Design Pitch for Sheep_Link - a Cluster-based GPS GSM Sheep Tracking System

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Executive Summary

In Mthatha, South Africa, many farmers face problems with missing sheep. It is tedious work to look for the missing sheep as neither the shepherds nor the farmers have cars and information on where the sheep are. Therefore, they are looking for a cost-effective solution to make finding missing sheep easier. Our team's values are sustainability, functionality, and accessibility. This helped to develop our scope, which is to make a reliable sheep tracking system that is accessible to everyone in the community and prevents sheep from wandering off or mixing with other flocks. Stakeholder analysis gives us the two prioritized objectives: cost efficiency and functionality to track the sheep. The prioritization of these two values scoped out alternatives such as fencing and existing tracking systems. However, fencing lacks the functionality to track sheep and pure GPS trackers have an excessive cost that cannot be afforded by the stakeholders. In the end, we decided to use Global System for Mobile (GSM) and Global Positioning System (GPS) to track the sheep with a clustering system which satisfies both of our prioritized objectives. GSM allows for the transmission of data through a 2G cellular network, which was chosen since the infrastructure exists to support this system in Rosedale. We divided the flock into small groups, called clusters, with each cluster having a leader sheep with a GPS tracker to locate the cluster. Each leader sheep pings the followers within the cluster based on the Received Signal Strength Indication (RSSI), and the followers reply with their ID which is unique for each sheep using the wireless transceivers. After getting each follower sheep ID, every leader sheep sends the information to the database using the GSM network. A clustering algorithm is used to detect missing sheep, and if there are any, those sheep will be displayed in the User Interface (UI) with their ID, the most recent location, and missing time. The customized color and engraved sheep ID on the tracker allow the stakeholders to easily identify and differentiate their sheep when looking for them. Our design allows for a delicate balance between cost efficiency and functionality by reducing the GPS modules needed, assuming that most of the leader sheep will be evenly distributed among the flock. Our sustainability demand is based on fulfilling the United Nations Sustainable Development Goal 12 (UN SDG12) which includes responsible consumption and production. Thus, the choice material of the tracker is PET which is a type of 100% recyclable polymer and can satisfy the demand for sustainability and protection of electronic units inside. In addition, we selected rechargeable batteries to minimize the cost and pollution.

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1. Introduction

Small sheep owners in the small town of Rosedale, Mthatha are struggling with retaining their sheep. As livestock farming plays a major role in their economy, losing sheep is critical [1]. There are several situations where a sheep could get lost; they could simply wander off, get mixed up with different owners' sheep, or could not be taken care of due to the absence of shepherds. Therefore, we and the stakeholders are seeking a solution that has reliable functionalities to track the location of lost sheep such that the loss can be prevented. Here, as the stakeholders include sheep owners and shepherds, the solution must be accessible in terms of cost (one of the most emphasized requirements by the stakeholder), portability, and ease of learning. Furthermore, as our team values sustainability as required by UN SDG 12, a design with a responsible consumption and production process that is durable is also preferred.

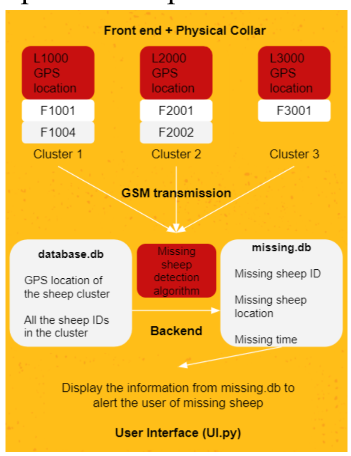

Figure 1 Sheep_Link conceptual design flowchart

Our solution is a system we have decided to call Sheep_Link. Sheep_Link is an accessible and reliable GPS GSM sheep tracking system that prevents sheep loss. The system includes the GPS GSM tracker collar, backend database and frontend UI. To balance between the two most highlighted high-level requirements by the stakeholders: cost efficiency and functionality of location tracking, we decided to use cluster tracking method. This allows the reduction of GPS modules needed by only tracking the location of clusters of sheep. There are two types of sheep trackers for each sheep to support this, a leader tracker and follower tracker. Each tracker stores a unique sheep ID: the leader's ID starts with an "F", and the follower's ID starts with an "L". Both types have wireless transceivers but only leader sheep has GPS GSM module to gather the location and transmit information to the backend database. When updating, leaders ping nearest followers based on the RSSI, and followers respond by sending their IDs to the leader. Following that, the leader sends all the IDs in the cluster and its own current GPS location to the backend database. The cluster size is customizable depending how many leader trackers the user wants, having smaller cluster size provides more accurate location tracking with a trade-off to be a higher cost because the GPS module is the expensive part of the tracker. A backend clustering algorithm will send missing sheep alerts including missing sheep location and missing time through the UI whenever a missing sheep is detected. Also, keeping the UNSDG 12 in mind, we designed the physical tracker to be using recyclable polymer [2], and rechargeable batteries.

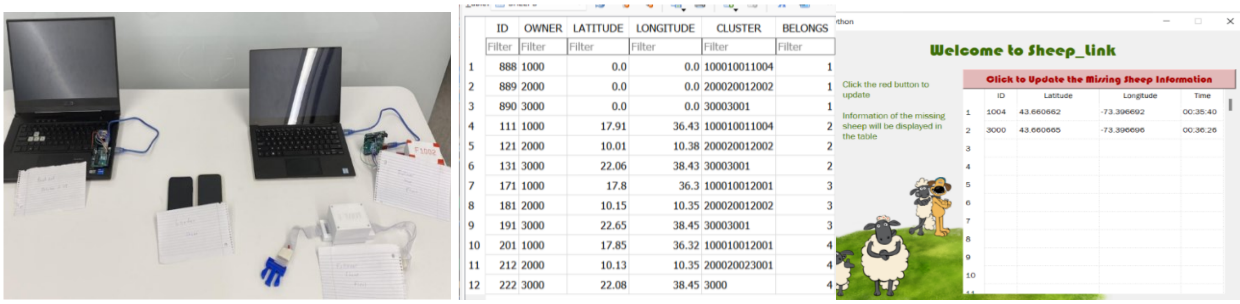

Figure 2 Final prototype of the trackers, the backend database and the UI

To verify this design, we prototyped two fully functional follower trackers (Figure 2) with the Bluefruit LE UART Friend module and Arduino UNO R3 microcontroller. The first follower collar has an ID of F1001 is powered by a 9V battery, and it has a complete case concealing the electronics with an adjustable belt strap. The second follower has an ID of F1002 is powered by the laptop but also has a case to store the electronics. We decided to use the phone as a proxy for the leader collar because the Bluefruit module app supports multiple UART modes, allowing us to ping several follower trackers at the same time, and it has the GPS location of the phone, making it the best representation of our concept. Once pinged by the leader, followers will send their IDs to the phone through the UART communication protocol over Bluetooth. This represents the GSM transmission module by manually sending the follower IDs and the GPS location to the backend database. The backend database and UI (Figure 2) was developed using SQLite and python and is fully functional. The algorithm can detect both missing leaders and followers. The UI displays all the essential information for the shepherds including the missing location and missing time of the missing sheep. The UI is also designed for better accessibility as it is available in both English and Xhosa and requires no technical training. The final prototype for one collar costs using MyFab facility prices amount to a total of $49.65 CAD (Appendix II. BOM)

2. Background

2.1 Stakeholders

The sheep owners in the rural town of Rosedale, Mthatha are the primary stakeholders. The stakeholders wish to have an economical solution that reduces their losses in owning a flock of sheep by reliably tracking the lost sheep. Currently, they need to search a vicinity usually 1-2 km away or nearby homesteads up to 5 km away without cars to find the missing sheep. To maximize benefits for most sheep owners, accessibility is highly valued. Considering the technical abilities of the shepherds, implementing the solution should be done in a way that is easy for the shepherds to handle. In this proposal, we prioritize the needs and values of our primary stakeholders; however, secondary stakeholders such as shepherds and sheep are also important. The shepherds are underpaid and are often given a high workload; thus, the owners have a precarious relationship with the shepherds. Reducing the shepherd's workload by introducing high functioning designs that can motivate them to work to minimize the chances of sheep getting lost is a priority. For the sheep, the solution should not reduce the economic value of the sheep both directly and indirectly, thus the solution should not harm the sheep.

2.2 Service Environment

The opportunity is set in the town of Mthatha in Eastern South Africa. Sheep farming is popular in this region, and many sheep owners share communal grazing areas. The grazing area is a (3) mixture of rural village land and hilly plains as seen by images provided by the stakeholder. The climate of the region is moderately cold, with a yearly high of around 27 degrees, so for most of the year, the sheep will be grazing in the cold. The design should serve the stakeholder's need to find the lost sheep and keep the cost minimized. With the local service environment described, the design functions should support successful tracking and finding sheep when they are lost while being easy and convenient for local owners and shepherds to operate. The durability and safety of the product should be suitable to local climate and environmental factors, which require features such as waterproofing and dustproofing.

2.3 Scoping

With internet and mobile network coverage, the assistance of shepherds, and the limitations on budget, we scoped to develop a **reliable** sheep tracking system that is **accessible** to every community member in Rosedale, which can **prevent** sheep from wandering off or mixing up with other sheep. The focus of the design will be its reliability to prevent the sheep from missing and its feasibility of being integrated into the daily lives of the shepherd. The product must be **sustainable** to fulfill **UN SDG12** which concerns responsible consumption and production.

2.4 Team Values

Our teams had three main values that will be incorporated into the requirements model: functionality, accessibility and sustainability. Functionality is one of the main priorities of the design since the shepherds are looking for a design that will address the issue of wandering sheep. This will include tracking capabilities and a system that is accurate and accounts for all possible instances of sheep wandering off. Additionally, we incorporated empathy into the design in the form of accessibility. We focus on making the product accessible to everyone in the community by keeping it affordable and easy to learn. Lastly, in keeping with the goal 12 of the UN SDG, sustainable consumption and production in mind, we aim to make the design durable to improve resource usage efficiency. The extended lifetime of the product reduces the cost for the stakeholders and is identified as responsible consumption promotion.

2.5 Reference Designs

Fencing is a popular solution for problems with animals wandering off. Fencing an area is simple and effective to prevent animals from leaving. However, for our stakeholders, it is not a valid solution. Because many shepherds in Rosedale share a communal grazing area, the coordination of fencing would be complicated. Also, the price is estimated to be 7500 – 15000 USD (9500-19000 CAD) for the area of grazing land the shepherds have, which is very expensive when compared to the price requirements provided later [3]. Another option that has been used to find sheep is GPS tracking. This has been used for sheep tracking in countries such as Norway [4]. The Telesport system is the current "market-leading" solution and makes use of a GPS to locate every sheep in real-time. However, this is also costly at 290 CAD per sheep, with no flexibility since each sheep's collar will make use of GPS technology [5].

2.6 Requirements Model

The requirements model was developed to fulfil the needs of our stakeholders by successfully preventing sheep loss and ensuring that the design would be feasible to integrate. We incorporated our value proposition by deriving the high-level objectives from the three values. From each high-level objective, we developed detailed objectives to be our specific testing protocols. We will validate the design by either physically testing if possible or otherwise theoretically predicting the outcome against each proposed requirement to assess to what extent our design delivers the values to the stakeholders.

Functionality: Location Tracking

The primary functions of the design should include a lost sheep notification system and finding system to fully address the missing sheep issue. The first functionality requirement is that it must track the location of the sheep.

Table 2 Criteria, metrics, and constraints for location tracking

Criteria: tracking range	
Farther is better (m)	Must ≥ 2000 m. Should ≥ 5000 m
Criteria: location accuracy: closeness of a measured location to the real location of the device at the time of measurement [6]	
The closer is better (m). GPS level accuracy is within 4.9m[7].	Must not exceed 20m to provide an accurate location of the sheep

Functionality: Reliability

Reliability requirements ensures handling the different cases of the sheep wandering off, and that the shepherds can be notified within time to take preventative action.

Table 3 Criteria, metrics, and constraints for the reliability

Criteria: reliability of the notification communication
Metric: Percentage error of false alert (%); lower is better
Constraint: Must not be interrupted and interfered with when transmitting messages.
Constraint: Should allow notification documentation, and record all the history notifications [8]

Accessibility: Affordability

The requirement that was emphasized the most by the primary stakeholders was cost-efficiency. The stakeholder provided an ideal cost of 150 * 12 CAD = 1800 CAD for the final product. However, recognizing the challenge to implement solutions with high functionality to track the sheep's location accurately and reliably, we justified cost constraint of the final design to be less than 3400 CAD because the average purchase price of the sheep in South Africa is approximately R1,300 and the average sheep output of small livestock owners is R3,000 [9]. The average profit efficiency of the sheep was estimated to be about 65.5% [9]. Therefore, the strict profit made by each sheep can be estimated to be around R2,000. On average, small livestock owners have 150 sheep, and the rates of sheep loss has an average of 8% [10]. Hence, the minimum loss would be about 12 sheep. Therefore, we set the constraints for the budget to be (the strict profit each sheep makes + the price of the sheep) * (the number of sheep that get lost) as the design should be profitable in the end. Therefore, our hard constraint is that our design *must* not exceed (R2,000 + R1,300) * 12 ≈ R39,600 = 3410 CAD per year.

Accessibility: Portability

As part of the design for travel and ergonomics, the solution needs to be able to move around freely to track the sheep at different locations. Portability requirements for handheld devices were taken from the 2005 US human factors guide for the design of handheld devices. Two of the main concerns for devices are the weight and dimensions of the device. Note that the dimensions of the device are specified as the stow-away size; some devices may unfold but must stow away to under the size constraint.

Table 3 Criteria, metrics, and constraints for portability

Criteria: Device needs to be easy to move around, and shepherds must be able to use the device over the range of the grazing area (~5km through hilly terrain and villages).	
A lighter device is preferred (weight in pounds)	Widgets should be under 5.1 pounds if handheld. [11]
A smaller stowaway volume is preferred (size of dimensions in mm)	Widget should stow away to under 100x125x255mm in size [11].

Accessibility: Ease of Learning

The product should have the option to display information in the local language Xhosa [12]. Since the solution will be implemented with local shepherds, there also needs to be education in teaching them how to use the design solution. The less time it takes for the shepherds to learn how to use the design the better. This will depend on the quality of the user interface and should contain features such as one-click information finding and intuitive graphics.

Sustainability: UNSDG 12 Responsible Consumption and Production

Responsible consumption and production objectives relate to the materials used for the physical collar [13]. The goal is to use materials that have the smallest carbon footprint and can be recycled if the product were to be taken apart. An additional consideration is the impact of the battery, using rechargeable batteries instead of lithium batteries reduced soil and air contamination [14].

Sustainability: Durability

High durability reduces product costs for the stakeholders by reducing the amount of maintenance needed. Besides the cost, durability also encourages responsible production by increasing resource efficiency. Considering the grazing area is close to water sources, the product needs to be waterproof, dustproof and drop proof.

Table 4 Criteria, metrics, and constraints for durability

Criteria: Device needs to work for an extended period without malfunctioning
Metric: The lifetime of design [15]
Constraint: Must pass waterproof and dustproof test from IP5 to IP6 [16]
Constraint: Must pass drop test for ANSI/ISEA 121-2018 [17]
Constraint: Must work for at least two weeks without charging [18]

3. Design Process and Key Design Decisions

In our project management plan, the team is divided into three divisions: hardware of the tracker, physical design of the collar, and software, which includes the backend database and front-end UI. Three engineers from our team are assigned to be the lead of each division, and deadlines for design milestones are set to check the progress of all three divisions and merge the work.

3.1 Conceptual Design Features

1. Using GPS to track the sheep's location: as required by the stakeholder, the design needs to track the exact location of the missing sheep. We interpreted this requirement to be minimizing the effort spent when searching for missing sheep. In our design, we use GPS tracking to monitor the sheep's location and notify the shepherds once the sheep leaves the cluster. This way the shepherds can efficiently target the wandering sheep and get it back immediately, reducing the workload. Thus, we believe it is the best solution that satisfies the stakeholder's needs.
2. Using clustering methods to reduce the cost: the tradeoff for using expensive GPS trackers is the excessive cost. The stakeholders not only value functionality, but also value cost efficiency. However, we recognized the conflict in satisfying both. The clustering method leaves the choice of whether to be cheaper but have a larger location uncertainty or to have a smaller location uncertainty but be more expensive to the stakeholder.
3. Using GSM to transmit information: from the context provided by the stakeholders, the town of Rosedale has mobile phone coverage. Furthermore, research has shown that Mthatha has full 2G GSM coverage provided by Vodacom, Telkom, and MTN [19]. Accessing the GSM network is cheaper than Wi-Fi, 3G, 4G, and 5G networks and therefore reduces the cost. Here, it should be noted that as great as GSM is for increasing affordability, this pricing is in exchange for the speed of the connection. Nevertheless, as 2G network is still integrated into our daily lives, the connection speed is sufficient for this application.
4. Accessibility of the UI: To make the product easy to use for the shepherds and sheep owners, we designed the UI to have both English and Xhosa versions. Also, the one-click-to-update feature is very user-friendly, requiring zero technical training.

3.2 Prototype

In our PM plan, we separately prototyped and tested our hardware and software subsystems, due to resource limitations, we did not prototype the GSM module and instead used Bluetooth to represent this feature. To demonstrate the full functionality of the conceptual design, we prototyped both types of the trackers, the physical collar, and the database with the UI. During our prototyping process, we identified that RSSI's inaccuracy in predicting the distance is the biggest problem to our design because our key concept, clustering method, relies on calculating the distance using RSSI. We would need to do more research to improve this situation. Except for this main problem, all other parts of the subsystem functioned as expected from our conceptual design. Our prototype is comprised of the following parts:

1. We prototyped one battery powered follower tracker with the hardware concealed in the physical collar to demonstrate the design concepts. The second follower prototype is only

powered by the laptop to save batteries (practicing UNSDG 12). We decided to prototype two followers because we need to test the clustering functionality based on the RSSI strength.
2. We decided to use Bluefruit Connect phone app as the leader sheep because the app has a multiple UART mode, accurately representing the idea of leader sheep calling multiple follower sheep at once. Furthermore, the app allows us to acquire the GPS location of the phone, representing the GPS module to be implemented in the product. The leader communicates with the backend using Bluetooth, which is a proxy of the GSM transmission because MyFab does not have a GSM module. Then we need to manually send the information (GPS and the collected follower IDs) to the backend.
3. We fully prototyped the backend database using SQLite and Python and prototyped the UI using PyQt5. We chose to use database because compared to txt files and excel, SQL database is the most efficient way to store and handle large number of update messages because we need to use python to extract write information into the database to detect missing sheep. We chose to use PyQt5 to write the UI because it is intuitive and widely used.

3.3 Influence of Reference Designs on Process

The most relevant reference design that influenced our thinking as a group was the Telespor system from Norway mentioned earlier in the reference design section. The main drawbacks of the solution that made it unsuitable for our opportunity were that it is costly and would be hard to integrate into the shepherd's operation due to language constraints (the Telespor system is not offered in the local language Xhosa). Our design addresses these two issues by offering flexibility on how many GPS modules to include, lowering the price point. Additionally, we have designed our UI to be usable in many languages including Xhosa, and features such as one-click updates ensure that the design is accessible to the shepherds. However, our design is not as developed as the telespor system, and further improvements on battery life and the design of the leader sheep's collar may increase the price of the design.

3.4 Verification

To ensure the high-fidelity prototype is functional, reliable and error-free, we tested each subsystem with repeated trials. Note that since our leader collars were proxied using mobile phones, this does not allow the collected information to be automatically sent to the backend, thus each component (hardware, software, and physical collar) was verified individually.

Electronic Subsystem and Hardware

To verify the electronic pinging system, we tested:

1. Whether RSSI range can be used for clustering.
2. Pinging the sheep and how it responds with the identification number.
3. The feasibility of powering the system and running the circuitry with the 9V battery.

Testing of the RSSI was done by graphing the RSSI against distance. The RSSI strength works for clustering but becomes unreliable at longer distances since the signal strength falls off exponentially (Figure 4). Then we verified different cases of pinging followers. We used the Bluefruit app to test if we can ping both sheep, and each individual sheep (simulating the case where the other sheep is out of range). We successfully pinged both followers using the multiple

UART function of the app, proving that in our final design we can ping all nearby sheep with a single message.

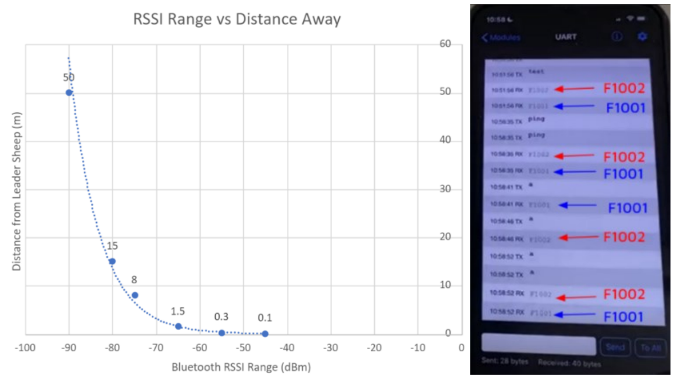

Figure 3 RSSI versus distance away plot and the cluster follower sheep response based on RSSI

Lastly, the Arduino was sufficiently powered by the 9V battery and supplied constant power throughout our 1 hour testing sessions, verifying that the battery life of the prototype was adequate and can be improved through further research and development.

Physical collar

The base of the tracker fits the Arduino (Figure 6), and the Bluefruit and the battery were physically taped onto the second layer, preventing the electronics from moving inside the case even when dropping to the ground from a 1-meter height (the standing height of a sheep).

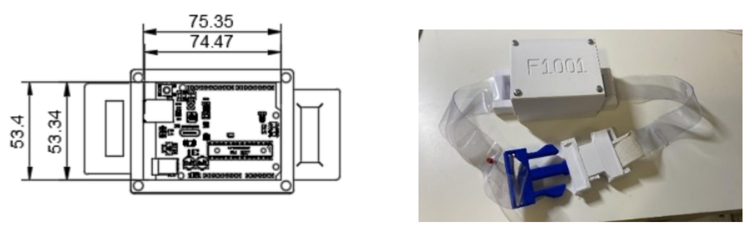

Figure 4 Dimension graph in mm of the tracker and final printed design

The hardware is waterproof such that the tracker inside was safe from any damage when proxy waterproofing in the form of rubber bands was added. This was tested by putting tissues inside the cover and sinking it underwater for 2 hours, following the test for waterproof and dustproof levels IP5 and IP6. The engraved sheep ID in 3D printing is clear and easy to see.

Backend Database and Clustering Algorithm

The backend algorithm passed all testing cases. We created a three-leader sheep flock for this testing, therefore there will be three data entries into the database for each update.

Table 5 Testing cases for the backend database and clustering algorithm

Leader ID	Follower IDs	Case 0 initializing the database
1000	1001, 1002, 1003, 1004, 1005	Algorithm output: no missing sheep.
2000	2001, 2002, 2003, 2004, 2005	
3000	3001, 3002	
1000	1001, 2001, 1002, 1003, 1005	Case 1: 2001 and 1004 changed clusters Algorithm output: no missing sheep.
2000	2002, 2003, 2004, 2005	
3000	3001, 3002, 1004	

1000	1001, 2001, 1002, 1003, 1005	Case 2: missing follower sheep when it leaves the flock Algorithm output: missing sheep 1004, the most recent GPS location of the cluster (sheep 3000's location), and the missing time.
2000	2002, 2003, 2004, 2005	
3000	3001, 3002	
1000	1001, 1002, 1003, 1004, 1005	Case 3: missing leader sheep when it has an empty cluster Algorithm output: missing sheep 3000, the most recent GPS location of 3000, and the missing time.
2000	2001, 2002, 2003, 2004, 2005, 3001, 3002	
3000		

User Interface

The UI displays missing sheep information in local languages with a clickable button allowing the user to manually refresh the page. One shortcoming of the database is that it does not automatically refresh. The user interface was done using the PyQt5 library.

3.5 Validation Chart

To ensure the high-fidelity prototype is delivering the values we would provide to the stakeholders, we assessed and/or tested the prototype against each detailed objective. We noted that all the requirements identified earlier were met.

Functionality

Criteria: tracking range
GPS has global coverage, allowing sheep to be tracked anywhere in the world.
Criteria: location accuracy: closeness of a measured location to the real location of the device at the time of measurement [6]
The leader trackers have GPS level accuracy which is within 1m < 20m [7]. Depending on the number of leader trackers the follower tracker location uncertainty is: Max location uncertainty = 14.5m < 20m (see Appendix I. Section 1. for calculations) Assumption: sheep activity range is 2m [20], worst-case scenario is all sheep standing in a row.
Criteria: reliability of the notification communication
Since the sheep are clusters based on the RSSI, and RSSI sometimes is not a perfect estimation of distance. Our testing result has a 20% failure rate (see Appendix I. Section 2.) when the follower tracker's distance from the leader sheep is further than the calculated cluster radius, but it still did not disconnect.
Bluetooth wireless transceiver and GSM both have stable, reliable signal.
The backend database is implemented in SQL, allowing to store large number of updates.

Accessibility

Criteria: low cost
Depending on the number of leader trackers the follower tracker location uncertainty is: Min cost with 50% leaders: 75*12.93 CAD + 75*17.28 CAD = 2265.75 CAD < 3410 CAD (See the BOM for each leader tracker and follower tracker is in Appendix II.)

Criteria: Device needs to be easy to move around, and shepherds must be able to use the device over the range of the grazing area (~5km through hilly terrain and villages).
Tracker is 0.22 pounds < 5.1 pounds. (See Appendix I. Section 3.)
Tracker is 85x70x45mm < 100x125x255mm in size. (See Appendix I. Section 4.)
Criteria: Ease of Learning
The UI has both English version and Xhosa version and is easy to use with no prior experience and/or training needed.

Sustainability

Criteria: UN SDG responsible consumption and production
The design can be fabricated using recyclable polymer PET [21] and rechargeable batteries.
Criteria: Device needs to work for an extended period without malfunctioning
The design can be designed to pass waterproof and dustproof test from IP5 to IP6 [8].
The design can be designed to pass the drop test for ANSI/ISEA 121-2018 [21] by soldering all the electronics onto the surfaces and using shock absorption polymers [22].
The design can use rechargeable batteries that sustain two weeks without charging [10].

3.6 GSU Reflection

We incorporated the GSU student's suggestion to include more stakeholders, such as governments, by making our design more sustainable by using green materials and rechargeable batteries to comply with local government environmental regulations. The material that we can use is PET which is a representative of recyclable polymer. PET is a clear, strong, and lightweight plastic [23] that can be used as the material for the case and can be able to pass the drop test and protect the inner modules. PET is fully recyclable, and it is the most recycled plastic in the U.S and worldwide [23], so this material can support us to pass the requirement of UN SDG12. The GSU student also brought up the issue of any alternatives in case of technical difficulties. We recognized that it is risky to assume fully reliable 2G GSM coverage in Rosedale. Research shows that near the water dam, Rosedale is not fully covered by stable 2G nor 3G/4G networks. However, further research tells us that in the future we can implement a hopping algorithm [29] to solve this problem if at least one sheep is in the 2G GSM coverage.

4. Discussion of the Final Outcome

With local context in Rosedale, Mthatha, our proposed design Sheep Link is a valid solution that prevents sheep from wandering by tracking the GPS location and notifying the shepherds when a sheep wanders off. Such preventive methods significantly reduce the efforts the shepherds and the sheep owners need to spend when searching for missed sheep. Sheep_Link delivers functionality, accessibility, and sustainability to the stakeholders by satisfying the corresponding detailed requirements. The requirements for functionality are location tracking and reliability, the requirements for accessibility are affordability, portability, and ease of learning, and lastly, the requirements for sustainability are durability and UNSDG12. Sheep_Link provides reliable tracking of the wandering sheep's GPS location, integrating the feature of the engraved sheep IDs on the physical collar and their customizable colors, shepherds/owners can easily find or differentiate their lost sheep. GSM signals are cheap but stable methods making our design suitable for the objective of cost-efficiency. Furthermore, to balance the functionality and cost-efficiency, the number of the leaders can be customized to increase or decrease the number of GPS modules, allowing stakeholders to decide to what extent they want to sacrifice location accuracy over cost or vice versa. The design is easy to be used by local people since it is in the local language Xhosa. The design of the case is durable in terms of waterproof and dustproof. Rechargeable batteries and green materials will be used for the product to fulfill the UNSDG 12. To summarize, besides the reliable functionality in preventing missing sheep, our design is also highly compatible with the local context financially, culturally, and environmentally, making our design a valid solution for the stakeholders.

4.1 Assumptions and Limitations

Assumptions were made for the conceptual design, which could lead to limitations in the design. The main limitations are outlined here. Firstly, the leader sheep distribution when calculating the cluster range was assumed to have a maximum of 2 metres. This range can be expanded by using longer range wireless communication hardware. Another assumption we made was that there exists adequate 2G network coverage over the service area. Although in our verification section, we found that the infrastructure for GSM exists, in reality the coverage may not cover the entire area sufficiently. A possible solution mentioned in the GSU reflection section is to implement what is known as a hopping algorithm. For the software component, we assumed all the stakeholders have access to an electronic device capable of running SQLite databases and has a PyQt5 library for the UI. This can be implemented on mobile phones, which the stakeholders have access to. Lastly, the shepherds have to depart to search the sheep immediately when the alert is received, which we have identified as a major limitation of the design.

4.2 Progress of the Prototype

The main feature of the conceptual design, the clustering method, is feasible for a group of second year EngSci students to prototype with limited resources, providing us with confidence that the final design would be feasible to do by the same team with more choices of the modules. The follower tracker, the physical collar, and the software are fully prototyped; however, the leader tracker and the GSM transmission features are only proxied by using the Bluefruit phone app manually sending the messages to the followers and to the backend because we do not have enough technical capabilities to design the more complicated leader tracker and MyFab does not have the modules we need. The physical collar prototype represents most of the important features of our final design: three layers to hold the electronics in place, an adjustable strap, waterproof/dustproof rubber band, and engraved sheep IDs. However, the dimension of the case should be smaller in the final design when we use different modules and minimize the space needed to fit the components. Green materials instead of 3D printing materials can be used in real design. The backend database is created, and the algorithm was able to report missing sheep correctly in all scenarios stakeholders might encounter. The software component is ready to work under real-life conditions. One improvement of the UI is that it needs to be improved using a better language instead of PyQt5 in Python for the real design because it does not allow automatic update and display of the missing sheep information. It can also be made into a mobile app, affording more options for the shepherds to access the software.

4.3 Team Process

Our team cooperated in a highly efficient and highly functional manner for this project. Arielle is the project manager; she monitors the progress of the project. Tab organizes the folders and documents everything. Yiqun is responsible for the procurement and budgeting. During the prototyping phase, there are three divisions, Ethan and Arielle are electrical engineers for the hardware division, developing the circuits for the tracker. Emre is the software engineer for the software division, developing the database and the UI. Yiqun is the mechanical engineer for the collar design division, designing the physical collar. Tabitha researched the application of GSM and 2G network, which is the only part of our system that we did not prototype due to limited access to resources. We update each other weekly in our group chat, and design milestones are set to integrate and merge the works from all three divisions.

5. Conclusion

Our value proposition was to develop a sustainable, reliable sheep tracking system that is accessible to every community member in Rosedale, Mthatha. Our final design uses two different types of sheep collars – leader and follower - to send information to a database, where the shepherds can easily interact with the user interface to find the location of missing sheep. The prototype of this design was split into 3 components – the hardware, software, and case design. From prototyping of the hardware, we have shown the validity of using RSSI to cluster sheep, multiple UART communication to ping nearby collars and having a battery to power the collar. The database and user interface showcase the functionality of the algorithm, and the design of the software with SQL databases allows for scaling with more sheep's collars. Finally, the physical case was tested to be durable, waterproof, and built with sustainable materials. These three aspects of the prototype combine to give our team confidence in recommending the design going forward.

5.1 Current Prototype

Our prototype can support the arguments by passing all the requirements that we have. For the physical collar, the design helps it to pass the waterproof and dustproof dust of the IP6 test. For the frontend and backend, we can collect data on the locations of our products and detect when sheep have wandered off through our test cases.

5.2 Future Steps for Prototyping

Further prototyping and testing that has been identified by the team include the creation of a leader sheep collar. Although the leader sheep collar is a crucial part of the final design, we have proxied this part of the system with two mobile phones. The downside of using mobile phones is that they contain very accurate GPS coordinates and can easily connect to many devices. Testing on the leader sheep collar would include its ability to be powered by a battery, whether it is able to seamlessly connect and disconnect with nearby devices and whether the additional hardware requirements would change the physical case structure.

6. References

[1] Encyclopædia Britannica, inc. (n.d.). *Mthatha*. Encyclopædia Britannica. Retrieved April 17, 2022, from https://www.britannica.com/place/Mthatha

[2] *An introduction to pet*. Fact Sheet - An Introduction to PET (polyethylene terephthalate) | PETRA: Information on the Use, Benefits & Safety of PET Plastic. (n.d.). Retrieved April 17, 2022, from http://www.petresin.org/news_introtoPET.asp

[3] *How much does an electric fence cost?* CostHelper. (n.d.). Retrieved April 17, 2022, from https://home.costhelper.com/electric-fences.html

[4] *The prevalence of lameness in the assessment of Transylvanian dairy herds by locomotion score and according to the Farmers' estimates*. Directory Indexing of International Research Journals. (n.d.). Retrieved April 17, 2022, from https://www.citefactor.org/article/index/47309/pdf/

[5] *Radiobjella Inkl batteri*. Telespor. (n.d.). Retrieved April 17, 2022, from https://nettbutikk.telespor.no/products/radiobjella-inkl-batteri

[6] *Location Data Accuracy - MMA*. (n.d.). Retrieved April 17, 2022, from https://www.mmaglobal.com/files/documents/location-data-accuracy-v3.pdf

[7] *GPS accuracy*. GPS.gov: GPS Accuracy. (n.d.). Retrieved April 17, 2022, from https://www.gps.gov/systems/gps/performance/accuracy/

[8] *Automated critical test result notification system: Architecture, design, and assessment of provider satisfaction : American Journal of roentgenology : Vol. 203, no. 5 (AJR)*. American Journal of Roentgenology. (n.d.). Retrieved April 17, 2022, from https://www.ajronline.org/doi/10.2214/AJR.14.13063

[9] Additional informationFundingThis work was supported by Intra-ACP Mobility Scheme: [Grant Number STRE1101630]. (n.d.). *Determinants of profit efficiency among smallholder sheep farmers in South Africa*. Taylor & Francis. Retrieved April 17, 2022, from https://www.tandfonline.com/doi/full/10.1080/20421338.2021.1879510?casa_token=SSCu9HK5fpYAAAAA%3AFbjWeE5EVe70_OuQcgL_iR4TL7cvC7aUDx82dMzo6eqSRXTJZvsurbmlvasMTHCH4hUKqMuSYsvwg4E

[10] *Developing alternatives to protect ... - escholarship.org*. (n.d.). Retrieved April 17, 2022, from https://escholarship.org/content/qt58r1g4wj/qt58r1g4wj_noSplash_c05614f4da5bcb8ba3ab41e0a5266bc8.pdf?t=qf25mm

[11] FAA human factors (ang-E25) 2005-human factors guidance for the use of handheld computing devices. (n.d.). Retrieved April 17, 2022, from https://hf.tc.faa.gov/publications/2005-human-factors-guidance-for-the-use-of-handheld/

[12] Wikimedia Foundation. (2022, March 14). *Mthatha*. Wikipedia. Retrieved April 17, 2022, from https://en.wikipedia.org/wiki/Mthatha

[13] *Goal 12: Responsible consumption and production*. UNDP. (n.d.). Retrieved April 17, 2022, from https://www.my.undp.org/content/malaysia/en/home/sustainable-development-

goals/goal-12-responsible-consumption-and-production.html?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=Cj0KCQjw0umSBhDrARIsAH7FCoetwmhbLRaDevO3Jz5fY2ThNbJ_K4X9jfM_JaE8l0L37L13g-6DvFQaAgWnEALw_wcB#targets

[14] Katwala, A. (2018, August 5). *The spiralling environmental cost of our lithium battery addiction*. WIRED UK. Retrieved April 17, 2022, from https://www.wired.co.uk/article/lithium-batteries-environment-impact#:~:text=According%20to%20a%20report%20by,livestock%2C%20and%20for%20crop%20irrigation.

[15] *Blog*. Concox. (n.d.). Retrieved April 17, 2022, from https://www.iconcox.com/blog/how-long-does-the-gps-tracker-last.html

[16] *Waterproof testing*. Applied Technical Services. (2022, April 8). Retrieved April 17, 2022, from https://atslab.com/environmental-testing/waterproof-testing/

[17] *Dropped objects testing (ANSI/ISEA 121)*. Element. (n.d.). Retrieved April 17, 2022, from https://www.element.com/product-qualification-testing-services/dropped-objects-testing

[18] Security, B. (n.d.). *How to choose a GPS tracker*. How to Choose a GPS Tracker. Retrieved April 17, 2022, from https://www.brickhousesecurity.com/gps-trackers/device-guide/

[19] *MTN 3G / 4G / 5G in Mthatha coverage map, South Africa*. MTN 3G / 4G / 5G coverage in Mthatha, South Africa - nPerf.com. (n.d.). Retrieved April 17, 2022, from https://www.nperf.com/en/map/ZA/946058.Mthatha/9863.MTN/signal/?ll=-31.58254062474099&lg=28.787187722045932&zoom=14

[20] Wikimedia Foundation. (2022, March 21). *Sheep*. Wikipedia. Retrieved April 17, 2022, from https://en.wikipedia.org/wiki/Sheep

[21] *An introduction to pet*. Fact Sheet - An Introduction to PET (polyethylene terephthalate) | PETRA: Information on the Use, Benefits & Safety of PET Plastic. (n.d.). Retrieved April 17, 2022, from http://www.petresin.org/news_introtoPET.asp

[22] *Shock absorbing material*. Sorbothane. (n.d.). Retrieved April 17, 2022, from https://www.sorbothane.com/shock-absorbing-material.aspx#:~:text=Sorbothane%20is%20the%20best%20solution,%2C%20neoprene%2C%20silicone%2C%20etc.

[23] *An introduction to pet*. Fact Sheet - An Introduction to PET (polyethylene terephthalate) | PETRA: Information on the Use, Benefits & Safety of PET Plastic. (n.d.). Retrieved April 17, 2022, from http://www.petresin.org/news_introtoPET.asp

[24] *9.08C$ 15% off: Leonardo R3 microcontroller Atmega32u4 Development Board with USB cable compatible for Arduino DIY starter kit: Integrated Circuits: - aliexpress*. aliexpress.com. (n.d.). Retrieved April 17, 2022, from https://www.aliexpress.com/item/32893459152.html?_randl_currency=CAD&_randl_shipto=CA&src=google&aff_fcid=76129e6a48e1479fb4c00939176c0381-1650074788503-05152-

UneMJZVf&aff_fsk=UneMJZVf&aff_platform=aaf&sk=UneMJZVf&aff_trace_key=76129e6a48e1479fb4c00939176c0381-1650074788503-05152-UneMJZVf&terminal_id=160f8da13d1947b8b014ed8eb88fb05b&afSmartRedirect=y

[25] *0.5US $ 12% off: NRF24L01+ 2.4G Wireless Data Transmission Module 2.4ghz NRF24L01 upgrade version NRF24L01+PA+LNA 1000 meters for Arduino - integrated circuits - aliexpress*. aliexpress.com. (n.d.). Retrieved April 17, 2022, from https://www.aliexpress.com/item/1005002975667834.html?spm=a2g0o.productlist.0.0.29c214f16Ebjz7&ad_pvid=202204151910071008745818235776000198090 6_2&s=p

[26] *0.33US $ 5% off: Smallest SIM800L GPRS GSM module Microsim Card Core Board quad-band TTL serial port - integrated circuits - aliexpress*. aliexpress.com. (n.d.). Retrieved April 17, 2022, from https://www.aliexpress.com/item/32283531730.html?spm=a2g0o.productlist.0.0.6f9e373fUlpkxQ&algo_pvid=beb77665-4025-4c10-8a41-078b594cc4ea&algo_exp_id=beb77665-4025-4c10-8a41-078b594cc4ea-8&pdp_ext_f=%7B%22sku_id%22%3A%2266535850095%22%7D&pdp_pi=-1%3B0.44%3B-1%3B-1%40salePrice%3BCAD%3Bsearch-mainSearch

[27] *Energizer Max 9V, 1 pack: Walmart Canada*. Walmart.ca. (n.d.). Retrieved April 17, 2022, from https://www.walmart.ca/en/ip/energizer-max-9v-1-pack/6000016945328

[28] *Jumper wires 6" m/F pack of 20 - robotshop*. (n.d.). Retrieved April 17, 2022, from https://www.robotshop.com/ca/en/jumper-wires-6-m-f-pack-of-20.html

[29] *Ragnar Stølsmark and Erlend Tøssebro.* (2014). Improving GSM-based Sheep Tracking Using a Cluster-based Multi-hop Approach. Retrieved April 17, 2022, from https://www.scitepress.org/Papers/2014/47309/47309.pdf

Appendix I. Testing Results

Section 1. Different number of leader sheep and corresponding cluster size, cluster radius, and RSSI threshold.

Leader Percentage (%)	Number of leader (# of sheep)	Cluster size (# of sheep)	Worest case cluster radius (m)	RSSI threshold needed (dBm)	Detected leaving successfully?
0.100	15.000	10.000	22.000	-83	
0.120	18.000	8.333	18.667	-81	
0.140	21.000	7.143	16.286	-79	
0.160	24.000	6.250	14.500	-78	20% missed alert
0.180	27.000	5.556	13.111		
0.200	30.000	5.000	12.000	-76	20% missed alert
0.220	33.000	4.545	11.091		
0.240	36.000	4.167	10.333		
0.260	39.000	3.846	9.692		
0.280	42.000	3.571	9.143		
0.300	45.000	3.333	8.667	-74	10%
0.320	48.000	3.125	8.250		
0.340	51.000	2.941	7.882		
0.360	54.000	2.778	7.556		
0.380	57.000	2.632	7.263		
0.400	60.000	2.500	7.000	-72	8%
0.420	63.000	2.381	6.762		
0.440	66.000	2.273	6.545		
0.460	69.000	2.174	6.348		
0.480	72.000	2.083	6.167		
0.500	75.000	2.000	6.000	-70	8%
0.520	78.000	1.923	5.846		

Figure 5 Different percent of leader sheep

Sample calculation for 20% leader sheep:
Number of leader sheep = 150 * 0.2 = 30 leader sheep
Cluster size = 150/30 = 5 follower sheep / cluster
Worst case cluster radius = 5 * 2m + 2 = 12m

Section 2. Missing sheep alert failure rate
We did 20 trials for each highlighted RSSI threshold in Figure 5. For larger cluster radius, there are maximum 4/20 times the followers fail to disconnect even when they are far away from the leader sheep, having the distance way further than the calculated cluster radius.

Section 3. Weight of the tracker
The final weight of the follower tracker prototype is 0.5 pounds as shown in Figure 6.

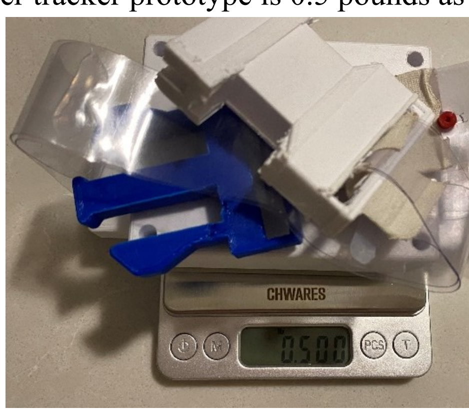

Figure 6 Weight of the follower tracker

Section 4. Dimensions of the tracker

The dimension of the tracker is 85x63x26mm measured from the CAD dimension diagram, shown in Figure 7.

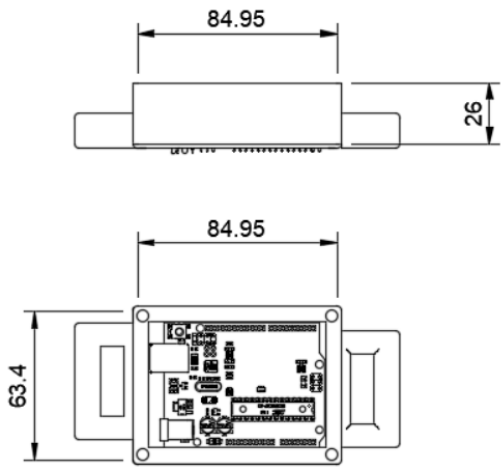

Figure 7 Dimension diagram of the tracker

Section 5. Waterproof and Dustproof

We used rubber bands as shown in Figure 8 as seals to maintain the level of waterproofing and dustproof, and the test is a tissue sinking test. We put some tissues inside the case and sunk them into the water for two hours and the dry tissues prove that our product passes the IP6 test.

Figure 8 Tracker rubber band

Appendix II. Team

Team Values Statement

Our team values related to this project include empathy, sustainability, functionality, and accessibility. We value empathy which allows us to perceive the stakeholders' needs and context on an emotional level, making us more passionate about solving the issue. Furthermore, this helps us to more sensibly balance conflicting requirements such as cost efficiency and functionality. Additionally, our value of empathy also connects to considering the environment which aligns with the UNSDGs and leads to our value of sustainability. Valuing sustainability helps us to be more conscious about the production process and lets us seek a more durable and cost-efficient design that matches the stakeholders' context. Nevertheless, being a team of engineers, our value of functionality is also apparent, making sure that despite us aiming for a sustainable design, the functionality is at its best. We are invested in taking care of all the functional needs of the solution and satisfying the stakeholder's needs. Moreover, we greatly value accessibility which is also rooted in our value of empathy. As we empathize with the financial and educational backgrounds of the stakeholders, we wish to produce a design that is accessible to all stakeholders by being affordable and easy to learn. We as a team truly make every design decision based on our team and the stakeholders' values, aiming toward the best design. We have developed a precise and rigorous requirements model derived from the values to efficiently and effectively assess all design candidates. As our final design and its prototype have met all values while passing the numerous functionality tests, we believe that our team is suited to continue with this project.

Role descriptions

Tabitha

She is in charge of our team's research and document management. Furthermore, in terms of the final design, she was responsible for researching and making theoretical applications of the Global System for Mobile Communication (GSM) for wireless communication. Her research experience in extracurricular design teams, as well as past in-course group work such as Praxis I and II, allowed her to better tackle research tasks. These research skills were also applied to securing the requirements model such that it was rigorous and detailed along with developing testing and verification methods for the detailed objectives. Moreover, highlighting her organizational skills, she was given the role of organizing the Microsoft SharePoint folder and documents. These organizational skills were also infused with artistic skills from previous experiences in graphic design and visual art competitions which helped with her designing the design pitch brochure for the final presentation.

Ethan

He oversees the integration of electrical components into the final design. This included the setup of the follower sheep Arduino and connecting the bluefruit Bluetooth module. The functionality of the follower sheep collar was controlled using C code on the Arduino IDE and linked through the bluefruit app on the mobile phone. His experience with circuitry from past courses helped to get the Arduino system set up, however, most of the specifics relating to the prototype had to be learned from scratch. Additionally, the integration of the battery and research into the possible routes forward in terms of power supply was a key role Ethan took on for the prototype. For the design pitch document, he contributed to streamlining the requirements model, background research, and the testing protocols for the collar.

Yiqun

He is responsible for the mechanical design and budget tracking. In terms of the final design, he builds the 3D design of the collar. His Cading skills learned from last year and practiced during widget labs support him in the tasks of the physical design of the final product. These skills combining the critical thinking of how to fulfill the requirements help him to develop a detailed physical collar. In addition, he keeps on track of the budgets carefully during the whole design process to take notes of every cost and keep eye on the remaining budget to have the team have enough money to complete the task. This knowledge is used when fill the bill of materials since we need to minimize the cost of the actual product.

Arielle

She is the team's project manager and tech lead. In Phase A, she was responsible for leading the team to frame the opportunity and explore different viable solutions. Her leadership experience with past extracurricular activities provides her insights in discovering the latent needs of the stakeholders. In Phase B, she continues her project manager role and divided the team into three divisions: hardware, software, and physical collar design. Her rich experience with managing group projects allows her to make the team highly functional by distributing tasks and assigning roles based on everyone's interests and strength. Furthermore, her experience in hardware research, software projects and CADing makes her suitable for the role of tech lead. She monitors and provides technical help for each division when needed and integrates the subsystems for each milestone to verify and validate the design.

Emre

He oversees both the database and the user interface. For the final design he was responsible for the creation and maintenance of the databases as well as making a user interface that was able to read the data from the database and display it to the user. His CADing skills were also useful in the early stages when making a 3D model of the final design. As Emre didn't have any experience with databases before, he had to learn from scratch. SQLite was used for the two databases. Python was used to get all the information from the database, for the missing sheep algorithm, to transfer data between two databases, as well as the user interface. He had previous experiences with PyQt5, which is a GUI toolkit, the library used for the user interface.

Appendix III. Bill of Materials

<u>MyFab Prototype Pricing</u>

Item	Pricing (CAD)
Arduino UNO R3	$24.95
Bluefruit LE UART Friend	$17.50
9V Battery	$3.7
3D printed tracker case and collar strap	$3.5
Total	**$49.65**

<u>Conceptual Design Pricing</u>

Components	Units	Unit Cost	Total Cost	Purpose	Links
Microcontroller plus USB	1	$8.82	$8.82	control the functions of embedded systems	[24]
Wireless transceiver	1	$0.66	$0.66	frequency is 2.4GHz, and it is a combination of radio transmitter and receiver	[25]
GPS GSM module	1	$4.39	$4.39	SIM800 is the module we select since it is cheap, and it is the module that can get the GPS data and transmitted by GSM	[26]
9V battery	1	$3.98	$3.98	Power up the whole product	[27]
Jumper wires	10	$0.1345	$1.345	Connect these important technical units	[28]
3D printing	100 grams	$0.03	$3	The design of the collar which is the case for these modules	

Note: there is no GPS module in the collar for follower sheep, so the price for follower sheep is $17.805 and the price for leader sheep is $22.195. The price is a little higher than what the stakeholders desire, but the reason why we want GPS is to maintain the accuracy of the tracking. Since there are 150 sheep, the trackers they purchase are for follower sheep, and the price for follower sheep is close to what they want. They can decide how many leaders they want and the more leaders, the more accurate they can view.