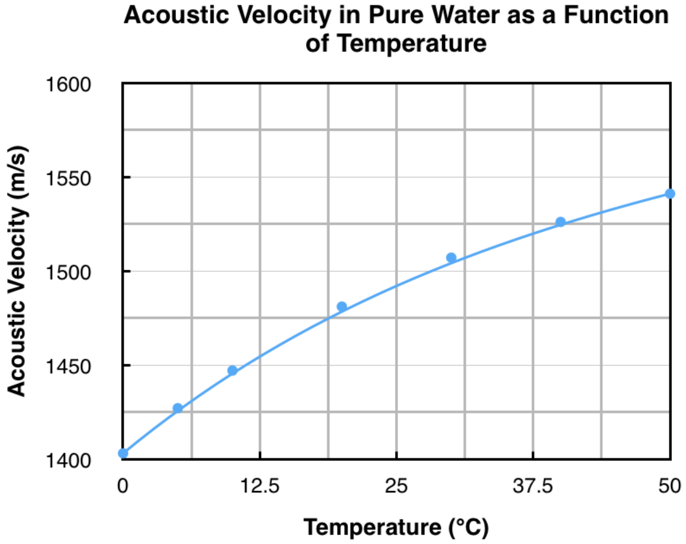
4.1.2.2.1 Salinity Revised Prototype Testing

The test methodology was comprised of three sections

- Validation and Calibration of the Sensor
- Comparison between Theoretical and Experimental Inferred Salinity
- Assessing the effect of other environmental factors

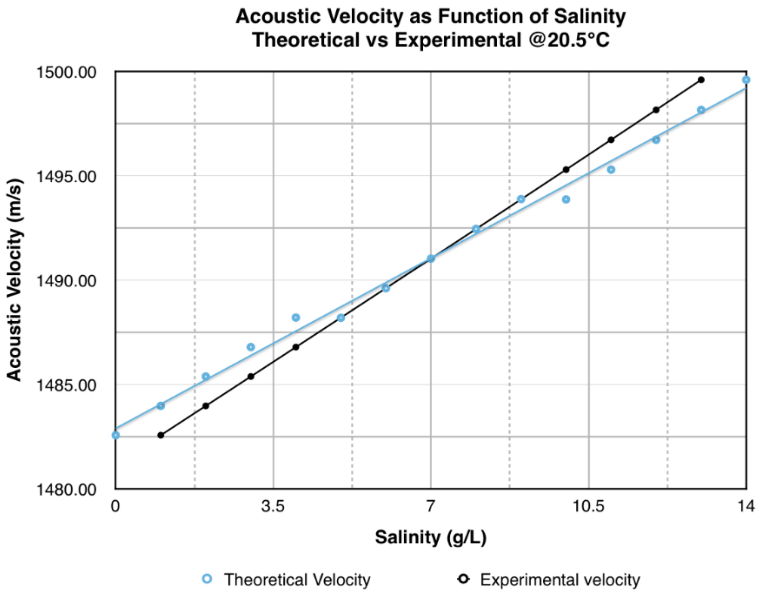
Validation and Calibration of the Sensor

To validate and calibrate the sensor, a range of TOF (time of flight) measurements were take over a range of temperatures using a bath of de-mineralised water. Using the established data for acoustic velocity as a function of temperature (see below), it was found to be consistent with the literature. Calibration was performed by the addition of offsets to compensate for inaccuracies in the temperature measurement, chamber length and other physical properties.

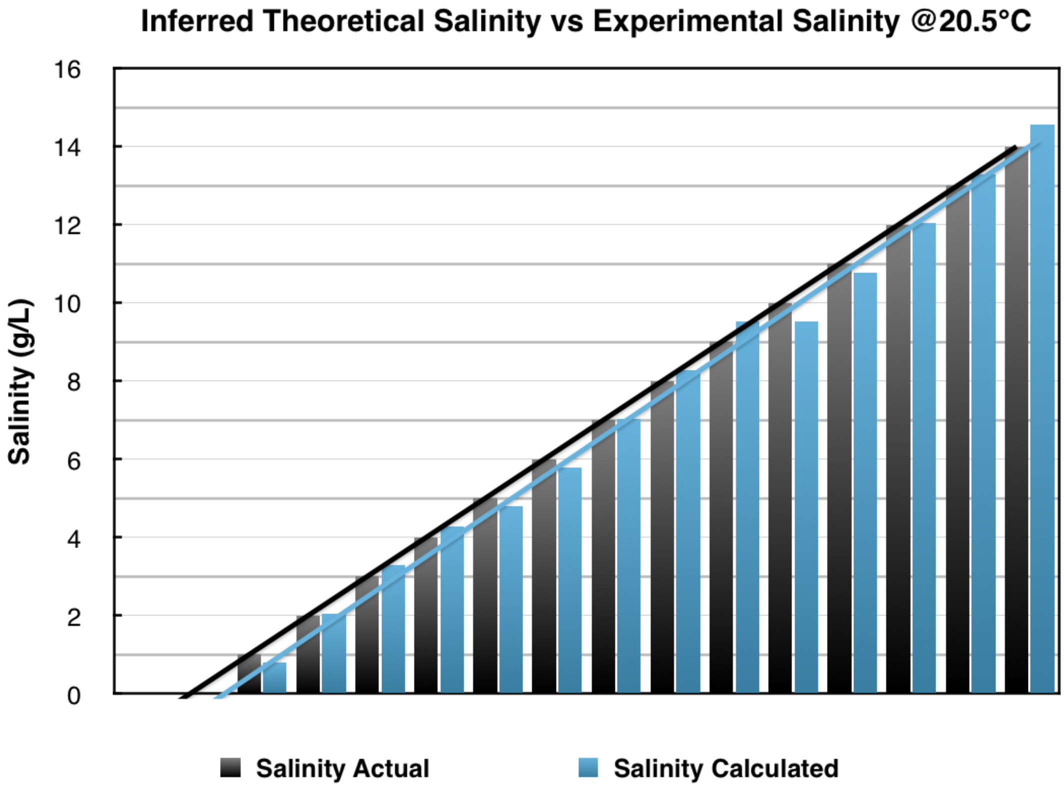


Comparison between Theoretical and Experimental Inferred Salinity

Assessment of the accuracy in salinity measurement was performed by starting with demineralised water and increasing the salinity by known amounts. The theoretical values for TOF and acoustic velocities were then calculated for the measured temperature. Similarly, the experimental TOF and corresponding acoustic velocities were measured. As shown in below, the experimental acoustic velocities are a close match with theoretical values.



Applying our algorithm on the experimental acoustic velocities yields a close approximation of actual salinity (see below graph). It should be noted that for salinities less than 2g/L the readings become increasingly less accurate. Due to the intended use of this sensor this is acceptable as expanded on in the discussion below.



At salinities greater than 2 g/L the average percent error is approximately 5%.

Assessing the effect of other environmental factors

As the sensor will be deployed in bodies of water with a wide range of conditions it was required to determine the effect of suspended solids. Two additives were chosen, black iron oxide and bentonite clay. At a known salinity, each additive was increased in gram per litre steps with measurement recorded while the suspended solids were evenly distributed in solution.

The result was there was not meaningful effect of either one on the measurement of salinity. This is probably due to the propagation of the acoustic waves around the higher density suspended particles.

Outcome

The revised salinity sensor has shown great potential as an affordable and long-term solution for remote salinity monitoring. The largest source of error in the system is the relative inaccuracies of the temperature sensor due to its large effect on the water density. In future iterations of the sensor, a more accurate temperature sensor and precise construction will result in further increases in salinity measurement accuracy.

The following DPI salinity table details levels and the effect of livestock. The results of our testing show we have a solution that will readily detect the salinity levels that are relevant for a broad range of livestock. At salinities greater than 2 g/L the average percent error is approximately 5%. This demonstrates that our salinity sensing device has a suitable level of accuracy acceptable for the livestock use case.

DPI Stock Salinity Impact Table

Effects of saline drinking water for various livestock types:

Livestock	No adverse affects on animals expects		Animals may have initial reluctance to drink or there may be some diarrhoea but stock should adapt without loss of production		Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually.	
Livestock	EC in uS/cm	g/L	EC in uS/cm	g/L	EC in uS/cm	g/L
Poultry	3100	1.98	4700	3.01	6300	4.03
Dairy cattle	3900	2.50	6300	4.03	10900	6.98
Beef cattle	6300	4.03	7800	4.99	15600	9.98
Horses	6300	4.03	9400	6.02	10900	6.98
Pigs	6300	4.03	9400	6.02	12500	8.00
Sheep	7800	4.99	15600	9.98	20300	12.99
Source	Department of Primary Industries		Water for livestock: interpreting water quality tests			
			1000 uS/cm =	640 mg/L =	640 ppm	
			1 uS/cm	0.64 g/L	0.64 ppm	

We chose to use grams per litre (g/L) as the unit measure as it is preferred by industry. This is more meaningful in agriculture than units such as conductivity (uS/cm).

4.1.2.3 Summary

Field trials will continue to determine the impact of extreme weather variations.

4.1.3 Water level & flow monitor

4.1.3.1 Test Results

A test rig was developed with 3 commonly available water meters - GSD-8 B-Meters (20mm). This provided a controlled environment where the end to end system could be tested under low to high flow rates. This allowed the volumes of water measured by the Flow Monitor to be validated.

- The system was run with a digital oscilloscope providing clear indication of when each reed switches fired
- The Farmbot Flow Monitor was configured to log all meter tick readings into audit files
- For each test run, flow counts of each of each meter was recorded.
- Tests were repeated many times with a range of flow rates to ensure the system will perform accurately in a wide range real-world scenarios.
- For each test run, the volume of water measured by each meter was compared to the volume detected by the Farmbot Flow monitor. Once all underlying bugs had been rectified, the system showed a maximum variation of 1 or 2 litres in 500. This was due to the fact that meters were not reset to zero at the start of each test. When the pump is turned off there was some reverse movement or syphoning occurring in the lines which caused small variations. There was no identified loss of flow pulses from the meters in the final version of the system.

The test identified the high and low accurate flow limits for the meters. These are detailed in the specification sheets of the meters. Flow rates below the minimum recommended rate for a given meter will result in incorrect readings. Typically, under readings. Air bubbles in lines can result in the flow meters running backwards and forwards leading to over readings. Very high flow rates will also produce inaccurate meter readings. The meter is the limit on accuracy of our solution.

The testing showed that the finalised system produced meter reading data that matches the accuracy of the specific meter used.

Transmission optimisation:

- The test flow rates were varied to generate a range of water level trend curve scenarios. This generated differing elapsed durations between data transmissions. The underlying algorithms ensured that the current forecast water level is always within the configured margin of the actual level (4 - 8 - 12cm).
- The flow specific algorithm modifications and control parameter settings resulted in sufficiently regular transmissions such that the aggregation of flow data did not result in excessive averaging. Excessive averaging can mask peaks in consumption that need to be highlighted to the user.
- The net result is a system that has a suitably responsive transmission pattern to deliver sufficient aggregate flow detail while still maintaining economical data costs.

Satellite control parameters

- Minimum duration between data transmissions: 20 minutes
- Maximum duration between data transmissions: 4.8 hours
- Trend deviation transmission trigger limit – 12 cm or 8 cm (additional charge)

3G/LTE control parameters

- Minimum duration between data transmissions: 4 minutes
- Maximum duration between data transmissions: 2 hours
- Trend deviation transmission trigger limit – 8 cm or 4 cm

4.1.3.2 Summary

The Flow solution is ready for general commercialisation

4.1.4 Transmission Algorithms

4.1.4.1 Initial Test Results

The data from testing of the other 3 sub-projects was compiled as the key input for this sub-project. The total of data transmissions per day and the margin by which the forecast water level deviated from the actual water level was analysed to ensure the total system performed within specification. The algorithms passed all integrated test cases.

5 Discussion

5.1 Electric Fence Monitor

Objective:

- The primary objective was to provide a simple to use device that would provide detailed electric fence power levels that would provide early warning of problems such as vegetation and other things shorting out the fence and reducing effectiveness.

Outcome:

- A simple robust device was created that can be mounted on or near a fence that will give an power indication on an 8 level scale. The Farmbot Satellite connectivity means that this can be used anywhere globally.

Next Steps / Further Research

- Subequent R&D will be required to develop wireless tools that can provide an indication of the direction and distance to a fault.

Improvements

- Generally the project went to plan and delivered
- Test beds were of limited value. The key to system validation was real fences on real farms. Access to larger and varied fence systems early on would have been beneficial.

5.2 Water Quality Monitor

5.2.1 BGA

Objective:

- The primary objective was to provide a simple to use device that would provide early warnings of BGA thresholds being exceeded.

Outcome:

- A simple robust device was created to detect BGA over standard thresholds in general waterways and storages and provide early warnings of outbreaks. The relatively low cost will make it very accessible to remote farm storages where excessive nutrients can lead to BGA issues. The Farmbot Satellite connectivity means that this can be used anywhere globally.

Next Steps / Further Research

- Subequent R&D will be required to increase the sensitivity and identify reliable lower cost optics to reduce the overall cost of manufacture.

Improvements

- Generally the project went to plan and delivered
- Test beds and the ability to quickly produce test sample ranges needs to be improved to allow faster test turnaround and more accurate results.

5.2.2 Salinity

Objective:

- The primary objective was to provide a simple to use device that would provide early warnings of Salinity changes and thresholds being exceeded.

Outcome:

- A simple robust device was created to detect Salinity with a better than 1 gm / litre in general waterways and storages and provides detailed data to initiate mitigation of unexpected changes as well as general water source management. The relatively low cost will make it very accessible to producers that source water from a range of inputs that may have seasonal and other content variability. The Farmbot Satellite connectivity means that this can be used anywhere globally.

Next Steps / Further Research

- Subequent R&D will be required to increase the sensitivity and improve overall design simplicity to reduce the overall cost of manufacture.

Improvements

- Generally the project went to plan and delivered
- Test beds and the ability to quickly produce test samples need to be improved to allow faster test turnaround and more accurate results.
- Early efforts to use off the shelf technology should have been abandoned earlier.

5.3 Flow Monitor

Objective:

- The primary objective was to provide a simple to use integrated Water Level and flow monitoring system to support up to 4 flow meters.

Outcome:

- A solution was developed that can utilise any commercially available pulse output water meter to accurately measure all tank outflows, provide detailed water level and calculate inflows. The Farmbot Satellite connectivity means that this can be used anywhere globally.

Next Steps / Further Research

- Subequent R&D will be required to develop non-invasive ultrasonic based water meters. This approach has the potential to significantly reduce the overall cost of the solutions as standard water meters are a large component on the total cost.

Improvements

- Generally the project went to plan and delivered
- The test bed created as part of this project was particularly effective as it allowed for a wide range of tests with varied flow rates and challenges to the electronicsand firmware to ensure no data loss.

5.4 Satellite Data transmission cost reduction

Objective:

- To develop trend analysis, data compression and noise reduction algorithms to reduce the volume of satellite and other data transmission and power consumption without impacting quality / detail of data sent.

Outcome:

- The data for the additional sensor options developed as part this project has been largely accommodated in the current payload structure of the core water level monitor. For example, the flow solution data for up to 3-4 meters can be acccomodated along with multiple water level points in a standard data transmission. We provide the option to have more frequent transmissions where more granular aggregate flow data is required.

Next Steps / Further Research

- Data transmission optimisation is an area of constant change. As new communications providers come to the market, new opportunities will avail themselves. Typically each new provider have somewhat unique features based on their technology. For example some new providers are very low cost but may provide data once a day. Their usefulness will depend on the particular Use Case in question.

Improvements

- Generally the project went to plan and delivered
- This part of the project ran well as it is one of our key areas of expertise.

6 Conclusions/recommendations

6.1 Further Research

Flow monitoring – water meter cost is a significant component of the solution – We plan to investigate non-invasive ultrasonic flow monitoring in a separate R&D project.

Modern ultrasonic tech is very effective and low cost – has potential applications for a range of areas including liquid depth/level metering

We plan to investigate the use of optics for detection of other forms of algae.

6.2 Insights

Our requirements discussion with our users highlighted the need for low cost, medium accuracy sensor technology that will give a timely warning of impending issues. Water quality solutions are typically high accuracy, high cost and lab grade. Our devices are designed for the end user, with accuracy appropriate for the application and robust.

Many rural areas are unlikely to ever be serviced by anything other than Satellite communications. Potential users in these areas requested that our solutions be effective over Satellite as well as 3G/LTE (for the lucky ones). With 3G/LTE we provide a more timely and detailed solution.

The Livestock industry will now have cost effective access to simple to use, cost effective Satellite and 3G solutions that will provide the following benefits:

Flow Monitoring – Producers will have a tool to provide clear quantification of water consumed by stock for each out bound water line. Quantification of tank inflow and hence bore/pump production rates. Diagnostic information on pump/bore issues, leaks and breaks. This provides additional data for stock management and saves time in dealing with infrastructure issues.

Electric Fence – Producers will be able have a near realtime view of electric fence function and receive alerts on failure. This will be a particular value for Cell Grazing operations where electic fence are key to pasture management. It can also provide early warning on issues that arestarting to compromise electric fence function.

Water Quality – Salinity and Blue Green algae are of particular concern to producers in certain areas. Early warning of changes allows timely response to minimise any the impact on their stock.

There would be benefit for funded trials to be run in a range of regions that will allow local producers ro see first hand the benefits of these solutions to their peers.

6.3 Conclusions

Farmbot is pleased with the outcome of the project and believe that we will get a good return on our significant investment of time, funds and key resources. The project resulted in the creation of cost effective and easy to use Water Flow, Water Quality and Electric Fence monitor solutions. These will now be made available to the livestock and other industries and will provide significant savings, improve certainty in optimum development and welfare of their stock and ultimately improve a farms productivity and ROI.

MLA have indicated their interest to consider producers looking to adopt whole of farm integrated sensors framework with a desire for more producers to have access to data and feedback on animal and feebase performance to inform production decisions.

6.4 Recommendation

The project shows that there is significant value in applying recent technical advances to longstanding problems. There is a virtually endless array of technology components and devices available at very accessible cost from China that allow for innovative low cost experimentation on a wide range of applications. We recommend the allocation of further resources and budget to explore potential solutions to many of the challenges faced by agriculture.

7 Key messages

The solutions developed in this project will provide immediate benefits to producers. These include the alerts and useful graphs that allow issues to be addressed in a timely manner. There are direct savings from the major reduction in labour, vehicle,fuel, OH&S etc. due to reduced need for inspections and timely remediations.

The bigger picture is what can be done with the data that is captured by these systems? Insights provided by analytics will be able to provide earlier warning of system issues such as reduced bore flows, leaks, etc. Also, quantification of stock water consumption, salinity of the water, overall capacity of water system provide key inputs into optimal herd management. This information coupled with BOM forecasts has the potential to provide early warning of stockwater shortages.

Producers need to start considering that this sort of information and systems will be a key part of productivity and quality improvements in the future.

The Farmbot " P.PSH.1111 Development of an Whole of Farm IoT Reporting and Analytics offering" project focuses on analytic that can deliver these benefits.

8 Bibliography

N/A

9 Appendix

N/A