CattleTECH: A Modular System for Cattle Visibility and Tetherless Containment for Thai Farmers
Final Report

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Executive summary

CattleTECH is a proposed system for envisioning sustainable, safe, and efficient cattle herding practices. The purpose of CattleTECH is two-fold: to increase the visibility of farm animals being herded on shared roads and to strategically control the placement of ruminant farm animals for tetherless grazing. Our team has partnered with Bryan Hugill, co-founder and owner of Raitong Organics Farm, an innovative farming cooperative in the rural province of Sisaket, Thailand. Raitong is currently transitioning from traditional farming into a free-range cell grazing system. One factor that has inhibited this transition is a proper system for ensuring the safety and containment of cattle within designated grazing area. Additionally, because they are a farming cooperative, they are limited by the economic and technological constraints of their farmers, who are often set in their ways of traditional herding practices.

The CattleTECH system is comprised of two major components: a high-visibility collar to be worn by cattle, and a post which communicates with the collar via radio.

The collar can be worn on its own as a means of making cattle more visible while roaming across fields, many of which are separated by municipal roads. The collar features an integrated foam hump to account for the particular anatomy of Thai cattle and is designed such that it is lightweight, comfortable, and remains secure to the cow while offering simple, passive visibility.

The containment module screws into the collar's metal frame for secure attachment, and contains a microprocessor with a Long Range (LoRa) radio module to receive and transmit radio signals with the locator post. Also housed in the collar is a shocking unit and speakers, capable of delivering a stimulus to the animal that communicates that it has entered an undesignated area. This module receives data packets transmitted through signals from a transmitter post and calculates the distance to the post internally using the Received Signal Strength Indicator (RSSI)

The transmitter post is designed to be moved intermittently, and be easily installed, per cell grazing requirements. The post is long-lasting thanks to a rechargeable battery and flexible solar panel and its lightweight and robust base design. The post has two types of modes that can be engaged using buttons on the outside of its electronics box. The Repel mode sets a radius within which collar-equipped animals cannot enter. This mode is likely to be favored by landowning farmers seeking to protect their crops from grazing animals. The Contain mode sets a radius beyond which collar-equipped animals cannot leave. This mode is likely to be favored by cattle-owning farmers with land that they have already designated for grazing.

Our deliverables constitute a prototype system. Future iterations of this design would begin with testing for failure modes of both software and hardware. Our software tests have indicated that large variation due to noise and signal variation in multiple outdoor environments have made current RSSI measurements unreliable. Further research and testing will need to be done one implementing anchor nodes for better localization, particularly for our contain function. Additionally, while research established mild electric shock to be the most effective method of motivating cattle, safety and testing constraints have prevented us from fully integrating this feature. Finally, while research and short-term testing have pointed to the effective visibility and durability of our collar and post designs, longer testing within our user's environment must be performed to confirm these results. We are currently sending our prototypes to Raitong in Sisaket in order to perform said tests.

CattleTECH offers a sustainable and accessible system for herding cattle. Unlike previous visibility solutions, it is long-lasting and catered to the anatomy of different cattle, and unlike previous virtual fencing solutions, it is completely open-source, inexpensive, and tailored for non-technologically fluent rural farmers. Allowing for future iterations, once implemented at Raitong Organics Farm, this system will allow for innovative herding that will benefit farmers, land, and cattle.

Design Requirements

Introduction

The CattleTECH system is designed to grant farmers in regions like northeast Thailand more control over their livestock and their land. Wireless radio communication between a device on each animal and a transmitter post offers an intuitive method for establishing an “invisible fence” that is portable and simple to use.

Each animal in a farmer’s herd would wear a collar designed to be highly visible, as farmers tend to herd their cattle along roads shared by drivers during hours of minimal sunlight. The collar’s aluminum-skeleton-and-foam-exterior design is visible from all angles, and provides a snug fit to support the weight and appropriate placement of an optional electronics housing box. The modularity of the electronics is important for users who may not have the means or motivation to upgrade to a wireless fencing system, but who do want to safeguard their cattle against dangerous road conditions.

The optional electronics housing for the collar is placed so that the electrode prongs, which deliver a stimulus to the cow that indicates it has entered an undesignated area, fit snugly against a muscle along the side of the neck. Prior to the delivery of this shock, the housing will also emit a ramping sound stimulus to deter further movement in the wrong direction relative to the post. The electronics housing itself has no interface for ease of use, and is powered by a D-battery for an extensive lifetime.

The transmitter post serves as an analog to a physical rope tether. It establishes the center of a 1-Rai radius which should not be crossed by collar-equipped animals. The post’s electronics are housed within a waterproof box, and feature two buttons as the interface. One button would determine the mode, either “repel” or “contain.” In “repel” mode, which our prototype is closest to achieving, cattle would be kept outside of the designated radius. Once they cross the boundary towards the post, they would receive the stimuli. This feature is ideal for landowners seeking to protect their crops from unauthorized grazing animals.

The second mode, “contain,” offers a method of keeping collar-equipped cows within a designated radius centered around a post. This function would require the use of multiple posts in communication with each other, as well as with each collar, to triangulate each animal’s position. This is a development we hope to see completed in the future.

The post's electronics box has an additional function designated by a "power" button, which can turn the system on, or set it in sleep mode during nighttime hours or when not in use. The sleep mode would significantly improve battery life, as it stops the transceivers from continuously sending and receiving data.

The post itself is powered by a flexible solar panel meant to capture the solar energy that this region of Thailand experiences so strongly. The panel is flexible to make it more robust to interactions with animals. Similar measures have been taken on the main shaft, which features a large spring designed to absorb some of the force applied by cows bumping into it. The base of the post is an open-top box, which can be filled with soil to weigh it down. The advantage of this is that farmers can easily fill and empty the box for portability, especially in the case of cell-grazing. The shaft of the post telescopes and assembles with pins for additional portability.

Client Information

Raitong Organics Farm is a farming cooperative in the Sisaket province, Thailand. Raitong owns and operates a rice mill, where organic-certified members of the cooperative process their whole grains. Additionally, Raitong keeps some livestock including cattle, chickens, and pigs. Farmers in the surrounding region, whether members of the cooperative or not, are primarily rice farmers. If these land owning farmers also keep cattle, they tend to take their cattle to graze in their own fields during the 6-month dry season spanning spring and summer. During this time, crops other than rice are cultivated in rice paddies, upon which cattle can graze. Some farmers may not own land, or not enough land to support grazing, but still own cattle. These farmers take their cattle to graze in neighboring fields, with or without consent from the landowner. This can put significant strain on relationships between farmers, as well as significantly deplete the crops upon which cows graze.

Location of Raitong Organics Farm, in Northeast Thailand

The geography of the region places additional constraints on our design. Precipitation is generally seasonal. Fall and winter experience heavy rainfall fit for rice cultivation, with spring and summer being considerably hotter and drier. High temperatures, humidity, rainfall, and topographical features like sparse vegetation and ground features all demand compensatory design elements.

Farmers in this area are generally of an older generation, therefore one design focus is to ease physical strain and to simplify the user experience. While technological literacy is low, interest and excitement for new tools such as smartphones is high. Additionally, traditions in agricultural practices among these users are very resilient.

Photographs of cattle-owning farmers in Sisaket

Current Herding Practices

In this region of Thailand, we observed a fairly standard process for herding cattle to grazing locations. Often before or at dawn, cattle were taken from their stables near the farmers' homes along public roads. Though cattle would occasionally wear the rope halter used for tethering, they were not necessarily tethered during herding. Farmers would walk at the back of the herd and guide their animals along the road until the arrived at the decided grazing field, whether their own or someone else's. Upon arrival, animals would be tethered to either a stake in the ground, a fence post, or an available plant, allowing them mobility to graze within a radius specified by the length of the leash. The tethering practice, while seemingly crucial to restricting cattle from roaming too far, was not universally observed.

Photograph demonstrating the herding process at dawn

Grazing fields in this specific region are not typically located adjacent to farmers' homes, and subsequently cattle must be herded to their grazing location. Farmers will guide their herds, consisting of any number of cattle between roughly 2 and 10, down paved roads that are shared by drivers and motorcyclists. This activity typically occurs during the hours of dawn and dusk, when visibility is significantly reduced due to lack of sunlight. This practice, as well as the prospect of escaped untethered cattle using these roads, pose risks to both the animals and farmers.

Once arrived at a grazing field, cattle are tethered using a rope to either a stake or shrub. This establishes a radius within which the animal is allowed to graze. The tethering practice is partially dependent on the presence of a rope halter that is tied through a cow's nose at roughly 1.5 years of age. The rope tether has additional failure modes, such as a loose knot, that can contribute to escaped cattle. The process is also painful for the cattle, due to the sensitivity of the skin area, and requires a long adjustment period.

Cattle with nose tether. Tether is often carried or tied to a post or stake.

An alternative employed by few farmers in the region is electric fencing. However, this practice is labor-intensive and only viable during the dry half of the year. Additionally, upkeep costs prevent this fencing from being constantly engaged.

Electric fencing used in the are, a single conductor wire with indicator flags

Images of cattle owned by Raitong Organics Farms

Thai cattle have a distinct anatomy that places significant constraints on the location of wearable devices. Thai cattle resemble Zebu cattle, whose chief anatomical distinction is a pronounced hump above the shoulders.[1] Though other placements on the body were considered for our wearable device such as the ankles, horns, and torso, devices affixed to the neck were the least intrusive to apply and remained on the animal longest when we conducted our initial tests. The presence of horns was not consistent, even among animals of the same sex and age, making this an unreliable placement. Cattle possessing Zebu's physical characteristics have proven to be successful draught animals, requiring them to wear weight bearing collars.[2] When worn by one of these animals, a flat collar was obstructed from view when observing the animal head-on and from behind. Our design's elevated collar accounts for the height of both the shoulder hump and head for visibility at all angles.

Because this design involves behavioral elements, research was done into cattle psychology. Cows have been observed to learn behaviors very rapidly, and retain such learning in long-term memory. [3] Dairy cows, for example, adopt very particular schedules for milking that involve precise timing and locations, as explained by Jon Kuester of the Wagner Farm. Rapid learning can be facilitated by both sound and physical shock stimuli.[4] This key insight into cattle behavior, combined with knowledge of existing market solutions, guided design decisions to opt for two forms of feedback: sound and shock.

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[1] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4627918/
[2] http://www.fao.org/3/v0600t/v0600T0j.htm
[3] https://www.psychologytoday.com/us/blog/animal-emotions/201711/cows-science-shows-theyre-bright-and-emotional-individuals
[4] http://animalbehaviorandcognition.org/uploads/journals/17/AB&C_2017_Vol4(4)_Marino_Allen.pdf

The directors of Raitong Organics Farm are exploring, among other things, a method of farming that involves rapid rotation of diverse group of crops. Planting a variety of crops within close proximity of one another enables farmers to cycle their grazing animals (be them cattle, chickens, pigs, etc.) and rapidly reconstitute the soil. Each cell in this system would be 1 rai, the Thai unit for land area. The brevity of each animal's stay in a particular cell makes physical fencing an inefficient option for this system. A wireless fencing system is optimal, as it is mobile and does not require set-up or breakdown time apart from designating a new reference point for the containment (i.e. moving a virtual tether post to a new cell).

Prior Art

The demand for both long-term cattle visibility and tetherless virtual fencing systems is growing, yet both issues fail to have long-term solutions with easily-accessible instructions for farmers globally. The rise of cattle-related automobile accidents has brought the issue of visibility to the attention of many municipalities around the world. Various communities have found short-term solutions to this issue through various practices such as high visibility vests and fluorescent paints (Appendix A.7). Few of these communities have found significant success in these programs, such as India's horn-painting initiative. However, these solutions are often tailored to specific cattle and must be constantly maintained by the users. Additionally, the details of how a farmer may implement one of these solutions is not made available online. In order to solve the issue of cattle visibility within our target area, there must exist a long-term solution that is applicable across many cattle and is easily accessible, with detailed instructions.

With the rise in agricultural tech, many startups are racing towards a mass-manufacturable virtual fencing system (Appendix A.6). Current market solutions, such as Agersens eShepherd, are under closed-door development and require corporate sponsorship, making access unrealistically expensive for both our target users and most farmers globally. Few open-source solutions (Appendix A.5), such as Alex Muir's OpenFence, exist online, but have yet to be fully implemented into an actual cell-grazing farming system. These open-source solutions also fail to be accessible to our target farmers as they rely heavily on GPS and computer-based graphical interfaces. Through user interviews, we discovered that our target farmers live in an area with little-to-no internet or computer access. Therefore, a more adoptable virtual fencing system for our target farmers would require it be open-source with easily-available materials, minimal upkeep, and the least amount of virtual interface possible.

Design Solution

Visibility Design: Collar

Summary

The selection of a raised collar came as a result of testing multiple different wearable devices on Thai cattle. Of five designs – ankle covers, horn covers, flat neck collar, raised neck collar, and hump cover harness – the flat neck collar succeeded in remaining on the animal and offered the quickest installation. However, it lacked the surface area necessary to be seen from all angles and at a distance. Webbing collar straps have been affixed to a sturdy aluminum skeleton to achieve the secure fit of the flat collar, while a lightweight foam appendage has been cast around the aluminum to increase surface area without disrupting the collar's balance. The foam is sealed with polyethylene plastic for water and UV resistance, and additionally covered with a brightly-colored water-resistant laminate fabric with reflective trim for visibility.

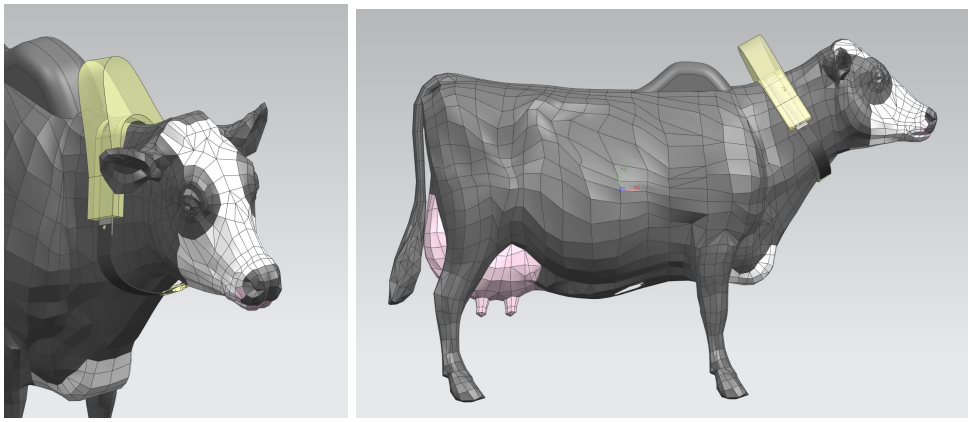


Figure 1: Collar design on a Dairy Cow Model[5]

Manufacturing

The collar's raised portion is constructed from open-cell 15x expanding castable polyurethane foam. To make the soft "v" shape, a mold was constructed from stacked MDF. *(Figure 2)* Slits were cut out in the mold to insert the Aluminium skeleton supporting structure. Placing the aluminum band inside the foam provides a layer of cushioning between the metal and the animal's neck, so it is more comfortable when worn long-term.

[5] Groninger Blaarkop from https://grabcad.com/library/3d-cow-1

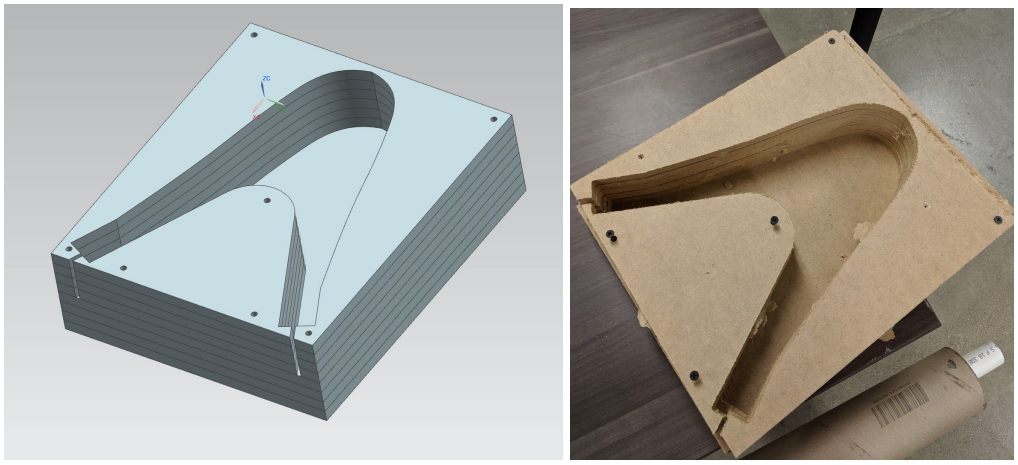


Figure 2: Mold CAD model and Assembled Mold

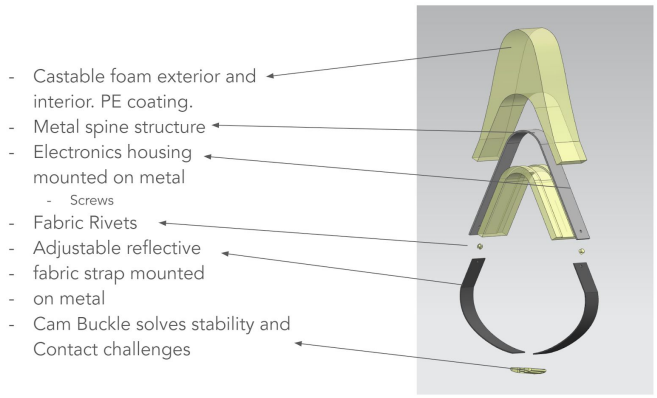
Once milled, the mold was post-processed by gluing separate layers, sanding it and coating it with polyester resin to eliminate the porosity of the material. The mold was then sanded again and coated with a layer of polyethylene tape. WD-40 was used as a release agent. The mold was overfilled to ensure that it assumes the required shape *(Figure 2)*. Afterwards, the excess material was cut off using a vertical bandsaw.

Figure 3: Filling of the mold

Since the chosen material is not inherently waterproof, the foam was covered with UV resistant polyethylene which was shrunk around the shape using a heat gun. Two layers of Polyethylene were added to the foam to eliminate the chance of missed spots.

Once covered with polyethylene, a fabric cover sewn from brightly-colored vinyl laminate fabric can be applied. The cover is sewn to fit the contours of the foam and features reflective trim on its front, back, and sides. The vinyl laminate is water resistant on its external face.

Rivets secure a strip of 1.5” high-visibility reflective webbing to the aluminum skeleton, which fastens at the bottom using a cam buckle to simultaneously adjust the tightness and secure the collar.



Potential Risks

Environment

The collar faces certain risks in its intended use environment. Topographic elements such as trees, shrubs, and stables may cause the collar to snag and compromise its waterproof seal. While this design maintains a nearly optimal balance of fitting snugly and possessing the necessary surface are to be seen from all directions, it also introduces a new threat of snagging.

Cattle Risk

There is some risk associated with leaving a collar, particularly one with metal prongs, attached snugly to an animal for long periods of time. Similar devices are used to train sporting dogs, and industry leaders suggest minimizing the amount of time that a shocking collar is left on the animal to prevent discomfort or injury.[6] The result can be a pressure ulcer, commonly referred to as a bed sore, at the location of the prongs. Even large draught animals like horses are subject to these injuries.[7]

The use of electric shock as a feedback stimulus does pose certain risks to both the animals and their handlers. Our current shocker circuit is rated for cattle industry-standard voltage, and

[6] http://ecma.eu.com/wp-content/uploads/2016/10/Training-with-an-Electronic-Remote-Training-System-EN.pdf
[7] https://www.vetmed.auburn.edu/wp-content/uploads/2015/01/C-17-Decubitus-Ulcers-in-Animals-1997.pdf

therefore should not harm the animal when used properly. However, that same voltage is considerably more harmful to humans and must be handled with caution. Until more accurate distance readings can be derived from signal strength, the implementation of shocking feedback is not viable.

Testing

The Polyethylene coating was tested by weighing the foam, submerging it in the water and weighing it afterwards. No noticeable change in weight was observed so the cover was deemed water resistant. Once fitted with the high-visibility cover, straps, and buckle, the collar was put on dairy cows at the Wagner Farm to test ease of application, fit, and duration. The collar maintained its fit despite sustained vigorous movement, and fastened and adjusted quickly.

Containment Design

Summary

We propose a modular two-part system for the virtual fencing of cattle that is comprised entirely of readily-available construction materials, open-source hardware and software, and easily-graspable instructions and installation. Research and interviews with our client and potential users revealed that in order to most easily transition into cell grazing farming, our farmers would need a tetherless system for containing and moving cattle. The most cost-effective and efficient method to implement this is to integrate it into our already-existing visibility collar through low-cost electronics and attachable housing. Our team has provided the framework for how a cooperative system such as the CattleTECH virtual tethering containment system may work, as well as the housing design for each our our collar and post components.

The CattleTECH system relies on the cooperation of multiple containment posts (one per each plot of land) and cattle collar modules (one on each collar). This system assumes that our target farmer is already implementing our high visibility collar. A farmer who owns cattle may then produce their own containment collar units and posts using the instructions, CAD models, and code provided on our Hackster page[8]. A farmer who does not own cattle may use the instructions provided to create their own post to keep collared cattle away and prevent them from eating their crops.

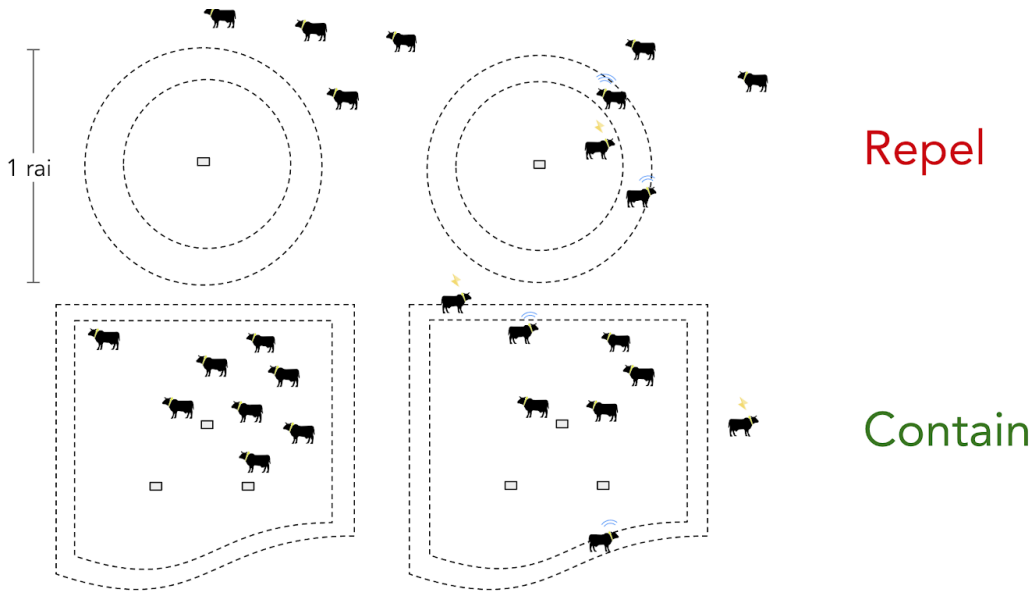


Figure 5: Diagram of proposed system.

[8] https://www.hackster.io/cattletech/virtual-fencing-and-visibility-solution-for-cattle-b37f41

Technical issues and additional testing still need to be addressed before a full-scale implementation of the CattleTECH system can be put into effect. Future teams may use our open-source literature detailing our approach, housing, and research in order to take our project into next steps: further implementation of debugging of software, experimentation of different radio frequencies, and testing in various environments and conditions. Once implemented, the CattleTECH system will provide a long-term, low-upkeep, and easily accessible virtual fencing system that can cross financial and technological communication barriers for our farmers in rural Thailand.

Containment Design: Software

Software Design Summary

Unique from other geofencing solutions, our system relies on radiowaves provided by LoRa (long range) radio transceivers on both collar and post to provide virtual tethering communications. This allows for lower implementation costs, the elimination of the need for a virtual interface, and radically increased battery life compared to other solutions that implement GPS. While GPS allots for the geo-fencing of complex areas and data acquisition, we have chosen to sacrifice that functionality based off of the immediate needs of our target users.

Our system is designed to create virtual fences via localized perimeters created by posts equipped with LoRa radio modules. Perimeters are created through timed radio signal bursts emitting from the posts, which are placed in the center of a circular area of land. These bursts contain data packets that will communicate the ID of the post and the mode of the post, either contain or repel. Once the bursts are sent out, all collars nearby will receive the data packet and determine the distance to the nearest post based off of calculations on the received signal strength indicator (RSSI). The type of calculation is determined by whether the packet received was indicated as a repel or contain mode packet.

Once turned on, the system is designed to run indefinitely until either the post or collar power button is pressed to the “OFF” setting or the battery runs out. Our current system is designed to run at full power until switched to low-power off mode. With the additional use of an accelerometer and magnetometer breakout we may also be able to implement automatic power-saving modes on the collar, based off of the measurable physical activity of the cattle.

We have written example code and performed basic testing for implementing the repel function of our system. This testing reveals issues in variance due to noise caused by radio interference and changes in radio propagations due to variable environmental conditions. To implement our proposed contain function, further research and testing will need to be implemented on the possibility of accurate localization through the triangularization of three or more radios.

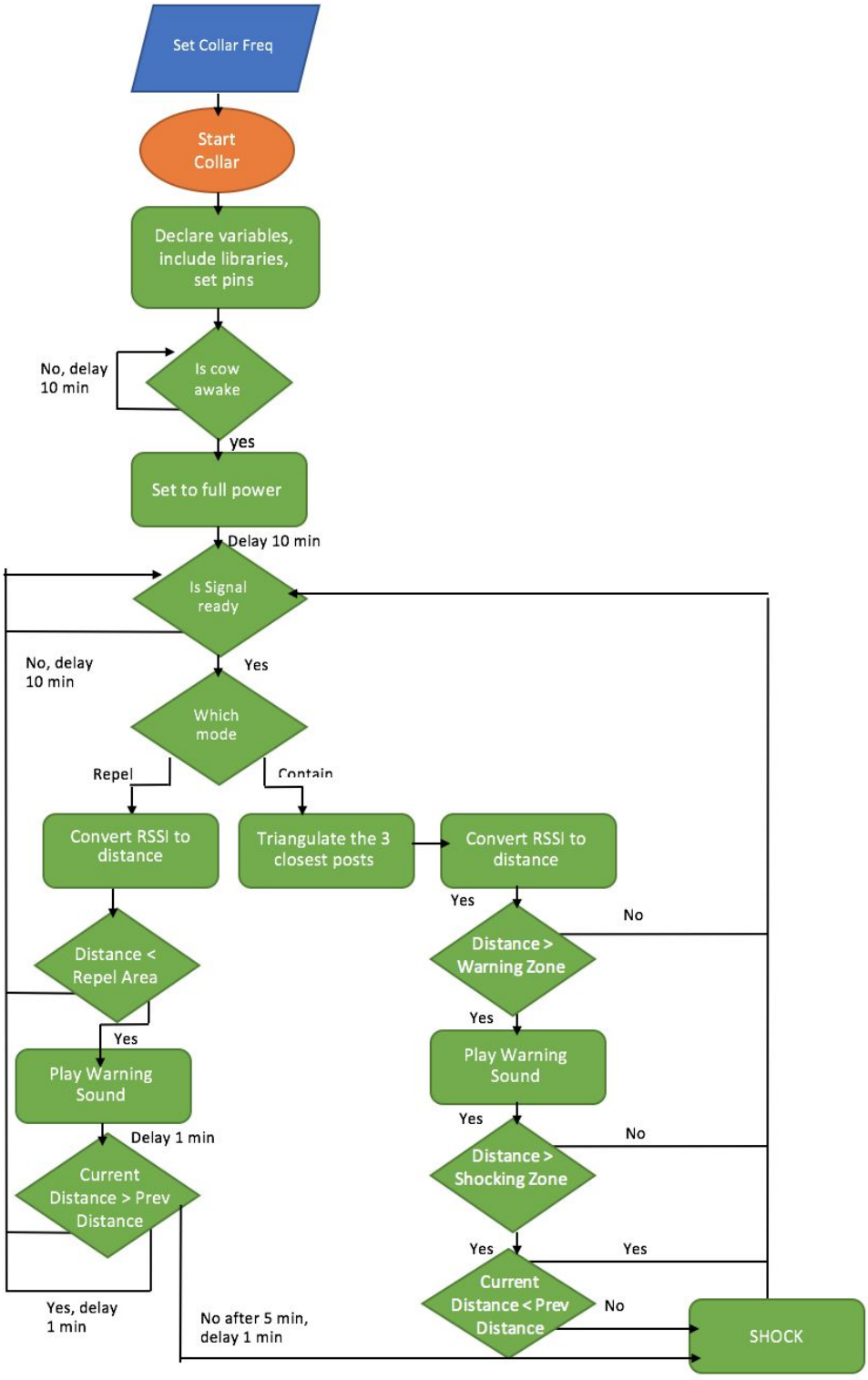


Figure 6: Collar Example Software Flowchart

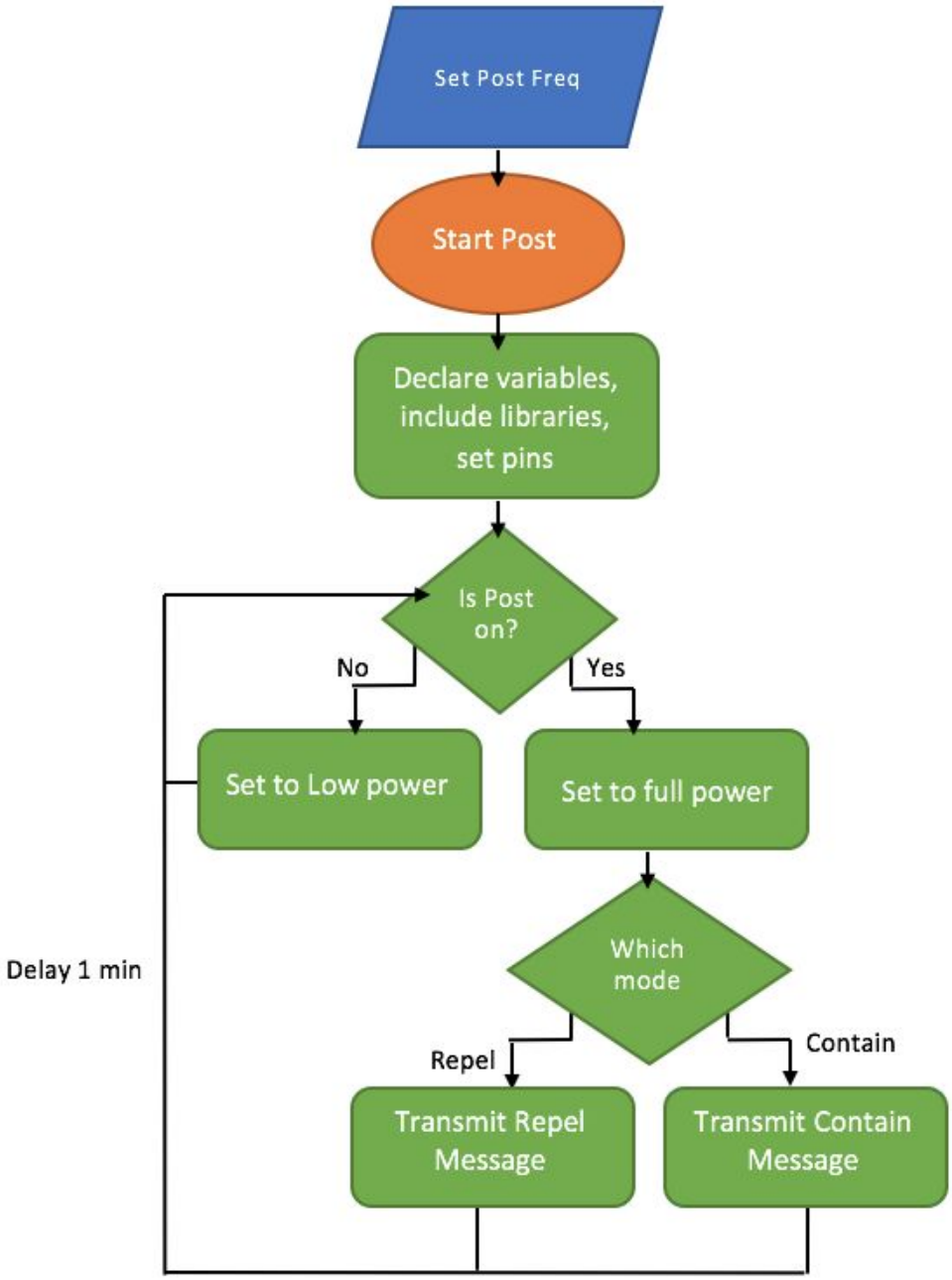


Figure 6: Post Example Software Flowchart

Accessing Code

Our source code is split into two Arduino sketches, one for the collar and one for the post. Users will download the sketches, which are publically available with comments on our GitHub repository.[9] At that point, pre-settings for frequencies, ID's, and desire range may be changed within the code itself if so desired. After creating their housing and electronics, users will then upload the code directly to the boards. Once the code has been uploaded and confirmed to be running, users may then permanently close the housing, as the rest of the interface with electronics will be through physical buttons.

Sketches were written using open-source code from the following libraries: Airspayce's RadioHead[10] and Arduino ToneMelody.[11] Much of the rationale of our code was taken from existing open-source projects, primarily Alex Muir's OpenFence.[12]

Software Features: Repel Mode

The first basic function of our containment system is the repel mode. The repel mode is an option that can be switched by the post. Pressing the mode button will change the transmission message from contain to repel. When in repel mode, a post will be put into the center of a plot of land, currently set to a single Rai, which is the unit of land measurement in Thailand. The post will then blast the data packet to all collars within its signal radius. The data packet will contain the Repel message as a simple string message.

A collar will receive the data packet and interpret that it is being sent a repel message. It will record the RSSI data of the packet it received, a function available through the RadioHead library. It will compare the current RSSI with the with the recorded RSSI indicating the beginning of the repel area. This area corresponds to the plot of land that the farmer wishes the cattle to be kept away from. If the cattle is far from this area, the loop will continue, checking for a new signal every few minutes. If the cattle enters this area, an internal timer on the collar will begin and the previous RSSI will be stored. The loop will continue, now checking for a new signal every minute. If the RSSI continues to increase, meaning the cow is getting closer to the post, a warning sound will be triggered. If after a few minutes this continues, a shock will be triggered. Once the cow leaves the designated area, the warning sound will stop.

[9] https://github.com/maddiehong/CattleTECH
[10] https://www.airspayce.com/mikem/arduino/RadioHead/
[11] https://www.arduino.cc/en/Tutorial/toneMelody
[12] https://hackaday.io/project/10725-openfence-digital-livestock-fencing

Software Features: Contain Mode

The second function is the contain mode. This mode is switched on the post with the same mode button on the post. Unlike our repel mode, contain mode will require the collar to have a more precise knowledge of the cattle's location at a given moment. This will require localization with at least three post signals. This fact adds an additional research question as few instances implementations of localization using the trilateration of LoRa modules can be found (see Appendix B). Future iterations of the project will need to determine this distance measuring algorithm in order to best determine a method of trilateration.

Further testing and recommendations

We have implemented a testing version of this code with our 433 mhz LoRa modules, by comparing measured distance with recorded RSSI signal strength. Our tests (results and figures in Appendix D.1) indicate that environmental factors, primarily distance to the ground, other bodies, and humidity, cause unreliable variance to the recorded signal strength. While lowering power levels allowed for finer resolution in the recorded signal strength, this also recorded variance. We propose further testing to be done, particularly in areas closer mimicking to rural Thai farmland (rather than the Evanston campus) and with the addition of a dedicated RSSI reader, in order to best determine how to account for noise and radio propagation in or distance measurement. Additionally, further tests using higher radio frequencies (our modules are only capable of sending lower frequencies) may allow for more refined accuracy over shorter distances.

Containment Design: Housing + Electronics

Housing + Electronics Design Summary

In order to satisfy the conceptual requirements of an attachable electronics housing design we need to ensure the product would remain durable in various conditions, namely very hot and humid environments as well as heavy rainfall. Additionally, the housing need be structurally durable as to resist any wear-and-tear from being affixed to the cattle. Lastly, the constraints require the design accommodate various electronic components without impeding their functions in any way. The current stage of the design solutions addresses these needs to the fullest given the underlying manufacturing constraints of our facilities. The housing is characterized by a semi-closed symmetrical structure wherein critical openings are sealed using o-ring gaskets or the appropriate water-resistant solution. Furthermore, the geometry of the structure is designed to withstand axial forces of significance as well as deflect forces received at an angle. The housing is 3d printed using PLA and thus does not interrupt any of the critical functions of the contained components. The presented design represents an iteration towards these design goals and is not a full fidelity recommendation. Steps as to how to test and further iterate on this design have been included.

Achieving the functionality outlined in the Software section required the use of electronic hardware. The components found in the coming sections are breakouts and modules that represent an iteration towards achieving the overall design goals outlined directly above and in the software section. Our recommendation for further testing and manufacturing potential are also found in the coming sections!

Feature Overview

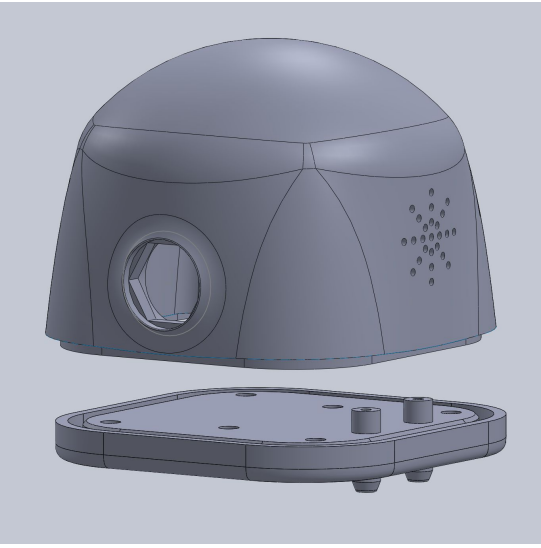


Figure 4: Housing Model

The housing geometry is constructed with a square base with near 90 degree walls and a spherical top. This aspect of the design intention allows for the mounting of an antenna to the side of the housing, which requires parallel vertical walls to seal effectively, as well as the mounting of the speaker into a press fit cavity. The base and upper portions of the housing are aligned via a U-channel in the base and an extrusion from the upper and are secured using four M5 screws.

The aforementioned antenna and speaker features are shown below in *Figure 4*. The speaker cavity ensures a press fit and includes spacing for

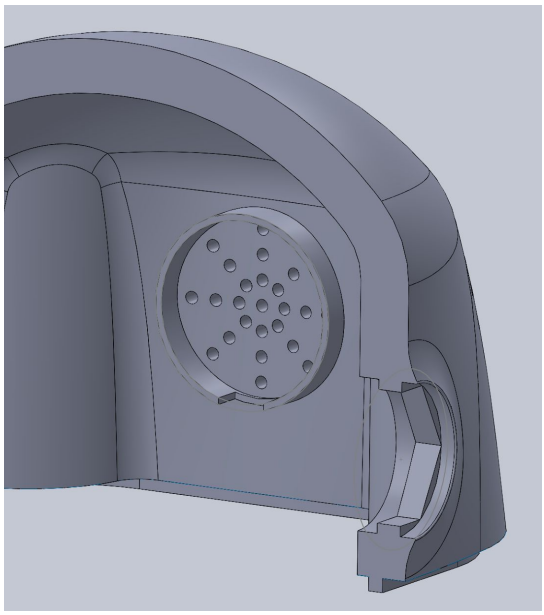


Figure 5: Housing, Speaker & Antenna Features

the inclusion of a hydrophobic film used to prevent water from entering the housing through the external sound holes. The antenna feature is designed to interface with PG11 cable glands and is adapted to using two additional o-ring gaskets at the exterior and interior faces-- in doing this, any chance of failure via water damage to the antenna or through the antenna opening is greatly reduced.

Geometry to allow for the facilitation of electric shock to the lower neck muscle (or upper, depending on collar placement) is shown in *Figure 5* below. The extrusion provides for a press-fit of the electrode in the base plate, leaving 0.485 inches of electrode exposed--based on shocker prod benchmark #2.

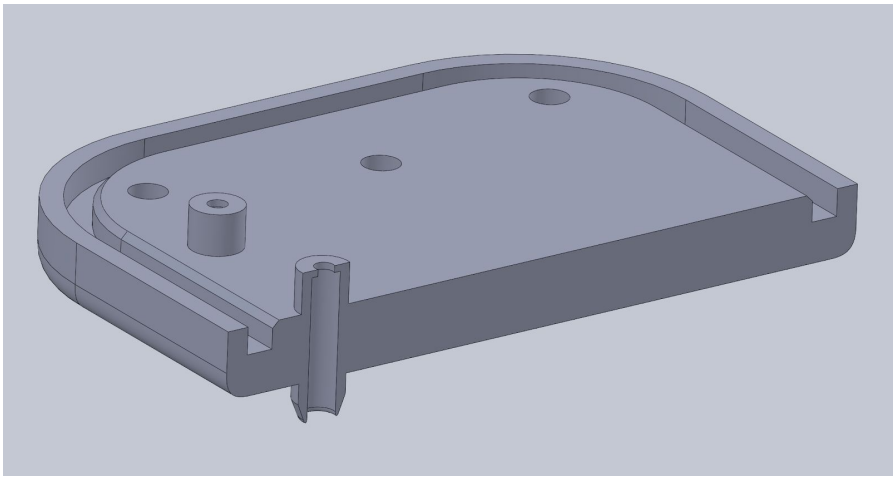


Figure 6: Housing, Base Electrode Feature and U-Channel

Material Selection and Manufacturing

The current versions of the housing are printed using PLA on Ultimaker 2+ FDM 3d printers. The final print setting was generated using the Fortus machine, PLA with dissolvable support material and an infill of 40%. The material selection process was limited by the complex geometry we've constructed. The only available alternative within our facilities was to injection

mold in polypropylene. Unfortunately, polypropylene's material properties aren't well suited for the Sisaket environment characterized by high temperatures and extensive UV exposure.

The highest fidelity housing was 3d printed in the rapid prototyping lab via FDM on the Fortus 380mc. While an upgrade from the Ultimaker 2+, the housing cannot be said to be completely water impenetrable thus further manufacturing methods would be required to satisfy the design goals. Limitations of the housing design and specific recommendations are outlined in the next section.

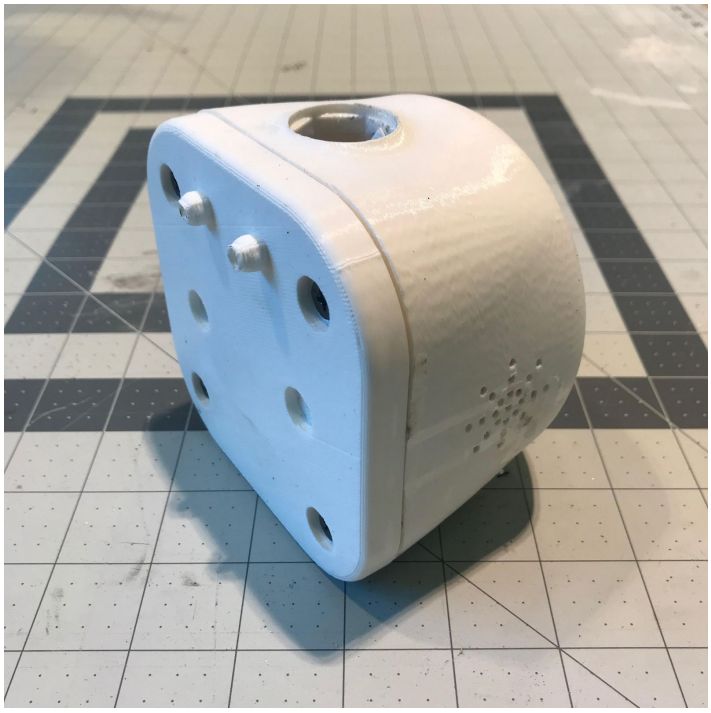


Figure 4.1: High Fidelity Dummy Housing Fortus 3D-Print

Limitations & Recommendations

Although namely limited by the manufacturing methods and associated material selections there are several design decisions and improvements that should be considered as immediate next steps. The first of these recommendations is to adapt the tolerancing of the U-channel to account for Silicon resin coating. This method of sealing a lid and body is effectively a two-fold piston/rod seal according to the Seal Design Guide. Moving forward, the largest manifestation of the limitations of the materials selection processes and manufacturing methods is that the housing is not water impenetrable. While the housing does provide marginal water protection, inherent in the FDM 3d printing process is the possibility for water to become absorbed through the layers of the PLA into the part--of course this would be a detriment to the internal electronic components. In order to prevent this, the housing body should be used to

create a two part mold suitable for injection molding. Readily accessible student resources at Northwestern University have the tooling for mold creation but not injection molding. The Rapid Prototyping Lab at the University theoretically has the ability to injection mold, however machine availability is limited and there are significant constraints on part dimensions that can be manufactured.

Further Testing

In order to address the limitations and evaluate recommendations the current design should be tested in the following methods. Although simple stress analysis of 3000 lbf (FEA, Figure 4.2,.3) was performed on the current design using the geometry and a simulated ABS mesh, the higher fidelity iterations would need to be developed before this information could be used to make any conclusions about the design. Rather than perform more FEA, extensive in-field-on-cattle durability testing should be performed to understand further the type of wear and tear this particular housing design can be expected to experience. Moreover, simulated testing for water effects can be performed via simple submersion and splash tests. A dummy housing (seen above, Fig. 4.1) has been included for testing in Thailand.

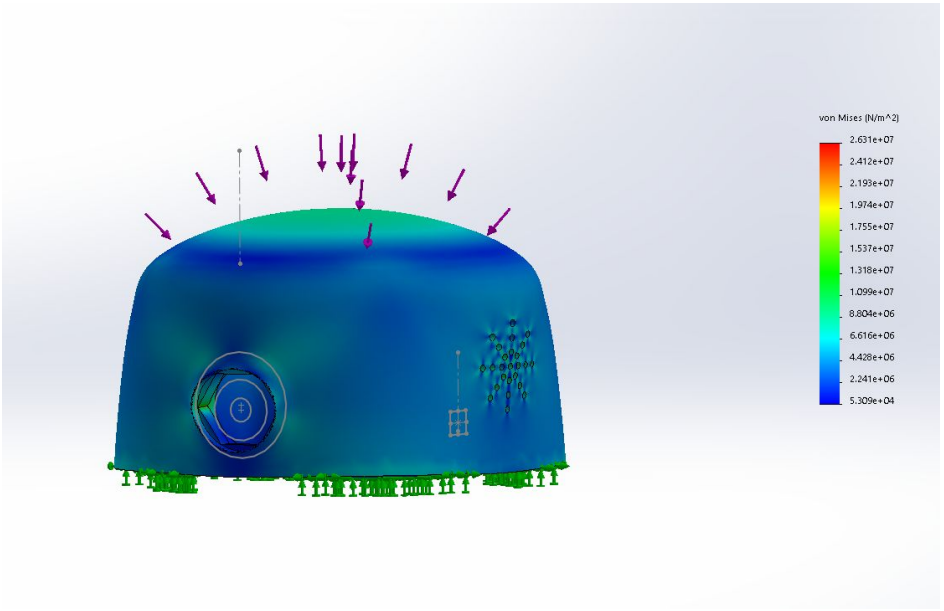


Figure 4.2 Simple FEA of housing assembly, Stress

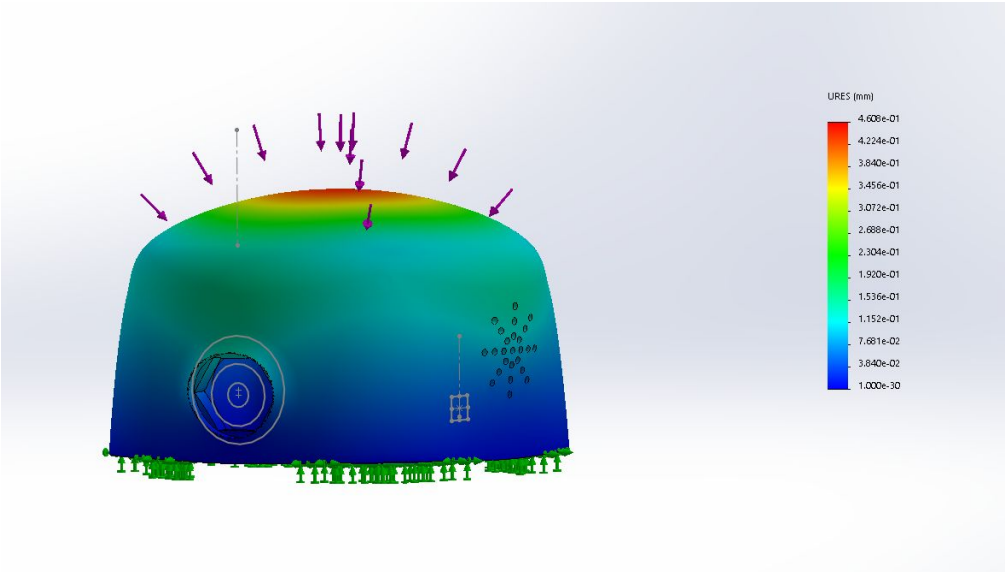


Figure 4.3 Simple FEA of housing assembly, Displacement

Electronics

Complete Electronics and Relevant Components List

Feather M0 + LoRa	Microcontroller, 433MHz Radio Module
D battery	3.7 V 19000mAh
D battery holder	
Shocker support battery	9V
Shocker Unit - PCB	
Shocker Unit - Transformer	Effective 444:1 (9V to ~4000V)
Shocker Unit - Electrodes	copper
Shocker Unit - Transistor	TIP102
Shocker Unit - Resistors	10k Ohms 5%, High Voltage 3000M 10% 1836 MX Ohmite
Shocker Unit - Capacitor	102M 6kV
Shocker Unit - Diode	
Speaker Unit - Speaker	8 Ohm 0.25W
Speaker Unit - Amplifier	3.7W Class D MAX98306
Accelerometer + Compass	LSM303DLHC
Antenna	433MHz Antenna High Gain 3dbi With SMA Male Connector with U.fl ipx to SMA Female Connector Cable
Adapted PG11 Cable Glands	

Function overview

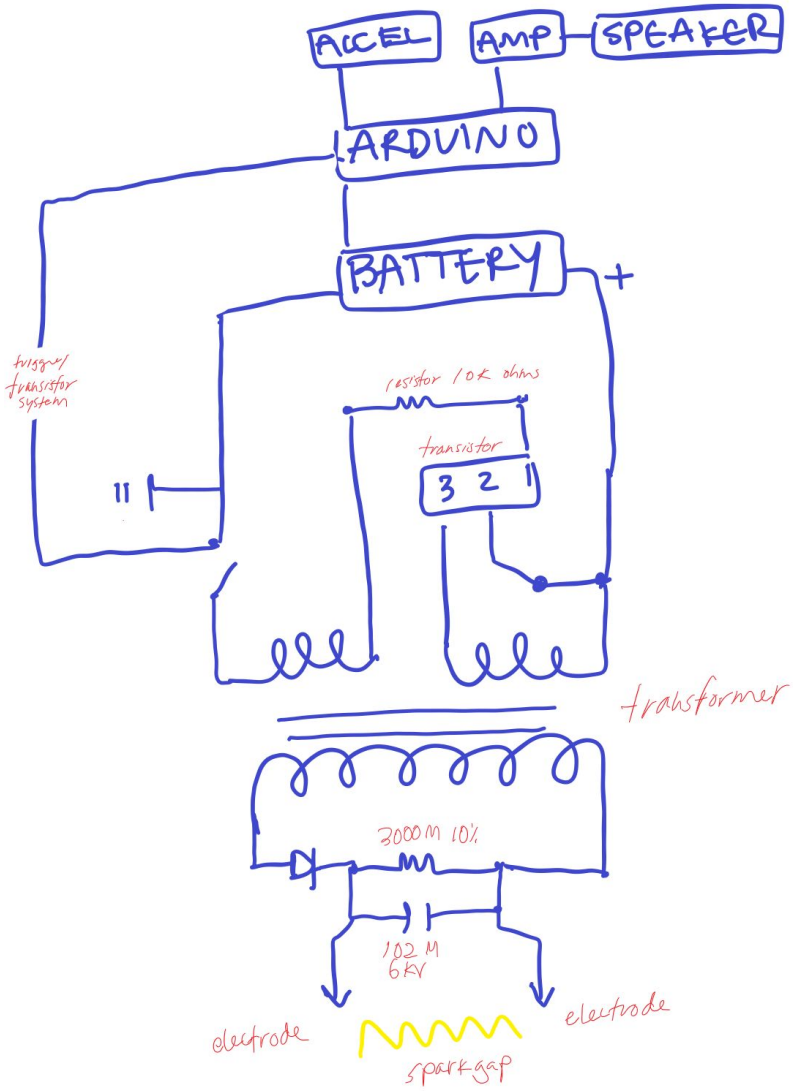


Figure 7 a. Electronic Circuit Design (back up shocker unit battery and antenna not included)

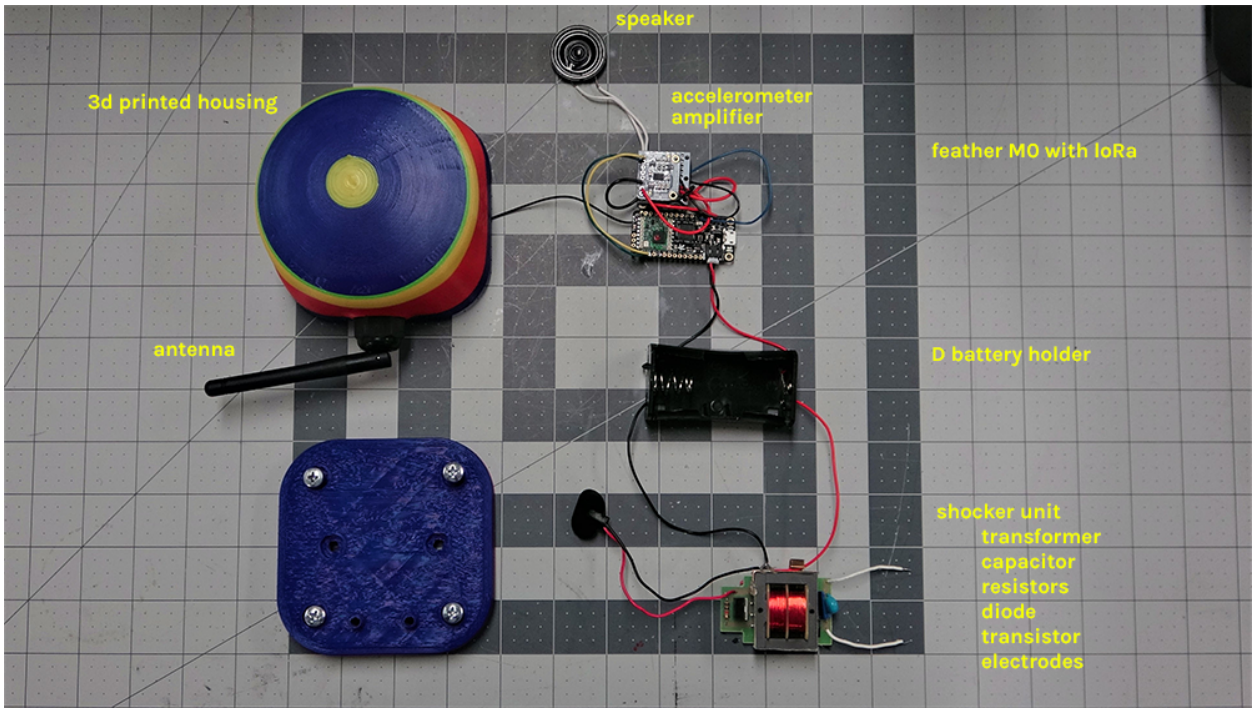


Figure 7 b: Housing part Layout

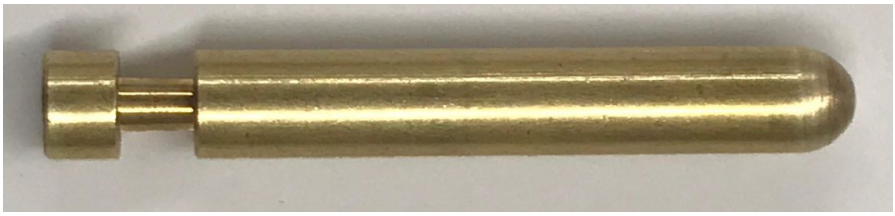


Figure 8: Electrode

The electronic components achieve the function of the conceptual models outlined in the software section; *Contain* and *Repel*. The electronics are powered by a single D-battery of 3.6V and 19000 mAh which is expected to last over 5 months without the use of the shocker. Given any anticipated frequency of shock during the cattle learning period an additional 9V battery can be added to reduce the draw on the D battery. Theoretically, the arduino triggers the shocker by completing the shocker unit circuit using an NPN transistor-- however this has not been evaluated due to the specialized skills and knowledge required to test at such high voltages. The speaker function allows for the 'warning sound' -- issued when the cattle approaches a theoretical boundary. An amplifier is used to route from the microcontroller to the speaker and ensure a suitable gain range for different conditions-- this hardware is a fail safe for the failure mode in which the cattle does not hear the warning sound and is thus shocked unexpectedly --lessening the effectiveness of the containment in training. The LoRa is used to receive data

packets at which the RSSI signal strength can be evaluated in order to determine the distance to a single post (as in *Repel*) or from three posts (as in *Contain*). Finally, the accelerometer is theoretically used to evaluate the movement of the cow; when the cow ceases to move for an indicated period of time, the accelerometer engages the microcontroller into a low-power mode.

Limitations & Recommendations

The limitations of the electronic hardware exist in the fact that for the duration of the project we have been using breakout modules in order to best test and adapt our design to fit emergent needs and existing design requirements. The use of existing breakout modules such as the amplifier, accelerometer, and feather M0 with LoRa pre-soldered is both costly and places a limitation on the housing design-- which must accommodate the dimensions of the breakouts which are significantly larger than they would be if their function were to be achieved using a custom PCB. Thus, in order to bring this aspect of the design to higher fidelity model in it's next iteration, custom PCB's should be designed and manufactured based on the testing modules used in the current version of the design.

Immediate next steps and testing

Identified immediate next steps for electronics include a full evaluation of the schematics; development of a shocker trigger system, in order to use the arduino to trigger the shocker switch, as well as the development and testing of a higher resolution RSSI measuring device. A higher resolution RSSI measuring system means that the contain and repel schemes can generate a clearly defined border using the signal strength from post arduino to collar arduino. The current hardware, 433MHz Long Range Radio uses wavelengths that are too long, generating low resolution. We recommend first upgrading the hardware to a higher frequency module, testing between 915MHz to Bluetooth frequencies. Beyond upgrading the hardware, the development of an independent Field Strength Meter could potentially provide the target resolutions and decrease in noise required to implement Contain and Repel safely.

Containment Design: Post

Post Design Summary

After initial testing with cattle, we determined that the post height should be 60" to exceed the height of the cattle in order to prevent excessive force exerted on the solar panel which is the most sensitive electronic component of the design. The height of the post in relation to the cattle can be seen in *Figure 9* below. The post has a ballast box filled with ground or sand, an electronic enclosure that houses the electronic components, a spring that allows for bending and a 25W Flexible solar panel that provides continuous charge to the batteries. The panel is angled at 13 degrees which is the optimal efficiency angle in Thailand (Appendix D). Once

disassembled, all components of the post can be held in the box for easy carrying or storage of the device.

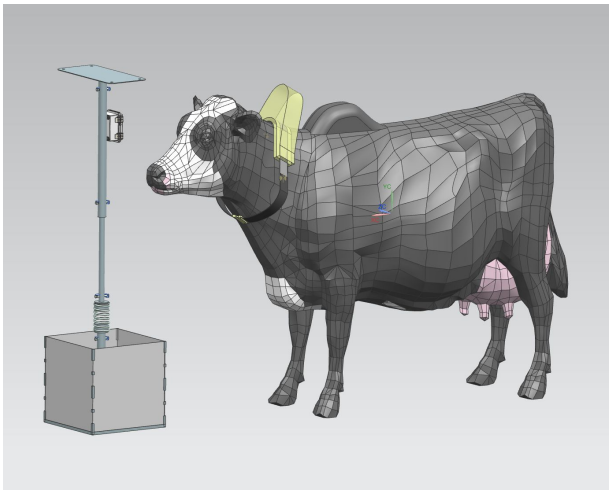


Figure 9: Post in relation to a cattle

Table 1: Hardware of the Post Electronics Box

Feather MO Lora	433 MHz, ~40mA draw
Lithium ion battery	3.7V, 6600mAh
Antenna	433 MHz, 15 cm long
Push buttons (2)	12V, operating 3A
LED (3)	12V

Materials Selection

PVC was selected for the structure of the post as it one of the cheapest rigid engineering plastics and is readily available in circular hollow extrusions commonly used for piping. It has excellent water, weak alkali and acid resistance as well as fair UV resistance so it will withstand the expected environmental conditions.[13] Aluminium was chosen for the supporting structure of the ballast box and the panel as it is lightweight and durable as well as not prone to oxidation in outdoor conditions.[14] The Spring is made from corrosion resistant Zinc coated Steel. The ballast box is made from Low Density PE as it has fair UV and chemical resistance while being cheap and lightweight.

[13] CES EduPack 2018, Level 1, tpPVC
[14] CES EduPack 2018, Level 3, Aluminum

Manufacturing

The exploded components of the post are shown in *Figure 10* below. The main structure of the post is made from 4 parts of PVC tubing that telescope and are connected with telescoping rod pins. The solar panel reinforced with an aluminum strip and attached to it with 3M VHB tape as per manufacturer's recommendations for ETFE laminated panels[15]. The electronics box is waterproof and installed with metal zip ties as per manufacturer's recommendations[16]. A spring located at the bottom half of the pole allows for bending in case of a cow interaction and was chosen to withstand being kicked and walked into by a cattle. The spring is attached with two machined plugs. The ballast box at the bottom of the post is a 15" sided cube made from Low density PE and reinforced with aluminium extrusions. When filled with ground or sand, the box will be sufficient to prevent the post from toppling over when cattle interact with it. The post and box connection is made using Loctite H3000 adhesive that has a sufficient shear strength[17] to withstand the expected forces. Calculations can be found in *Appendix D.*

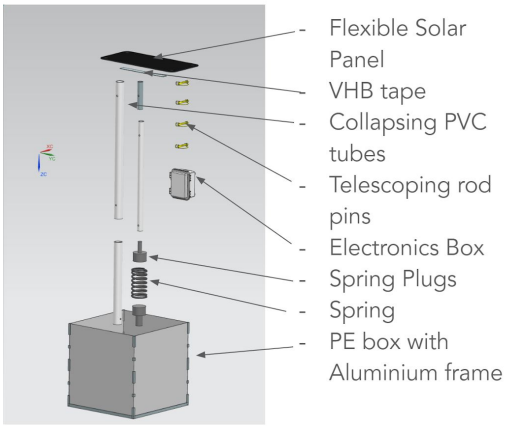


Figure 10: Post components

The electronics box is rated to be waterproof by the manufacturer. Two physical buttons, an antenna, 3 LEDs and the solar panel wire was routed to the box using Waterproof Cable Glands *(Figure 11).*

[15] https://www.flexible-solar-panel.com/flexible-solar-panel/
[16]https://www.polycase.com/wh-02?gclid=Cj0KCQjwtMvlBRDmARIsAEoQ8zSoq3J_3BPjuUbfmlGIVgq_0JRtPVFj5BvxljSZFFplTskkeZEALLcaAq-UEALw_wcB
[17] https://www.mcmaster.com/6430A57

Figure 11: Cable Gland Connections

Testing

The concept design of the post with a plywood box was tested at Wagner Farms where 4 different cattle interacted with the post (*Figure 12*). It performed as expected and did not experience failure under normal use. The ballast box was not filled all the way but prevented the post from toppling.

Figure 12: Cow interacting with the post

Final design of the post was tested by the team by putting a heavy clamp in the box and kicking the post to see if it springs back. The maximum angle experienced was less than 45 degrees that the post was designed to reach. It sprung back to a vertical position within seconds (Figure X).

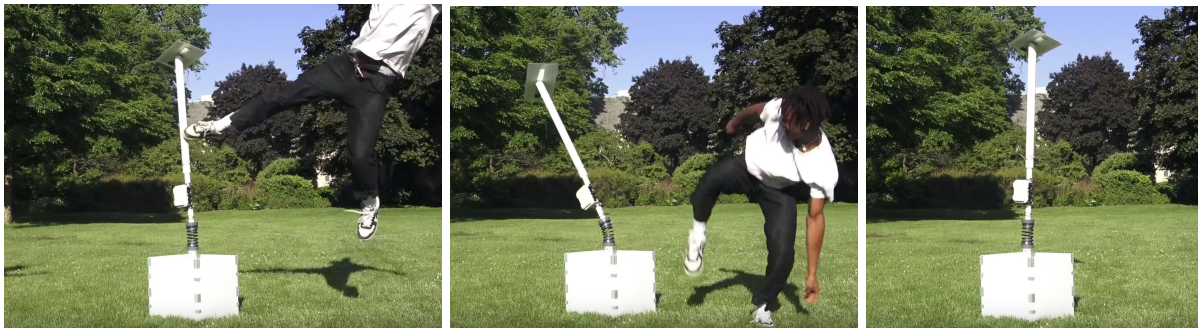


Figure 13: Post testing

Risks

The Loctite attachment failed during testing. The reason for failure is most likely improper bonding between PVC and PE as the adhesive is rated for sufficient shear strength. The options for improving the bonding are to rough surfaces of the plastics before bonding or, alternatively, utilize physical connectors instead of adhesives.

The chosen spring was less stiff than expected and was reacting to wind making the post not stationary in normal conditions as well as bending under the weight of the electronics. Continuous motion as such would reduce the solar panel efficiency. The spring experiences lateral displacement so a spring with a tighter lateral spring coefficient could be used in the next iteration of the design.

Immediate next steps

Utilize physical connectors instead of adhesives to ensure more stable connections. Increase the lateral stiffness of the spring utilized. Consolidate the wires to reduce the number of cable glands required to be added to the box.

Conclusion

This past winter, we were presented with a fairly ambiguous design space. Upon visiting our client, speaking to users, and observing current behaviors, we were able to identify the core needs that require improvement. Cattle ownership in this particular part of Thailand is at the same time casual and contentious. Boundaries of land ownership are unclear, literally and metaphorically. Our two-part design solution aims to make concrete some of the ingrained agricultural practices that experience breakdowns.

The visibility collar presently makes herding cattle less dangerous, as working around the existing road infrastructure would not be feasible. At the same time, it can quite literally bring to light the often covert operations of grazing on other farmers' land. With increased visibility comes increased accountability, and a clearer understanding of land usage negotiations. The containment solution does the same. For the repel feature to work in an area like Raitong's, it would require the consent of both cattle farmers and landowners, contributing to a more efficient and transparent agricultural community. The containment feature can at the same time advance more experimental farming practices like cell grazing, which have decades of conventional farming practices stacked against them.

Our client has suggested to us that his is a community that feeds on a curiosity for what others are doing. Perhaps this has contributed to the closed loop of conventional farming practices. A design as unconventional as brightly-colored collars for cows and solar-powered posts on springs would ideally have the effect of sparking conversation among farmers about the way they share their land and raise their livestock.

Before this can happen, our design must be iterated upon. The work we have done thus far has been identifying the core needs of our users and developing a system that meets as many of those specifications as possible. We hope to see this project continued to the point of achieving a fully-functional system. The key areas for further improvement will be:

- Generating reliable distance readings from radio signal strength, as radio is more cost-effective and minimizes the need for digital interfaces
- Coordinating the system to involve multiple posts, expanding the coverage map of the system
- Generating a safe, neatly housed shocking circuit that delivers only enough stimulus to aid cattle learning
- Selecting collar materials that are more easily manufacturable and possess all of the specified qualities, so to avoid having multiple layers of material

With these significant developments, our system design would be functional within the Raitong cooperative, which would spark additional curiosity from surrounding farmers. We believe that our system design has the capacity to build more stable agricultural communities with more transparent negotiations and more streamlined practices.

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Appendices

Appendix A: Background Research

This section is a compilation of our most relevant research findings around the design problem. Among these findings are details about the client, potential users, and benchmark solutions.

A.1: Primary client research and resources

Primary resources	Link
Website	http://www.raitongorganicsfarm.com/
Shop	http://www.prolevelbiz.com/app/munchbox/index.php
Facebook	https://www.facebook.com/RaitongOrganicsFarm/
Instagram	https://www.instagram.com/raitongorganics/?hl=en
WordPackers	https://www.worldpackers.com/locations/raitong-organics-farm-co-ltd
IDDS Sisaket 2017	http://www.iddssisaket.org/team/

A.2: Thai Farming Practices Research

Author	Title	Summary	Takeaways	Link
Journal of Animal Science	Prognosis of Zebu Cattle: Research and Application	Southeast Asia Thai cattle genetics/ anatomy.	The main difference between Zebu cattle and European cattle are the humps located behind their necks.	https://academic.oup.com/jas/article-abstract/50/6/1221/4662923?redirectedFrom=PDF https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4627918/
The National Academy of Sciences	Traffic risk behavior and perceptions of Thai motorcyclists: A case study	Causes of traffic accidents in Thailand.	Road safety is lacking content geared towards motorcyclists.	https://trid.trb.org/View/1114533

Sustainable Food Trust ; Francesca Price	Mob grazing	Mob grazing: intensive rotational grazing system. i.e. 300 cows on ¼ acre for one day. 3 days rest, chicken on acre, then turkeys. No chemical fertilizer.	• Brainchild of Joel Salatin, American farmer • Breaking records in "cow days" and $$$	https://sustainablefoodtrust.org/articles/mob-grazing-offering-an-alternative-to-gmos/
Permaculture	Multispecies Grazing	Leader- Follower System: involves rotating one type of animal on the field for a day each.	Benefits • Mimics nature • Parasite control • More uniform grazing • Improved weed control • Decreased wildfire fuel loads • Increased carrying capacity • Increased profit	http://tcpermaculture.com/site/category/homesteading/livestock-and-animals/multispecies-grazing/

A.3: Solar Viability Research

Based on adafruit specifications

Assume it needs to be able to supply enough to satisfy peak amperage requirements

Name	Voltage	Operating Amperage
Feather	3.3	100mA
Radio Transmitter		120mA
Radio	2.4-3.7	100mA
GPS breakout	3	25mA
Battery	3.7	350mA

Typical panel efficiency is about 15%[18]. The average temperature in mainland Thailand is about 30C[19] which reduces max efficiency by some 20%[20]

Simple way to test solar panel efficiency in given conditions + humidity, wind and temp effects[21].

We would want the battery to cover passive electronic needs during the night (8 hours) and solar cell to supply enough energy for day time (16 hours). In case of clouds etc, the battery should be able to last up to a week/month of usage?

During rainy season there will be significantly reduced panel efficiency for half a year.

There are some 12 hours of daylight every day[22]

There are commercial small solar panels available to buy that are used for small electronics such as string lights etc.

Need to define how much area we want solar panel to cover. It is sensitive to stabbing, scratching and bending. Could choose to cover with a hard film/epoxy/glass but would reduce the efficiency further.

If chosen 8x8cm panel, 5V & 160mA[23]. Covers ~ half of max amp and voltage needs.
Could choose smaller ones that are connected in series to cover different parts of the collar.
Solar panel efficiency is very dependent on direction the sun hits them so that could optimize performance[24] especially because cows move and the sun moves throughout the day[25]

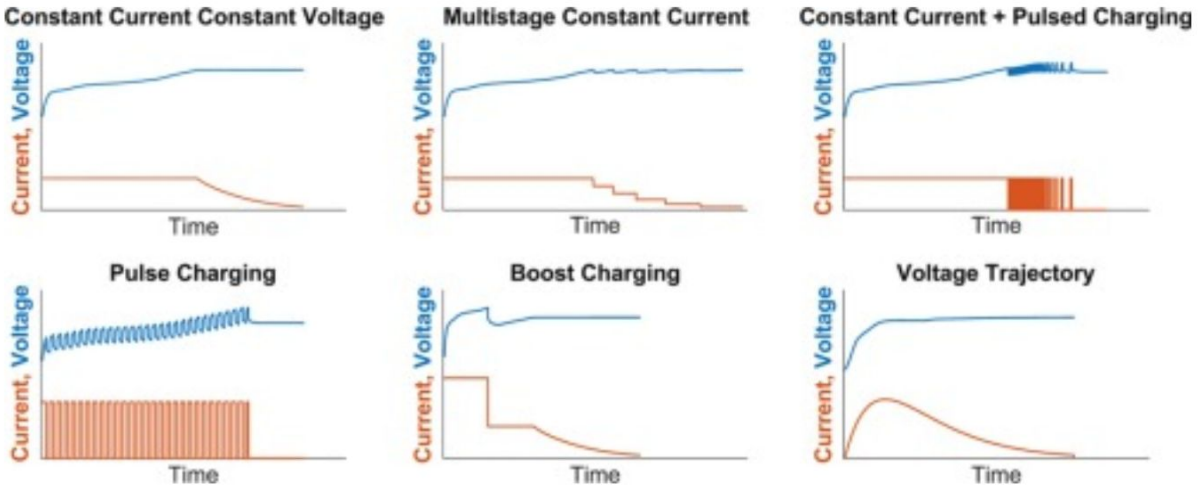
[18] https://sciencing.com/average-photovoltaic-system-efficiency-7092.html
[19] https://www.climatestotravel.com/climate/thailand
[20]https://www.mitsubishielectricsolar.com/images/uploads/documents/specs/MLE_260Wp_Spec_Sheet_Feb2013_lr.pdf
[21] https://iopscience.iop.org/article/10.1088/1757-899X/420/1/012051/pdf
[22] https://www.timeanddate.com/sun/thailand/bangkok
[23] https://www.amazon.com/AOSHIKE-Photovoltaic-Charger-Projects-54x54mm/dp/B07BLTMFMK/
[24]https://www.aliexpress.com/item/Mini-0-15W-5V-Solar-Panel-Power-Panel-System-DIY-Battery-Cell-Charger-Module-Portable-Panneau/32816051299.html?src=google&albslr=205958598&src=google&albch=shopping&acnt=494-037-6276&isdl=y&slnk=&plac=&mtctp=&albbt=Google_7_shopping&aff_platform=google&aff_short_key=UneMJZVf&&albagn=888888&albcp=1582410664&albag=59754279756&trgt=296904914040&crea=en3281605129 9&netw=u&device=c&gclid=EAIaIQobChMIo8eE-vHD4AIViENpCh23ZgE-EAQYAiABEgIp7vD_BwE&gclsrc=aw.ds
[25] http://store.sundancesolar.com/small-solar-panels/

Rigid models are much cheaper but there is a possibility of flexible modules such as ones from sunpower[26]. Sunpower type cells also do not experience thermal degradation and work best st 35-40C ambient temperature (ideal)[27]

Batteries have a certain # of charge cycles before they are worn out. Charge cycle is reset when it goes below 15% or above 85%.
Continuous charging can lead to mini charge cycles where parts of the battery have discharged more times so it doesn't age evenly.

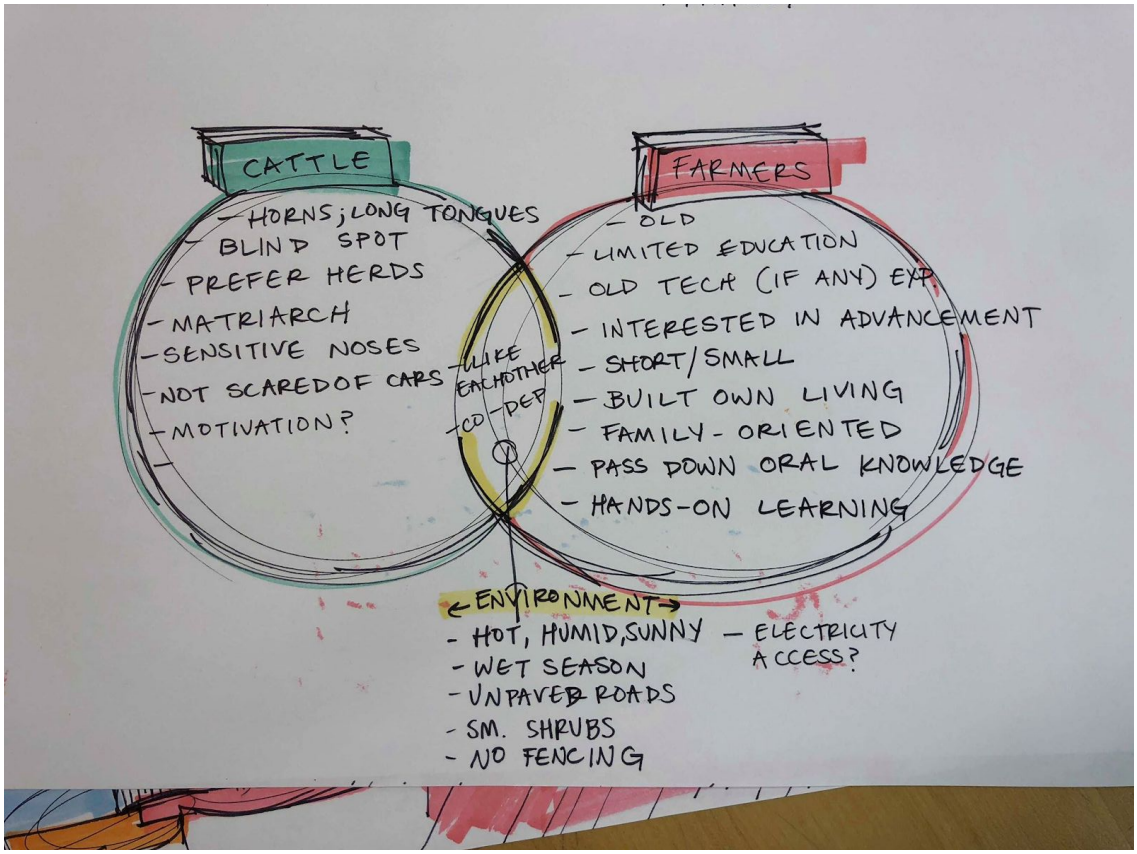
Charging increases temperature, using the battery also increases temperature. The battery can hold less charge when it is hot. A potential solution is to have two batteries that are charged and used alternatingly.

Overview of charging protocols and affect on cycle life of Li-On Batteries[28]



[26]https://us.sunpower.com/sites/sunpower/files/media-library/spec-sheets/sp-sunpower-maxeon-solar-cells-gen2.pdf
[27] http://eshop.terms.eu/_data/s_3386/files/1379942540-sunpower_c60_bin_ghi.pdf
[28] https://www.sciencedirect.com/science/article/pii/S2352152X16300147

A.4: Persona chart based on research



A.5: Existing/In Progress Open Source Solutions

Table 1: GitHub Solutions

Link	Comments
https://github.com/ClusterLabs/fence-virt	I don't get this at all, but it seems similar to any virtual fencing tech out… in C By ClusterLabs - open source
https://github.com/hallahan/VirtualFence	Demo: http://virtualfence.theoutpost.io/# Gps tracking in javascript… not too bad
https://github.com/isangyoon/VirtualFence	Virtual fence for use with collar - adafruit, code looks good but no commits for 2 years - looks like a good starting point if we wanted to use adafruit gps stuffs
https://github.com/sigmunjr/VirtualPet	This is in norwegian. no commits for 3 years.

Fence	Appears to be working well

Table 2: Hackster solutions

Link	Comments
https://www.hackster.io/kburns/gps-cat-tracker-f2884c	https:/akezine.com/projects/make-37/gps-cat-tracker-2/ Easy mode
https://www.hackster.io/alvarowolfx/asset-tracker-using-cloud-iot-core-firestore-and-mongooseos-a92d63	Very secure
https://www.hackster.io/rick-kawamura/making-cows-smart-with-iot-soracom-4a712e	Connecting cows to IOT, integrating with Farmnote (herd management software)
https://www.hackster.io/ekalyvio/cowbit-5bc653	Fitbit for cows

A.6: Market competitors in virtual fencing

Competitor	Summary	Link
eShepherd (2018)	- GPS enabled collar and mobile application to fence, move or monitor livestock. - Audio cue as animal approached boundary. DElivers a single “mild but aversive” electric pulse - Collar cue animal based on resting of moving behavior in relation to virtual fence - Solar powered - Includes: collar, internet accessible base station, and a tablet to run the software - Only cattle rn (no sheep/goats) - Can automate rotational grazing - Main challenges: - Power management	https://www.agersens.com/history-virtual-fencing/

	- Range of signal - Connectivity challenge - Just won an Australian award in design  -	
Vence (2018)	- Virtual fencing and autonomous animal control - Also monitors animal well-being - Optimizes grazing through application - Based in Silicon valley	http://vence.io/
Nofence (2018)	- Norwegian company that started 10 years ago - Works with goats, cattle trial in 2017 - Solar powered GPS collar and digital boundary with mobile app - Warning sound is a beep, followed by a weak shock	https://www.indiegogo.com/projects/nofence-the-virtual-fence-for-grazing-animals#/
Venue	- Body belt instead of collar - Around the ear tech as well?	http://v-e-n-u-e.com/Invisible-Fences-An-Interview-with-Dean-Anderson

A.7: Market competitors in herding livestock

Research Summary

- This problem is incredibly common across the globe

- Existing solutions:
  - Reflective collars using radium (bells optional)
  - Stickers or paint on horns
  - Reflective ear tags
- Materials:
  - Reflective strips sewn onto cotton collars
  - Radium reflective paint/stickers
- Problems:
  - Can't see collars around neck is the cow is facing away from driver
  - Collars that fall off
  - Reflective material wears down over time/contact with shrubs/impaired by dirt

Hindustan reflective collars (2018)

- Police initiation for stray animals
- Consist of radium stickers and cotton strips

Radium belts (2018)

- India
- Police tied radium bands on horns and necks of stray cattle
- Town also has foggy mornings

Glow-in-the-dark strips on cow horns (2017)

- Project successful
- Authorities plan to permanently paint horns with glow-in-the-dark radium paint

High-visibility reflective jackets *proposal* for cows (2015)

- Location: Hungerford, Berks
- Solution for cows to graze in poor light conditions
- Also proposed strings of flashing lights
- Herd size: 175 cows
- Project cost: 3000 pounds
- Farmers thought idea was ridiculous. **"The bottom line is that it's all down to the speed of cars. If a cow had a fluorescent strip around its neck, you wouldn't be able to see it if it had its back to you or if it was facing you head on."**
- **"The thing about fluorescent collars is that they'd only get them off anyway and litter them all over the common."**
- "The cows would just pull it off in hedgerows and shrubs."

Reflective Collars (2015)

- $3.25 each
- Also distribute reflective ear tags

Cattle collars (2012)

- Reflective collars + bells
- Bells function to help farmers find cows that are separated from herd
- "Girls will take a little getting used to collars and noise following them everywhere."
- Comment section:
    - Bob Scambler tried using reflective belts designed for school children
    - Heather Fisher: bought black cattle collars from scatts, sewed on reflective strips from Fabric Land. Collars are working well but reflective material is wearing down and will need replacement in one year

Reflective Collars Minchinhampton common (2015)BBC - collars on cows (2004)

- Location: Gower Commoners'
- In 3 months, 90 cattle/sheep/ponies died from traffic accidents
- Town placed 40 collars on cows
- Petitioning for lower speed limits
- No news on effectiveness
- **Project failed**
- Collars fell off during summer or were impaired by dirt
- Herdsmen are considering painting cows with luminous paint
    - "An idea from Finland where they lose 4000 reindeer each year. They've been painting their antlers."

A.8: Original problem statement - Virtual Fencing

Virtual fencing for livestock

Building fences around farmland

- Expensive
- Time consuming
- Constant inspection and repair
- Cost of electrification for livestock pens
- Farmers have to choose which fences to electrify, when to fence them, type of fence, long term

Goal: controlling the movement of pastured livestock to reduce conflicts with

1. Neighbors when livestock stray into adjacent fields
2. Authorities responsible for conservation areas adjacent to fields (e.g., riperian zones, etc.)

Additional info:

- Large predators are not an issue
- Raitong Organics Farm also farms sheep, goats and pigs

Goals of virtual fencing

- Automating the movement of livestock for mob-grazing, etc. to allow farmers to focus on
  maintenance of pasture health and other farm activities, especially during the peak times
  on the farm (planting/harvesting crops);
- Having the ability to split the herd (via tagged collars?) to keep down male-male conflicts, manage the herd composition, mob-graze various fields at the same time depending on the season (pasture growth);
- Being able to remotely shepherd livestock on from pastures to stables at night or during inclement weather.
- Ideally, the virtual fencing system would link into the farm weather system to override movement instructions to, for example, keep herds out of sensitive areas automatically, such as flooded fields.

An added challenge to this system would be to develop an eShepherding system for pigs, as pigs tend to learn and adapt very quickly to overcome barriers both as individuals and by working as a group, their basic anatomy prevents the attachment of a collar (thick shoulders/neck vs. head size), and their burrowing/wallowing habits tend to wear any collars/tags out very quickly. In addition, pigs are usually sold when they reach market weight (+/- 100kg) at the age of about 5.5-6 months. Having said that, pigs (and chickens) work well with cows in a multi-species intensive/mob grazing system (cattle → chickens → pigs → fallow
period → repeat) to improve pastures, sequester huge amounts of carbon, and produce healthier livestock.

Objective(s) of the project

- To develop a virtual fencing system for grazing ruminants

- To develop a virtual fencing system for pigs

Key requirements

- The system should be easy to implement and maintain, and should be robust enough to withstand being exposed to the elements throughout the year
- The system should be software driven, with a mobile phone app to make changes on-the-go
- Assuming the system uses collars/ear-tags,
    - Collars/tags should be robust to withstand daily wear by livestock
    - Collars/tags should be charged by solar PV cells, and should transceive data via lora to the fenceline system

In addition to the above requirements, the student team will also be required to provide full documentation about the project, which should preferably be published online (e.g., github.com,
hackaday.io, hackster.io) and Open Source for other interested parties to use and improve Upon.

Available resource materials

- Agersens eShepherd (https://www.agersens.com/eshepherd/)
- Multispecies Grazing (http://tcpermaculture.com/site/category/homesteading/livestock-and-animals/multispecies-grazing/)
- Mob grazing (https://sustainablefoodtrust.org/articles/mob-grazing-offering-an-alternative-to-gmos/)

A.9: Original problem statement - Herding Livestock

Herding Livestock

Problem statement

In Thailand, as in many developing countries, cattle and buffaloes (as well as sheep and goats) are usually moved between their housing to the pastures at sunrise and sunset via general roads. With the sun low in the sky and because of their subdued fur colours, cattle and buffaloes
are difficult for other road users (motorcyclists and car/truck drivers) to see, posing a high accident risk to the cattle, their handlers and other road users.

The aim of this project is to develop a low-cost, robust reflective collar for pastured ruminants that can be easily put on and removed from the animal, and exhibits minimal interference with the animal's movements.

Objective(s) of the project

- To develop a low-cost, durable reflective collar for cattle and buffaloes, and other smaller ruminants

Key requirements

- To integrate an LED strip into the design, charged by a small solar PV panel
- The collar should allow the animal to be seen when the sun is behind the animal or behind the motorist, as well as at night
- The collar should be low cost and easy to repair/maintain
- The collar should be durable enough to withstand daily wear and tear by the animal, as well as UV-protected against sun damage
- Any electronics should be waterproof against sweat and rain
- The collar should be easy to put on and removed from the animal
- The final collar should not look absolutely ridiculous!

In addition to the above requirements, the student team will also be required to provide full documentation about the project, which should preferably be published online (e.g., github.com,
hackaday.io, hackster.io) and Open Source for other interested parties to use and improve upon.

Available resource materials

- Reflective collars fitted to cows on Minchinhampton common (https://www.bbc.com/news/uk-england-gloucestershire-32711171)
- Reflective collars for livestock (http://www.sundaynews.co.zw/reflective-collars-for-livestock/)
- Cattle Collars have finally arrived! (https://thechasenaturereservent.wordpress.com/2012/03/22/cattle-collars-have-finally-arrived/)
- Bright idea to cut cow crashes (http://news.bbc.co.uk/2/hi/uk_news/wales/south_west/4054763.stm)

- Cows 'should wear fluorescent jackets and strings of lights' at night, council says (https://www.telegraph.co.uk/news/newstopics/howaboutthat/11758512/Cows-should-wear-fluorescent-jackets-and-strings-of-lights-at-night-council-says.html)

Appendix B: Design Research

This table contains a list of scholarly work done on particular areas of our design space. Each row offers a summary of each source, as well as key relevant takeaways for this project.

Author	Title	Summary	Takeaways	Link
National Association of City Transportation Officials	Vehicle Stopping Distance and Time	Relates vehicle velocity, perception reaction and stopping distance	Total stopping distance is 109 feet at 30mph, 304 feet at 60 mph	https://nacto.org/docs/usdg/vehicle_stopping_distance_and_time_upenn.pdf
Department of Animal Breeding and Genetics, Bangladesh Agricultural University	Prediction of Live Weight for Brahman Crossbred Cattle Using Linear Body Measurements in Rural Area	Body measurements of mixed brahman cattle in Bangladesh	No neck circumference but other measurements available	https://www.researchgate.net/publication/295541516_Prediction_of_Live_Weight_for_Brahman_Crossbred_Cattle_Using_Linear_Body_Measurements_in_Rural_Area
J C Lawrence, CP Bull	Therman Conditions Which Cause Skin Burns	Relates what temperature and time conditions cause skin burns upon contact.	Total stopping distance is 109 feet at 30mph, 304 feet at 60 mph	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.887.1571&rep=rep1&type=pdf
Stafix electric fencing	Animal Voltage requirements	Summary of voltage required for electric fencing of animals	2000V for dairy cows, 3000V for bulls.	https://www.stafix.com/en-us/helpful-information/animal-voltage-requirements
The Physics Teacher 52, 479 (2014)	Backpack Weight and the Scaling of the Human Frame	Comfortable weight a human can carry based on their weight	30%-50% of their weight	https://aapt.scitation.org/doi/full/10.1119/1.4897584
Countryside Daily	Proper Fence Post Depth to Build Strong Fences	Proper fence post depth for non-cemented application	About 1/3 of the total past length is recommended.	https://countrysidenetwork.com/daily/homesteading/fences-sheds-barns/proper-fence-post-depth-to-build-strong-fences/

Agriculture and Food, Dave Henry	Virtual Fencing	Outlines principles of virtual fencing with conditioned (audio) and unconditioned (shock) stimulus. Did research on bos indicus (similar to zebu) meat cattle	Mentions no animal welfare considerations are made in these solutions. Shock most effective, followed by audio then tactile (vibration). 99% successful at keeping animals away from the tasty food. Cattle learned Virtual Fencing after **1 DAY. Proof of concept, no commercial approaches**	www.csiro.au
Applied Animal Behaviour Science Volume 113, Issues 1–3, September 2008, Pages 32-42	The effect of low energy electric shock on cortisol, β-endorphin, heart rate and behaviour of cattle	This study suggests that the stress response of cattle to low energy electric shocks is minimal and is similar to that induced by restraint in a crush.	The cows don't seem to mind the electric shock as much as we thought. It is still the most effective at invoking response.	https://www.sciencedirect.com/science/article/abs/pii/S016815910700319X
Computer Science and Artificial Intelligence Laboratory, MIT Cambridge MA	Dynamic Virtual Fences for Controlling Cows	Simulation results and data from experiments with 8 cows equipped with Smart Collars (shock and auditory responses, GPS locator)	When in the neighborhood of a fence, the animal is given a sound stimulus whose volume is proportional to the distance from the boundary, designed to keep the animal within boundaries. naturally occurring sounds that are scary to the animals (a roaring tiger, a barking dog, a hissing snake) and randomly rotating between the sounds. Animals respond to artificial potentials of sounds generated by the virtual fence by moving forward if they are on their own (see Figure 4(b)), or toward the group if they are in close proximity to the group.	N/A
Computers and Electronics in Agriculture	The evolution of virtual fences: A review	Two important development areas are the energy use of the device and provision of a system that animals can easily understand, in order to assure welfare standards. The paper critically analyses the wide range of developments to date and points out the advantages and	Animals can be kept contained or separated (i.e. in the case of bulls) with stimuli. All solutions utilized some combination of auditory, tactile and electric stimuli. It is mentioned that cattle domain experts suggest using a library of naturally occurring sounds that are frightening to the animals and to randomly rotate among the sounds. Butler et al. (2004) used various sounds but they had also the option to trigger an electric cue. The authors state that sound stimuli were not very	https://www.sciencedirect.com/science/article/pii/S0168159100700319X

		challenges virtual fencing offers. It also provides an indication of how far we are from a marketable product.	effective. **Repeated and louder sounds were more effective in eliciting a response.** It should be emphasised, that as long as the power issue is not resolved, the system will not be ready for practical use on farms. Therefore, the provision of **power needs to be regarded as one of the key issues** in the development process.	
Applied Animal Behaviour Science Volume 200, March 2018, Pages 71-77	Virtual fencing of cattle using an automated collar in a feed attractant trial	12 heifers tested with an automated experimental virtual fencing collar prototype.	Audio values: 2.5 s audio cue (785 Hz ± 15 Hz, 58DB), Electric Shock: (800 V electrical pulses delivered in less than 1 s). Took 6 interactions for 50% of animals to learn the expected behavior. Learning process varied with the character of the cattle. Each cattle was trained individually.	https://www.sciencedirect.com/science/article/pii/S0168159117303295
Applied Animal Behaviour Science, Volume 147, Issues 1–2, July 2013, Pages 34-42	Can the location of cattle be managed using broadcast audio cues?	Therefore, the aim of the study was to test "irritating" sounds from the sonic range (8 kHz and a mix of 8–10 kHz) in order to establish if they could discourage beef cows from spending time in a specific area. A third treatment using "acute alarming" sounds as a comparison was also tested.	The results indicated that irritating sounds are as effective as acute alarming sounds at discouraging animals, but not sufficiently effective for commercial application when played from loudspeakers mounted on posts. However, a highly significant effect of the use of sounds was identified, showing that sounds can be used as adverse stimuli. This **(talking about electric shock)** is a problem in some European areas, such as Wales and Switzerland, where electric shock collars for dogs are banned (e.g. Animal Welfare Regulations, 2010, Wales) and this principle is likely to be upheld for other species.	https://www.sciencedirect.com/science/article/pii/S0168159113001275
January 2015, Rangeland Ecology & Management 68(1)	Cattle Responses to a Type of Virtual Fence	The objective of this study was to test the efficacy of a new virtual fencing product and measure impact on behavior, thus potentially allowing positive development of virtual fence systems. 10 cow study	The system successfully prevented the animals from crossing the virtual fence line. No changes in general activity or lying behavior were found. There were significant changes in the pattern of use of the rest of the field area when the fencing system was activated. When only the unactivated cable was left on the ground in a final control period, t**he visual cue alone deterred animals from entering the**	https://www.researchgate.net/publication/273791469_Cattle_Responses_to_a_Type_of_Virtual_Fence

			exclusion area. The trial showed the effectiveness of a collar-based electrical stimuli system.	
Innotek, Inc., Garrett, IN	ANIMAL SHOCK COLLAR WITH LOW IMPEDANCE TRANSFORMER	Uses a transformer. Needs AC power supply, batteries provide DC, not ideal because needs a pulse generator to function. Good background of why water impedes performance	A remote receiver unit is for use in an animal behavior modification System that applies an electrical shock to an animal. The remote receiver unit has an electrical shock including two electrodes configured for contacting the animal, a source of alternating current Voltage and an electrical transformer with a primary coil. The primary coil is electrically connected to source of alternating current Voltage, secondary is connected to the electrode.	https://patentimages.storage.googleapis.com/24/a3/b8/544196482d893c/US6184790.pdf
B.E.R.T.S. Inc., West Des Moines, Iowa	ELECTRONIC COLLAR FOR LOCATING AND TRAINING ANIMALS	A device for locating and training an animal includes a hand held transmitter and a multi-function electronic collar assembly to be worn by the animal. T	Possible microprocessor layout for shock and sound	https://patentimages.storage.googleapis.com/c3/8d/a4/d900288b1fc334/US5815077.pdf
Journal of Energy Storage, Volume 6, May 2016, Pages 125-141	Charging protocols for lithium-ion batteries and their impact on cycle life—An experimental study with different 18650 high-power cells	Recommendations for optimized charging strategies	All in all, the conventional CCCV protocol is an excellent starting basis for an optimized charging method for lithium-ion batteries (constant current constant voltage)	https://www.sciencedirect.com/science/article/pii/S2352152X16300147
	Good virtual fences make good neighbors: opportunities for conservation	Literature review of alternatives to traditional fencing for animal/wildlife conservation	cost-benefit analysis of real time virtual tracking solutions vs other alternative fencing techniques (seems to be pro VF)	https://zslpublications.onlinelibrary.wiley.com/doi/pdf/10.1111/acv.12082
Ashita Vermani Vidhi Rana, Surabhi Govil	Virtual Fencing for Animals Managment Using RF Module	VF system using RF Modules, was effective but not yet tested on a wide range of cattle	Possible to Virtually Fence without need of GPS	https://download.atlantis-press.com/article/6335.pdf

Vladimir Skvortsov, Keun Mvoung Lee, Seung Eui Yang	Inexpensive radar-based surveillance: Experimental study	Using radar to create a perimeter fence	algorithms for measuring range	https://ieeexplore.ieee.org/abstract/document/6606976
Equine Department of the Vetsuisse Faculty, University of Zurich, Switzerland	Evaluation of the Tekscan F-SCAN system for measurement of the kicking force in horses	Measured kicking forces of horses	About 2000N force can be exerted. Horse and cattle weight is comparable. Horses seem to be able to kick stronger than that so	https://sat.gstsvs.ch/fileadmin/datapool_upload/IgJournal/Artikel/pdf/SAT_09_2016_Fuerst.pdf
David U. Hillstrom, Novi, MI (US);	Patent No.: US 7.996,980 B2	A portable sign stand with wheels or rollers, an adjustable weighted base member, and a sign display member.		https://patentimages.storage.googleapis.com/69/c9/40/227c685508975b/US7996980.pdf
Apple Inc., Cupertino, CA	Patent No.: US 9,176,530 B2	Bistable spring with flexible display		https://patentimages.storage.googleapis.com/c8/8c/47/6abb8c1880ffbe/US9176530.pdf
Journal of Dairy Science	Measurement of acceleration while walking as an automated method for gait assessment in dairy cattle.	mean acceleration didn't exceed 1.8g		https://www.ncbi.nlm.nih.gov/pubmed/21605759
Journal of Research in Agriculture and Animal Science	Monitoring Cattle Motion using 3-axis Acceleration			https://pdfs.semanticscholar.org/ba7f/38850d9772b28b36d080b2a120a014649f5b.pdf

Appendix C: Interview Transcriptions

The team (Natalie, Ieva, Freesoul, Maddie, Henry) spent five days in Sisaket, Thailand. We tested prototypes, interviewed and recorded local farmers in the area, tested and iterated visibility prototypes on Toi's cattle, and visited a local agriculture farm. The transcribed interviews are below.

C.1 Agriculture University

Translator: Areeya
Interviewees: Saman Srook, vice director of the agriculture college
Mr. Watana Dooma, professor who looks after dairy cattle

The university raises (20) buffalo and (70) meat and dairy cows. The buffalo are mostly free range and the cattle are kept in pens.

N: What is the daily routine for the meat cows?

A: So the buffalo are free range to keep the cost down. For the meat cows, they feed them hay and feed that they make themselves with fermented beans.

H: Do you find that a lot of students grow up raising cows similarly or do they learn new practices here?

A: Many students may have a background with cattle. When they come here, they have limited space so students learn a different system of feeding them in the pens.

I: Have they tried electric fences with the buffalo?

A: The buffalo have someone to take care of them and make sure that they don't go to far. Before, they were raising buffalo for milk and now they're raising the buffalo for the different types. So the buffalo stray into muddy areas instead of clean water.

I: So there's someone watching the buffalo and there are no fences?

A: They only have a pen and someone to take care of them. But no, no fences.

N: Do they have nose tethers?

A: There are too many of them so they don't do that.

H: Do you have any stats or instances of cows getting hit by cars?

A: Sometimes they have diseases or pregnancies.

I: Do they have any measurements of the cattle that we could look at?

A: They have some measurements, usually just when the calf is born and then weight after they stop drinking milk and before they are sold.

H: Also if they have market value stats that would be great.

A: there are two ways to determine the price. Either by each cow or buffalo or by weight. At the market here, they determine price by weight. They do it one by one while the cow is still alive.

I: Traditionally the cows would be herded and here they keep them inside. What are the advantages of this system?

A: The villagers use herding and pasture. The plants and grass grow fast enough. Now many farmers also grow beans during this time. If the buffalo ate the beans that would cause a lot of conflict. This system is easier to manage at least for the space. The goal is how to make limited space the most beneficial for you and to use it to your advantage. So you have to deal with gender and sex of the buffalos as well as their age not to mix them up too much so that they can live together.

N: Do they rotate their crops here?

A: The do rice, hemp, and mung bean. And rotate those 3.

I: You mentioned that keeping the cows penned makes more sense for the farmer. Do they take into account the welfare of the animal, like if the cows get sad or sick?

A: For pasture and herding, of course it's healthier for the cows. But they're also selective. If you raise the cows in the pen, they will eat all of the grass that you cut for them instead of eating only certain parts of a field.

One guy leaves

H: Do you use any electric fencing around the college? Do you see any strengths or weaknesses to using this method?

A: He uses it. He's about to set it up today. He's waiting for the students to come back.

A: If you grow the grass like this, and then you have some left, you just put up the electric fences and let the cows and buffaloes go and eat it all.

A: Usually electric fencing is good for grazing. So you can get them to eat a certain space and then move them. Grazing is much better than herding as well because if you feed them the same way in the pen or outside. If they're free range, the milk yield is 10% higher if they graze around. If you keep them contained for too long, the methane from the manure can make the cows sick.

I: Are there any benefits for meat cows to be let to free range?

A: It relates to the stress level. If they are not contained in a certain space, their body system: digestion, how they eat, reproductive system, everything works like it should.

Part 2: After milk and ice cream break

I: When you said it takes too much time to tether them, were you referring to the time it takes to pierce their noses or to tether them in the field?

A: It's more about taking care of it - you have to go find the tree, you have to go deliver water to them. If you tether them, and put the rope in their nose, rebar from fences can injure their noses and break them.

N: Do they try to learn new technologies to teach students or do they teach more traditional herding techniques?

A: They use the male breeder to control the herd. If it's cows, they use artificial insemination (AI). Technology is good, but then you have to do it as an example for other farmers to see and adopt it. But if you do that, every farmer is different. You could probably do a subsidy and get the farmers enough money to buy a pen, but then there's also the cost for buying the feed. If the farmers get drunk somewhere they will forget where they tied up or need to feed the cow. There are some groups that can work really well and take care of their livestock and they can make a lot of money every month.

I: How old if that buffalo in the back with a nose piercing?

A: Close to one year.

I: Do the buffalo ever wander off?

A: They usually just go together. If one buffalo goes somewhere, the whole herd will go together.

I: Is it dangerous to put something on them?

A: Why would you want to put collar on buffalos?

I: Maybe for making them visible or keeping them together with a GPS collar.

A: I think it's a good idea but I don't think it's necessary yet. Maybe in other countries, but in Thailand I don't think it's necessary.

N: Why?

A: The behavior of farmers here, say they put the cows or buffalo somewhere, they would also go where the cows and buffalo and stop doing farming. As well, there's a problem with the knowledge transfer and the farmer's ability to receive new ideas and new technologies takes a lot of time so he thinks that it's not necessary. Tracking system and GPS is a good idea. That would be nice to have as well.

If you have a medium sized farm with 20 or more cows, it would be very useful. About 30 years ago when he started he had a big herd and used technology like computers to keep track and treat each buffalo.

Part 3: Beef cattle

How many cows do you have?

About 20. We let them outside of the pen today and they went ahead and ate the other department's vegetables. Your project would have helped in this case at least! What can you do when they decide to eat these vegetables, you can't just pull them away.

Did you lead all 20 of the cattle to the field by yourself?

I just opened the pen and they went to graze. I didn't have to follow or lead them.

Do you let the penned cows out at all?

No, just the baby calves.

The land is more limited these days as people started to grow more cultures off not during the rainy season (such as beans). Because of that, the grazing land is becoming harder to access so the cattle farmers are moving more towards containing cattle in pens.

Started talking about ear tags

The tags are temporary. A permanent solution is to have identifying tattoos on the cattle's ears.

How do you attach the tags to the cattle's ears?

Use a stapling gun of sorts

Some of the cows are branded, why?

It's to teach the students about different ways of identifying the cattle and how to use the branding tools.

Are the tags temporary because they fall out?

They don't fall out easily but it is possible for that to happen.

Is it hard to attach the tags?

It is not hard, one person could do that but it usually takes three to keep the cattle calm.

When the tag falls, is it because the plastic breaks or does it tear off from the ear?

When they're fed and they stick their head through the fence, it can get caught. The cattle can sometimes fight also.

Part 4: Office Visit

Interviewee: Professor Kumron, Former head of meat and AI division of cattle and buffalos.

The cattle are supposed to be full sized after about 1.5 years. Since their weight is important for price and quality of cattle, that's the only thing recorded as the cattle grows.

American Brahman Breeder Association should have some more data on the animal measurements.

There has been a project for the past 60 years at creating a hybrid cattle from native thai, brahman and "chalolet" cattles.

C.2: Thirteen Cattle in Field

BACKGROUND: man, mid 60s, found his cattle in a field and chatted him up.

What do you feed your cattle?

Cut the grass and feed it to the cows

How many cattle do you have?

13, 10 full-grown and 3 calves

What is your daily routine with the cattle?

Brings them out early in the morning and lets them be. In the evening he brings them back by calling them over.

Have the cows ever escaped from the area?

No, they are afraid of the electric fence after hitting it once.

Do other cows ever try to come to your fields?

No, they are also afraid of the electric fence

How long do you have to wait before you tether the cows? How long do they take to learn about the electric fence?

They need to be about a year old before they can be pierced. The small cows do not learn after being shocked once. They are stubborn and try to escape whenever they can.

How long have you had the electric fence? Do you need to maintain it during rainy season?

This is the first year, prior to that he would tether each cow individually. The fence does not need to be taken out, just the motor.

How long did it take you to set up the fence? Was it expensive? Was it a good investment?

About a day to set up the fence and draw the wire. The motor was some 1000 Baht, the wire was 50 baht/kilo. This was a good investment, it is easier than tying cows to the trees, all I need to do is open the pen and they get out. In the evening, I just need to call them over. They start coming back once they see my pickup truck returning to the field. I also put grass in the pen prior to calling the cattle over. That's how I raised them so they know their routine.

Are you raising them as breeders or market cows?

Breeders. Used to raise buffalos prior to that but it was harder. Cows are fine with the sun and heat, buffalo prefer being in cooler areas.

How many of your neighbors also use electric fencing?

Just me and another person.

Has it been more common to put up fences/electric fences in the recent years?

No, it's still not that common. But there are more buffalos around than cows because of governmental incentives. Cows are easier to slaughter, buy, sell and transport.

Do you think you will keep using the fencing? Would you recommend it to other people?

He will keep using it. The shop can easily explain how to use the fence and set it up, it is quite simple.

Do you think that some people are unwilling to use fences?

People who don't want to invest won't. My son paid for this and initiated my transition to electric fencing. The son is using this as his retirement plan so he is looking for innovative ways to farm the cattle.

C.3: Woman Who Owns Three Buffalo

BACKGROUND: woman, mid 40s, was taking her 3 buffaloes (2 grown ups, tethered, one teenager, free roaming) out to the field next door to her house. A mallet and metal pins were used to tether the buffalo.

Did you pay to put the fences around your field?

No, these are my neighbors

Have the buffalo going on the road ever caused a problem?

Not to her because her rice paddie is facing a small road. If it was close to a larger road, it could be a problem.

Do you know of anyone whose cow was hit by a car?

No, I don't think accidents happen around here. Maybe closer to town.

Do you usually take your buffalo out or do you leave them in the pens?

I bring them out every day.

Do you tether all of your buffalo?

The two big ones, I let the small one roam.

Do the roaming buffalo ever cause damage to the surrounding areas?

A lot of the farmers she knows complain that buffalo go to their fields and eat their munk beans and soybeans. Not her buffalo in particular, as far as she knows. (Very sly haha)

Did your buffalo ever run away? How did you find them when that happened?

Yes, especially during mating season. I walked around until I found them. *(Side: another person also mentioned that animals running away are more common when they are in heat or they are unhappy with how much food/water there is in the stables)*

C.4: Twelve Cows, Fish Man

BACKGROUND: Man, mid 40s, 12 cows, big area with cows in the pens, a pond. We drove out to his farm in a truck and he caught us fish and his mother gave us peppers and vegetables. He is part of the Raitong farming cooperative. (SO nice, also very well off)

Do you take your cows outside of the pens?

Because of the dry season, there is not enough water and grass outside, so he has to keep the cows in the pen and feed them with hay and cow feed.

If there was more water, would you let your cows graze? Is keeping them in a pen temporary?

Yes, it is temporary. I use the pen now and during the rainy season when there is not much grass around. I feed them rice hay and food from the store.

How many cattle do you have?

10 grown ups and 2 calves. The cows I have are Brahmin, one European cow and one Brazilian cow.

Are the buffalo on the other side of the fence yours?

No, they are my neighbors. We only grow cattle.

Has the fence always been up around your territory? Did you ever use to share the grazing land with the neighbors?

The fence is to protect from the baby cows that want to escape. I have 18 rye of land and not all of it is fenced up, just where the cows are.

Are your mung beans fenced off right now since cows like them?

They are fenced off with a barbed wire but cows still manage to get in. Because it is so dry outside, the cows really try to get anything green.

Have you tried electric wire? Would it be too expensive to set up and take down?

I use electric fencing already but it is too dangerous for the baby calves. I have 120V running and the baby cows were visibly shaken upon contact. I noticed that if a grown cow touches electric fencing, it affects their breeding, making you need to wait longer in between times she can have calves, instead of waiting 3 months, it becomes 6 months or so. This also varies with the breed. That's tough because we have different breeds in the same herd.

Have you ever lost a cow? Have they escaped and ran off?

No, the barbed wire makes it impossible for them to go outside. I also keep them in the pen whenever there's nothing for them to graze on outside. When there is fresh grass, the cows eat some 40 kg/day. With dry food, they eat some 10kg/day so I am worried that they will become skinny.

C.5: Two Cows, Mid 70s Man

BACKGROUND: Man, mid 70s, Areeya arranged the interview.

How many cattle do you have?

I raise 3 cattle at the moment but I used to be a middleman to buy cows.

Do you keep the cows on your own land?

I keep my cows on my daughter's fields. I bring water to them several times a day.

Do you tether the cows when they're in the field?

Loosely tethers them, being especially careful when they're young so they can grow into the tether.

When you used to herd cows in the past, was traffic ever an issue?

If you keep an eye on your cows it is not a problem.

Do you give any treats to the cows?

Molasses and fermented hay to make them have a better digestion.Have to be careful with how much rice bran you give to the cows so they don't get an upset stomach.

C.6: Electric Fence, Son in College Man

3/23 We walked to this farmer's land and he showed us his electric fence set up, which his son had recommended and he just recently installed. He sold cattle to pay for son's vet schooling.

Before recording started: Man aged 40-50s has 4 cows and made a joke about the rest of his cows going to university. He sold 13 of them to pay for his son's university education in Bangkok to become a veterinarian. His son graduates uni on March 29 (this Friday).

H: So you said you had like 12 cattle before your son went to school?

A: I had 17 cows before. When he was raising 17 cows. He just let them within his property which was about 20 rye. At that time he was also using chemical fertilizer to feed the plants. Since then he's converted to organic farming so he's growing less grass and not using chemical fertilizer. At the same time he has less cows.

F: Do you still let them to pasture on your property?

A: He keeps them inside maybe 7 days and then let them out walking around here. Because if you let the cows out then they may go into other people's farm.

H: But don't you have enough land to let them graze on your own land?

A: It's enough for all of them here. He also fed them rice bran. One kilo per cow and he feeds them two times a day. Morning and evening. He's not like raising them and fattening them up for sale and stuff. It's mainly to raise them and not keep them too fat, just for babies and stuff.

F: Do you have fences on all of your land or just here?

A: And so you get grass growing and in dry season he has to protect his land so that other cows are not coming in. And he also uses electric fencing and basically just lets out the electricity.

F: Is it hard for maintenance?

A: Just to make it clear: the fences around the perimeter are electrified but the inside fences aren't.

A: The cost isn't that much because even though he uses the electricity he only uses 15 units he doesn't have to pay that much. It's considered no cost at all.

F: If the cow gets shocked do they know not to go near there again?

A: Some cows run away, some cows try to jump over the fence.

I: When the land floods during the rainy season, do the pole come off?

A: During the rainy season he doesn't have the electric fencing. He just let it be. He doesn't have problem with flooding.

H: When other cows come and graze on your field do you coordinate in advance or does it happen by surprise and then you get upset by them?

A: So other cows come in and graze in his area first. And then he went and talked to the owners and said my cow your cow, we have to find a way to manage it. And then he put up the electric fences.

N: Does he still let his cattle graze day to day or do they stay mostly inside?

A: Right now they're just mainly inside.

F: When you do let them out, do you tether them or just let them range free?

A: Mostly right now just inside. So during the time when he doesn't grow anything and he got electric wires around, he let them out and they just graze in his land.

F: What's their reaction with the shock?

A: His cows when they touch the electric shock they just won't go near it again. One try and they'll learn it. They won't go close.

I: Do you mind telling him what we're working on and see if he has any feedback? Anything he would recommend.

A: He has other jobs so he doesn't have time to go with the cows like that and herd them. So that's why he doesn't do it.

A: *tells him about project*

A: He said raising cows is easy. They have to get familiar with you. Once they get to know you you can pet them. They're not stubborn. If you let them free range like that, they will become afraid of strangers easily.

F: Since he's one of the only people we've seen with fences, does he think that having fences is moving to a more innovative system? Or is it just because he has more cattle than most people?

A: Many people would probably prefer to take the cattle out but that means that they will use a lot more energy. That means that taking the cattle out makes them more thin.

C.7: Mung Bean Woman

Mung bean wife. She lives across the street from Raitong farm. Currently sitting at home and sifting through mung beans.

H: Have you ever lost either of your cows?

A: Nope. they don't seem to go anywhere.

H: Do they mostly stay on your own land?

A: He sister. She ties them up at her sister's farm. He husband will take them out and tie them to trees somewhere.

H: How many ryes is your farm?

A: 8 rye.

H: And your sister's farm?

A: About 12 rye.

H: Is there sort of treat or special treatments that you give the cow that they like?

A: She feed them rice bran. Grass. And she mixes molasses, rice bran and hay. And they like that.

A: I asked her if she sang to the cows and she say no haha.

H: When you're taking them to your sister's farm do you take the roads or just go straight across?

A: She take the brim. So, yeah, just go through the paddy fields.

N: What else does she farm?

A: Mung beans and rice. She's also part of the group that we're working with. The co-op.

H: your cows, they seem like they're pretty young, at least that one. How valuable are your cows to you in a subjective way?

A: She used to have 5 cows and sold 3 last year. Now the price is really low so she doesn't want to sell it. Now it's about 10k baht. So she doesn't want to sell it. So she uses the manure as compost. So yeah if the price goes up and people are willing to pay the price she wants then she's willing to sell it.

N: Has she ever lost a cow?

A: No.

N: Does she know of anyone who's lost a cow?

A: No, she doesn't know of anyone who's lost a cow.

F: Do the cows ever come and eat her mung bean? Or someone else's cow?

A: She's close to the cows so if she sees other cows coming she shoos them off. Her daughter's cows come and eat her mung beans.

H: Is that frustrating?

A: She will tell them not to let the cows go around. Especially when the beans are this big.

I: Are they ever in the roads? (Can't hear question)

A: She doesn't know anyone who's cows have been hit by a cow. He daughter's cows sometimes run across the road.

F: Does she put them out to pasture every day? What's the daily routine?

A: It's too hot. The sun is too bright and they won't take them out. She takes them out around 6am in the morning for water. If it's too hot she won't take them out and then around 4pm she will take them back.

F: Does she always tie them?

A: She ties them to trees using the hole in the nose.

A: They're really tame.

M: Do they pull on the rope when they're being herded?

A: they just keep holding the rope and let the cows walk in front of them.

F: Do you ever hit your cow in the butt?

A: She doesn't hit the cow.

F: Has anything ever happened where they got scared and went out of control?

A: She doesn't have that problem. They are pretty tame.

C.8: Two Cattle Farmers Making Charcoal

Background: We drove over to a nearby farm where two farmers were making charcoal in a small clay dome and walking their fields. One was peeling a ripe mango.

Areeya: He said there's a law that if you hit a cow at a certain time in the morning or evening, it's your fault. But if it's past that time then it's the cows fault.

F: Is the law enforced?

A: Yes, a lot of people have their cows get into accidents. So even at night, if the car hit the cow then they can also take the cow if it's the cows fault. So if the cow costs 1000 dollars

F: So if it's the driver's fault, it's a fine or something?

A: They have to pay the fine. The fine is up to the worth of the cow. So it depends. If it's the cows fault then you have to pay the maintenance and repair for the car. I'm not sure which law this is either so you might have to do research.

Stops to move car that had gotten suck falling off the edge of the road into a dry rice paddy

N: How many cattle so they each have?

Farmer 1: 7

Farmer 2: 4

F: What are their names?

Farmer 1: San Dta (He doesn't know how to spell his last name.) 56 years old

Farmer 2: Siem Duang Pon. 57 years old

F: How much land do you have?

San: 3 rye of his own land.

Siem: 18 rye.

A: So usually land requires that they have to go to other paddies to steal their grass to feed the cows. So that's why they have to leave early so the owner doesn't know.

F: Are you mainly cattle owners or do you just have them as insurance?

A: Mainly sell it and land. You can also get the manure. They're also trying to do organic farming so you can use it as fertilizer. They also have baby cows you can sell for money. The price in the market can go up to 25-35k baht per cow. That cow could give you 25k baht. I'll as more about the land.

A: I asked him if you can have as much land as you want to raise cattle how much would you need? He said he doesn't know, just unlimited. If he doesn't have his own area but just to graze, 5-6 rye would be enough.

H: So you might not have enough land for you cattle to graze on yourselves, but if you want the manure do you try to keep that on your land or does it wind up on the land the cattle graze on?

A: For some land owners, they're fine with it for them to go but they can also get the manure.

F: So what's like the overall maintenance of having cattle?

A: You have a pen like this and then you grow the grass and find something to feed them. If you have more you have to take care a lot more.

F: So every morning and night you herd them?

A: Yeah. Morning they take them out and noon time they come like this and drink the water. And then they go and tie them up by the trees.

F: So when they're out, they're tied.

A: Yeah

F: Does everyone do that?

A: The babies, they just let them go and the big ones they time then. About a year and two months they do the rope through the nose.

I: Do they choose where to tether each cow each time?

A: So he try to find a place that's got some grass growing and tie them up there. So because it hasn't rained in a while he has to walk farther to find a place where they can eat grass in one place.

F: Is there a time where the cattle was hurt and they just knew it? So if the cattle was sick or something, how they knew it was sick.

A: It kinda stop eating and become really sad and lonely. Tears dropping down. They give them pills to take out their parasites. They usually just don't eat much.

F: Do cattle have any sort of special treats or fruit?

A: Cows love mangoes!

F: What positive things do they respond to?

A: They'll demonstrate when the little cows come to drink the water. They pat the head, pat the back.

F: Do they every hit or shock the cattle?

A: They try to familiarize the cattle and get used to it. They hit them at the back. Not on the head. It will die. With a little bamboo stick or something.

N: Have they ever had a cattle get lost?

A: Yeah. They have to go into different village. Make like announcement. Last month, a lot of farmers couldn't come to the meeting because they have to go and help other people find their cows. Especially the new cows if they're not used to the owners they just run away?

I: How long does it take the cow to get used to a new owner?

A: 2-3 months. They will know the smell of the owner and then they get friendly.

N: What happens that makes them get lost?

A: Either the rope is broken or someone comes and steals the cow. Or the tether comes out of the ground. Some of the cows get lost or escape. Then they come back. Sometimes they just go look for mangoes to eat and come back. They usually come back in the evening. Especially around mango season they get lost. If they can reach, they'll eat all the mangoes.

F: Is there anything that scares them?

A: The small ones are scared of dogs. The big ones are not. The dogs are afraid of the big ones. The cows can also be scared of loud concerts at night. Sometimes they have loud concerts in the village and the cows will run away. You try to hold them and you can't.

A: If you have the rope tied to your hand they will take your hand away. One of the cows in the other village was tied to a person's thigh and broke their hip. You can get cut as well.

F: So when they get scared, they're really strong?

A: You have to let it go. Just let it run away. And then it calms down.

F: Is there any sort of insurance for cows?

A: No.

A: But if you become group of livestock farmers then they'll get blood samples and test it of diseases to prevent disease outbreak. But insurance for like lost cows or accidents. No.

N: Would they pay for something to be able to know where their cattle are when they get lost or be able to keep their cattle out of the roads?

A: Maybe, yeah. If there is such thing then maybe they can give it a try.

F: Do you have any questions for us?

A: Are you gonna become cattle professors.

I, F, N: No. Probably not.

A: What do you study?

F: We're engineers.

H: I'm like a marketing student.

M: Film.

Appendix D: Testing Results Summaries

Table 3: Initial Electronics Outline for Testing

	Requirement	Way to quantify	Idea for testing
1	Withstand high temperatures	Research average temperature of summer in Thailand. Use device at this temperature.	Heat device (oven?) to this temperature for one hour, take out and judge device function.
2	Long battery life Able to continuously charge without overheating the battery in hot/humid conditions	Judge function over time. Temperature of the battery and its charging/discharging rate or capacity	Leave device on for as long as it takes to run out. Test under different use cases as well: In heat, rain etc. Make a humid hotbox. Put a plugged in Li-On battery in there with a temperature sensor and an ampere meter. See if increasing humidity/heat significantly affects performance.
3	Communication range	Research distance from farmer to cattle.	Test device signal at this distance.
4	Interface with Cattle	Put on humans or similar sized animal. comfort	Wear collar for a day. Check for wear/comfort level Do they try to take it off?
5	Sends data to user	Look at the collar and visually determine if it is in the location that the data reports.	Code data to decipher geographical location and test in shop/Ford lawn.
6	Responds to remote	See if it responds to remote.	Try to use remote.
7	Waterproofing without adhesives	Measure humidity/liquid seeped into a plastic container	Try silicone, gaskets, snap fits. Submerge the plastic part in water for a controlled period of time. Measure the humidity

			inside the case / any visible water content.
	Durability	Cycle Testing	1. Stamping 2. Dragging 3. Scraping 4. Scratching 5. Water exposure and submersion 6. Pulling (tensile) 7. Heat 8. On cattle field test

Table 4: Initial Visibility Outline for Testing

	Requirement	**Way to quantify**	**Idea for testing**
1	Interface with cattle	Security - based on cattle movement and habits to quantify the security Cattle Comfort Can be put on and off	Check for chafing
2	Doesn't get obscured over time	Check visibility after being exposed to the elements.	Cover in mud. Stamp into dirt.
3	Visible when exposed to car lights/effectiveness of the photo reflective material	1. Choose distance that a car would need to see cattle. 2. Digitally: either see the overall color balance of a picture or spot pick the lightness of the reflective material	1. Measure amount of reflected light with device. At Dawn/ Dusk. Considering obstructed view (i.e. through trees) 2. Make a dark box setup and take pictures of the object with flash. Digitally analyze the taken pictures. Must be careful that the pictures are taken in the same setting for uniformity.

4	Visible at night and day time with an active light source	Digitally: compare the overall brightness of a picture or different LEDs	Make a dark and lightbox setup and take pictures of different prototypes/light sources. Analyze digitally.
5	Durability	Cycle testing	1. Stamping 2. Dragging 3. Scraping 4. Scratching 5. Water exposure and submersion 6. Pulling (tensile) 7. Heat **8. On cattle field test**
6	Sustainability	Able to be repaired and recycled	
7	Cost Effectiveness		Is repairable, is resistant
8	Intuitive Interface for user	Test screens with users in the US and Thailand	XD prototyping

Table 5: Initial Outline for Post Testing

#	Description	Procedure	Collected Data
1	Maximum bend angle of panel.	Bend until stops conducting. Measure angle.	Angle
2	Force required to reach the bend angle	Use a strain gauge to measure force required.	Force
3	Maximum shear force of structural glue	Apply force to the glue until delamination is reached.	Force
4	Time taken to complete panel attachment	Perform 10 attachment runs, average the time	Time
5	Force required to change panel incidence angle	Attach the panel at the required angle. Apply force until it displaces.	Force
6	Time taken to hammer the post to the ground as deep as required	Hammer the post to the ground until required depth is reached.	Time

		Perform 10 runs. Average the time.	
7	Number of hits with a mallet required to reach the required mounting depth	Record the # of mallet hits required to reach the mounting depth. Perform 10 runs	Number of hits
8	Lateral force withstood by the box without deformation	Apply lateral force to the box until deformation is reached	Force
9	Normal force withstood by the box without deformation	Apply normal force to the box until deformation occurs	Force
10	Normal force withstood by the zipties without displacement	Apply normal force to the zipties until they start sliding	Force
11	Drop force required to break a panel	Drop things on the center panel module until it stops conducting	Force
12	Number of drops from post height required to break the panel	Drop the post until the panel stops conducting	Number
13	Cable attachment force	With cables attached to the post, measure how much force is required to pull cables off	Force
14	Cable attachment size	With cables attached to the post, measure what size of thing can get in between cables to pull them off	Size, cm
15	Box waterproofing	Submerge the box in water for 30 minutes. Record observations.	
16	Battery temperature	Run the post at full capacity. In hot room. Measure temperature change.	
17	Force to tear post off the ground	Exert force on the post until it shears off the ground	Force

D.1: Software Testing on Campus

Software testing was conducted in various locations on campus, including: along Sheridan Road, inside SPAC pool, at south beach, and Long Field Park. Testing was also conducted with wire

antennas in covered/uncovered environments, with special antennas intended for outdoor use, and power ranging from minimum to maximum.

For each test, five RSSI readings are taken at distance increments ranging from 1 to 150 feet. The approximate size of one rai is 131 ft. The signal strength is then graphed in order to measure the accuracy of the arduinos at these distances.

The synopsis of the results is that the 433MHz arduinos that we used were not sensitive enough to create a viable containment system. We recommend continuing the project with an 866MHz arduino or device meant for shorter range.

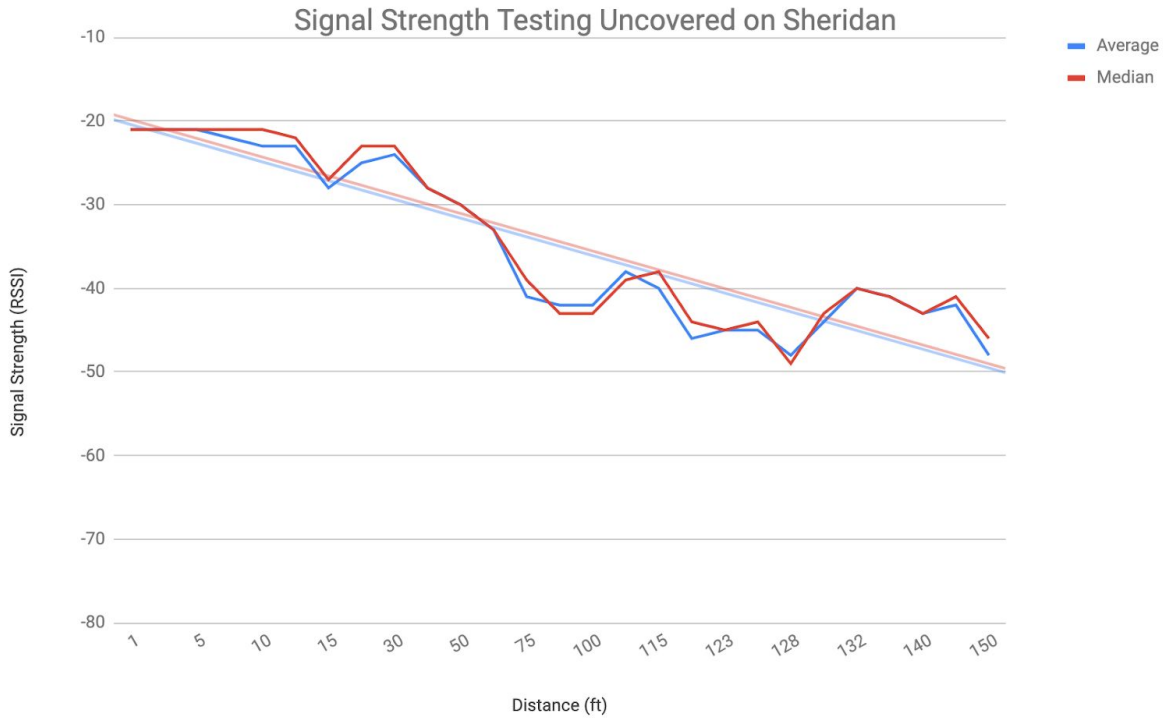


Figure 14: Signal strength testing, using uncovered wire antennas along Sheridan Road.

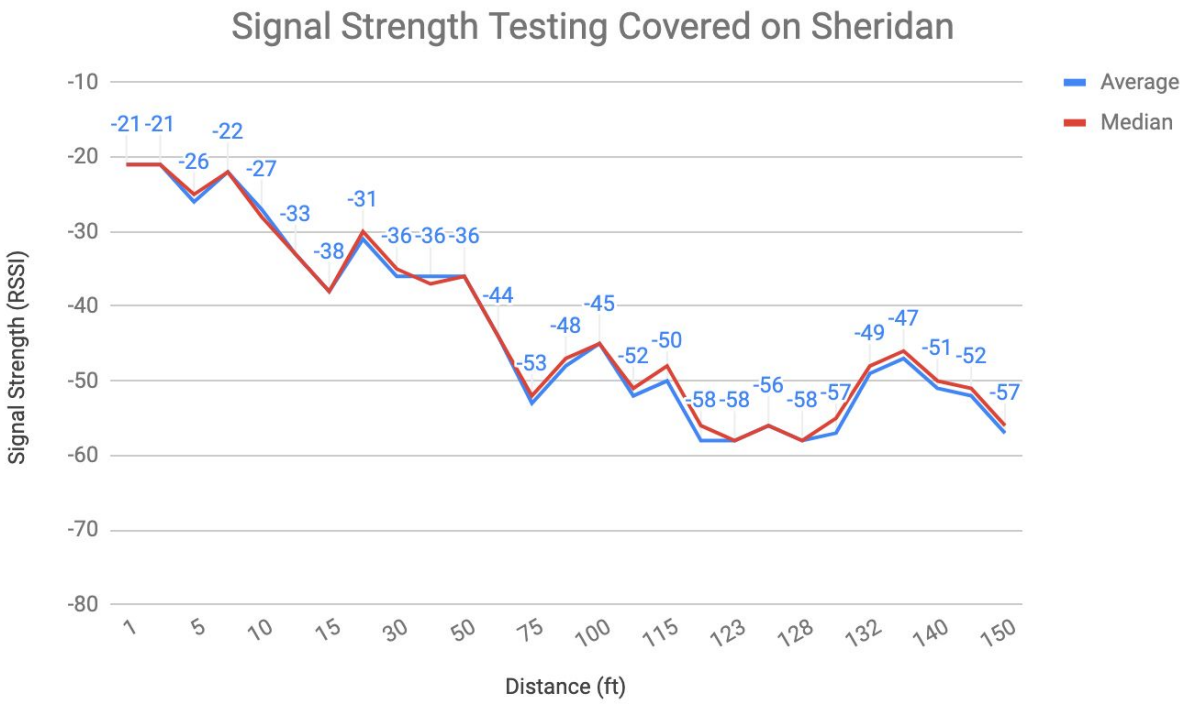


Figure 15: Signal strength testing, using covered wire antennas along Sheridan Road.
*covered = both transmit and receive arduino feathers and antennas were inside thin tupperware

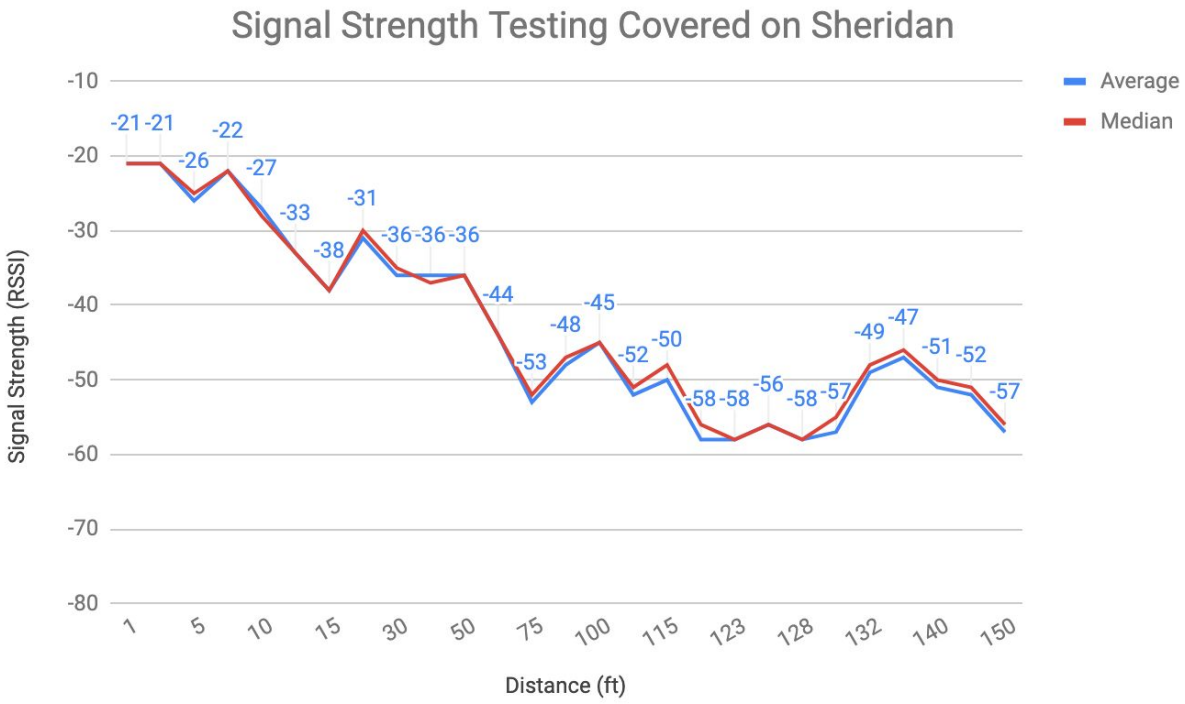


Figure 16: Signal strength testing along Sheridan Road using 15cm outdoor antennas specified for arduino

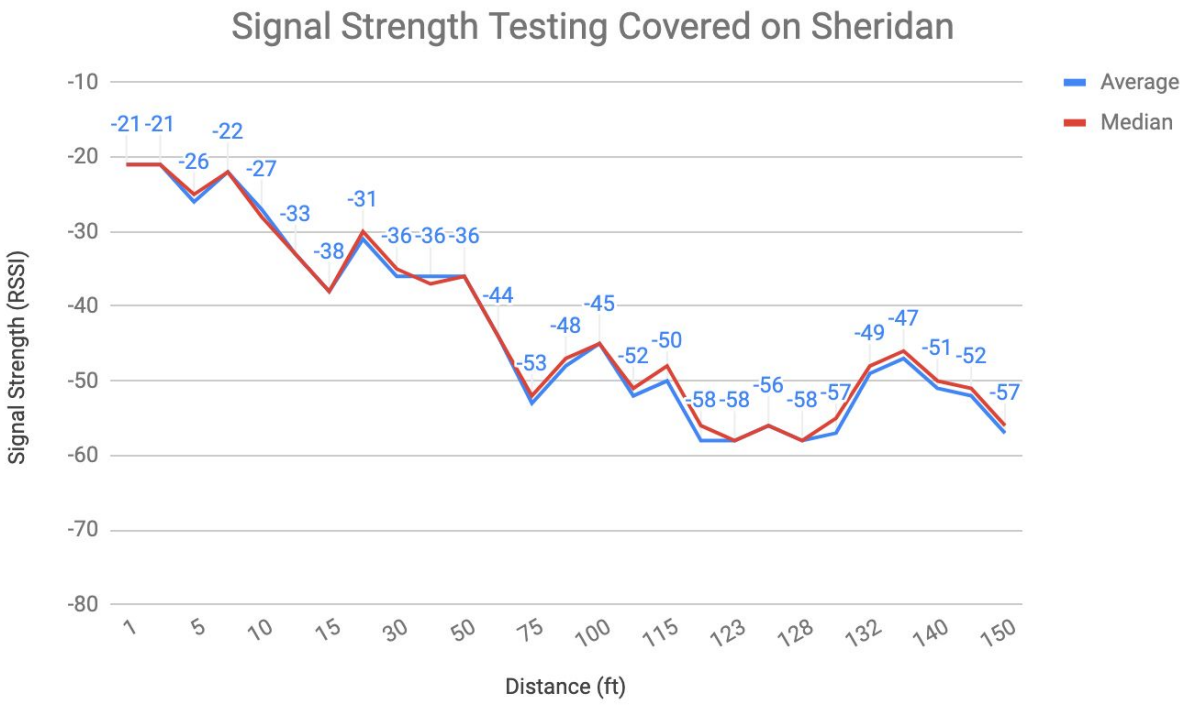


Figure X: Signal strength testing at south beach

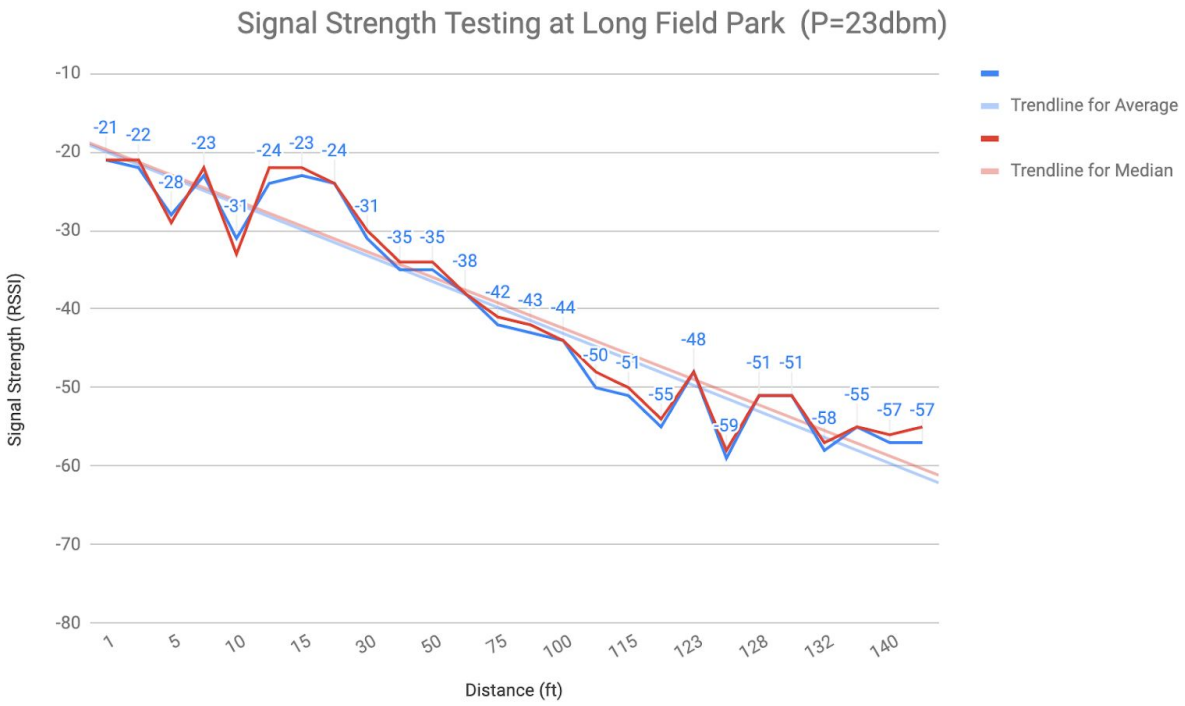


Figure 17: Signal strength testing at Long Field park using full operating power (23bdm)

All tests up until this point had been operating on full power.

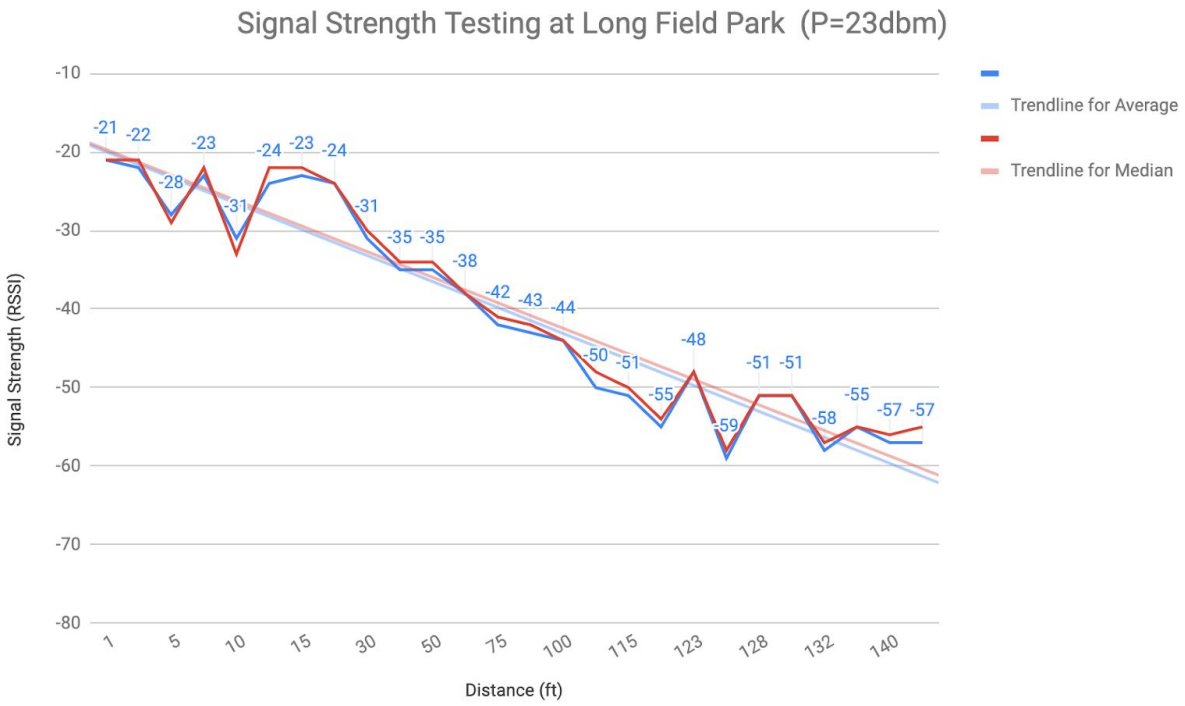


Figure 18: Signal strength testing at Lincoln Park with medium power of 13dbm.

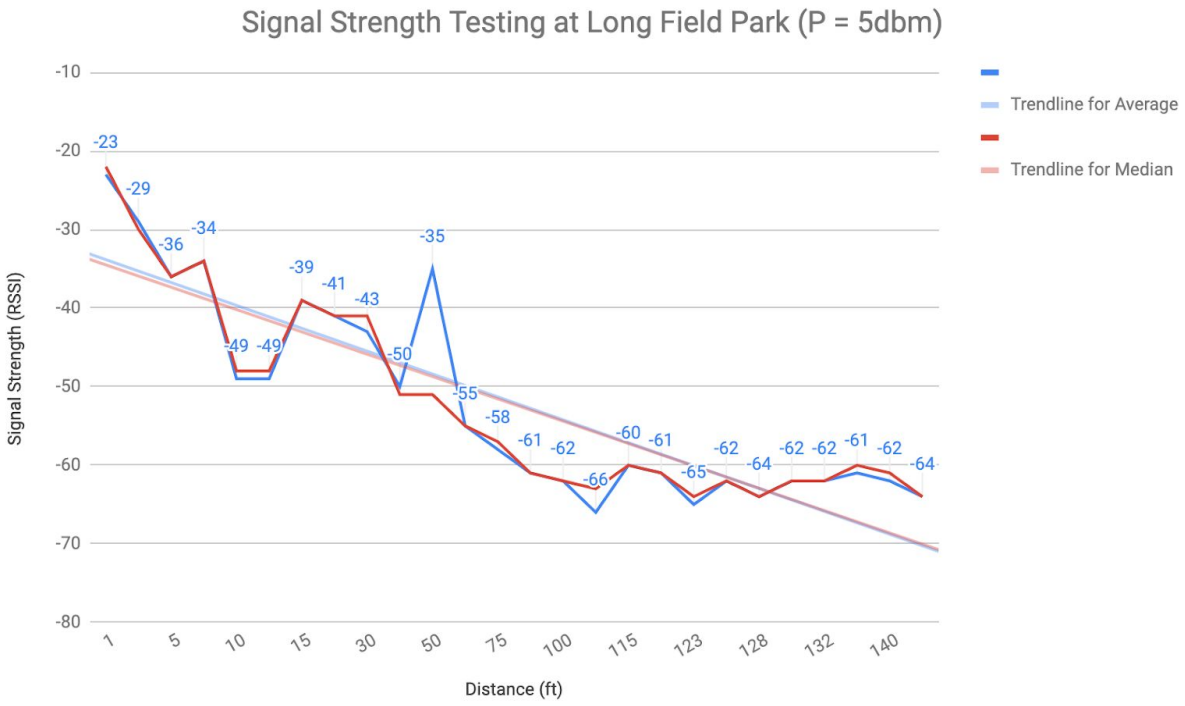


Figure 19: Signal strength testing using minimum power of 5dbm.

D.2: Testing at Raitong Farm in Thailand

Testing Summary 1 - March 30, 2019
Visibility - Qualitative Field Assessment
Raitong Organics Farm

Given the opportunity to visit Raitong Organics Farm meant we were able to test our initial visibility prototypes in-situ. By observing and timelining the processes of affixing our prototypes to cattle, cattle behavior once prototypes were on, the approximate duration a prototype remained functional on the cattle and prototype durability given a consistent cattle environment: the pen, we aimed to reveal and gain intuition as to the feasibility of different physiological locations on cattle for our visibility prototypes. An additional purpose of our qualitative assessments was to evaluate our material selection choice. While not extensive, we were able to identify a direction to pursue in testing nylon ripstop versus a polyester blend for further material selection.

Our testing revealed several major oversights, particularly limitations in our prototypes ability to interface with certain physiological areas such as the ankle/lower leg and hump. Furthermore, we learned that in short-term durability nylon ripstop out performs the polyester blend in observable dirt and debris uptake.

Additionally, we saw the success of two prototypes, the collar and the hat. The collar's success was of no surprise, as we've seen it implemented before. The hat however presented an interesting solution as it was highly visible from all angles--its limitation however was that it had to be affixed to horn, which not all adult cattle breeds have.

Methodology:
The methodology for our testing proceeding in the following manner:

1. Wrangle cattle, place in standchen
2. Apply prototype to cattle [comparative assessment of time to load]
3. Observe cattle immediate reaction
4. Observe cattle and status of proptype after ~1 hour
5. Observe cattle and prototype status after ~5 hours
6. Observe cattle and prototype status after 1 day
7. Observe cattle and prototype status daily onwards

Results:
[Ankle failure IMG]
[Hump failure IMG]
[Polyester vs Nylon]
[Hat success]
[collar success]

Our testing results inform our decision to pursue a neck located collar that specifically addresses the constraint of needing to be seen from all angles around the cow. The decision not to iterate on the other prototypes stems from particular immediate needs of the client and the limited time frame of the project.

D.3: Testing at Wagner Farms

Wagner Farms Testing Summary - April 24, 2019
Prototypes Tested
1: Foam 1 (adjustable) 2: Foam 2 (cobra weave) 3: Shocker collar on adjustable nylon strap, 4: Post with solar panels.

Shocker testing

The farm was not comfortable with us testing electric shock on their cattle with the standard collar. They were open to a possibility of testing if the integrated version of visibility collar/shocker has a good enough skin contact to deliver a shock but just to see if it works and not to see how different shock levels affect their cattle.

Table 6: Mounting, removing and failure observations

Prototype	Mounting Time	Removing time	Duration secured	Reason for Failure	Observations
Foam 1	26 seconds	<5 seconds	6 minutes	In both cases, the collar got snug but the angle of the foam cap was not steep enough to rest on the ridge of the spine - it slipped right off to the side.	The foam cap was appropriately sized for the adult cows, but not for the younger. The calf bucked around, as the foam was resting closer to her head than on the adult. The Wagner cows were far more docile than any of the cows at Raitong.
Foam 2	15 seconds	<5 seconds	3 minutes		
Shocker	40 seconds	<5 seconds	N/A	N/A	The shocker can only be attached to the convex part of the neck to achieve required surface contact. There are two possible mounting locations: the muscle right below the spine on the side, the muscle below a large triangular concave part of the neck. Wagner farms confirmed that attaching the shocker to a bony part (i.e. spine) would likely cause calluses in the cattle.

Post	3 minutes	10 seconds	10 minutes	Epoxy bonded to smooth polymer case beneath solar panels was the first to fail - might need to etch/score plastic for a better bond or look into alternative securing solutions (VBH tape)	Cows come up and inquire about the post - sniff, lick, at most a nudge. At this height, they are able to get their snout under the panels and flick up (which popped the panel off the post). Post stayed firmly in the ground. Could be easier to use a metal stake and place the pvc tube around it.

Table 7: Foam visibility evaluation

Note: Thai cows have a hump so the prototype back visibility will be diminished

	Area visible from the front (in2)	Area visible from the back (in2)	Area visible from the side (in2)
Value			
Image			

Table 8: Misc observations and action items

#	Prototype	Observation	Action item
1	Post	- Repeated hitting with a mallet caused displacement of the metal zipties securing the electronics box - To reach the specified 15” depth, continuous hitting for about 3 minutes was required even when chosen ground was fluff.	- Consider changing the box attachment or constraining it vertically - Consider making the post stay on the ground instead of hammering it into make the post work better in dry season when the ground is harder - Instead of tapering the PVC for attachment, consider attaching a cone end to it

2	Foam	- The prototype slid off because of semi-circular shape. - The prototype fit some cows better than the others - A single attachment at the bottom didn't prevent the shocker from sliding sideways	- Make the shape look more like a "V" to contour to cows neck - Make the width of the prototype easily adjustable to fit different cows - Incorporate a method of securing the foam to the side of the neck as well as the bottom.
3	Shocker	- Adjusting the strap to fit the cow well had to be done with the prototype not on the neck of the cow - Adjustable part of the prototype got disattached and had to be redone - The adjuster got looser with use	- Make the adjuster easy to operate when it is on the cow - Make the adjuster permanently attached to the strap - Use an adjuster that does not get loose quickly

Figure 20: Neck Cross section and Shocker location analysis

Wagner Farms Testing Summary - May 31, 2019
Prototypes Tested
1: Foam 1 - final prototype 2: Post prototype with wood ballast
(No electronics were tested at the farm.)

Visibility testing

Appendix E: Post Calculations

This section contains the mathematical reasoning behind the design for the transmitter post hardware.

Average mass of the cattle $\overline{m} = 330kg$ (Thailand data)

Average body acceleration $\overline{a} = 0.75g \cong 7.35\frac{m}{s^2}$

Average leg acceleration $\overline{a_{leg}} = 1.8g \cong 17.64\frac{m}{s^2}$

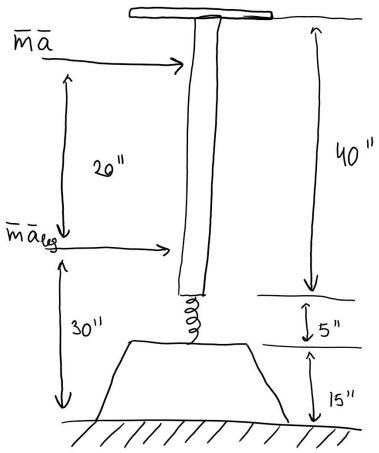
Previously determined required post height $h = 60" = 1.52m$

To introduce some constraints, assume the base and spring together will be about 20" tall so the post will start 20" off the ground.

Previously determined cow kick height $h_{leg} \cong 30" = 0.76m$

Cow head height $h_{head} \cong 50" = 1.27m$ (Thailand data)

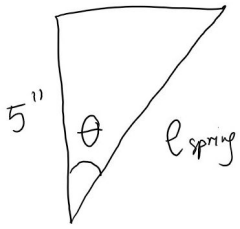
Considering heights above spring, $l_{leg} = 10" \cong 0.25m$ and $l_{head} = 30" \cong 0.76m$



$$M_{leg} \cong \overline{ma_{leg}} l_{leg} = 1455.3Nm \quad M_{head} \cong \overline{ma} l_{head} = 1819.2Nm$$

So the force exerted by the cattle's head will be a limiting factor.

In order to prevent the spring from bending excessively and hurting the cattle, limit the spring bend to $\theta = 45°$. Then $l_{spring} = \frac{5}{cos\theta}$ and $\Delta l = l_{spring} - 5"$.



Assume all force from cows head interaction is translated to spring. Then

$$F_{spring} = k\Delta l = \frac{M_{head}}{l_{head}}$$

$$k = \frac{M_{head}}{l_{head}\Delta l} = 38.8\frac{kN}{m} \cong \frac{220lbs}{in}$$

So a 5" corrosion resistant steel spring with the specified spring constant was ordered for the design.

To prevent the ballast box from tipping, we need to satisfy

$$F_{spring}l_{spring} \leq \frac{W_{box}a}{2}$$

Where a is the width of the box.

The dimensions of the box are then controlled by the ballast material.

As an example, assume square box of side length $a = 0.5m$. Then $W \leq \frac{2F_{spring}l_{spring}}{a} \leq 388N \cong 40kg$.

If the box were to be filled with sand, $\rho_{sand} \cong 1600\ kg/m^3$ and be rectangular in shape with height h,

$$V\rho = a^2h\rho = 40h \cong 0.1m \cong 5"$$

This relationship was used to verify chosen box dimensions.

Solar Panel Angle

The efficiency increases by 4% by adjusting the angle twice a year[29]

	Fixed	Adj. 2 seasons	Adj. 4 seasons	2-axis tracker
% of optimum	71.1%	75.2%	75.7%	100%

[29] https://www.solarpaneltilt.com/

The optimal angle depends on the latitude of the location.
Ubon Rachatani province is latitude ~15.
The optimal angle is 0.87*15=~13 degrees

Then the increase of the adjustment will be some 2% → not worth the effort of making the panel more adjustable.
The panel should be at 13 degrees tilt throughout the years.[30]

[30] https://www.solarpoweristhefuture.com/how-to-figure-correct-angle-for-solar-panels.shtml

Appendix F: FMEA

The following section is a failure modes and effects analysis framework for the transmitter post.

Table 9: FMEA Rating System

Rating	Severity (S)	Occurence (O)	Detection (D)
1	No effect to Minor. May be noticed by customer	Rare	Certainly detected
2	Customer is inconvenienced	Infrequent	Reasonably detected
3	Reduced performance level. Dissatisfied customer	Frequent	Detectable before reaching the customer
4	Inoperable item. Loss of function.	Very Frequent to High	Detectable only by the customer / during service
5	Safety related catastrophic failure. Regulatory noncompliance.	High to very high	Undetectable until catastrophe

Table 10: RPN Descriptions

RPN := Risk Priority Number. Interpretation Criterion	
RPN Value	Interpretation / Action
1-17	Minor Risk: little or no action is required
18-63	Moderate Risk: requires selective product validation and evaluation of the design/redesign to reduce the number
64-125	Major Risk: should be given high priority and design revisions should be taken to reduce RPN

Table 11: FMEA of Post

System	Description	Comments
Subsystem	FMEA for the post system	The post system is considered to be made of the following parts: solar panel, panel to post attachment, electronics container, post spear, antenna. FMEA for the electronics within the

Component		container will be done separately.													
1	2	3	4	5	6	7	8	9	10	11					
Function	Failure Mode	Effects of Failure	Mechanism/ causes of failure	Current Controls	S	O	D	RPN	Recommended Corrective Actions	Actions Taken	S	O	D	RPN
Solar Panel	Mechanical failure	Cell stops working, module stops working, reduced energy output, attachment mechanism failure	Animal stepping on module	Above animal leg level				0						0
			Animal kicking the module/post	Above animal leg level				0						0
			Adhesive overcuring due to temperature conditions	Using glue with high curing temperature				0						0
			Heavy weight falling on module	If side: flexible panel will bend. If center: could shatter the module				0						0
	Electrical Failure	Cell stops working due to temperature, connectors breaking, connection from panel to battery breaking	Heavy rain, extreme temperature conditions	Waterproofing				0						0
			Animal stepping on module	Above animal leg level				0						0
			Animal getting caught in the wiring and tearing it	Tightly attaching the wire to the post				0						0
Panel to post attachment	Mechanical failure	Adjesive failure on post or panel side. Fastening mechanism failure (over-shearing the threads).	Adhesive overcuring due to temperature conditions	Using glue with high curing temperature				0						0
			Shear force experienced exceeds adhesive	Using Structural Lock-tite				0						0

		Improper attachment leading to panel separating from post.	shear force										
			Incomplete attachment by the user leads to failure	Rework the attachment mechanism so it can't be partially secured				0					0
	Mechanical failure	The hinges of the box failing to open/close. The metal zipties sliding off the post. Attachment tabs deforming	Impact with an animal	Above animal leg level				0					0
			Repeated use wear	Externally sourced box				0					0
	Waterproofing failure	Door bending. Door/connector gaskets deforming.	Impact with an animal	Above animal leg level				0					0
			Repeated use wear	Externally sourced box				0					0
Electronics Container	Electrical failure (battery)	Shorting of connectors. Overheating due to outside temperature or demand/supply ratio.	Connection with water and metal. Continuous charging and discharging in hot temperatures.	Battery breaker circuit and two separate batteries. Externally sourced box for waterproofing				0					0
Post Spear	Mechanical Failure	Failure to attach to the ground. Failure to attach to the panel attachment. Mechanical failure due to repeated hitting. Material damage from water	Improper attachment depth by the user.	Mark the required depth on the spear				0					0
			Adhesive overcuring due to temperature conditions	Using glue with high curing temperature				0					0
			Exposure to water for prolonged periods of time	Use waterproof material				0					0
			Nailing the spear to the ground for repeated uses	High cycle strength material				0					0