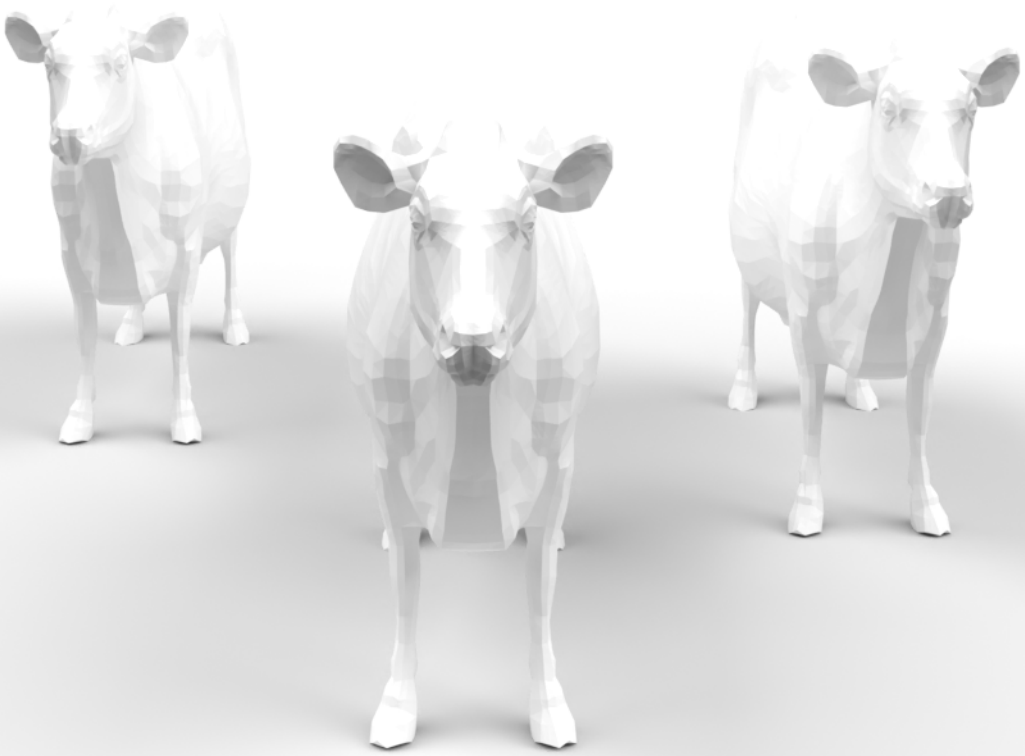
Bringing farmers and cows together

Designing a solution to locate specific cows in real-time



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List of Definitions

Channel Sounding (CS)
A new wireless ranging technology developed by Bluetooth to measure the distance between two devices.

Time-of-Flight (ToF)
A distance measuring protocol, used by technologies like Ultra-Wideband (UWB) and GPS, measures the distance between two nodes by calculating the time it takes for a signal to travel between these nodes.

Phase-Based Ranging (PBR)
A distance measuring protocol, used by Channel Sounding, measures the distance between two nodes by sending two signals of slightly different frequencies and measuring the phase difference between the signals upon their return. By analysing the phase difference and knowing the difference in frequencies, the distance between the nodes can be calculated. This method is less influenced by environmental factors than ToF.

Traveling Salesman Problem (TSP)
A common problem in computer science. In this problem, a "traveling salesman" must visit a set of locations, with each pair of locations having a different travel cost. The objective is to calculate the route that allows the salesman to visit all locations while minimising the total travel cost. The challenge lies in finding the most efficient route, as the number of possible routes increases factorially with the number of locations.

Multipath
A phenomenon that occurs when a signal transmitted from a source to a receiver follows multiple paths. These paths can include direct line-of-sight as well as reflections, refractions, or diffractions from various surfaces such as buildings, mountains, or even the ground. As a result, the signal arrives at the receiver at slightly different times and with varying amplitudes and phases. This results in noise, bad signal quality and high errors for distance measurement protocols.

Trilateration
A method used to determine the position of a point by measuring its distances from at least three known reference points.

Summary

This graduation project, conducted in collaboration with Agis Innovations, aimed to develop a cow localisation solution that could be integrated with existing ear sensors for cows. This addition was crucial as current cow localisation solutions were inaccurate, expensive, or not user-friendly. The inability to promptly locate cows can cause unnecessary pain for the animals and reduce farm efficiency. Moreover, timely cow localisation can reduce the need for fertility hormones and antibiotics.

The project was divided into two main aspects: technology and user interaction, allowing for separate evaluation and design optimisation. A comprehensive literature review on cow localisation technologies and the existing market revealed the need for a solution that is highly accurate, cost-effective, supports long battery life, and offers a long detection distance. No existing solutions met all these criteria. The technology analysis identified an unused, novel, and promising new distance measuring technology. User research highlighted the shift from small to large farms, requiring a larger, often low-literacy workforce. Literature and empirical data from farmer interviews and worker questionnaires pointed to low work engagement, particularly in cow localisation tasks. Consequently, two user evaluation criteria were established: intuitive user touchpoints and a user interface (UI) that enhances work engagement.

From the user perspective, analysing the complete workflow of cow localisation revealed three phases, each having different detection distances and accuracies. Integrating these phases provided a solution with both a long detection distance and high accuracy. Insights into farm workers' engagement revealed unmet fundamental needs. By incorporating personal profiles, hands-on tutorials, and gamification features like leaderboards and rewards, the UI was designed to enhance workers' sense of competence, recognition, and purpose. This improved engagement is anticipated to enhance cow care and increase productivity. The UI's intuitiveness was based on the three localisation phases, with each phase having tailored visualisations to guide users towards the cows effectively.

In the technology aspect, the new technology was first evaluated through field testing and Python simulations to prototype localisation ideas. A physical prototype demonstrated the feasibility of locating a tag device, achieving an accuracy within 2 metres. This met the accuracy requirement, allowing users to identify cows easily. The limited use of routers kept costs low, while smart location update frequencies minimised power consumption, supporting long battery life.

Integrating the user and technology aspects addressed the research question. The localisation solution is feasible, requiring minimal hardware changes for Agis Innovations. It is viable, leveraging the latest technology with a user-centred development approach, and desirable, providing an essential tool for efficient herd management. This solution not only boosts productivity but also enhances cow wellbeing, aligning with the project's ultimate goal of improving animal welfare.

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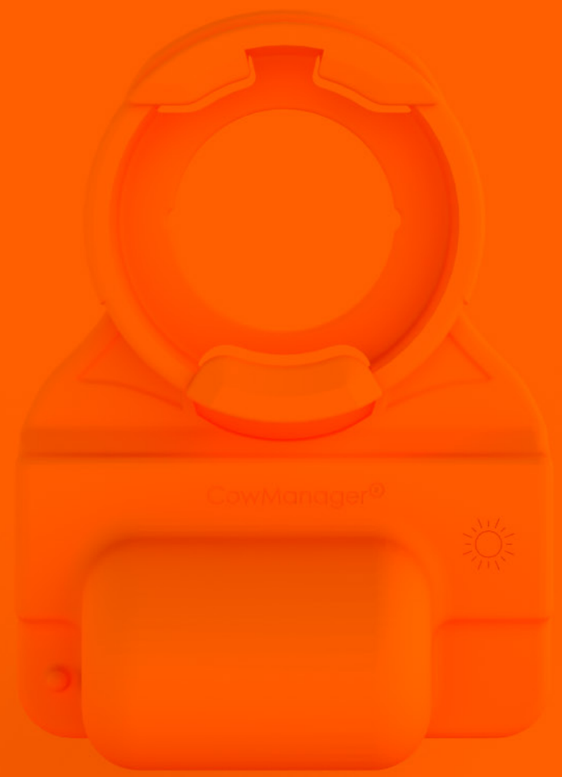
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Chapter 1

Introduction

1.1 The Project
1.2 Project Outline

Milk and its products are among the most consumed food items globally (Delmergroup, 2023). In recent years, technology and automation have significantly transformed the dairy industry, enhancing its efficiency, productivity, and sustainability. This chapter introduces the project partner and the initial assignment. Additionally, it discusses the project outline.



1.1 The Project

In the 1850s, it was estimated that nearly every family in the United States owned its own cow for food (Clover Meadows Beef, 2023). Nowadays, more than half of the cows in the U.S. are housed on farms with more than 1000 cows (MacDonald et al., 2020). This shift towards large-scale farming has created technological opportunities to develop solutions aimed at making farms more efficient and productive. However, this industrialisation came at the expense of the original level of care and attention given to cows.

1.1.1 Project Partner

The project is conducted in collaboration with Agis Innovations. Their branch, CowManager, established in 2004 (CowManager, 2023), adopts farming innovations developed by Agis and markets them to farmers worldwide. They offer a herd health monitoring system based on data collected by an ear sensor, available through a subscription model. Depending on the subscription tier, farmers receive insights into the health, nutrition, and/or fertility of each cow on their farm. The ear sensor is unique due to its placement, which results in more accurate and earlier health alerts. Additionally, it collects data 24/7 while consuming very little power, giving it a battery life of 10 years—ensuring it lasts for the entire life of a cow without needing replacement.

The next advancement in herd health monitoring is the addition of cow localisation, enabling farmers to rapidly and accurately respond when a health alert occurs. Quick treatment is crucial as cows are difficult to control, necessitating the farmer to locate and reach the cow swiftly. This task becomes increasingly challenging on larger farms, which can house up to 10,000 or more cows. Early treatment improves the cow's health and wellbeing, potentially reducing the reliance on chemicals such as antibiotics. This proactive approach not only benefits individual cows but also enhances overall herd health management strategies.

1.1.2 Initial Assignment

For the efficiency of the farm, the health and wellbeing of the cows, and the quality of its products, it is crucial to treat, locate, and navigate to the cows as soon as possible. Although localisation solutions exist, they are often not user-friendly, inaccurate or too expensive according to farmers. Therefore, the project began with the initial problem statement:

"Cow localisation solutions are not accurate enough nor user friendly."

1.1.3. Cow Welfare and Ethics

By addressing this problem, a step has been taken towards a healthier and more ethical treatment of cows on farms. Locating and getting to sick cows faster prevents pain and reduces the need for antibiotics. The use of fertility hormones can be reduced as well by locating cows in heat within the 10 hour insemination window (López-Gatius F. 2022).

1.1.4 Aim of the Research

The objective of this research was to develop a user-centred cow localisation solution. Current cow localisation solutions on the market are predominantly developed from a technological perspective, often neglecting the needs and preferences of the users. Additionally, existing literature revealed a significant gap in knowledge concerning a localisation solution optimised for accuracy, cost, battery life, and detection distance. Although several products or solutions available on the market, or discussed in literature meet up to three of these criteria, none fulfil all four. Achieving all four criteria is essential for the localisation solution to be feasible, viable, and desirable. Therefore, the main research question for this project was "How can a localisation solution be designed and integrated with the existing ear sensor to optimise user experience and efficiently locate cows, considering the diverse needs and preferences of farmers?".

Moreover, this research aimed to connect the technology to the user in an desirable way. Consequently, the user was placed at the centre of the project, and their needs, preferences, and challenges were thoroughly mapped out to develop a user touchpoint that effectively connects the user to the technological solution. By prioritising the user throughout the project, new insights were gained regarding work engagement and challenges faced by farm workers and their employers in the context of cow localisation.

During the project, the initial brief and research question were expanded using additional research questions about the technology aspect and about the user aspect. These questions were based on insights gathered from literature about the technology, and interviews about the user experience. For the technology aspect the research question was "How can a localisation solution be designed that is accurate, low cost, has a low battery lifetime and long detection distance?". For the user aspect, the research question was "How can a user touchpoint be designed that is intuitive and enhances work engagement?".

1.2 Project Outline

From the start, the project was divided into two primary components: the technological aspect and the user aspect. By exploring and developing these components separately, a comprehensive understanding and robust development was achieved prior to integration, thereby maximising the project's overall outcomes.

The initial phase, as discussed in the background chapter, involved desk research, which included a comprehensive review of literature on localisation solutions. Additionally, market, technology, and stakeholder analyses were carried out. Research was also conducted on trends in farm sizes and literature on work engagement. This phase provided the essential background knowledge. In this chapter, a new distance measurement technology called Channel Sounding was discovered, which was claimed to be more accurate than current technologies.

The interaction chapter explores the user aspect through interviews with farmers and a questionnaire for farm workers to identify and define their needs, preferences, and challenges in locating cows. Eight main motivations for locating cows were identified, revealing conflicting values. Farmers aspire to run productive farms while ensuring the best care for their cows. A study on work engagement indicated that current localisation solutions fail to meet the fundamental needs of competence and recognition. Therefore, it was concluded that a user interface should address these aspects.

Data analyses were conducted to gain empirical insights into the problem. The data suggested that an improved solution could save more than 30% of the time spent locating cows each day. This chapter also outlines three phases in cow localisation, laying the groundwork for designing both the technology and user experience aspects. It further discusses the desirable user touchpoints and defines them. All insights gained were crucial before commencing the ideation phase.

The ideation chapter began with testing and validating the chosen technology for accuracy. Python simulations were conducted to develop the localisation solution's algorithm based on the characteristics of the technology, facilitating rapid development of a viable real-world solution. Tests on Channel Sounding demonstrated that it has a maximum range of 150 metres and an accuracy of approximately 2 metres. Subsequently, a physical proof of concept was prototyped and evaluated, validating the simulations and confirming the precise localisation of a tag device. The test demonstrated that the localisation concept can accurately navigate to a cow in an open field with an accuracy of 2 metres.

The second part of the ideation chapter centred on the user aspect. Drawing from insights gained in work engagement research, a user interface was iteratively developed in three stages, continually evaluated in workshops with CowManager employees and farmers. The interface for the localisation process was designed to be intuitive, displaying minimal data while clearly communicating the estimation and its confidence level to the user. Features such as a personal profile, interactive tutorials, and in-app rewards were incorporated to enhance work engagement.

The integration chapter shows how the technological and user aspects were combined. It features an annotated user interface highlighting all developed features and presents a comprehensive system overview that integrates the technology. The user interface includes a data flowchart to illustrate their interconnections. Finally, the chapter examines the solution's implications for all stakeholders and validates the plan of requirements.

The thesis concludes with a discussion on the solution's feasibility, viability, and desirability. It was demonstrated that the proposed localisation solution is technologically straightforward and cost-effective to integrate into the existing infrastructure of sensors and routers. The cost-effectiveness is also a key factor that enhances the solution's desirability among farmers, especially considering it uses cutting-edge technology that is continually advancing.



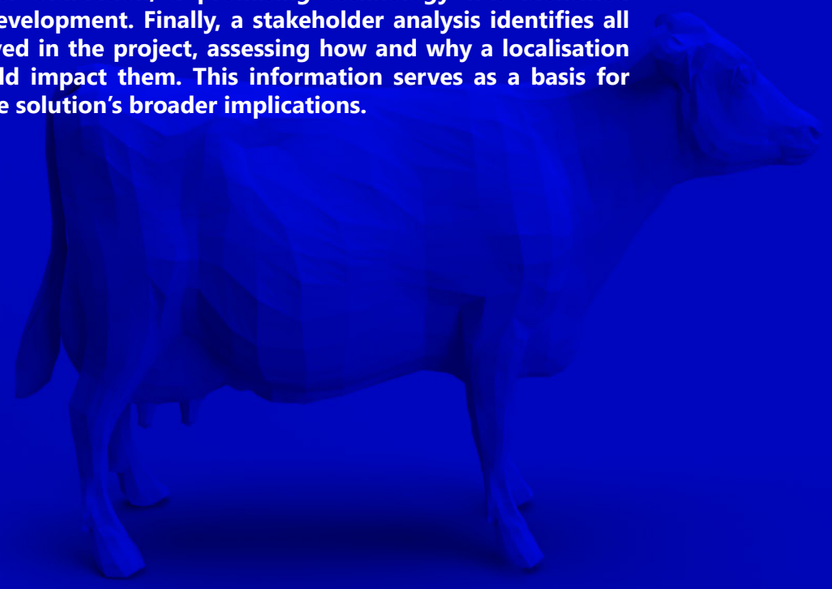
Figure 1 Curious cow on the test farm of Agis Innovations.

Chapter 2

Background

2.1 Sustainable Development Goals on Farms
2.2 Farm Size and Automation
2.3 History of Localisation Services
2.4 Localisation in Literature
2.5 Market Analysis
2.6 Technology Analysis
2.7 Stakeholder Analysis

In this chapter, the context of cow localisation was explored. It begins by outlining how large farms are progressing towards sustainable practices using the CowManager system. Trends in farm size and automation were then examined to understand their impact on farm operations. The technological aspect delves into the evolution of location services, exploring the motivations behind human desire for such technology. Subsequently, the market for cattle localisation and personal use was investigated to analyse competitors' systems and their performance metrics. Furthermore, a technology analysis was conducted to explore specific technologies suitable for a localisation solution. After evaluation, a promising technology was identified for further development. Finally, a stakeholder analysis identifies all parties involved in the project, assessing how and why a localisation solution would impact them. This information serves as a basis for evaluating the solution's broader implications.



2.1 Sustainable Development Goals on Farms

Healthy cows not only produce more milk and require fewer fertility hormones and antibiotics, but they can also play a role in advancing the Sustainable Development Goals (SDGs) adopted by all United Nations Member States (United Nations, n.d.). These goals serve as a framework for promoting peace, prosperity, and sustainability for both people and the planet. The goals encompass 17 categories aimed at ending poverty, improving health and education, and addressing climate change. Large farms have the capacity and responsibility to contribute to these goals by prioritising the health and well-being of their animals. Healthy animals make substantial contributions to several SDGs, as outlined by HealthforAnimals (2023), and shown below.



Livestock plays an important role in providing income for many people, offering them a way out of poverty, while also providing nutrition for communities.



Healthier animals have a smaller environmental footprint as they require less chemical or medicinal treatment, as well as reduced water and feed consumption.

Additionally, HealthforAnimals (2023) is the global animal health association that represents the animal health sector. They have adopted six sustainability principles to commit to healthy animals.

Principle 1: Strengthen global cooperation – "Cooperation and partnership that embrace one health"
Principle 2: Data driven decision making – "Sustainability decisions must be guided by clear, transparent and verifiable data"
Principle 3: Minimise our footprint – "Healthy animals are more sustainable"
Principle 4: Innovate for a better world – "Committed to building a deeper understanding of animal health"
Principle 5: Support animal caretakers – "Veterinarians and animal owners need greater recognition"
Principle 6: Prioritise animal health and welfare – "Good animal care is at the heart of sustainability"

CowManager already adheres to (almost) all of these principles, as their entire service is centred around enhancing the health of cows through data-driven decision-making. In the United States, dairy farms have achieved a 19% reduction in carbon footprint compared to 2007 (US Dairy, n.d.), demonstrating that the agricultural sector is indeed progressing towards sustainable farming practices. Developing a localisation solution for CowManager's portfolio aligns well with the outlined principles and SDGs. It contributes to prioritising animal health and welfare, promotes data-driven decision-making, fosters innovation for a better world, demonstrates responsible production practices, and facilitates climate action.

2.2 Farm size and Automation

Understanding the implications on a farm resulting from the shift towards automation is crucial for recognising the need for a cow localisation solution. MacDonald et al. (2020) have demonstrated a significant decrease in the total number of dairy farms in the US. However, the decline in farm numbers is not mirrored by the number of cows. This is the result of the rise of large-scale farms. In 1992, the majority of cows (30%) were housed in farms with 50-100 cows, whereas today, over 50% of all cows in the US live on farms with more than 1000 cows. This increase of larger farms is driven by technological advancements and automation within the dairy industry (Delmergroup, 2023). This technology has not only improved profitability, animal health, and milk quality but has also significantly reduced the workforce required to operate a farm. Consequently, a single farmer can effectively manage more cows, triggering the expansion of farms while smaller operations have become economically unrealistic (Lakhani, 2023). Figure 2 shows the trend of the increasing numbers of large farms while smaller farms fade.

"Dairy policies drive small farms to 'get big or get out'" – Lakhani (2023)

However, the concentration of more cows on a single farm also implies a greater need for treatment and attention, underscoring the growing necessity for a localisation solution, creating development opportunities as farms continue to expand. As farms continue to expand, a smaller workforce can manage more cows, but the increasing size of farms means they can no longer be managed by just one family. Consequently, there is a need to hire additional employees to strengthen the workforce. According to the US National Center for Farmworker Health (2022), in 2021, 70% of farm workers in the US were foreign-born. Additionally, 68% of these workers speak little to no English. Hernandez et al. (2018) discovered that 71% of farm workers have limited or no ability to read English, revealing a very low literacy rate among farm workers.

Moore et al. (2020) identified a lack of employee engagement and satisfaction, along with a high turnover rate, as major issues in US dairy farming. Their research involved a questionnaire for farm workers, using quotes about working on a farm. It was found that employees who received more training and had more autonomy in their work were more satisfied. However, overall work engagement was significantly low. A correlation was observed between employees' relationships with management and their job satisfaction and work engagement (Moore et al., 2020). This indicates that the psychological needs of autonomy, relatedness, and competence, as discussed by Ryan and Deci (2000), were not being met on farms. Ryan and Deci suggest that employers can engage their employees by providing training and the right tools, thereby enhancing the feeling of competence.

The low literacy rate and poor work engagement were critical evaluation criteria that needed to be addressed during the development of the localisation solutions from a user perspective. Overcoming these challenges was essential. As later revealed through farmer interviews, if a system does not operate intuitively according to the user, then they may choose not to use it, even if the solution itself is desirable.

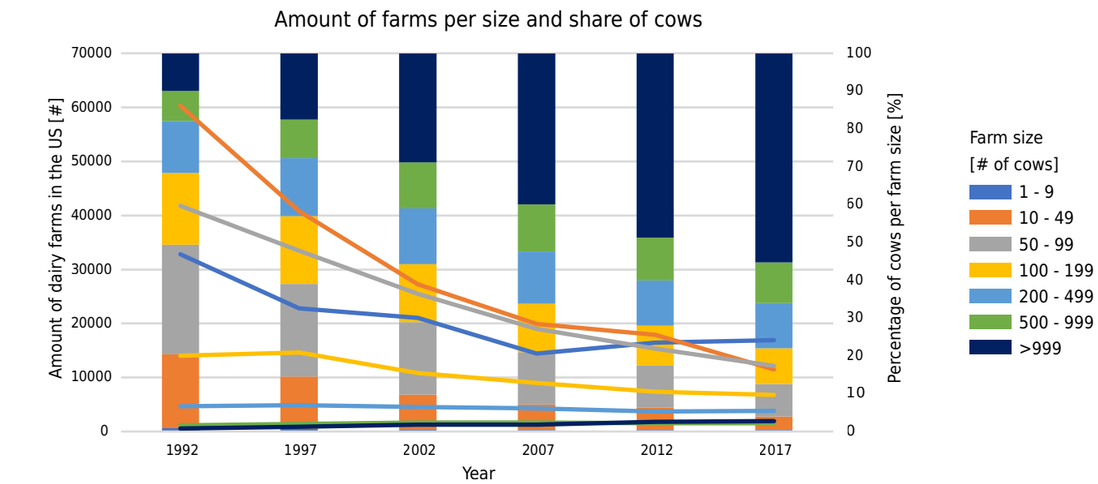


Figure 2 Graphs showing the amount of farms categorised by size (lines), and percentage of all cows in the US that are housed in a category of farm size (bars).

2.3 History of Localisation Services

Being able to use locations is essential to make sense of the complex world around us. The history of locating and tracking objects started during the space race between the Soviet Union and the United States (Walker, 2023) when the Soviet Union launched Sputnik 1 in 1957 (Royal Museums Greenwich, n.d.). The launch of Sputnik 1 scared the Americans after which they developed a way to track the satellite from earth's surface. The United States started conducting more tracking experiments, leading to 6 satellites that could track submarines in 1960 (Walker, 2023). The idea of tracking grew further and the United States Department of Defence wanted a robust navigation system leading to a constellation of 24 satellites that became operational in 1993 (Walker, 2023) and GPS was born. In 1996, GPS was made mandatory for mobile network providers to find a way to accurately pinpoint the location of people who called the emergency number (Proximity MX, 2018). However, GPS did not become as successful as anticipated. Starting from the early 2000's, the first smartphones were introduced and brought to market. These smartphones started implementing GPS sensors that paved the way for the location based services we know today (Aerospace Corporation, 2024). It was estimated that, nowadays, 67% of all smartphone owners use a turn-by-turn navigation service occasionally (Smith, 2015), underlying the importance of both smartphones and location services in the world as we know it today.

As can be suggested by Figure 3, the trend of using smartphones keeps increasing while already, smartphones are a big part of our lives. Our lives, however, mainly exist indoors where GPS does not work while we do want to use location services indoors. This resulted in a trend of localisation services using wireless networks like Wi-Fi and Bluetooth which have been widely implemented. Using these localisation services, an indoor location can be roughly estimated. However, these estimations are prone to a lot of errors and a lot of research and development is still being done to create an accurate indoor positioning service. Figure 3 shows the trends of technologies and important events that influenced positioning and localisation services as we know them today. This analysis highlighted the significance, convenience, and versatility of location services. It also suggests that a localisation solution for cow management aligns with the broader trends in location-based technologies.

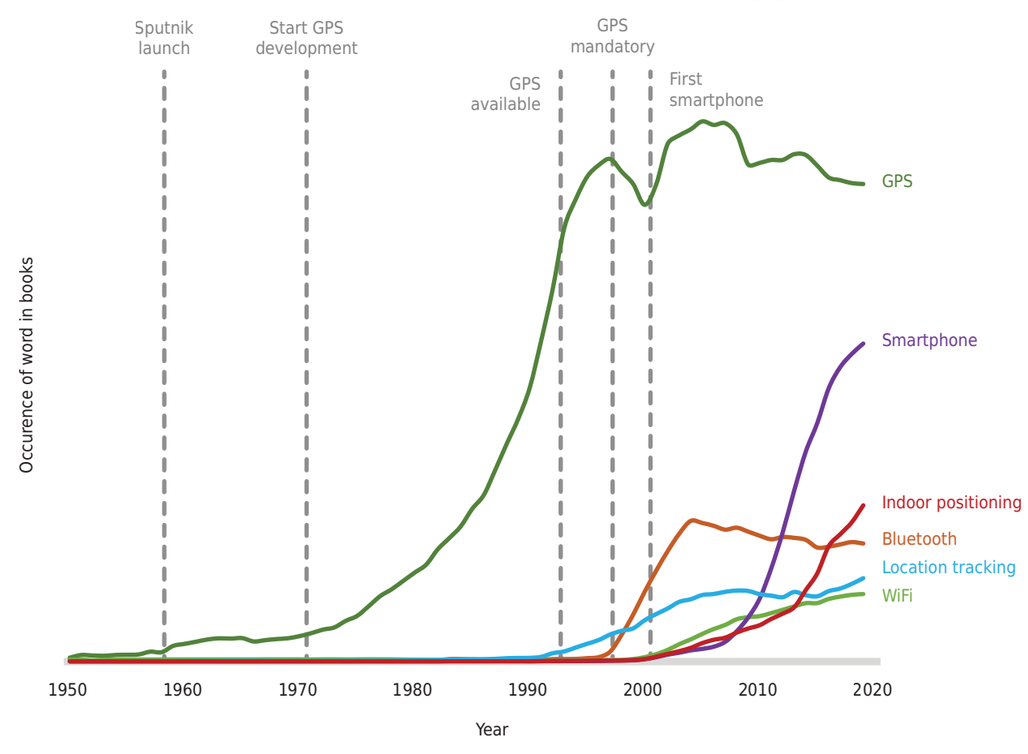


Figure 3 Visualisation showing trends in word usage in books from 1950 until 2019.

2.4 Localisation in Literature

A significant amount of research has been conducted on tag localisation across various contexts and environments. The choice of technology is highly dependent on the required accuracy. Additionally, in the context of cow localisation using an ear sensor, the power consumption of the localisation solution greatly influences the technology choice. This research aimed to explore the advancements made in this field to establish evaluation criteria that the proposed solution must meet.

Most research on tag localisation has explored two categories of localisation systems: active and passive localisation. Deak et al. (2012) classified active localisation as a system where the user carries an electronic device that actively transmits information to a positioning system to help determine the location of the tag. Several studies on active cattle identification and localisation use a system with Ultra-Wideband (UWB) (Figure 4 left). For instance, Porto et al. (2014) developed a cow localisation system capable of identifying cows with an accuracy of 0.98 and locating cows with an error between 1 and 2 metres. The accuracy of this technology is very dependent on the number of beacons used. Porto et al. (2014) employed four beacons in a 20m x 20m square. Research by Monica and Ferrari (2013) discussed the number of beacons required to accurately locate a UWB tag, finding that more beacons result in higher accuracy, typically requiring beacons every 10m to 20m to maintain accuracy, which supports the findings of Porto et al. (2014). However, the need for a large number of beacons results in high investment costs, particularly in the context of farms.

There are two types of dairy farms: open fields and barns. Barns have a space requirement of approximately 4m² per cow (Food and Agriculture Organization, 1999). While a barn provides spaces to optimally place UWB beacons, four beacons are required for every 100 cows. For a barn housing 5000 cows, this necessitates an investment in at least 200 beacons if the barn is optimally designed and free of metal obstacles. Additionally, in open fields, there are limited places to install beacons, making the optimised beacon placement proposed by Monica and Ferrari (2013) unfeasible, and thus requiring even more beacons.

Passive localisation is classified as a system that determines the location of a person, body, or object without a device transmitting information to a positioning solution. An example of this is RFID tracking, where the presence of these tags, which do not have batteries, can be scanned using a device (Figure 4 right). In addition to presence, the scanners read an identification number from the tag. Moreover, using Ultra High Frequency RFID (UHF-RFID), signal strength and/or phase difference can be measured to estimate the distance between the tag and the reader (Wegener et al., 2016).

Deak et al. (2012) also discussed passive localisation solutions that can determine the position of a person, body, or object without any tags. One example is using computer vision to determine the position of an object from an image. Tassinari et al. (2021) conducted a study to identify cows based on their pelt patterns using deep learning, achieving an accuracy of up to 0.73. However, this method is less effective for breeds like Jersey cows that lack distinct pelt patterns. Another study by Smink et al. (2022) focused on cattle identification using computer vision to read ear tags from images, which has broader applicability. They found their system could identify cows with an accuracy of 0.71, though this was highly dependent on the readability of the tags, which often fade or break over time in farm environments.

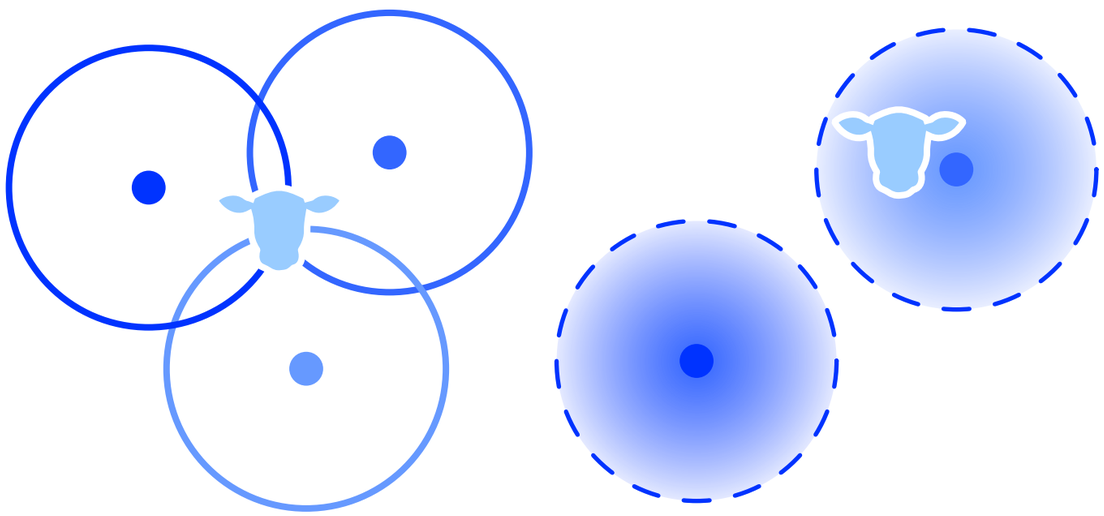


Figure 4 Active trilateration versus passive RFID tracking.

While most passive localisation solutions only identify a tag in close proximity to a sensor, most active localisation solutions are capable of locating tags at larger ranges, thereby increasing the detection distance. Nearly all these solutions use trilateration to determine the position of a tag, which requires the tag to be within range of at least three beacons. To determine the location of the tag, each beacon must know its own location and the distance between the beacon and the tag. Teoman and Ovatman (2019) discussed that this distance usually comes from either a distance estimation based on signal strength or a measured distance, usually via Time-of-Flight, as in the case of UWB.

Considerable research has been conducted on indoor trilateration solutions using various technologies. Noertjahyana et al. (2017) developed a solution using the signal strength of Bluetooth devices but found that the signal strength is unpredictably influenced by the environment, resulting in highly inaccurate location estimation. Measured distances, mainly using the Time-of-Flight method, which measures the distance between two devices using the speed of light and the time it takes for a signal to travel between them, show higher accuracy and are less impacted by the surroundings. GPS, one of the most well-known localisation solutions using the Time-of-Flight method, achieves an accuracy of approximately 4 metres, with the beacons being numerous satellites in space (Barbeau, 2021). UWB, as explored by Porto et al. (2014), requires an investment in beacons but proves to be accurate and adaptable for use in the complex environment of farms if suitable locations for beacons can be found.

Localisation Evaluation Criterias

To determine the most suitable method and technology for this project, four evaluation criteria have been established: accuracy, cost, battery lifetime, and detection distance. While substantial research has been conducted on optimising and evaluating localisation technologies for each of these criteria individually, including some studies on dairy farms, there has been no research focused on developing a localisation technology that simultaneously optimises all of these factors.

Accuracy is a crucial evaluation criterion as it directly measures the performance of a localisation technology. Cost is also significant, influencing farmers' decisions regarding investment in a particular solution. Battery lifetime is another important consideration for Agis CowManager, aiming for sensors to maintain a lifespan of 10 years. Lastly, detection distance is crucial. While GPS offers a long detection distance, its accuracy is lower. On the other hand, RFID solutions provide high accuracy but have a limited detection distance. Therefore, the capability to detect cows from a significant distance and accurately guide to their location was deemed essential for this project.

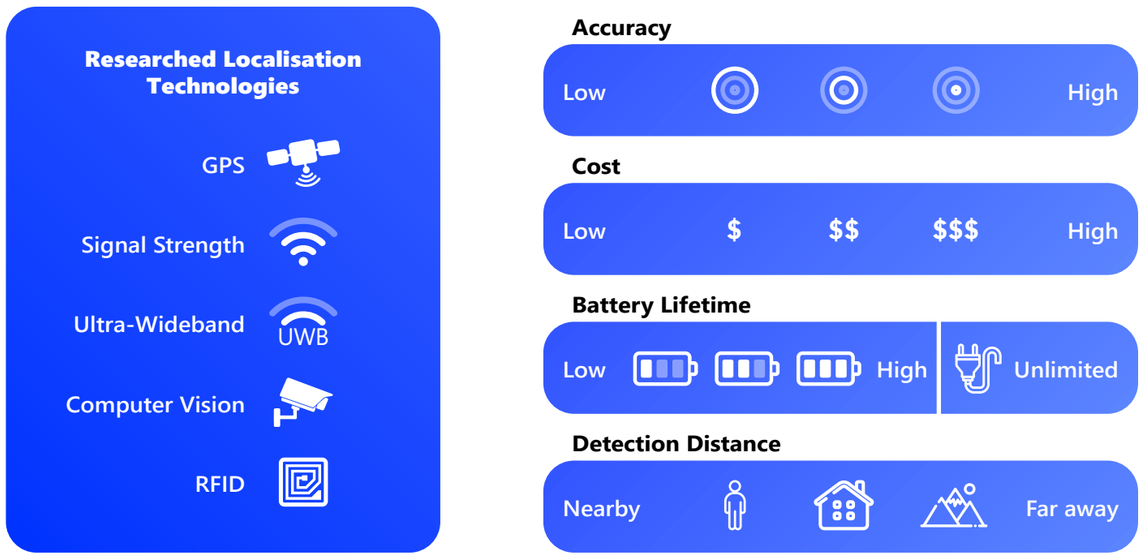


Figure 5 The five technologies that are mainly used for tag localisation and the four evaluation criterias with their scale.

2.5 Market Analysis

There is a substantial market for automation on farms, ranging from robots that milk and feed cows to automated climate control in barns. Exploring the technologies of competitors provided insights into how well other localisation solutions in the market are performing. This information was used to quantify and set the threshold for the evaluation criteria of battery lifetime, ensuring that the proposed solution outperforms the competitors.

In this market, numerous competitors offer localisation services, with many relying on Ultra-Wideband (UWB) or signal strength combined with trilateration methods to determine the location of cows. However, UWB is known to consume a lot of (peak) energy (Wurms, 2022). Nedap, a competitor, has a long battery life of 10 years, achieved by placing a larger sensor around the neck of a cow to accommodate for a larger battery. In contrast, Smartbow, another competitor using Ultra-Wideband in an ear sensor, has a short battery life of just 2 years as they locate cows 24/7. Alternatively, some competitors use GPS for localisation, but this method requires substantial energy and operates only outdoors (Millward, 2023). CowManager's Find my Cow solution, however, uses signal strength in an innovative way. It measures the signal strength between a cow and a phone carried by the user. However, this method is often too inaccurate. Competitors using Ultra-Wideband or GPS for cow localisation often show a live map with the locations of multiple cows, which farmers find easy to interpret (as noted in interviews). Conversely, another approach to cow localisation focuses more on identification rather than navigation. On most large farms, cows wear RFID tags in their ears, eliminating the need for batteries. However, a drawback of this method is the time-consuming nature of scanning every cow to find a specific one, or the potential delay if a cow takes time to pass by a scanner.

Localisation technology has a significant market not only in agricultural settings but also for personal use. The Apple AirTag is an outstanding example of this. What sets them apart is their use of other Apple devices as beacons, simplifying and reducing the cost of deployment. Other companies, such as Oxts and Mapsted, employ a combination of localisation services to achieve precise location estimates. These companies use multiple sensors like an IMU, which can derive a relative position from a starting point with reasonable accuracy through dead reckoning. However, it's worth noting that IMUs typically consume a significant amount of energy.



Figure 6 Competitor overview showing the technology, accuracy, cost, battery lifetime and detection distance. A full numerical analysis can be found in Appendix A.

2.6 Technology Analysis

Based on the market analysis, the technologies used by competitors were analysed and evaluated. Localisation technologies can be classified into three main categories: tag identification, motion tracking, and tag ranging. Most identification technologies have a limited range, typically up to 0.5 metres. However, visual IDs, such as numbered ear tags, can be read from several metres away. The smaller range of identification technologies contributes to higher accuracy in location estimation.

On the other hand, tag ranging technologies aim to determine the distance between two devices and can cover a wider range. However, environmental factors like metal significantly affect the accuracy of the distance estimations. In environments with a lot of metal, such as a barn, there are numerous multipath interferences, leading to inaccuracies in the distance estimations. Additionally, cows themselves can obstruct wireless ranging results, weakening the signal and altering signal speed, which is used to estimate distance. Figure 7 categorises all localisation technologies.

2.6.1 Comparison

There are four widely available technologies that are capable of estimating distances; Zigbee, Bluetooth, Ultra-Wideband and GPS. These technologies can estimate distances using signal strength, phase based ranging or time of flight measurements. Additionally, an IMU is often used to enhance the accuracy of location services. On the next page (Figure 8), these five technologies have been explored to determine their theoretical potential in a new localisation solution.

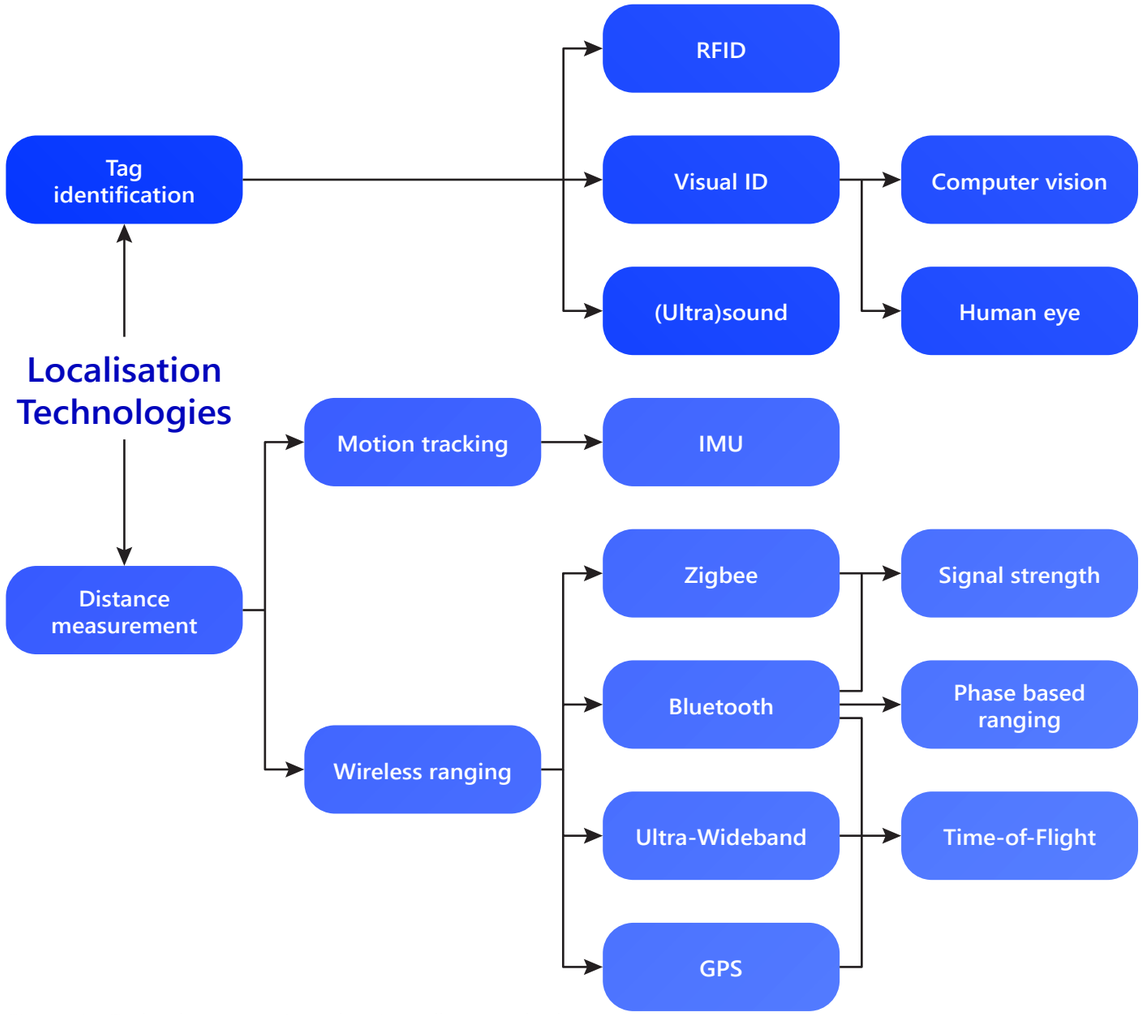


Figure 7 Technology overview showing all researched technologies and their categories.

IMU
An inertial measurement unit (IMU) is a sensor designed to measure the movement and orientation of itself (King, 1998). One significant advantage of an IMU is its independence from wireless communication. However, IMUs are vulnerable to errors and drift in measurements due to the lack of reference points in space. Moreover, the measurements are time-dependent (Seel et al., 2020), requiring continuous sensing, draining batteries quickly. Nowadays, IMUs are used in combination with, for example, GPS, fusing their data to improve an estimated location (Caron et al., 2006).

GPS
While GPS may not offer the highest level of accuracy in object localisation and operates best outdoors, it boasts global coverage without the need to install additional beacons. Similar to Bluetooth and UWB, GPS is integrated into nearly all smartphones, making it readily accessible as a location service. Additionally, smartphones have enhanced the location service by fusing GPS data with other localisation services from cellular towers, Bluetooth, and the integrated IMU (Google n.d.). The result is a localisation service that works indoors as well as outdoors.

Ultra-Wideband (UWB)
Ultra-Wideband has recently gained more attention as an accurate indoor distance measuring technology, claiming an accuracy of up to 10cm (Pothuganti & Chitneni, 2014). UWB uses Time-of-Flight (ToF) measurements, which calculates the distance between two devices by measuring the time taken for a message to travel between them (Terabee, 2024). This method results in greater accuracy compared to distance estimation based on signal strength. UWB technology has been recently integrated into smartphones and has demonstrated its potential, as proven by its inclusion in products such as the Apple AirTag (Apple, n.d.). Competitors like Lely and Smartbow also use UWB in their localisation solutions. However, despite its promising capabilities, according to several farmers, UWB solutions fall short in accuracy due to the occurrence of multipath interference in the farming environment (Esa, 2011), resulting from the presence of metal that disrupts the signal.

Zigbee
Zigbee is a commonly used wireless communication protocol (Pothuganti & Chitneni, 2014). Within this category, Zigbee is used for devices requiring low power consumption and minimal data transfer. Additionally, Zigbee commonly operates as a mesh network, facilitating communication among multiple devices. However, the only method to determine the distance between two Zigbee devices is by using the signal strength. These values can be recalculated to estimate distance (Blumenthal et al., 2007). Nevertheless, these estimations tend to be highly inaccurate due to various factors influencing signal quality.

Bluetooth Low Energy (BLE)
Bluetooth was initially developed for communication between devices as a cable replacement (Pothuganti & Chitneni, 2014). Nowadays, Bluetooth also offers distance estimation using signal strength, similar to Zigbee. Additionally, Bluetooth can be used for more accurate localisation using direction-finding services, requiring multiple beacons to be installed (Bluetooth, n.d.).
Moreover, the Bluetooth Special Interest Group (SIG) community has recently introduced a new high-accuracy distance measurement technology called Channel Sounding (CS). Bluetooth claims that the CS technology can achieve distance measurements with an accuracy of 10-30 cm (Hillyard et al., 2023). CS is a phase-based ranging technology that calculates distance by measuring phase differences between multiple signals.

Technology	Protocol	Accuracy	Battery life	Simplicity
IMU	Dead reckoning	Medium	Low	Medium
GPS	Time-of-Flight	Medium	Medium	High
Ultra-Wideband	Time-of-Flight	High	Low	Low
Zigbee / Bluetooth	Signal Strength	Low	High	High
Bluetooth CS	Phase difference	High	High to be tested	Low to be improved

Figure 8 Technology comparison. Full comparison can be found in Appendix B.

2.6.2 Competitor Patents

There are six major competitors that hold patents for cow localisation solutions. Nedap measures the signal strength from a tag in the three perpendicular directions to static beacons (Van Dijk & Rooseboom, 2011) of the 802.11 link (Wi-Fi, Bluetooth, Zigbee, etc.). Using signal strength, they can estimate a distance after which they use trilateration to estimate the position of the tag. Centrak uses a similar trilateration method using signal strength between a tag and static beacons. They also use an accelerometer to calculate the distance that the tag has moved, fusing this data with the trilaterated position to improve the estimated position of a tag (Smith et al., 2004). Geissler also uses trilateration to estimate the position of a tag. However, they use a Time-of-Flight method on a very low bandwidth to calculate the distance between the a beacons and a tag (Geissler & Lewis, 2018). Smartbow uses trilateration using Time-of-Flight distances from Ultra-Wideband to estimate the location of a tag (Auer, 2020). The last two competitors use passive localisation techniques. Paralec uses a camera that identifies LEDs worn by cows to determine their position (Braiman, 2004). DeLaval estimates positions using static beacons that detects tags in close proximity and stores the associated timestamp of the event (Elfgren, 2008) to precisely know which tags were in what area.

As can be seen, most competitors patented their localisation method of trilateration using distances that are obtained from a variety of wireless technologies. Looking at other localisation solutions like GPS and cellular position estimation, most services use trilateration to estimate the position of an object, suggesting that this method is suitable to implement in a wide variety of use cases, including cow localisation. Following the patents and technology that is available, there are two patented ways of measuring or estimating distances wirelessly. Either measuring distance using a Time-of-Flight method or estimating distance using the signal strength between two devices.

2.6.3 Technology Selection

Time-of-Flight and Channel Sounding are compelling technologies for distance measurements. ToF measures the time it takes for a signal to travel between two devices, leveraging the speed of light to calculate distance. This method is straightforward but faces challenges in environments with obstacles and reflective surfaces, such as farms, where metal and walls create multipath interference. The typical accuracy of ToF, around 3 metres, is also constrained by the limitations of most microprocessors.

Channel Sounding, on the other hand, uses phase-based ranging to determine distances by measuring the phase difference between transmitted and received signals. This technique offers higher accuracy, ranging from 10 to 30 centimetres, and is better equipped to handle multipath effects by using multiple frequencies. This makes it a more robust solution for environments with complex signal paths. Additionally, Sukumar (2023), working for Silicon Labs, has conducted an initial test to compare the power consumption between Channel Sounding and Time-of-Flight (UWB). They found that Channel Sounding uses half the energy compared to Time-of-Flight. Using the results of Sukumar, it was calculated that Channel Sounding would decrease the battery lifetime of the ear sensor with less than 2 months if it is used with the same intensity of Find my Cow. It was determined that the localisation solution must consume no more power than the current Find my Cow solution to meet the evaluation criteria for a long battery lifetime. An extensive comparison between Channel Sounding and Time-of-Flight can be found in Appendix C.

Multiple competitors like Smartbow and Geissler have patented their use of ToF and other ranging methods, highlighting the industry's recognition of ToF's suitability. Channel Sounding, with its recent developments and integration into Bluetooth LE, has emerged as a promising technology, offering a yet unpatented high-accuracy solution that can mitigate many of the issues faced by ToF.

Given these advantages, Channel Sounding was chosen as the technology to test and develop further with. Its claim of superior accuracy and robustness in complex environments make it a suitable technology for precise localisation, essential for the application of cow localisation in complex farm environments.

2.7 Stakeholder Analysis

A stakeholder analysis was conducted to identify and understand who would be affected and how they would be impacted by the development of a new localisation solution. The stakeholder analysis revealed stakeholders of various kinds. While there were only a few key figures, there were numerous stakeholders who influenced the outcome or have an interest in a localisation solution, such as competitors. The categorisation of stakeholders can be found in Appendix D.

2.7.1 Business Perspective

Agis Innovation Centre
The Agis Innovation Centre is a small company within Agis dedicated to innovating and developing new products and services for sale by CowManager. As such, it was the primary stakeholder with the greatest interest and influence on the project.

CowManager
CowManager serves as the public face of the company, responsible for selling products and services and offering support to farmers. Although they were not directly involved in the project, they had to be satisfied, and understand the potential of the localisation solution.

Competitors
Localisations solutions for cows are a hot topic. Numerous competitors are actively working on localisation, closely monitoring each other's progress. Moreover, competitors hold several patents that influence this project, defining what can and cannot be done.

Suppliers and Factories
Suppliers of components had significant influence over the final outcome. Their decisions to continue or discontinue production of specific components severely impacted the project. Thus, it was important to gain insight into their future development plans.
It was important to maintain the satisfaction of the factory that is responsible for producing the products, ensuring they retain the capability to manufacture the product effectively. This means that the solution was designed to be easily producible by the factory.

2.7.2 People Perspective

Farmers
Farmers were key figures in the project as they are the ones seeking a localisation solution. Given their decision to invest in such a solution, it is essential to fulfil their requirements. As a stakeholder, they held a unique position. They are not only individuals and users of the localisation solution but also company owners. This means that they must make reasonable decisions for their company while simultaneously adhering to all rules and regulations their government has established.

Farm Employees
While farmers decide to invest in a localisation solution, farm workers are the actual people who will be using the solution the most. This means that it is crucial to understand how they want to work with a localisation solution and how this fits in their workflow.

Cows
The aim of the localisation solution was to enhance the treatment of cows, ensuring it is better, faster, and more ethical. Therefore, the solution had to deliver on these objectives to meet the desired outcomes.

Society
Society is becoming more aware of the origins of their food (Mingay et al., 2021). For dairy farms, this translates to pressure to reduce practices such as injecting fertility hormones and the reliance on antibiotics (Higgins et al., 2013). Although society itself may not have been a direct stakeholder in the project, it applies pressure on the government, which was a direct stakeholder and influencer, thereby indirectly influencing the project's direction.

Inseminator and Veterinarian
The inseminator and veterinarian are external workers who come to the farm almost daily. Their job involves medically inseminating and treating specific cows which the regular workers cannot do. Consequently, their interest in a robust localisation solution was high, although their direct influence was lower compared to regular farm workers.

2.7.3. Government Perspective

Governments
Given that CowManager serves customers globally, the solution must comply with regulations and standards established by various governments. This is specifically important when using radio frequencies in a localisation solution, as different governments have distinct rules and regulations concerning transmit power (4GON, n.d.).

Animal Welfare Organisations and Inspector
Animal welfare organisations had direct influence on the project as they advise the government and monitor farms (European Union, n.d.). Therefore, they have a high interest in localisation solutions as it has the potential to enhance the health and welfare of cows.
The inspector inspects the quality of dairy products on a farm (Department of Agriculture and Markets, n.d.). Therefore, they are indirectly inspecting the health and welfare of cows which can be stored in the logs of a localisation solution.

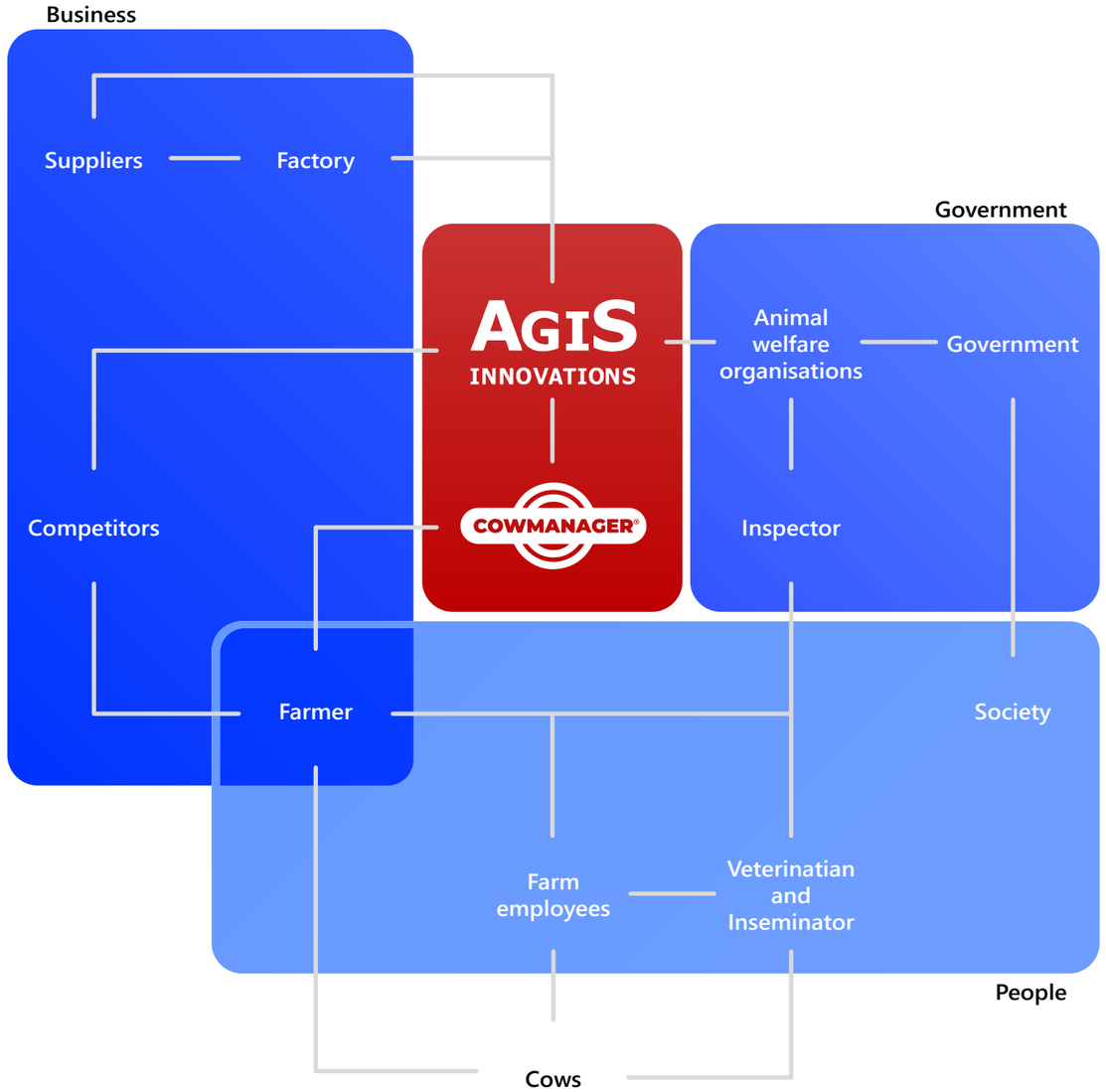


Figure 9 A stakeholder map, showing all stakeholders and how they are interconnected.

Chapter 3

Method

3.1 Scope
3.2 Users & Technology

In this chapter, it was determined what next steps were necessary to develop a cow localisation solution to answer the main research question. Additionally, in the scope, the timeframe, opportunity gap and focus area were discussed.



3.1 Scope

3.1.1 Main Research Question

Considering the developments in localisation technologies and the diverse needs of stakeholders in modern dairy farming, it was crucial to explore how a new localisation solution could help to enhance both cow welfare and farm efficiency in large-scale dairy operations. By exploring emerging technologies and understanding stakeholder requirements, a solution was designed that not only addresses the challenges faced by farmers, but also promotes sustainability and improves animal welfare. The main research question was:

"How can a localisation solution be designed and integrated with the existing ear sensor to optimise user experience and efficiently locate cows, considering the diverse needs and preferences of farmers?"

3.1.2 Place and time

The primary focus was on the US, given the large number of farms with 5000+ cows seeking a localisation solution. However, the solution required global applicability and had to be modular to adapt to diverse farming environments worldwide.

Regarding the timeframe, it was determined that the solution should be implemented in the next generation sensor. This sensor had already been scheduled for new hardware, which could still be adjusted to integrate a localisation solution. Therefore, the projected timeline fell within 1 to 2 years. Additionally, there was a sense of urgency to bring the solution to market quickly, as competitors are also moving quickly in this space.

3.1.3 Opportunity gap

The primary opportunity gap lay within the technology sphere. Channel sounding, as a novel technology demonstrating promising distance measurements, presented a chance to pioneer and refine the first localisation solution utilising this technology. Moreover, a localisation solution that optimises accuracy, cost, battery life, and detection distance was not found in the existing literature, revealing a significant knowledge gap with the potential for development.

Furthermore, there was a significant opportunity in prioritising the user within the design process. By focusing on the farmer's requirements in shaping the user interface and the process of locating cows, the solution was tailored to effectively meet their needs. This approach contrasts with many existing solutions that are primarily driven by technology. By aligning the solution with the preferences and workflows of farmers, trust in the system could be established, presenting a valuable opportunity for success.

Additionally, the literature indicated a low literacy rate and a lack of work engagement among farm workers, which needed improvement. However, no literature was found that addressed how a tool could be used to mitigate low literacy while enhancing work engagement in the context of farm work.

3.1.4 Focus area

As previously mentioned, the focus area encompasses two key aspects: technology and user experience. In the final concept, these elements are seamlessly integrated to create an optimal cow localisation solution. The technology aspect involved thorough testing of Channel Sounding to assess its advantages and limitations. Afterwards, it was determined how the technology can be used to accurately determine the location of cows.

On the user side, the focus was on designing and implementing a touchpoint how farmers prefer to locate cows. This was uncovered using interviews with farmers, a questionnaire with farm workers, and design workshops with CowManager employees and farmers.

3.2 Users & Technology

As discussed in Section 1.2, it was crucial to explore and test both technological capabilities and user needs separately. This separation allowed for a thorough understanding of each aspect before integration. Specifically researching the user aspect enabled a user-centric approach, which was essential because competitors often develop solutions from a purely technological standpoint, neglecting user needs and preferences. It was also found that many farmers refrain from investing in technological solutions if the user interface does not meet their expectations. Ultimately, the technological and user aspects had to converge into the final cow localisation solution, ensuring that the chosen technology aligns with user preferences and is seamlessly integrated through carefully designed user touchpoints. Figure 10 visualises how all methods are used and integrated, resulting in a localisation solution.

The next steps were carried out using an adapted version of the double diamond approach (Figure 11) as this method was developed to be user-centric (Design Council, 2005). The first phase of discovery involved conducting my own research on the user aspect through farmer interviews and farm worker questionnaires. The second phase of defining was completed in the latter half of the interaction chapter, establishing the thresholds for the evaluation criteria based on the insights gathered from the users. In Chapter 5, the solution was developed in smaller pieces, and Chapter 6 delivers and integrates the entire solution.

3.2.1 User Aspect

The user aspect was explored through data research, farmer interviews, and farm worker questionnaires to understand their needs, motivations, and work engagement.

Data Research

The data research involved combining data from CowManager's current localisation service with user interviews to validate how cows are located, including time efficiency and locating cows in groups. I analysed quantitative data collected by CowManager to detect patterns in the cow localisation process. This analysis provided numerical insights, validating farmers' input and helping to identify areas for improvement in the localisation system. Additionally, I developed process trees to visualise workflows, highlighting inefficiencies for improvement.

Farmer Interviews

The farmer interviews provided insights into current practices and motivations for cow localisation. Additionally, the interviews aimed to reveal the farmers' perspectives on their workforce in terms of literacy rates and work engagement, validating the findings in the literature. These interviews acted as a starting point to determine what exactly needed to be improved. The interviews were also used to uncover not only the motivations behind cow localisation but also how localisation fits into the daily workflow, and what the general struggles on a farm are, which a localisation solution should also take into account.

Farm Worker Questionnaire

The questionnaire aimed to identify gaps in work engagement. Understanding these gaps was important as it determined what needed to be improved from a user touchpoint to enhance work engagement, as farm workers were found to lack responsibility and care. The questionnaire identified these gaps by connecting work engagement to humans' fundamental needs to understand, from a fundamental level, what was lacking to improve work engagement.

Additionally, personas were crafted from the interview and questionnaire data to highlight user needs and frustrations, identifying gaps in the user experience of cow localisation. This also made it easier to compare the two archetypes and determine their similarities and differences in needs and preferences for a localisation solution.

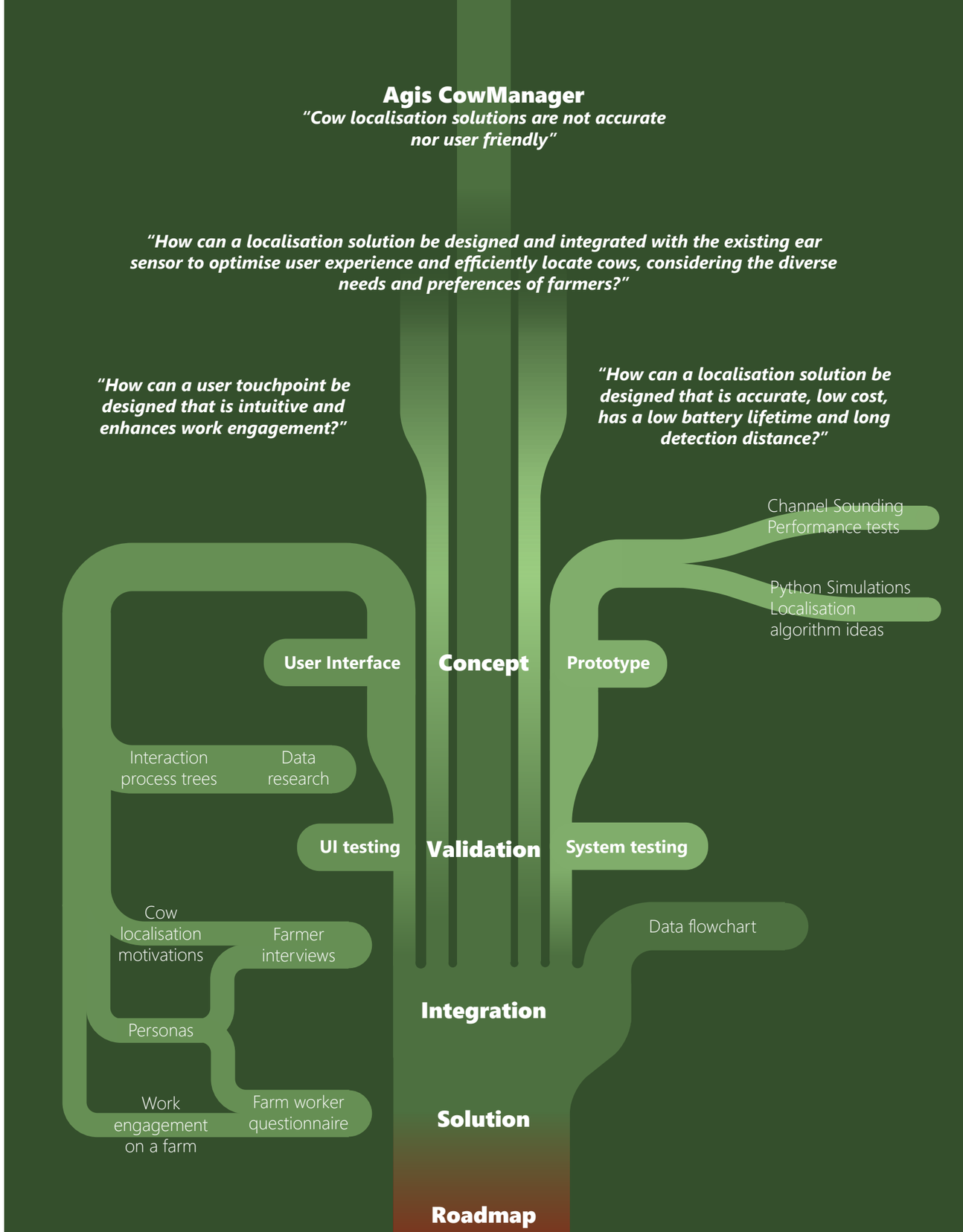


Figure 10 Visualisation showing how all different methods are connected, resulting in the localisation solution.

Based on the data gathered, a clear user-centred design direction was established, including a vision that was used to continuously validate choices throughout the design phase.

User Interface Development and Testing
From all the user insights, a user interface was iteratively developed, with continuous improvements made using qualitative feedback from tests with CowManager employees and farmers. In these iterations, the interface was developed and tested in quick succession. This phase aimed to develop an intuitive user interface for use while in the process of locating cows.

All participants from the farmer interviews and user tests are listed in Table 1 to provide an overview of participants that were relied on during this project.

3.2.2 Technology

As highlighted in the technology analysis from Chapter 2, Channel Sounding showed considerable promise. To develop a localisation solution, Channel Sounding first had to be tested for its performance. Additionally, simulations in Python were developed to quickly test localisation ideas for their performance. Finally, a physical prototype was made to prove the results of the simulations while using Channel Sounding.

Channel Sounding Performance Tests
Initially, I gathered quantitative data to assess its performance, providing empirical insights into the accuracy and reliability of the technology. This was done using development boards capable of Channel Sounding and a measuring tape to determine the errors in the measurements. This was carried out in an open field to determine the basic performance. Additionally, tests in different environments were conducted to understand the performance in environments with metal and obstacles, representing the actual farm environment.

Concept Simulations
Additionally, I wrote Python scripts to simulate localisation ideas, offering a rapid prototyping approach. These simulations provided valuable insights into the performance of different ideas, aiding in the identification of promising opportunities for further exploration. These simulations helped determine various variables that could be tweaked in the localisation algorithm. This was tested using the measurement errors and noise found from the performance tests.

Prototyping and Testing
Using the most promising localisation idea from the simulations, I prototyped a proof of concept to test and validate the idea and chosen technologies for their performance. This was done by following the directions given by the system to determine if the solution would work. Additionally, its accuracy was tested by standing on the actual location of the "cow" and logging the error.

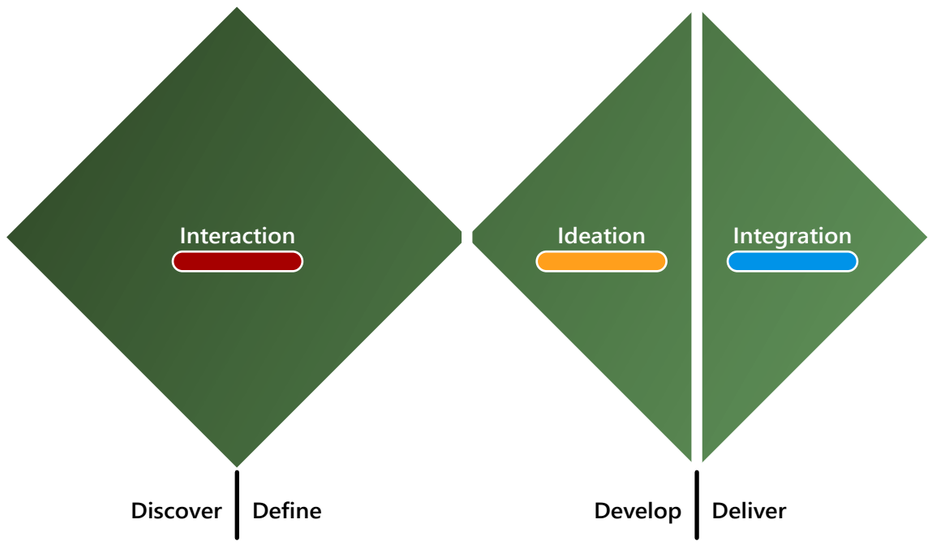


Figure 11 The project approach following the method of the double diamond.

3.2.3 Integration

Finally, I combined the proof of concept with the designed user touchpoint to establish a seamless connection between the user and the technology, ensuring a desirable user experience. This integration demonstrates how the solution is used and how data flows within the system. Furthermore, I developed a roadmap to outline the next steps for implementing the solution in the market.

Using the methods described, this thesis aimed to generate knowledge in both technological and user aspects. On the technological front, the objective was to develop a localisation solution optimising for four key evaluation criteria: accuracy, cost, battery life, and detection distance. Concurrently, from the user perspective, the goal was to develop a user touchpoint that assists users in their work by addressing low literacy levels and enhancing work engagement.

Table 1 Overview of all active participants from farmer interviews and user tests.

Participant ID	User Study
F1	Farmer visit
F2	Farmer interview
F3	Farmer interview
F4	Farmer interview
CM1	CowManager employee UI test
CM2	CowManager employee UI test
CM3	CowManager employee UI test
CM4	Cowmanager employee UI test
F5	Farmer UI test and validation
F6	Farmer UI test and validation

Chapter 4

Interaction

4.1 User Archetypes
4.2 Motivations to Locate Cows
4.3 Work Engagement on a Farm
4.4 Design Vision and Goal
4.5 Interaction Data Analysis
4.6 Current Interaction
4.7 Desired Interaction
4.8 Conclusion

This chapter aimed to generate the necessary knowledge from the user's perspective, which was utilised in the subsequent ideation chapter to develop an intuitive user interface that enhances work engagement. Personas were developed to construct archetypes of the two main users. Subsequently, the motivations for locating cows were uncovered from the farmer's perspective. Additionally, the study on work engagement aimed to identify the fundamental needs that required improvement. From this user-centric approach, a vision and goal were established to guide the ideation and validation phases.

Finally, an analysis of data was conducted to provide empirical insights and validate the findings from the farmer interviews and work engagement study. This analysis was used to identify gaps in efficiency and determine areas for improvement, which were visualised using process trees. From this chapter, it could be concluded how users want to locate cows, setting the stage for the technological solution. Additionally, it aimed to uncover the farm workers' needs in work engagement, which had to be improved using an intuitive user interface.

4.1 User Archetypes

On big farms, there are two types of people. The owner who has been a farmer for most of their life, and there are farm workers that are mostly low educated and from a different culture that do the hard physical work on the farm. Therefore, I created two personas to show their differences and motivations for using the same localisation solution. The situation outlined by the personas is used to design for the target audience as it shows the archetypes for a cow localisation solution.

The personas represent a farmer and one of his employees on a farm of 5000 cows in Wisconsin, USA. This fits the context of the scope as discussed before in the scope in Chapter 3. Additionally, a farm in the US housing about 5000 cows is a common farm and client of CowManager, and therefore, personas were made that fit this common client.

While the farmer's entire life revolves around the farm, the farm workers are likely to move between jobs quickly. This means that the farmer has to hire and train new employees on how the farm operates multiple times per year. The only consistent "employee" on the farm is the CowManager system, on which the farmer relies implicitly. Additionally, the farmer primarily decides what needs to be done on the farm, sometimes assigning tasks that might not be necessary—tasks they would never have undertaken themselves.

"I often select more cows to find because I do not have to search for them myself" - Farmer (F3)

4.1.1 Dairy farmer

General information
Age: 46
Location: Wisconsin USA
Character: Open minded, Proud, Independent, Conservative
Education: Farm school
Family status: Married and 4 children

Biography
He was born and raised on a small farm in Belgium. Due to the many regulations on dairy farming in Europe, he and his family moved to the US 15 years ago where he currently owns a dairy farm of 5000 cows. As a farmer, he works 7 days per week, but he also has employees that work around the clock to keep the farm running. The farm also has a lot of automated tasks and robots like milking and feeding machines.

Localisation values
Keep it simple
Fast localisation
Minimise human errors

Goals
Run a productive farm
Provide the best care for their cows
Provide a future work environment for my children



Figure 12 "realistic photo of an American dairy farmer, age 46, working in a farm office behind his computer" - Fotor.com

Fundamental needs
I need to work the way I want to
I can show my competence
I have a purpose in life

Frustrations
Locating cows takes too long
I cannot check on my workers while they locate cows
I get pressured by the government to document and show how my cows are taken care of

4.1.2 Farm worker

General information
Age: 31
Location: Wisconsin USA
Character: Impatient, Courageous, Simple, Worried
Education: Elementary
Family status: Married in Mexico

Biography
He was born in Mexico but moved to the US two years ago to support his family back home. Nowadays, he is part of a team of 30 employees at a dairy farm and has been working there for four months. His schedule involves alternating day and night shifts weekly, with six days of work each week. He has limited education and does not speak or read English.

Localisation values
Keep it simple
Fast localisation
Structured tasks

Goals
Provide for their family abroad
Get an education and high paying job
Being successful in life



Figure 13 "realistic photo of a mexican migration worker, age 31, working on a big american dairy farm. Standing upright, looking into the camera" - Fotor.com

Fundamental needs
Locating cows is one of the more comfortable tasks on the farm
I cannot show my competence while locating cows
I do not feel recognised

Frustrations
I do not understand the app
The US culture is very different
I do the job no one else wants to

"My employees often tell me 'I do not understand the computer' when they have to locate cows" - Farmer (F3)

The main differences between the farmer and the farm worker lie in their goals. For a farmer, the farm is their entire life and ultimate goal. For a farm worker, working on the farm is just an intermediate step, as their goals involve obtaining an education or a high-paying job, with the aim of quickly moving on to better-paying employment than that on a farm.

In addition to the differences in life goals between the farmer and the farm worker, there is often a significant educational and cultural barrier between them. According to interviewed farmers, and validated by the literature, a large part of the workforce responsible for locating cows does not speak the same language as the farmer, making communication difficult. Furthermore, a substantial portion of the workforce has low literacy levels, which results in challenges understanding which cow to find and what action to perform. During the design phase for the user interaction, this insight was crucial. The main goal of the user interface was to be intuitive for everyone, regardless of their educational level.

4.2 Motivations to Locate Cows

This section reveals the motivations of farmers to adopt a localisation solution. These insights were gathered by interviewing farmers that own more than 4000 cows. The farmers all employ around 40 people that run the farm around the clock. The goal of the interview was to explore the motivations of locating cows and understand the methods to do so. While every farm has their own way of working, the study revealed similar motivations among farmers for cow localisation.

4.2.1 Motivations

Efficient Herd Management

Efficient herd management
Locating specific cows on big farms is a time-consuming process that frustrates farmers. This daily task requires farm employees to locate 2% of the total cows. A localisation solution streamlines this process. Moreover, 1% of all cows are in the wrong pen due to human errors, efficiently locating these missing cows enhances the efficiency of herd management.

Improving Health and Welfare

Improving health and welfare
Quickly locating cows is essential to provide timely healthcare and treatment. With a localisation solution, farmers can quickly find sick cows flagged by the CowManager system, ensuring immediate attention and care. This proactive approach not only improves the health and welfare of the cows, but it also reduces the need for antibiotics. Additionally, a cow's illness can escalate rapidly and potentially lead to its death within hours. Locating these cows fast is essential for their chance of survival.

"I can use less fertility hormones and antibiotics when I find a cow on time" - Farmer (F4)

Enhance Breeding

Enhance breeding
Breeding cows is a big part of dairy farming. As the CowManager system provides the optimal insemination window, it is important to locate a cow within this window. By doing so, farmers not only optimise breeding outcomes but also minimise the need for fertility hormones.

Increase Productivity

Increase productivity
Efficiently locating cows contributes to a productive farm. By reducing the time and effort spend on locating cows, farmers can allocate employees to other essential tasks or even reduce the workforce, thereby maximising productivity.

Error Prevention

Error prevention
Accurate cow identification prior to its treatment is essential to prevent errors. A localisation solution can offer reliable identification, minimising human mistakes. Additionally, the behaviour of cows can make identification challenging, underscoring the importance to make identification easier, preventing mistakes.

Comply with Regulations

Comply with regulations
There are a lot of regulations in the farming industry regarding animal welfare. A localisation solution can facilitate accurate documentation of human-cow interactions. This helps farmers to demonstrate compliance with the governments rules and regulations.



Employee Efficiency and Accountability

Employee efficiency and accountability
Implementing a localisation solution not only improves the employee's efficiency but also enhances accountability. By providing the employees with tools to efficiently locate cows, farmers can run an efficient and productive farm. Moreover, the solution can prove farmers with concrete evidence of employee interactions with specific cows, reinforcing to adhere to the high standards of the farmer.

"My employees tell me 'Cow not found, too bad'" - Farmer (F2)



Cost Reduction

Cost reduction
Farmers highlight the need for cost-effective solutions. Locating cows efficiently reduces costs in medical treatment and improves productivity, reducing the costs of running a farm. However, this only works when the solution itself does not require high installation and usage costs.

4.2.2 Insights

The motivations depicted are based on two seemingly conflicting values as visualised in Figure 14. On one hand, farmers prioritise the wellbeing of their cows, striving to provide them with the best care. On the other hand, farmers aim to operate productive farms with high milk production, as this is essential for their profitability. Therefore, the localisation solution had to strike a balance between these opposing values, making the farm efficient and ethical for the cows. Nevertheless, Ali (2021) states that healthy cows positively impact a farms productivity, suggesting that prioritising cow wellbeing can also enhance the overall farm performance. One way to improve the cows' wellbeing, is to improve the work engagement of employees.



Figure 14 Motivations to locate cows, categorised in cow wellbeing and productive farm.

4.3 Work Engagement on a Farm

From the literature and the farmer interviews it was found that most of the users who actually need to find cows are low educated, and often migrant workers, who do not always have the love for a farm like the farmers do. The work that they have to do is simple but labour intensive. All things considered, Christian et al. (2011) and Moore et al. (2020) suggested that this results in employees who are not very engaged or feeling responsible while doing their work, resulting in lower work performances. This results in little care for a cow, making the workers treat a cow more like a machine instead of a living animal. As a farmer, it hurts to know that their cows do not always get the most attention and care that they believe is required. The localisation solution should therefore aid in enhancing employee engagement while locating cows on a farm.

Anitha (2014) has researched seven determinants of employee engagement which are based on Kahn's (1990) three psychological conditions or employee engagement. These are as follows:

1. **Work environment:** A supportive working environment created by the management encourages employees to show their concerns and develop new skills, solving work related problems (Deci & Ryan, 1987).
2. **Leadership:** Good leadership is inspiring for employees because a leader should communicate the importance of the work that an employee has to do. Understanding this importance as an employee results in an increase in involvement, satisfaction and enthusiasm for the work (Schneider et al., 2009).
3. **Team and co-workers:** The relationship between employees is important as an open and supportive environment results in the employees feeling safe and as a result increase work engagement (Kahn, 1990).
4. **Training and career development:** Training employees does not only improve performance, but also their engagement as confidence builds up, motivating the employees to be more engaged in their job (Paradise, 2008).
5. **Compensation:** Both financial and non-financial rewards like a bonus or extra holidays are significant drivers of employee engagement as the employee feels recognised (Saks, 2006).
6. **Organisational policies:** Policies that support flexible work arrangements can help in balancing an employee's work and home environment, resulting in more engaged employees (Devi, 2009).
7. **Workplace wellbeing:** Wellbeing is defined by Rath and Harter (2010) as "all the things that are important to how we think about and experience our lives". This is an important measure to understand the influence which an organisation has on its employees which in turn is an important driver of engagement (Anitha, 2014).

The seven determinants of employee engagement are rooted in the thirteen fundamental needs described by Desmet et al. (2020), which build upon the psychological needs outlined by Ryan and Deci (2000) as discussed in the literature. These thirteen fundamental needs are essential for our functioning and development, serving as a vital source of meaning and happiness across different cultures, ages, and lifestyles. The relationship between the determinants of employee engagement and these fundamental needs is detailed in Table 2.

Table 2 Interconnection between work determinants and the fundamental needs.

Fundamental need	Quote captured from Desmet and Fokkinga (n.d.)	Fitting engagement determinants
Autonomy	"I get the freedom to do my work the way I want to"	**1** 2 3 4 5 **6** 7
Comfort	"My work is manageable and stress-free"	**1** 2 3 **4** 5 6 **7**
Community	"I am part of a renowned organisation with proud members"	**1** **2** **3** 4 5 6 **7**
Competence	"My work challenges me and lets me use my skills"	**1** 2 3 **4** **5** 6 7
Impact	"I can see the impact of my work in the lives of people"	1 **2** 3 4 5 6 7
Morality	"My work helps me to promote my personal values"	**1** 2 **3** 4 5 6 **7**
Purpose	"My job fits well with my personal interests and ambitions"	1 2 3 **4** 5 6 **7**
Recognition	"My work provides me with a certain status and position"	1 **2** **3** 4 **5** 6 7
Relatedness	"I have a close connection with my colleagues"	**1** 2 **3** 4 5 6 7
Security	"My job is steady and dependable"	1 **2** **3** 4 **5** **6** **7**
Stimulation	"My work is varied and interesting"	1 **2** 3 **4** 5 6 7

It is clear that most fundamental needs are covered by the determinants of employee engagement. To better engage employees in locating cows, it is essential for them to feel that their underlying fundamental needs are met. This can be validated using quotes: if an employee agrees with a quote while using the localisation solution, they will feel more engaged.

When considering the work of farm employees, not all fundamental needs can be fulfilled solely by the task of locating cows. Some needs must be addressed by management or other farm tasks. Understanding how farm employees feel about their work, particularly locating cows, is crucial for developing an effective localisation solution. This was assessed using a short questionnaire featuring quotes that employees could agree or disagree with. The questionnaire comprised two parts: quotes about general farm work and quotes about locating cows, as shown in Table 2. The complete list of quotes, the questionnaire, and the results can be found in Appendix E.

Due to the low literacy levels of farm workers, as discussed in the literature, the number of responses was limited. Nevertheless, initial conclusions could be drawn to identify gaps in the fundamental needs of farm workers. The questionnaire results indicate the extent to which farm workers feel their fundamental needs are met by working on the farm and specifically by locating cows. These results align well with the findings of Moore et al. (2020) as described in the literature. However, this study also contributes new knowledge by identifying differences in work engagement between general farm work and the specific task of locating cows.

Figure 15 illustrates each engagement determinant with two bars: the left bar represents the determinant in the context of general farm work, while the right bar represents it in the context of locating cows. As described in Table 2, each determinant may encompass several fundamental needs. Thus, each bar in Figure 15 reflects how these fundamental needs influence the height of the determinants. This comparison allows for an analysis of the impact of different fundamental needs in the contexts of general farm work and locating cows.

The analysis reveals that locating cows is one of the more comfortable tasks on a farm. However, it is the only fundamental need rated higher than others in the context of farm work. Significant gaps were found in the fundamental needs of competence (grey bars) and recognition (green bars). While every participant feels somewhat competent and recognised when working on a farm, they remain neutral regarding these needs when it comes to locating cows. These gaps presented a design opportunity to develop a new user interface to better complement the technology and tap into these fundamental needs of the users.

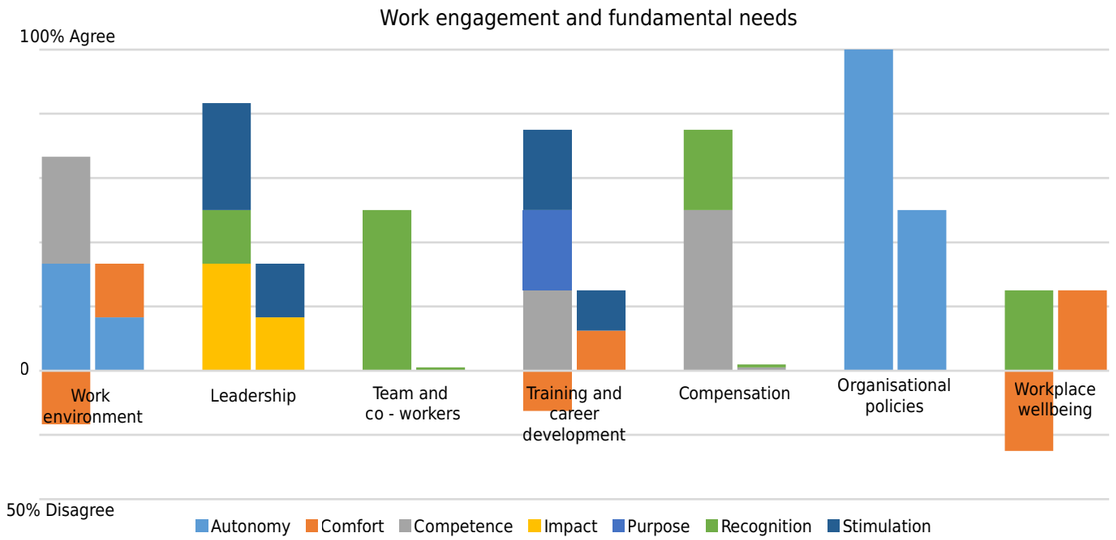


Figure 15 Work determinants build from fundamental needs. Left bar shows "general farm work", right bar shows "locating cows".

4.4 Design Vision and Goal

In this section, the vision and analogy were created to serve as guiding principles for validating the proposed solution. The analogy helped in conveying the vision and objectives of the project, while also providing a relatable context to better understand the overarching vision.

4.4.1 Vision and analogy

To gain a better understanding of the project's design direction, a vision was created using the VIP method by Hekkert and Van Dijk (2017). This method contains two phases: deconstructing the current product and formulating a new one. The complete analysis can be found in Appendix F.

During the interaction phase of the VIP method, it became clear that there are two conflicting quality clusters, both desired on a farm, which were also found in Section 4.2.2. On one hand, farmers aim to operate their farms efficiently, like a productive factory. On the other hand, they strive to care for their animals with attention and care, resembling a petting zoo environment. These quality clusters lie at opposite ends of the "Attitude on a farm" dimension. Given the global shift towards more sustainable and ethical treatment of farm animals (Buller et al., 2018), it was logical to move away from the factory-like approach. Therefore, the vision statement for this project was:

"Empower farmers to provide care for their cows like in a petting zoo, using an intuitive localisation solution."

An analogy that encapsulated this vision is:

"Operating like a seasoned chef, who relies on their knife as an extension of their body to craft culinary masterpieces."

Similar to the intuitive use of a chef's knife, the localisation solution should feel like a natural extension of the user's body, offering precise guidance to locate specific cows. The desired product qualities include precision, durability, versatility, reliability, efficiency, universality, power, and intuitiveness.

4.4.2 Design direction

This improved design direction gave an insight into what had to be designed. This design direction was more specified than the original one, providing better guidance for the next phases of the project.

Problem statement
The initial problem statement, "Cow localisation solutions are not accurate enough nor user-friendly," led to the main research question: "How can a localisation solution be designed and integrated with the existing ear sensor to optimise user experience and efficiently locate cows, considering the diverse needs and preferences of farmers?" Through the research phase, insights were gained that imposed a revision of the main research question, resulting in a new research question:

"How can an intuitive cow localisation solution be designed that embodies high accuracy and low investment costs to suit the diverse preferences of farmers and their employees?"

Design statement
Using the WWWWWH method (Van Boeijen et al., 2014), the design statement incorporated specific design points derived from the problem statement:

"Guide farmers and their employees to cows (WHO) by designing a cow localisation solution (WHAT) for big farms that need to locate cows (WHERE) on a daily basis (WHEN) in order to improve a cow's health and wellbeing (WHY) by developing an intuitive user touchpoint and accurate wireless localisation solution, integrated in the existing ear sensor (HOW)."

Plan of requirements
During the research phase, the requirements plan was continuously updated as new insights emerged. The complete plan of requirements can be found in Appendix H.

4.5 Interaction Data Analysis

I conducted a research study for a farm in the US to examine how cows are located from a data perspective. This farm holds 5000 cows in an open field, approximately 4000 of which were equipped with an ear sensor. The farm used Find my Cow from CowManager to find their cows. The data revealed that the farm cannot maintain optimal productivity throughout the year due to significant phases of sick cows and cows in heat during specific periods, as shown in Figure 16.

The Figure illustrates that, as a group, the majority of cows experience most heat periods between autumn and spring. Additionally, similar to humans, cows experience discomfort when exposed to extreme temperatures. The comfort zone for cows ranges between 4 and 20 degrees Celsius (DairyNZ, n.d.). Within this temperature range, cows function optimally, with their bodies and organs performing at their best, resulting in more heats.

Figure 16 also displays the average monthly temperatures of the farm, revealing a correlation with the state of the cows. Cavestany et al. (1985) have demonstrated that the conception rate of cows is directly influenced by environmental temperature, with higher temperatures correlating to lower conception rates. This relationship is reflected in the Figure, which illustrates an increase in cows in heat during the winter months when temperatures align with the cow's comfort zone. However, the winter season also brings the risk of "Winter Dysentery" (Saif, 2009), resulting in more sick cows and decreased milk production. On the other hand, during the summer months, the heat also contributes to the increase of sick cows. It was calculated that the farmer selects between 30% and 60% from all alerts to actually be found, resulting in 1 - 2% of the entire cow population to be found on a daily basis, dependant on the season.

Alongside the number of cows that need to be located, the data includes information on the time taken to locate the cows and any human errors, including the occurrence of mixed cows. However, it was important to note that not all data of the found cows is complete due to an error in the logging process. As a result, there are some discrepancies in the analysis.
Nevertheless, Figure 17 illustrates two key points. It displays all logged found cows on each day, with the x-axis representing the total time it took to locate each cow after the farmer initiated the localisation service. This provides insights into the time taken to move between pens, locate cows within a pen in quick succession, and find lost cows. Additionally, the colours on the Figure indicate the group to which each cow belongs. By analysing the colours, the number of mixed cows can be assessed.

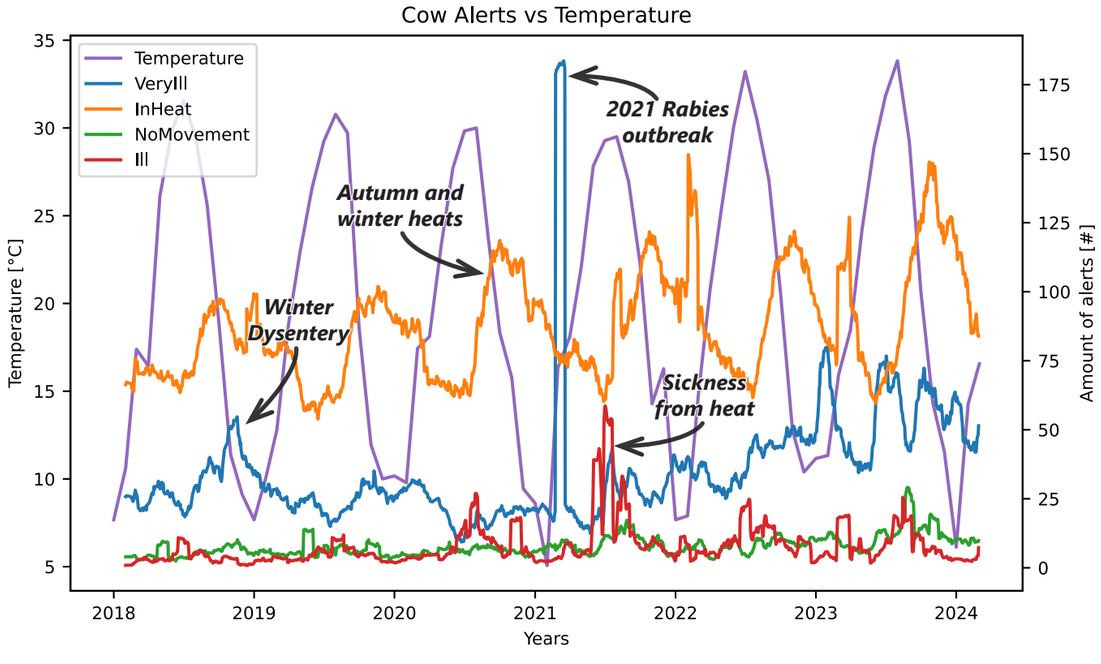


Figure 16 Weather data on a farm (NOAA's National Weather Service, n.d.) and data on health alerts

Cow groups
Farmers typically group their cows based on their health or breeding state. In this analysis, the farmer had organised the cows into 18 groups, with each pen on the farm housing only one specific group of cows. If this holds true, Figure 17 should reflect this by showing series of dots with the same colour. Currently, every day, workers start by locating cows in group 4, followed by group 3, then group 6, and so on. If there is an odd colour present among a series of a specific colour, it indicates that the cow was in the wrong pen and should be moved back to its original location. As depicted in Figure 17, there are approximately 10-15 mixed cows per day, which is more than what the farmer reported in the interview (40 cows per week). Upon examining the first few days in Figure 17, it became clear that locating cows within groups was chaotic at first, as there is not a clear order of searching for cows group by group, and the time between finding two cows was also longer than nowadays.

Localisation time
The time taken to locate cows has shown improvement over time. At the bottom of Figure 17, it is clear that the data points are more widely spaced, indicating that it took longer to find cows consecutively. At the top of the Figure, the gaps between found cows are narrower, suggesting that cows were being located faster compared to a year earlier. This implies that either the workers have become more skilful using the service, and/or the farm has optimised the workflow of finding cows. Using the data, it was calculated that it takes around 3 minutes to locate cows in a group, as suggested by the farmers. While in the past, for this farm, it took around 10 minutes to find a cow in a group.

As discussed in the workflow of locating cows, there are two parts in localisation; localisation within groups and the localisation of individual cows. Figure 17 illustrates the transition between these parts well, particularly near the most recent dates. After all groups had been done, there were still individual cows that were missed. The latest data indicates that this number was around 10 cows, consistent with the number reported by the farmer in the interview. The part of locating individual cows reveals that, as discussed, it took considerably longer to find these cows. The data suggests that it took between 10 to 15 minutes to locate an individual cow.

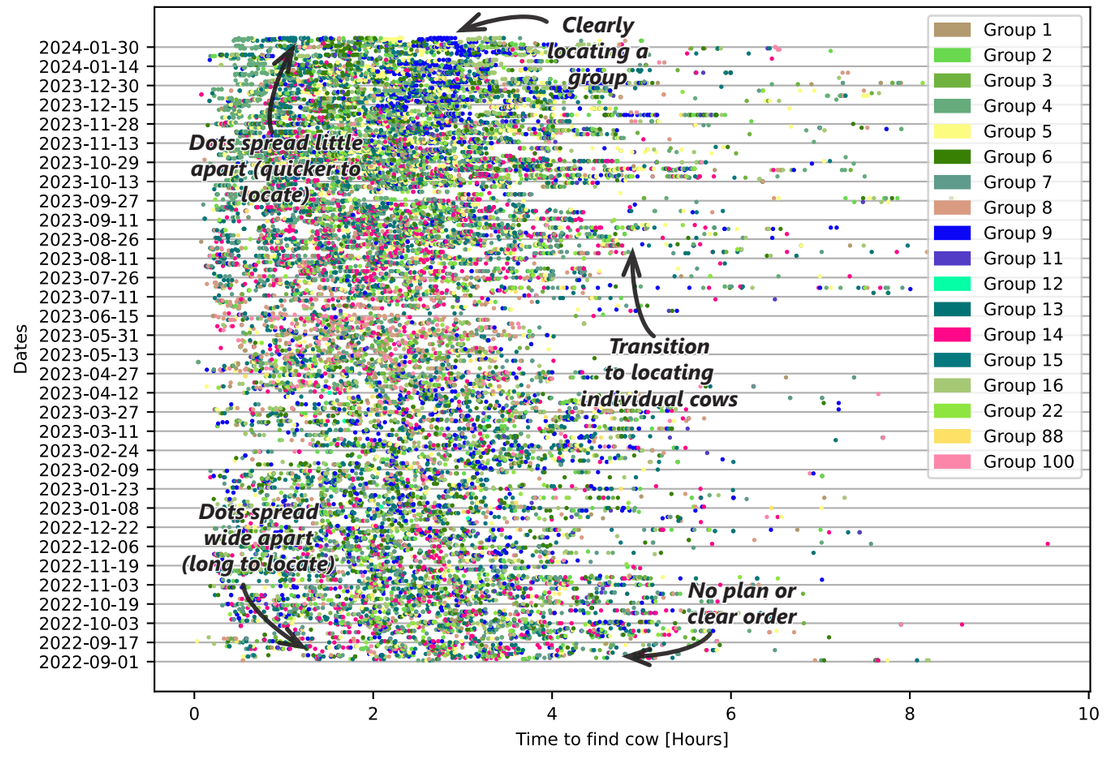


Figure 17 Time to locate cows after the service was initialised. Every dot is a cow found x hours after the service was initialised. The colour depicts the group of the cow.

4.6 Current Interaction

The interviews with farmers also explored their current cow localisation methods. A detailed step-by-step process tree (Figure 18) was made based on these insights. The process tree encompasses every task involved in locating cows, no matter how small. Currently, the whole process takes approximately 7 hours to complete for an average farm with 5000 cows.

For instance, within the CowManager system, around 4% of cows (200 cows) are flagged to check if they need to be found. Approximately 2% of all cows (100 cows) are actually selected to be found. 90% of these cows (90 cows) can be found immediately when an employee walks though the groups of cows. The remaining 10% (10 cows) roam freely making them challenging to find. Table 3 shows the times for the current method.

Table 3 Time to locate cows - current interaction.

Task within process	Time per cow	Total time	Part of entire process
Select cows	15 seconds	50 minutes (200 cows)	12%
Locate cows in groups	3 minutes	4.5 hours (90 cows)	64%
Locate individual cows	10 minutes	100 minutes (10 cows)	24%

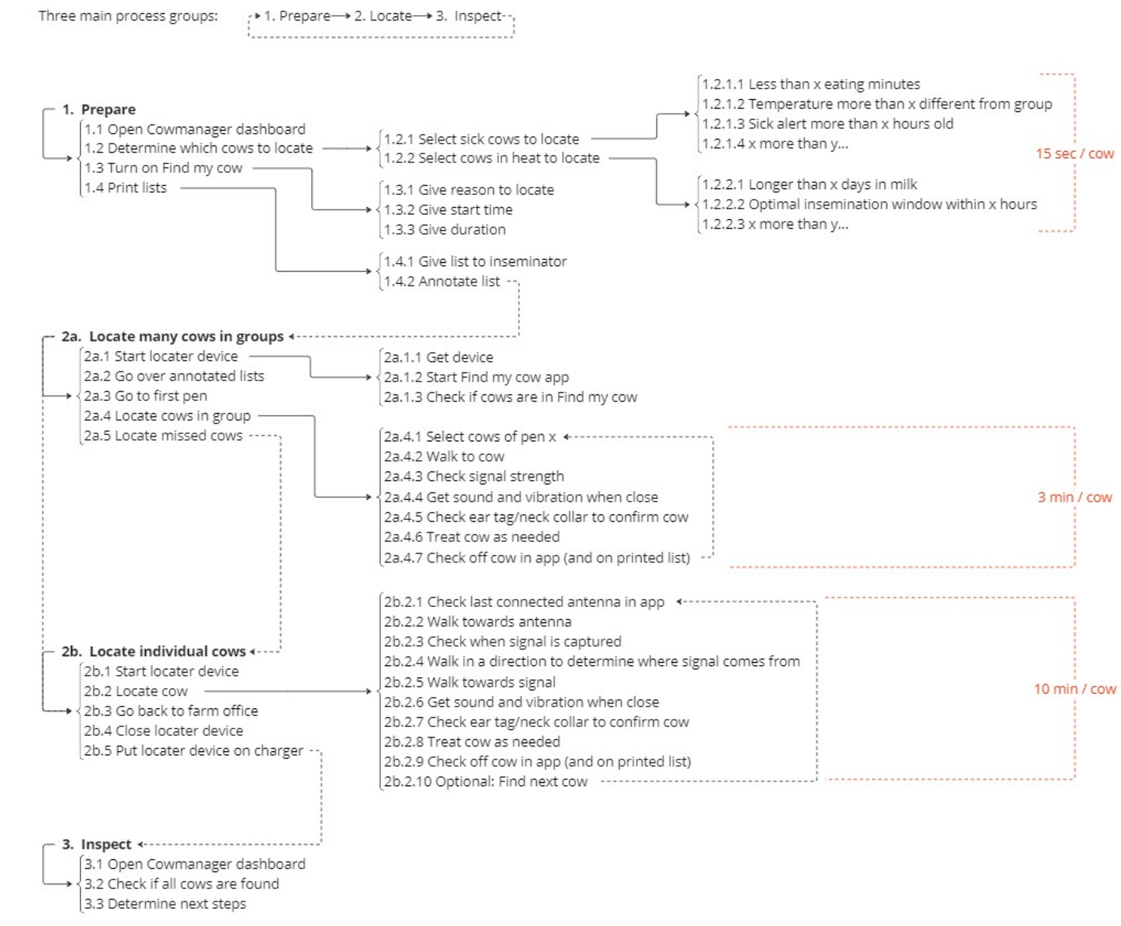


Figure 18 Process tree showing all current required steps to locate a cow.

4.7 Desired Interaction

During the interviews, the future of cow localisation was also discussed. This mostly resulted in ways to automate various tasks. By automating tasks, two things can be improved. On one hand, time can be saved as selecting the right cows can be done using thresholds set by the farmer. On the other hand, automating systems in the identification part reduces costly human errors. Additionally, a new intuitive system to navigate to a specific individual cow should be designed which also saves time while minimising any frustrations in trying to find a cow. The improved step by step process tree of cow localisation is visualised in Figure 19.
Using this system on a farm with 5000 cows again, the whole process of selecting and locating cows will take approximately 4.75 hours. This is 33% faster than the current method of locating cows. Table 4 shows the times for the improved method.

Table 4 Time to locate cows - desired interaction.

Task within process	Time per cow	Total time	Part of entire process	Improvement
Select cows	3 seconds	10 minutes (200 cows)	4%	80%
Locate cows in groups	2.5 minutes	3.75 hours (90 cows)	79%	17%
Locate individual cows	5 minutes	50 minutes (10 cows)	17%	50%

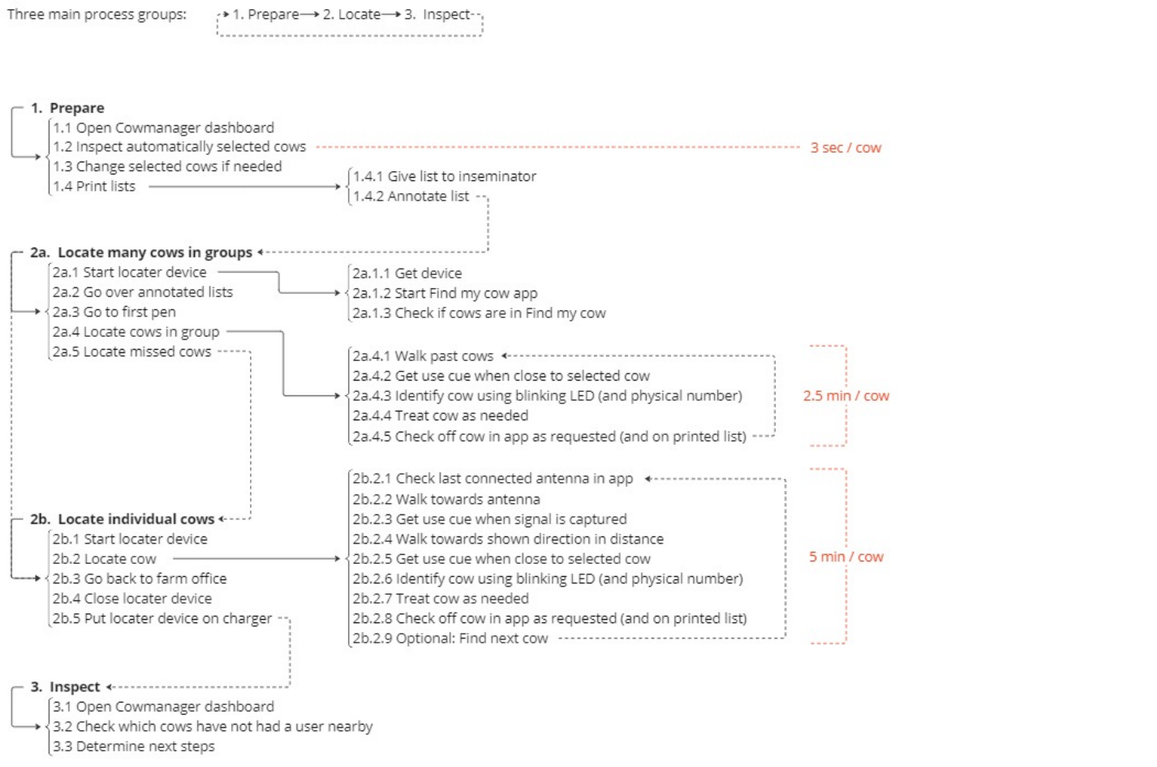


Figure 19 Improved process tree showing all required steps to locate a cow.

4.7.1 Interaction Improvements

Percentagewise, the best improvement could be made by automating the selection process, allowing farmers more time for other essential tasks. While the time spent locating cows in groups was challenging to reduce as this was more of an identification task, rather than a navigation task, the accuracy and error rates in identification could still be improved. The most considerable time savings came from locating individual cows, transitioning from a guessing game to following specific directions. This allows users to walk directly toward the cow, significantly reducing time. Additionally, a better and faster identification method reduces the time to identify cows and minimise errors. The process trees highlight three major process groups, with a primary focus on process group 2: locating cows. Although preparation and inspection are crucial, the main emphasis of this project was on the localisation process.

4.7.2 Phases to locate individual cows

The process trees ,step 2b.2, revealed that locating an individual cow involves three distinct phases: Uncovering, Navigating, and Identifying. These phases combined encompasses the process of finding a specific cow using signal strength and reading the ear tag.

Uncovering
In the uncovering phase, the user walks in a roughly known direction until a signal is captured. This direction is determined by the location of the router to which the sensor was last connected, making the solution cost-effective by reducing the need for many beacons. Interviews with farmers revealed that they do not need the exact location of a cow when it is not in close proximity. Thus, it was recommended that the user is roughly guided towards the cow, which is already feasible.

Navigating
The navigating phase begins once a signal is captured, using signal strength to move closer to the cow. This phase is particularly challenging in a pen with many cows, like 300, where finding a specific cow resembles finding a needle in a haystack. Unlike road navigation with set paths and clear directions, farm navigation lacks defined paths, making traditional commands like "turn right in 40 metres" impractical. However, familiar environments such as farms allow farmers to navigate using memory and spatial awareness. Research by Vinson (1999) suggests incorporating landmarks into navigation aids helps users determine their position and orientation relative to the real world. Farmers confirmed that landmarks like router names and large objects such as water tanks are essential for orientation in barns, although they are less useful in open fields where these landmarks are lacking.

Identifying
The identifying phase starts when the user is near the cow. The user must then identify the correct cow by reading the ear tag. This final step ensures the accurate identification of the cow within the pen, completing the localisation process. However, many human errors occur in this phase, as users are not always able to correctly read the ear tag. It was therefore recommended to integrate an identification feature in the localisation solution as it is part of the localisation process.

The research conducted in this section, combined with insights from localisation motivations and interaction data, revealed that the localisation solution requires three distinct phases: uncovering, navigating, and identifying. While the uncovering phase was already well established, the navigating and identifying phases needed to be developed and tested to ensure a comprehensive and effective solution, with the biggest technical emphasis on the navigation phase.

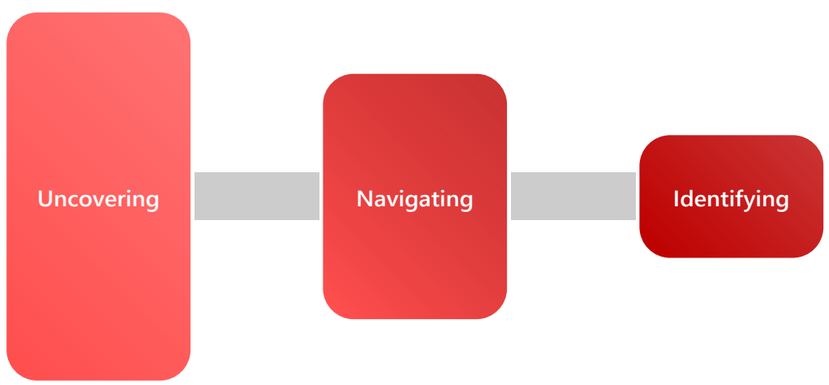


Figure 20 The three phases of localisation as revealed by the process trees.

4.7.3 Interaction Device

Current touchpoints for cow localisation mainly involve computer interfaces for initialisation, such as CowManager, and viewing cow locations, as used by SmartBow (n.d.). Alternatively, mobile devices like smartphones (with additional antennas) are also used in setups like CowManager's. Interviews with farmers revealed that some prefer hands-free localisation solutions, while others find smartphones insufficient for displaying all the information. Hence, a balance was needed between the information required for localisation and the device type and size used.

In addition to smartphones, wearable devices such as smartwatches, smart glasses, and hearing aids are becoming popular for tracking activities and accessing information. 43% of wearable users believe wearables may eventually replace smartphones (Mishra, 2018). While smartphones are the most straightforward option due to their widespread use, integration with other wearables might be beneficial. Additionally, farmers prefer employees to use their own smartphones and devices, believing they take better care of personal devices. Callanan (2023) suggests that this also enhances productivity and satisfaction. While nearly everyone owns a smartphone, regardless of their education, less than half of those with lower education levels own a wearable device (Shandhi, et. al., 2024).

All things considered, the primary touchpoint for cow localisation was chosen to be a smartphone, as it is widely owned and familiar to users. To accommodate preferences for hands-free solutions, the design incorporates options for other wearables as visualised in Figure 21. This approach provides users with the autonomy to use the solution as they prefer, balancing the need for information with the practicality of the device type and size.

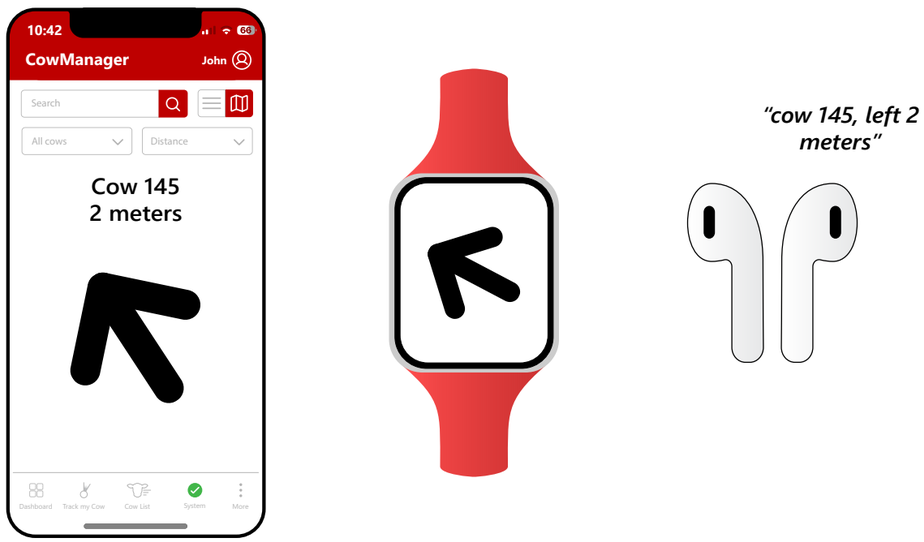


Figure 21 The smartphone as main user touchpoint and possible integrations with other wearables.

4.8 Conclusion

This chapter aimed to generate the necessary knowledge from the user's perspective, which was used in the subsequent ideation chapter to develop an intuitive user interface that enhances work engagement.

The personas revealed the two archetypes of people on a farm. While the farm is the end goal for a farmer, for the farm worker it is merely an intermediate step, with tasks that need to be completed to progress to better-paying jobs. It also revealed that farmers tend to select more cows to locate, just in case, as they do not have to do the work themselves. This might result in some friction, as employees might feel that they are performing unnecessary work, not understanding their impact or purpose, which is a fundamental need. This, coupled with the lack of fundamental needs such as competence and recognition, results in farm workers who are not engaged with their work or the farm.

Additionally, from the eight common motivations of farmers to locate cows, two conflicting values were found. On one hand, a farmer wants to run a productive farm. On the other hand, the farmer wants to prioritise the health and wellbeing of their cows. The low work engagement leans more towards running a productive farm, where the animals are treated like machines. However, the literature suggests that improving work engagement also improves productivity, resulting in a better balance between the two values, while simultaneously enhancing both. Therefore, the vision created for the ideation phase was: "Empower farmers to provide care for their cows like in a petting zoo, using an intuitive localisation solution."

From the data analysis, it was found that the number of cows to locate varies depending on the season, as the environmental temperature significantly influences the health of cows. There are more heats when the temperature is between 4 and 20 degrees Celsius. However, too cold or too hot temperatures result in more sick cows. The data also provided empirical insights into how groups of cows and individual cows are located. It was found that it takes 3 minutes to locate a number of cows when walking through a group and 10 minutes to find an individual cow.

By visualising all the required steps of locating cows in a process tree, inefficiencies were revealed. Combining this with the empirical insights validated the farmers' claims that it takes about 7 hours per day to locate cows on a farm of 5000 cows. However, the improved process tree suggests that approximately 30% of time can be saved from the entire process. Much of the process could actually be automated, which not only saves time but also reduces the number of human errors.

The process trees also revealed the three required phases for a localisation system with a long detection distance: Uncovering, Navigating, and Identifying. It was concluded that these phases were needed in a new solution to maintain the long detection distance while also enabling high accuracy.

4.8.1 Evaluation Criteria Thresholds

Based on the knowledge generated from this chapter, thresholds were established for the evaluation criteria, reflecting the farmers' needs and preferences. The next chapter, "Ideation", was dedicated to developing and designing the actual localisation solution, guided by the vision and validated using the evaluation criteria outlined in Table 5.

From the farmer interviews, it was concluded that the navigation phase of the localisation solution must bring the user to within at least 5 metres of the cow. After that, the identifying phase must take over. Groenendaal et al. (2004) calculated that it costs approximately $70 per cow per year when a cow is not optimally bred. For the entire battery lifetime of a sensor and a cow, this means that a localisation solution in a sensor with a 10-year battery lifetime must cost the farmer less than $700 per sensor. This, however, is a large number, which most likely will result in a subscription service that must cost less than $5 per cow per month for the localisation solution to be cost-effective for a farmer.

The battery lifetime must be no shorter than currently. The long battery life is one of the key strengths of the ear sensor; therefore, this must not be reduced by adding a new localisation solution. Based on the uncovering phase, farmers have shown that it is necessary to know at least the rough direction to walk from any given distance to the cow. This means that the detection distance must be technically "infinite".

It was determined that the new localisation solution must consist of three phases: uncovering, navigating, and identifying, as this approach has proven effective in guiding the user. However, four out of the six evaluation criteria still needed to be designed for. Based on the insights from the study on work engagement, it was found that the user interface must enhance the fundamental needs of competence and recognition.

Table 5 Evaluation criteria thresholds.

Criteria	**Threshold**
Accuracy	< 5 metres
Cost	< $700 / cow
Battery lifetime	No shorter than currently
Detection distance	Infinite
Intuitiveness	Use 3 phases
Work engagement	Enhance competence and recognition

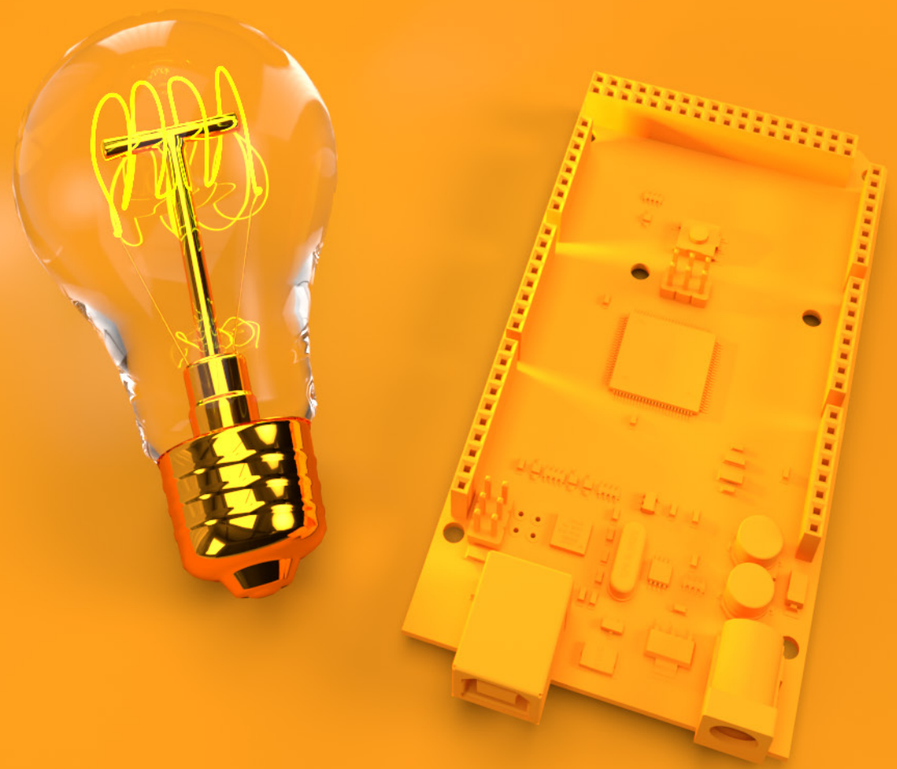
The knowledge generated in this chapter facilitated a user-centric approach, which was the overall aim of this research. By addressing gaps in the existing literature, the needs and preferences of farmers regarding a localisation solution were uncovered. This understanding enabled me to develop the solution from the user's perspective. Following this, the technology was developed and then integrated with the user perspective again to ensure a seamless and desirable connection between the user and the technology.

Chapter 5

Ideation

5.1 Technology Aspect
5.2 User Aspect
5.3 Conclusion

In this chapter, the localisation solution was developed and designed based on the knowledge gathered from all previous chapters. Since the project was divided into the technology and user aspects, each has its own ideation phase. In the first section, Channel Sounding was tested for its performance, and its found properties were used in simulations, paving the way for a prototyped proof of concept that had to score positively on the evaluation criteria. In the second section, the user interface was developed to be intuitive and enhance work engagement. This was done using literature and workshops with farmers and CowManager employees to validate its intuitiveness. The user aspect concludes with two use cases showcasing intuitive user interfaces developed for specific scenarios.



5.1 Technology Aspect

The biggest challenge in designing the localisation solution was found in the navigation phase. In this phase, the location of the cow must be determined with an accuracy below 5 metres as discussed in the evaluation criteria. As stated in Section 2.6.3, Channel Sounding shows great potential as a distance measuring technology that could be used to determine a cow's location. In the technology aspect of this project, the main focus was on testing and developing the technology for the navigation phase, which is based on Channel Sounding.

5.1.1 Channel Sounding Tests

As previously mentioned, Channel Sounding holds significant promise for accurately measuring distances between two devices. Although the concept of phase-based ranging has been around for some time, its implementation in Bluetooth, as the first widely accessible wireless network to adopt the technology, paves the way for broader availability in the future.

In this project, the Channel Sounding technology was evaluated using development boards. Since comprehensive data on the technology or the development boards was not readily available, initial tests were conducted to explore and understand the fundamentals. Consequently, the first Channel Sounding test was performed in an open field to measure the accuracy and range.

Test 1: Basic Performance
Test Setup
The test setup comprised two main components: the user device and the reader device. The user device was essentially a development board connected to a power bank. Meanwhile, the receiver component consisted of another development board, 1.5m above the ground set to receive mode, connected to a computer for logging the data. To establish reference points, a 150-metre measuring tape was laid out on the ground to determine the actual distances involved. Figure 22 shows the test setup. The test was conducted in an open field to assess the performance of the technology under ideal conditions, free from any metal obstacles that could interfere with the signal. Furthermore, this setup allowed for the examination of the maximum range achievable with the connection without any optimisations.





Figure 22 Test setup of test 1.

Method
The reader remained stationary at 0 metres, while the computer continuously recorded incoming data. The user device was used to initiate distance measurements from various specific distances, using the reference distance provided by the measurement tape on the ground. For each distance measurement, 10 consecutive measurements were conducted and logged to the computer. Measurements were initiated at intervals depending on the distance: every 1 metre for distances below 10 metres, every 2 metres between 10 and 30 metres, and every 5 metres beyond 30 metres.
Subsequently, all collected data was analysed to evaluate performance. Given the 10 measurements recorded for each distance, different methods of averaging were explored to determine the most accurate approach. Additionally, an analysis was conducted to discover the optimal number of consecutive measurements required.

Results - RSSI
Alongside the distances, the measurements provided signal strength values. Given that competitors use these RSSI values for localisation, these measurements were also analysed. However, the result (Figure 23) shows clearly that RSSI cannot be used to determine the distance using this chip. As signal strength has a logarithmic correlation to distance (Hing et al., 2019), the distance can be estimated using a formula as described in Appendix C. However, as Figure 23 shows, the measured signal strength does not represent a logarithmic curve, and therefore it cannot be used to estimate distance.

Results - Channel Sounding
The Channel Sounding data consisted of several parts. Although direct access to the raw phase-based ranging data was unavailable, the development boards featured two built-in algorithms for distance calculation: RADE (Rapid Accurate Distance Estimator) and CDE (Complex-domain Distance Estimator) which were both logged. Alongside the distances, each algorithm also provided a quality percentage.

Three methods of averaging the 10 consecutive measurements were analysed. Table 6 shows the measurement errors using these methods:
1. Plain distance error: Averaging the 10 measurements and calculating its error to the actual distances.
2. Weighted quality error: Averaging the measurements using the quality percentage as weights.
3. Remove extreme values: Removing the lowest and highest values from the measurements and averaging the remaining 8.

Table 6 Measurement errors of default Channel Sounding algorithms and averaging methods.

	Average error (m)	Weighted error (m)	Removed extremes error (m)
RADE	0.365	0.369	0.365
CDE	2.336	0.456	2.336

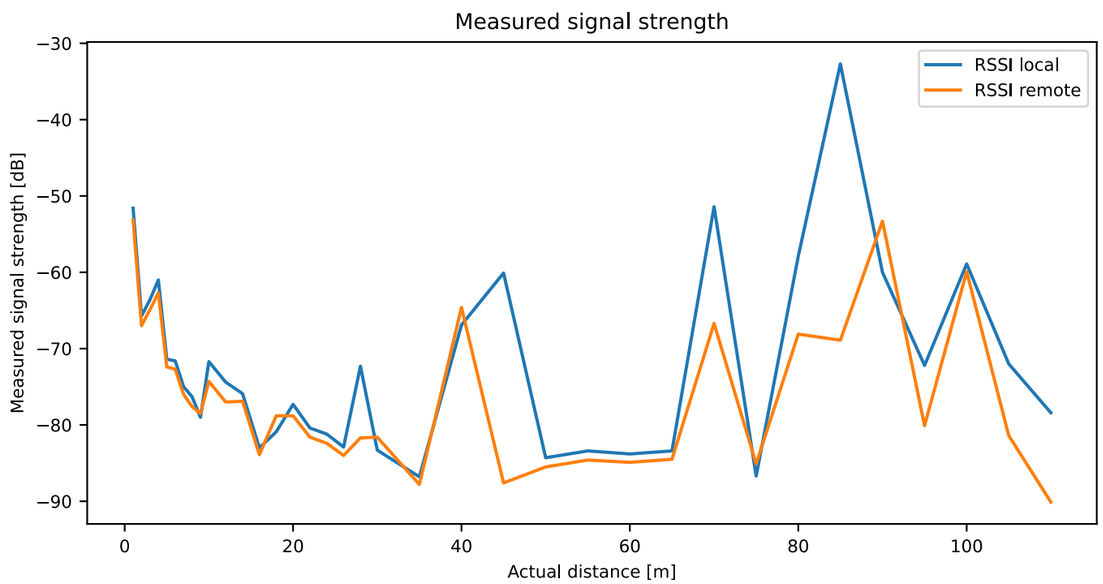


Figure 23 RSSI values, showing no logarithmic curve, meaning it cannot be used to determine large distances.

The findings from Table 6 revealed that the RADE algorithm is more consistent with better accuracy compared to the CDE algorithm, which shows significantly worse accuracy and stability. When using the RADE algorithm, there is minimal variance observed between the different averaging methods. Consequently, using the RADE algorithm and averaging the measurements was preferred for further tests. This conclusion is further supported by Figure 24. By examining Figure 24 (left), it is clear that the errors remain relatively small across a large distance range. The majority of the highest errors occurred at shorter distances, whereas at longer distances, the results appeared to stabilise, with errors around 0.5 metres.

The tests also revealed that the connection quality experienced a slight decline beyond the 100-metre mark. However, a noteworthy observation occurred during a distance measurement at 150 metres: the measurement started from 0 metres again. This suggests that the signals were equal at this distance (no phase difference), indicating that Channel Sounding has a maximum operational range of 150 metres, if the connection remains stable. This find was validated by an application note of Texas Instruments (Nisarga, 2024).

To optimise energy consumption and the refresh rate of an estimated location, it is essential to minimise the number of consecutive measurements required. To analyse this, the errors and qualities for every x out of 10 measurements were averaged and analysed.

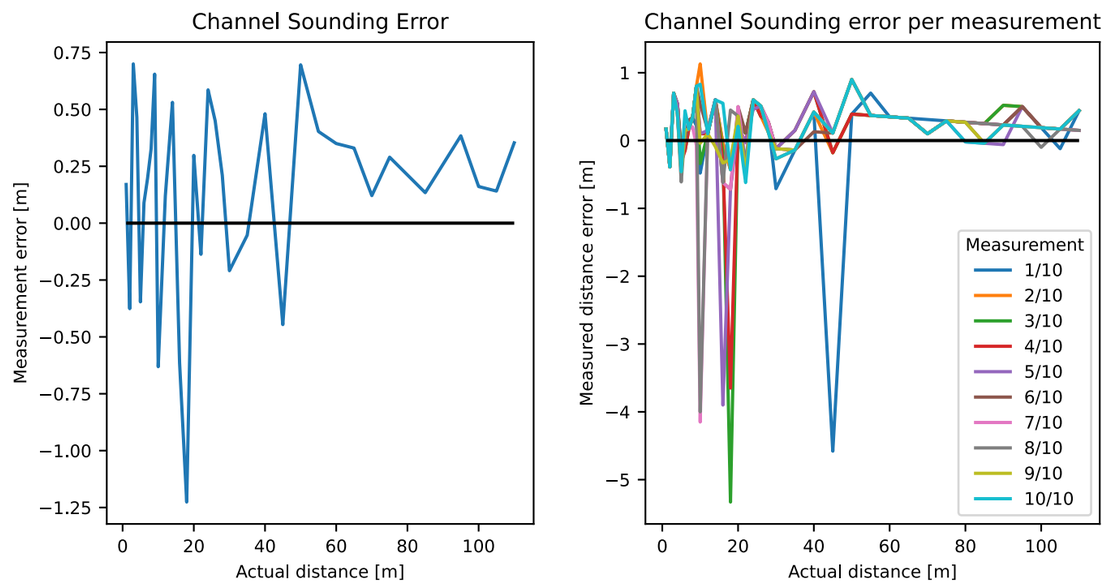


Figure 24 Measurement errors in an open field with direct line of sight up to 110 metres.

Figure 24 illustrates that the highest errors are observed at shorter distances, particularly during the first few measurements (1, 3, 4, and 5 out of 10). Furthermore, the quality measurements show fluctuations at almost every distance, suggesting useless in predicting accuracy. Despite this, given the higher errors observed in the initial measurements, future testing continued with 10 measurements per distance. In a final proof of concept, the feasibility of reducing the number of measurements can be re-evaluated and analysed to determine if fewer measurements are viable.

Test 2: Various environments
In this test, Channel Sounding was evaluated in various environments: outdoors between cars in the parking lot, indoors along the feeding path in the barn, and indoors in the barn with cows and/or metal objects obstructing the path between the localisation devices. The test setup remained consistent with the previous test, except in the barn with cows present, where a laser pointer was used to determine the actual distance instead of a measuring tape.

Results
Figure 25 (right) shows the results of the measurements. These results indicate a decrease in accuracy, which is expected due to the presence of objects affecting the signals. It is logical to observe high spikes in accuracy in the car park environment, given the abundance of metal surrounding and between the devices. Similarly, reduced accuracy was shown inside the barn. However, in most instances, it remained well below 5 metres, which appears acceptable. Certainly with shorter distances, the error was not larger than 2 metres.

Conclusion tests 1 & 2
The field tests showed promising outcomes for a distance measuring service relevant in a cow localisation solution. As expected, optimal results were achieved in an open field, with accuracy decreasing as the number of objects and metal in the environment increased. It is important to note that CowManager's routers are typically positioned at least 2.5 metres above the ground. This arrangement ensures that, on average, all cow sensors have a direct line of sight to the routers, maximising connectivity and minimising the impact of otherwise obstructing objects. Therefore, in the final proof of concept, careful consideration should be given to router placement to optimise direct line of sight to most cows.

Channel Sounding Limits
Range: 150m
Accuracy: 2m
Time: 1sec / measurement

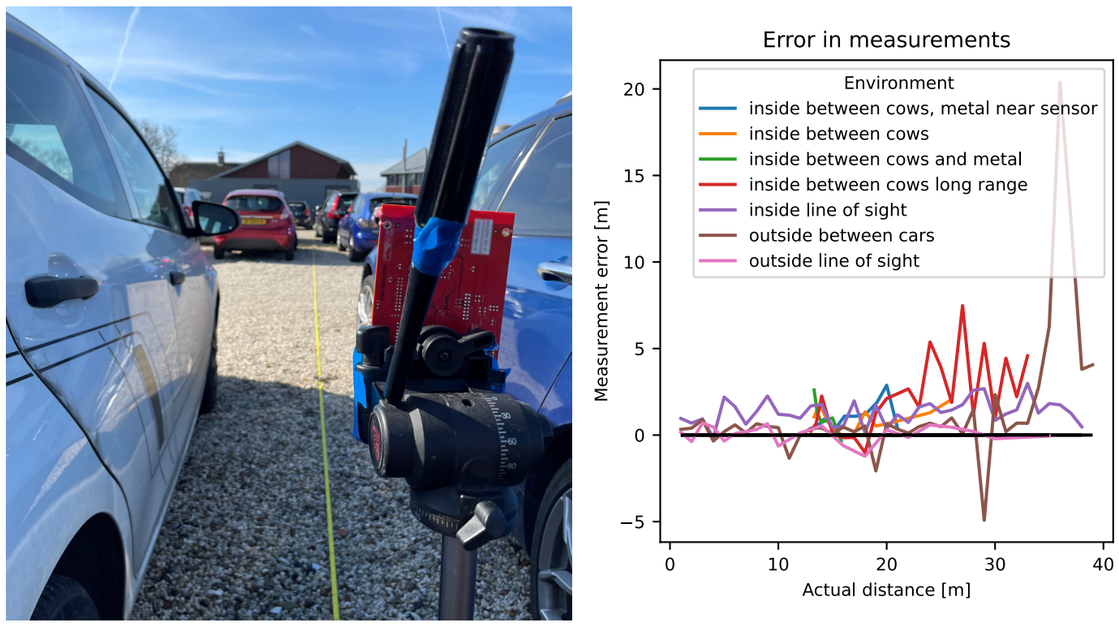


Figure 25 Test setup and result of test 2.

5.1.2 Channel Sounding Trilateration

Given that many localisation solutions use a trilateration method, it was logical to consider implementing it as well. Trilateration relies on measuring distances from at least three known, usually static, beacons to a tag device. This can also be done using Channel Sounding, which had never been applied in this context before. However, this method requires the tag device to be within range of at least three beacons, posing a significant challenge on large farms. The requirement to place numerous beacons every few metres becomes very expensive. While barns offer many locations for beacon placement, open fields lack such facilities, making this basic trilateration method unfeasible for a farm-wide localisation solution.

However, as stated before, farmers do not need to know the exact location of a cow at all times. If a cow needs to be found, knowing the exact location is unnecessary when the farmer is not nearby. Consequently, it would be disproportionate to force a farmer to invest in a multitude of beacons that will rarely be used.

"I do not care about the location of a cow that is not near me" - Farmer (F1)

Given the request to minimise costs and ensure integration with the existing infrastructure, the question arose: what are the minimum hardware requirements for a trilateration method that can be integrated into the current network of sensors and routers? Presently, routers cover the entire farm, allowing sensors to transmit their data to the main coordinator. These routers are strategically placed to minimise their number, resulting in minimal overlap between their ranges. This makes standard trilateration impossible, as it requires overlap between at least three routers.

By integrating the localisation solution with the current router placement, each router can serve as one of the three required trilateration beacons, utilising the existing infrastructure. Since all sensors can connect to a router, the rough location of a cow is already known, similar to current practices where precise locations are unnecessary when the cow is far away. This means that a trilateration method is only needed when the user gets closer to the cow they need to find. Since Channel Sounding is a feature of Bluetooth, it was anticipated that Bluetooth will release this service in an upcoming version, which will be available in smartphones as well. Smartphones have many advanced features, including highly optimised location services. This means that accurate locations can be obtained both outdoors and indoors using the built-in location service. By combining the location service with the Channel Sounding feature, a smartphone can function as a beacon, meeting the two requirements of measuring distance to the cow and knowing its own location. This enables the smartphone to act as the second of the three beacons required for the trilateration method.

Building upon the idea of a smartphone serving as a beacon, it can function as a mobile router, updating its location as it moves with the user. This means a smartphone effectively becomes a new router with every step. Consequently, the phone can act not only as the second beacon but also as the third beacon. In theory, it means that a cow can be located using only one router and a smartphone. As a user always carries their smartphone, they would always be able to navigate to a cow in their proximity while knowing the exact location of a distant cow is not necessary at that time.

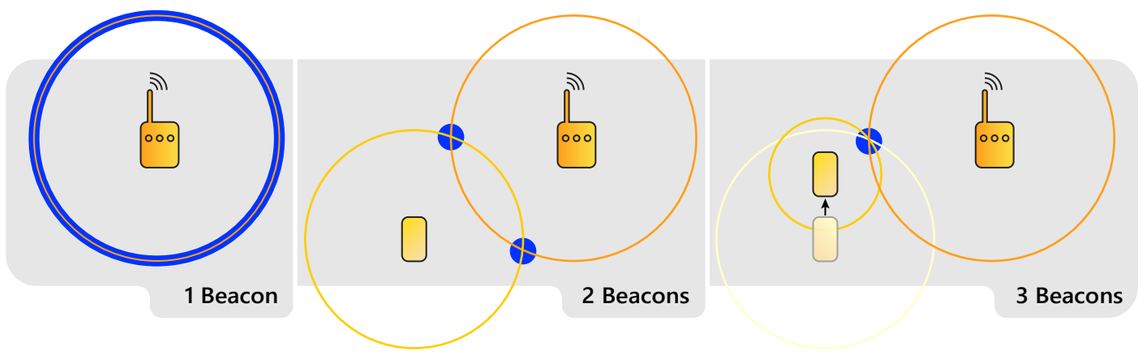


Figure 26 All possible cow locations (blue) based on the number of beacons.

5.1.3 Trilateration Simulations

The concept of using a smartphone as a walking beacon was simulated in Python to evaluate the system's performance and identify parameters that could optimise such a solution. The simulation aimed to understand the dynamics and potential improvements in accuracy and efficiency when using a smartphone as a mobile beacon within the existing infrastructure. Accuracy in this context was defined as the average distance between the cow and the predicted location. Thus, higher accuracy corresponds to a lower distance error, with 1 metre being better than 5 metres. Four parameters with a high impact on trilateration accuracy were investigated:

Channel Sounding Accuracy: It was logical to assume that higher accuracy in Channel Sounding (CS) would result in higher trilateration accuracy. From the simulations, it was concluded that the trilateration accuracy is approximately one-third of the CS accuracy. Currently, without an optimised CS algorithm, the average CS accuracy of 2 metres would result in a trilateration accuracy of approximately 0.5 metres.
GPS accuracy: For the smartphone's location service, it was also assumed that higher GPS accuracy would result in higher trilateration accuracy. However, simulations indicated that this parameter has less impact than expected. Given that GPS typically has an accuracy of 2-5 metres (Barbeau, 2021), it was found that trilateration accuracy is approximately 0.5 metres.
Update Interval: This parameter depicts the distance the smartphone must move before it updates its location as a new beacon. It was assumed that a shorter update interval would result in lower accuracy because the GPS and CS inaccuracies would dominate over the small distance traveled, creating larger errors. Simulation results validated this assumption, showing that the optimal update interval is approximately 20 metres. However, between 5 and 30 metres, trilateration accuracy is not significantly influenced, suggesting that this parameter can be adjusted in real-time depending on the distance to the cow. More frequent updates may be necessary when the user is closer to the cow.
Buffer Size: This parameter represents the number of previous trilaterated positions averaged to determine the final trilaterated location. It was assumed that a larger buffer size would yield more accurate trilateration. Simulation results supported this assumption. However, a buffer size larger than 40 does not significantly improve accuracy and might substantially impact the calculation and storage requirements of the application, especially when tracking multiple cows.

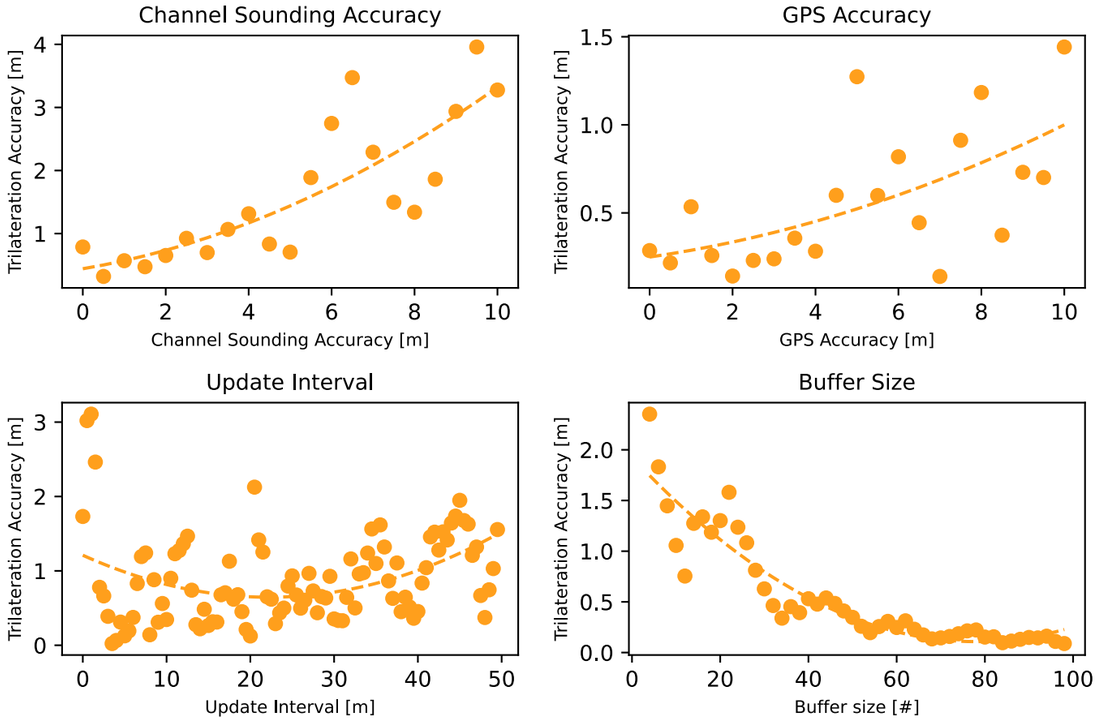


Figure 27 Trilateration simulations of four parameters.

In the plan of requirements, it was specified that a farmer must be brought within a five-metre range of a cow. The simulations demonstrate that this level of accuracy is achievable. Given that Channel Sounding and GPS accuracies are relatively constant at around 2 and 4 metres respectively, it is crucial to understand how varying the update interval and buffer size can influence overall accuracy.

To explore this, a heatmap (Figure 28) was generated by altering these parameters. The update interval ranged from 1 to 50 metres, with increments of 0.5 metres. When translated to time based on average human walking speed, updates would occur every 0.75 to 40 seconds. The buffer size varied from 4 to 204, with increments of 2, to examine the impact of a very large buffer on system performance. Additionally, this simulation included scenarios with a moving cow, unlike previous simulations where the cow remained stationary.

Buffer Size and Update Interval relation: The analysis revealed that the buffer size should ideally hold less than 80 items. As the update interval increases (towards 40 metres), the optimal buffer size decreases. This inverse relationship is logical because when a user is closer to a cow, more frequent updates are required to maintain high accuracy. A large buffer smoothens the location data by averaging previous positions, but if the update interval is long, a cow's movement over that time introduces higher errors that stay in the buffer longer.
Optimal Buffer Size: A buffer size of around 10 items appears to be optimal for most update intervals. This balance allows for sufficient averaging to smooth out inaccuracies without introducing significant lag from outdated data points.
Update Interval Impacts: The accuracy of the trilateration system improves with smaller update intervals. This is expected as more frequent updates reduce the impact of any single positional error. However, at a large distance of a cow, as suggested by a larger update interval, the accuracy is also high.

This analysis confirmed that the system could meet the required accuracy for practical farm use, allowing farmers to efficiently locate cows within the required five-metre range. The system was optimised by maintaining a small buffer size of 10, and it was recommended to adjust the update interval based on the distance to the cow. This dynamic approach ensures high accuracy while minimising unnecessary calculations, data storage and battery consumption, making it a practical and efficient solution for farm-wide cow localisation.

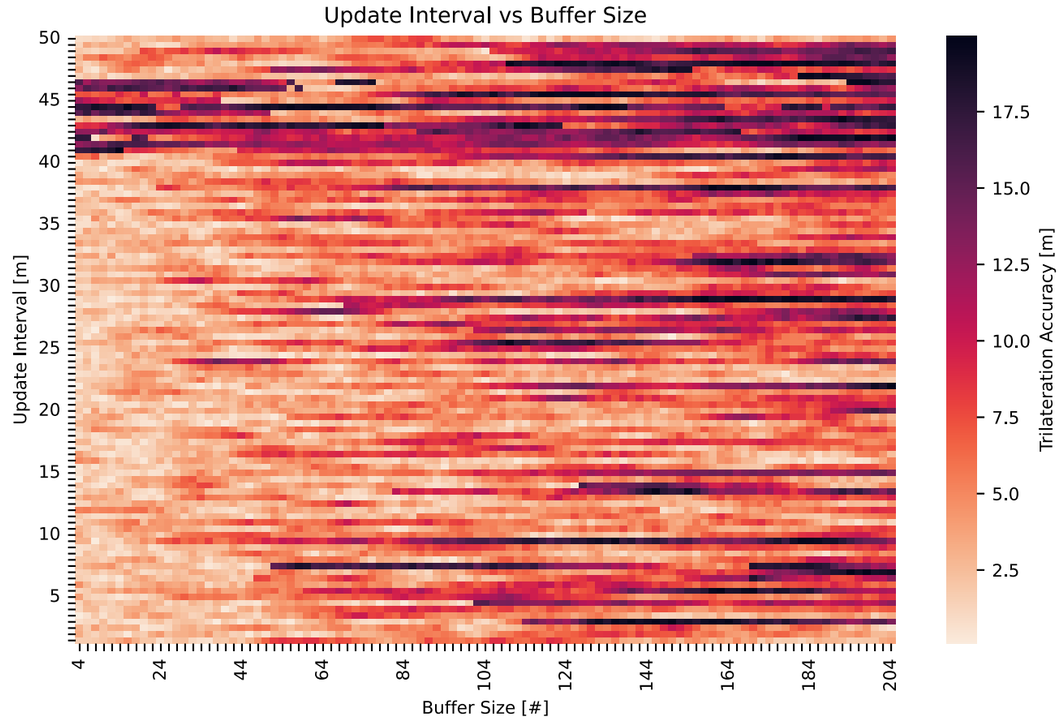


Figure 28 Trilateration simulations accuracy of buffer size vs update interval.

5.1.4 Proof of Concept

To establish a proof of concept, a field test using a prototype was conducted. This prototype comprises three components as shown in Figure 30:

Beacon: The beacon simulates a static router as detailed in section 5.1.2. It incorporates the development board, which was used for testing Channel Sounding. Additionally, a GPS module was integrated to determine the beacon's location. The data collected was transformed and transmitted to the smartphone via an Arduino and an NRF24L01 module.
Smartphone: The smartphone receives the distance measurement and location of the beacon. It also measures distance itself as it contains the development board. Through a serial connection, the measured distances of both the beacon and the phone are sent to the smartphone, where they are integrated with the GPS readings of the phone. This data is then processed by the algorithm, resulting in the determination of the tag's location.
Tag: The tag simulates a cow. It comprises the development board, which is controlled by an Arduino.
The system diagram and data flowchart of the entire prototype can be found in Appendix G.

Method
The field test comprised two phases: first, to uncover whether the solution functioned, and second, to evaluate its accuracy. In both tests, the beacon was positioned in an open field with an unobstructed line of sight. In the first phase, the tag was placed at various random locations between 10 and 60 metres from the beacon. To test the system's functionality, the smartphone was initially positioned beyond the Channel Sounding (CS) range and subsequently moved towards the beacon at a walking pace. Upon establishing a CS connection with the tag, the algorithm determined the tag's location. The smartphone showed an arrow which was followed until it indicated a distance of 0 metres, at which point it was assessed whether the smartphone was in proximity to the tag. For the second phase, a 60-metre measuring tape was laid out in the field, starting from the beacon. The tag was positioned at 5-metre intervals, beginning at 0 metres. The test procedure was similar to the initial test: the smartphone was directed to the tag using an arrow and distance to the tag. To determine accuracy, the smartphone was moved to an actual distance of 0 metres from the tag, after which the estimated distance to the tag was recorded. This discrepancy between the estimated and actual distances represented the measurement error, which could then be analysed.

Results
From the initial test, it was quickly evident that the system performed admirably. It consistently determined the tag's location with seemingly high precision in 9 out of 10 instances. Although there was one occasion when the system incorrectly identified the location, this error was rectified after approximately three updates. The results of the second test (Figure 29) indicate a consistent accuracy of approximately 2 metres, regardless of the tag's distance from the beacon. This suggests that the cow, wearing the tag, can be accurately located irrespective of its distance from the beacon, provided it maintains a Channel Sounding connection.
From these results, it could be concluded that the localisation solution meets the evaluation criteria of accuracy, which had to be lower than 5 metres.

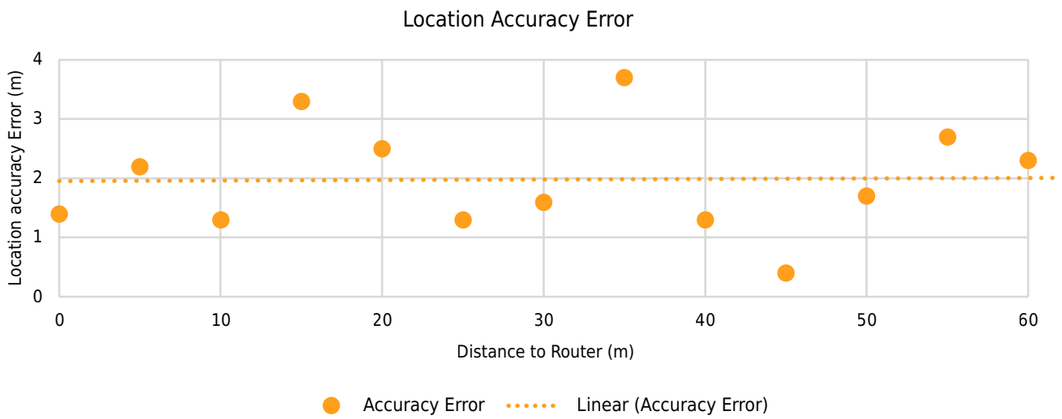


Figure 29 Accuracy results of proof of concept test in an open field.

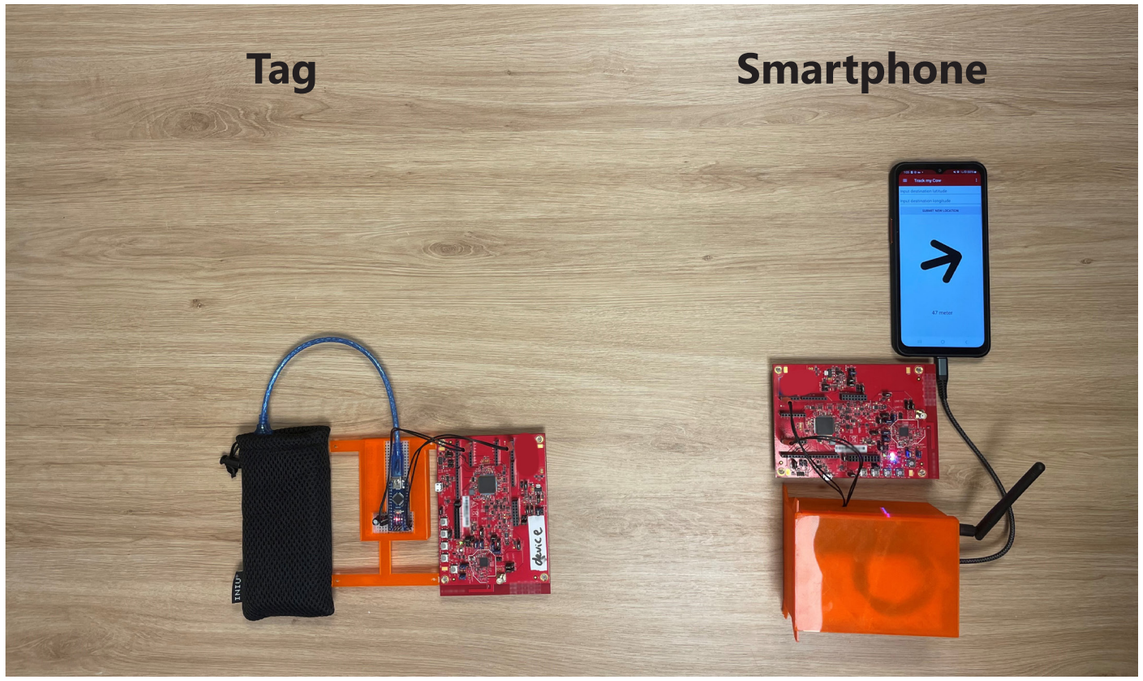


Figure 30 Prototype consisting of the beacon, smartphone assembly and tag.

5.2 User Aspect

As the technology aspect had been designed, tested and proven to work, the user aspect had to be designed to connect the user to this technology in a desirable way. In Chapter 4, it was found that locating a cow should consist of three phases: Uncovering, Navigating and Identifying. Using the last known router connection to have a rough estimation of where to go first was again used in the Uncovering phase. The technology aspect of this chapter has proven to work for the Navigation phase. However, the user interface of these phases, and the entire Identification phase still had to be explored and designed. The exploration of the interface was divided into two parts; Design for Work Engagement, and Design for Intuition.

As highlighted in the literature and the persona of the farm employee, a significant proportion of workers have a limited level of education with low literacy. Particularly in the US, many employees are foreigners, further complicating matters by introducing language barriers. Consequently, intuitive design became crucial for the effectiveness of the localisation solution. Moreover, the user interface should aim to reduce the learning curve associated with the localisation process. Furthermore, as emphasised by the literature and validated by farmers, the solution should strive to enhance work engagement on their farms, seamlessly integrating within the context of cow localisation.

5.2.1 Design for Work Engagement

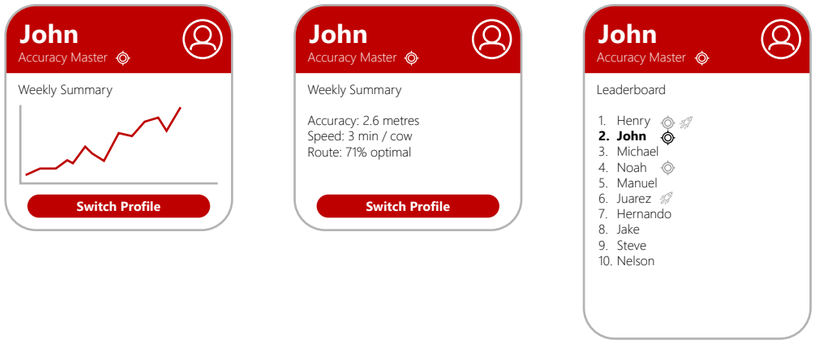
From the findings of the study on work engagement in Section 4.3, it was determined that two fundamental needs are deficient in the process of locating cows: competence and recognition. This aligns with the findings in the literature. Cardona and Rey (2008) discovered that individuals possessing a sense of competence typically demonstrate a well-defined sense of recognition. Various methodologies exist to enhance recognition and competence within the context of cow localisation.

Enhancing Competence
The system should be introduced to users through interactive tutorials that explain its features and their visualisation in the interface. During the process of locating cows, metrics such as navigation accuracy, time taken, and the number of successfully completed tasks are tracked. Displaying these metrics at the end of a shift provides users with feedback, fostering a sense of competence. Feedback is crucial as it enhances confidence, motivation, and engagement (Markovic, 2020). Regular feedback helps users deepen their understanding, affirming their competence or indicating areas for improvement (Markovic, 2020).

Enhancing Recognition
Gamification has been proven to enhance recognition, competence, and overall work engagement (Silic & Back, 2017). Incorporating features like rewards and leaderboards can significantly boost recognition and competence in the workplace. Achievement badges such as "Fastest Navigation," "Accuracy Expert," and "Most Cows Located" serve as motivational tools which are included in the interface.

Enhancing Purpose
Silic & Back (2017) similarly concluded that improving competence and recognition leads to an improved sense of purpose. The questionnaire results also revealed a lacking fundamental need of purpose, which is logical given its correlation with competence and recognition. Nevertheless, enhancing the sense of purpose holds significance, as it is important for employees to grasp the importance of their tasks in contributing to the success of the business (Cardona & Rey, 2008).

Work Engagement and Interface Design
In practice, enhancing the feeling of competence and recognition was designed in two ways (Figure 31):
Personalisation: Providing employees with personal profiles enhances their sense of belonging and purpose, improving recognition. These personal profiles track performance and display rewards enhance the user's sense of competence and recognition.
Training: Providing a clear, hands-on walkthrough that explains all system features extensively to new users ensures they can use the system to its full potential which enhances the feeling of competence.



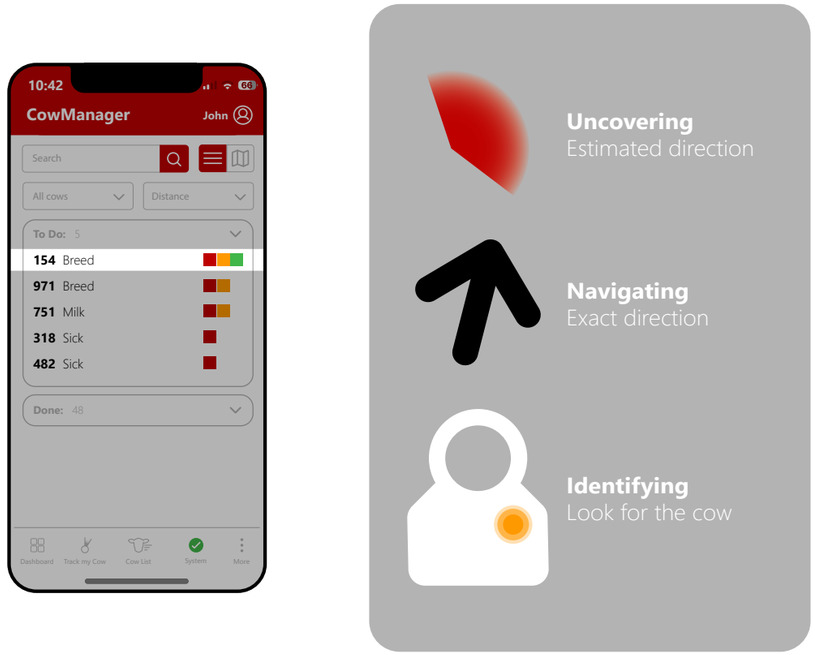


Figure 31 Visualisations of a training and personalised page in the app, including feedback and leaderboards.

Ethical and Privacy Implications of Personal Profiles

Currently, personal profiles are not utilised to their full potential in the CowManager system. Typically, a single general profile is logged in on every device on the farm. The primary advantage of this approach is that it eliminates the need for individuals to continuously log in and out of devices. However, studies suggest that the benefits of using personal profiles far outweigh the convenience of a general profile.

Gaudiino and Di Stefano (2023) found that personal profiles on the work floor foster a sense of ownership and responsibility. As discussed in Section 4.3, these feelings of ownership and responsibility fulfil fundamental needs such as recognition, purpose, and competence. Consequently, it can be argued that having a personal profile enhances these fundamental needs, thereby boosting work engagement.

Personal profiles also positively impact work engagement by enabling employees to mentally disconnect from work. Leiter (2019) discovered that personal profiles facilitate mental detachment from work by creating a clear boundary between work and personal life. The act of logging in and out at the beginning and end of a workday helps establish these boundaries, clearly marking the transition between work and personal life.

The literature has clearly demonstrated the benefits of using personal profiles on the work floor to improve work engagement. Furthermore, personal profiles allow management to better track individual employee performance, thereby providing more precise feedback. Currently, one of the frustrations among farmers is that localisation solutions only confirm that an employee found a cow, not that the cow received treatment. This confirmation can be given even if the employee was not near the cow. Logging the distance between the cow and the employee using a personal profile provides proof that a specific employee attended to the cow, making it more credible that the cow received proper treatment.

However, monitoring employees individually raises ethical and privacy concerns. Employing someone should inherently involve a level of trust, implying that employers should respect their employees' autonomy. Monitoring employees can feel intrusive (Blackman, 2021). Therefore, a balance must be struck between monitoring for productivity and maintaining trust. The metrics tracked by a localisation solution must be carefully chosen. These metrics should focus solely on performance in locating cows and be entirely transparent to employees about what is being monitored and how this data is used by the system and the farmer to provide valuable feedback. A study by Kropp (2019) found that employees' acceptance of performance monitoring significantly increased when employers were transparent and explained the necessity of the monitoring. Moreover, monitoring should be used not to oppress employees but as a tool for improvement, helping and rewarding employees for their efforts. The localisation solution, along with the farmer, should convey that performance data is used to identify areas for improvement, making the employees' work more comfortable.

Regarding privacy, the localisation solution must never record personal data as it is unnecessary for evaluating work performance. Additionally, employees must consent to being monitored. The only data required for monitoring work performance in the context of cow localisation includes:

1. Data on the cow that was located
2. The timestamp of when the cow was found
3. The distance between the employee and the cow when the cow was found
4. The location of where the cow was found

None of this data includes personal information and using only this data, the time it takes to consecutively locate cows can be tracked, enabling management to understand and improve the workflow of locating cows more effectively. By analysing the location of the found cow, the efficiency of the user's route can be assessed, and potential improvements can be identified.

The data gathered does not require personal profiles, yet it allows employers to evaluate the work performance of individual employees over time. If one employee exhibits unusual behaviour during the localisation task, it would not be noticed among the data of employees who perform the task well. Furthermore, when the data is linked to an individual, the task can be gamified, providing a leaderboard and rewards. This, in turn, enhances work engagement, which is one of the key goals of this project. By implementing personal profiles that provide feedback on employees' work performance, their fundamental needs for competence, recognition, and purpose will be enhanced. This, in turn, improves work engagement, which subsequently boosts productivity on the farm. Additionally, it results in better care for the cows, as everyone on the farm becomes more motivated and possibly enjoys their work more.

5.2.2 Design for Intuition

One of the primary frustrations for farmers regarding localisation solutions is that they are not user-friendly. In terms of the interaction between the technology and the user, this means that the user interfaces of existing localisation solutions are not intuitive. These frustrations can become significant problems, particularly when users have low literacy levels, making it challenging to interact with text-based interfaces. Therefore, it was essential to develop a user interface that was optimised for intuitive use.

User - Cow Interaction

During the CS tests in the barn, I found that most cows begin looking at nearby people as they are curious animals. This means that a human can easily see the ear tags and the sensor as the ears are pointed towards them. To identify a cow, in addition to reading the ear tags, a short study was conducted to test whether it was possible to identify a cow using visual or audible signs.

For the audible signs, a buzzer was installed next to the ear sensor. However, it was found that cows do not understand where the sound was coming from, turning their ears backwards, making it harder for humans to determine the sound's origin. Additionally, when multiple cows were standing side by side, it was not possible to determine from which cow the sound was coming.

For the visual signs, the unused LED in the ear sensor was used. As a cow looks at a human, it was easy to see and identify the light, even in bright environments. The light did not seem to have any effect on the cows, keeping them calm. Additionally, it was easy to identify a cow when multiple were standing side by side. However, an LED was assumed to consume a significant amount of energy which could drain the battery quickly. It was calculated by CowManager that blinking the LED for 5 hours, once every month, as that is how many times a cow has to be located, results in a power loss of 2 months on the battery lifetime of 10 years. This suggests that the LED has significantly less impact than anticipated while users can benefit greatly from it during the identifying phase in cow localisation.

Transitioning Focus Area

During a user test in Germany with CowManager's "Find my Cow" solution, I observed that users continued to watch their phone screens to locate a cow, even when the cow was standing right in front of them. As a result, I decided to remove the navigation aid from the user interface when the user is in close proximity to the cow. This change was intended to encourage users to look up from their phones and search their immediate surroundings. According to farmers interviewed, they can easily identify a cow from 5 metres away, so a visual feature was designed specifically for the identifying phase.

To test whether users would look up from their phones, an app was developed for the last two phases: navigating and identifying. From a distance, the app displayed an arrow pointing to a pre-programmed coordinate and the distance to that location. Participants were given the phone and asked to locate the cow by walking towards it.

During this test, I observed that participants could easily follow the arrow. However, similar to the observations in Germany, the use of the arrow caused participants to focus more on their phones than their surroundings. At the precise moment the arrow was removed from the user interface, all participants looked up from their phones. Initially, they were slightly confused, but they quickly realised that the cow had to be nearby due to the short distance remaining. This prompted them to start looking around to locate the cow.

"Oh, the arrow disappeared... ... The cow must be nearby right." - CowManager employee (CM1)

Designing and Evaluating Intuitive Features

The design phase for this intuitive user interface comprised three iterations. Each iteration involved creating a design, which was then evaluated by different stakeholders during workshops. In these workshops, participants were informed that they would be viewing an animation of a user interface demonstrating how to locate a cow, and they were asked to assess the intuitiveness of the visualisations. The animations were played once, followed by an open conversation where each feature displayed in the animation was discussed in detail.

In the first iteration, three interface features showing distances or locations for each phase of localisation were designed and animated (Figure 32). These animations aimed to help participants understand the movement and function of the designed features more easily. The animations (https://youtu.be/46iW4OTpzI4) were shown to two CowManager support employees during a

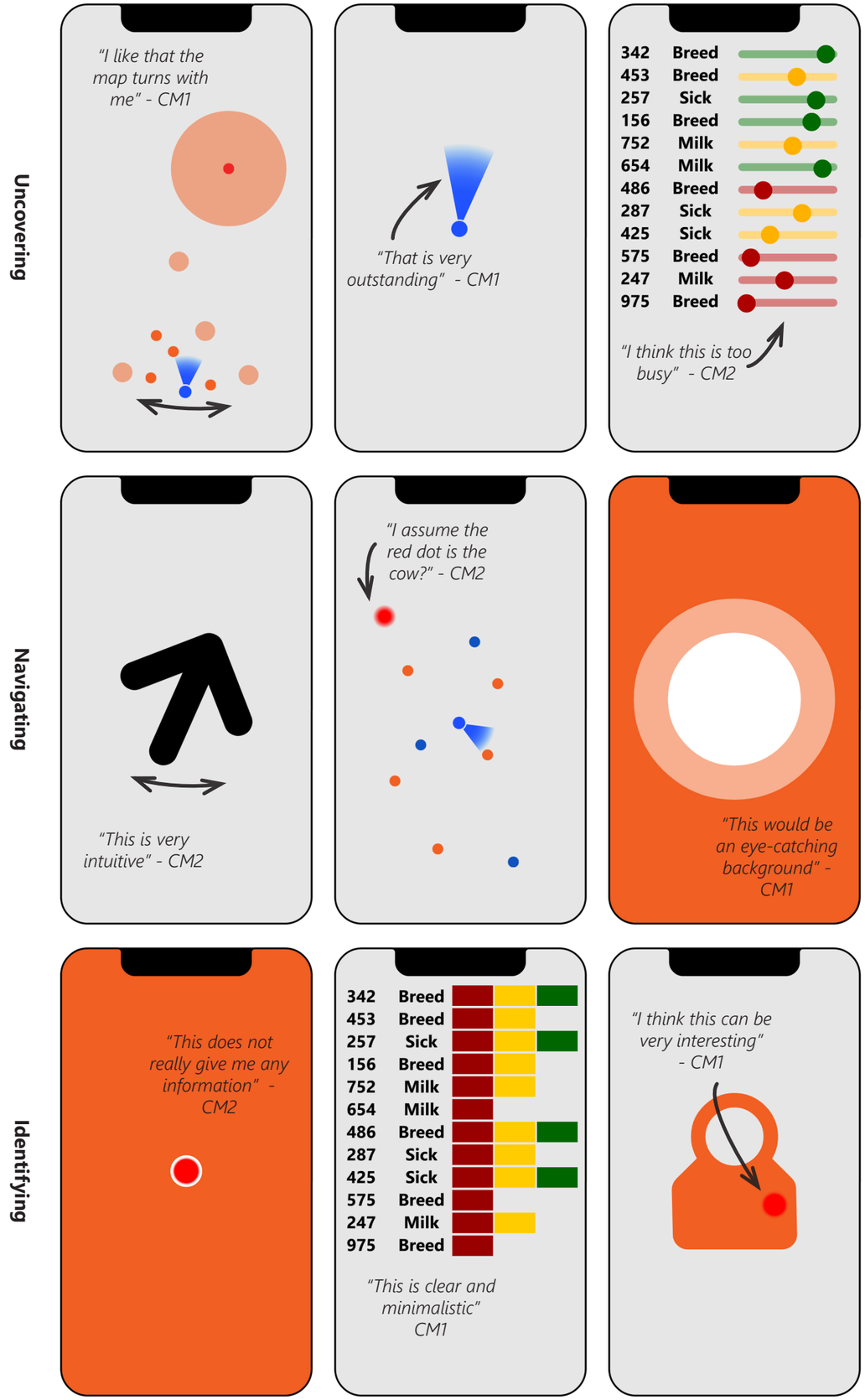


Figure 32 9 interfaces showing different visualisations for the phases of uncovering, navigating and identifying.

workshop. The goal was to determine the intuitiveness of the features and identify which ones were necessary for the full process of uncovering, navigating, and identifying cows. It was found that minimal information was needed, particularly an overview. High accuracy in distances was deemed unnecessary; instead, an indicator with three colours representing far, medium, and nearby distances sufficed to provide a good overview of all the cows that needed to be found.

Based on the insights from the first iteration, a new animated user interface was designed to walk through the three phases of cow localisation (https://youtube.com/shorts/a1avkFZNXhg and Figure 33). This was evaluated during two workshops: one with farmers and another with CowManager's UX designer. During the workshop with farmers, it was revealed that they preferred an overview of the cows using a map rather than a list. This preference was because they could easily orient themselves based on landmarks such as feeding paths and routers. However, it was discussed that this approach works well inside barns but not in large open fields where landmarks are scarce. Therefore, having the option to switch between a list and a map was necessary. Additionally, the farmers found the visualised features of the three phases intuitive. Discussions concluded that their employees, many of whom have low literacy, would also find the visualisations easy to learn and use, demonstrating the interface's desirability.

The third iteration focused on integrating all gathered insights to create a final user interface (Figure 34), which was validated within CowManager.

Chosen Intuitive Features

Before locating an individual cow, it was established that the user should have an overview of multiple cows from which they can select the cow to locate. This is communicated using a list and a map, depending on the user's preferences. Offering a choice to users is important as farmers desire autonomy in their work methods. Providing this autonomy is crucial in interface design; even when a feature, is not strictly necessary, many farmers using a localisation solution are accustomed to a specific feature and will only adopt a new solution if it includes one.

For the uncovering phase, it was noted that it is important to communicate that the system only knows the rough direction of the cow, not the exact location. Therefore, it was decided that using a fan-like visualisation (Figure 32, top centre) effectively conveys this uncertainty.

The navigation phase requires a clear arrow (Figure 32, centre left) as this is a highly intuitive way to indicate direction, as validated by all users during user tests. Displaying an arrow also implies that the system precisely knows the location of a cow rather than just the rough direction. During this phase, the map can also be displayed to the user, highlighting the cow's position among other cows and landmarks. As mentioned in the Section 4.7.2, landmarks are essential during navigation for users to orient themselves.

The changing background in Figure 32 (centre right) initiates the identifying phase. It was observed from user tests that this eye-catching background change alerts the user to an upcoming important event. During the background transition, the arrow disappears.
User tests revealed that users tend to keep watching the arrow, trying to follow it, even when a cow was standing right in front of them. To encourage users to shift their focus from the phone to the cows, the arrow disappears when the user gets within 5 metres of the cow. Additionally, an animation of a sensor appears with a blinking LED (Figure 32, bottom right), indicating to the user that they should start looking around for a cow wearing a blinking sensor.

Limitations and Design Parameters

It is important to consider that none of the participants in the workshops were the actual target group of low literacy farm workers. Nevertheless, the farmers demonstrated a strong ability to empathise with the farm workers, generating valuable insights. Additionally, collaboration with the UX designer from CowManager yielded some intriguing insights regarding the intuitiveness of several features.

From the workshops, two key insights emerged as essential design parameters for the final user interface. Firstly, the interface needed to clearly illustrate the differences between the three localisation phases: showing the uncertainty in uncovering, the accuracy in navigating, and encouraging the user to trust themselves and start looking around. This approach positions the localisation solution as an extension of the body, aiding in finding a cow, while the user must actually perform the tasks of localisation and identification.

The second key design parameter identified was the use of colour rather than text and numbers, thereby minimising the amount of information displayed. This makes the interface more accessible and easier to use for farm workers with low literacy.

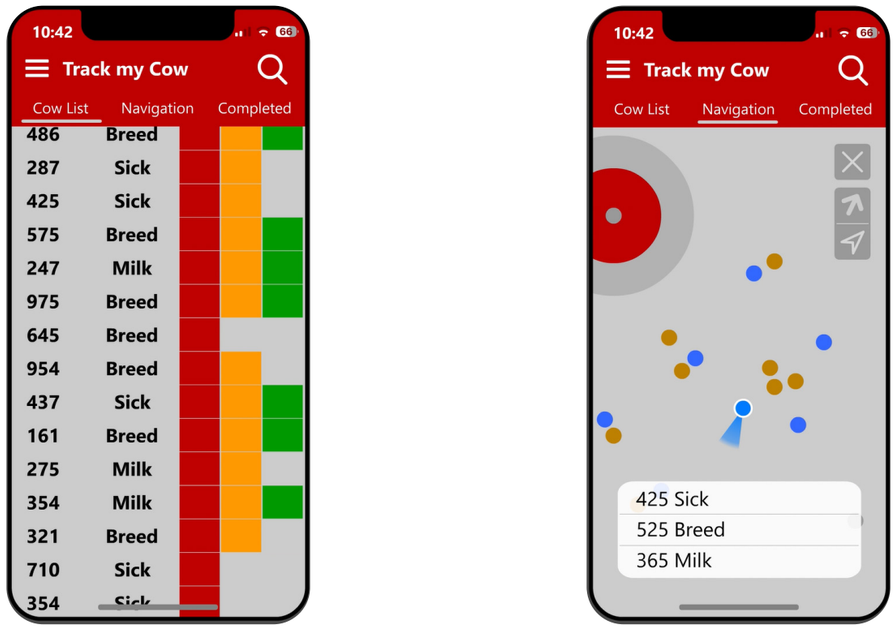


Figure 33 Iteration 2 showing the list and map overviews.

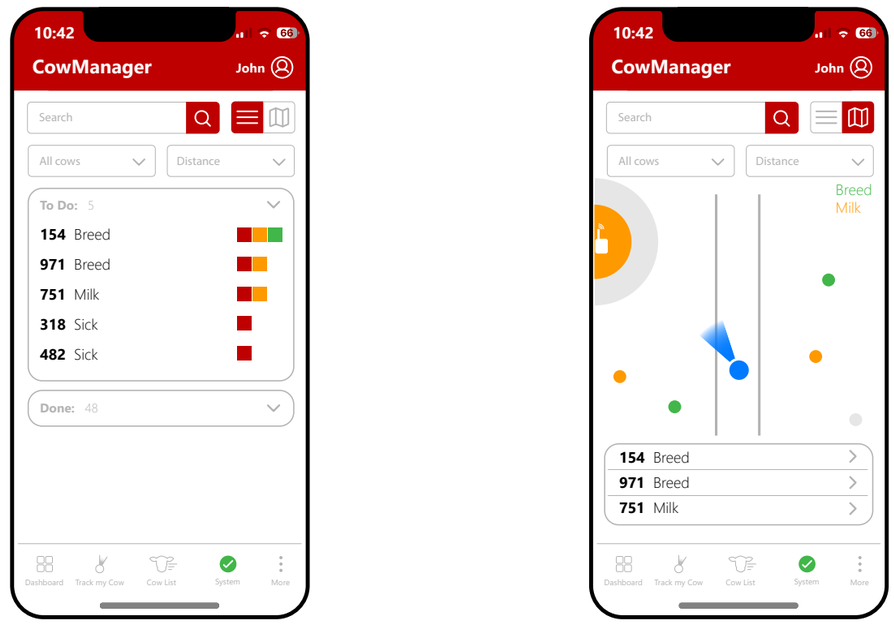


Figure 34 Iteration 3 showing the list and map overviews.

5.2.3 Use case: Optimised Route

One of the key frustrations with current localisation solutions is the time it takes to locate a large list of cows. Currently, users determine their own route through the pens and the order in which to locate cows. The proposed solution addresses this by using the system's knowledge of the cows' locations to determine the most efficient route (Figure 35, top), thereby minimising the time required to locate all cows for the day.

An important use case for the optimised route is inseminating cows. When a cow needs to be inseminated, the farmer must retrieve a straw of semen from the fridge, which must be used within 6-8 minutes to prevent spoilage (Diskin, 2008). An optimised route guides the user efficiently to multiple cows within this insemination window. Ultimately, the interface could instruct the user on how many straws to take and directly guide them to the cows within the optimal timeframe.

Implementing the optimised route requires the system to know the approximate locations of all cows, transforming the task into a "Traveling Salesman Problem" (TSP). The TSP is stated as: "If a travelling salesman needs to visit a certain number of places at least once and return home, what is the least costly route to take?" (Dror, 1986). In this use case, the time (cost) of the problem dictates the number of cows that can be visited in one run, and the total number of runs required. The TSP is then adapted to determine the optimal number of cows and the best path between them to minimise the overall time required to inseminate all cows efficiently.

5.2.4 Use case: Fetching LEDs

An important use case for the LED is fetching cows. Typically, an employee is required to enter the barn or field, locate multiple cows, and escort them to a designated area. Currently, this involves the employee walking to the far end of the barn or field and gradually moving through the herd to identify the cows that need to be fetched. Upon identifying a cow, the worker directs it towards the specified location. The worker then continues, guiding the cow, until another cow to be fetched is identified. At this point, the worker must guide both cows to the location. This process continues, with the employee gradually assembling a group of cows and directing them simultaneously to the predetermined location. Having a clear overview and a strategic path to follow is crucial for making this task less frustrating and more efficient.

To enhance this process, it was determined that the overview should not only be displayed on the interface (Figure 35, bottom) but also be visible in real life. While the interface indicates the locations of the cows to be fetched and the route to take, LED lights on all the relevant cows blink continuously. This provides the worker with a better overview in the barn or field without the need to constantly refer to the user interface for identification. The LED lights turn off simultaneously once the worker has fetched all the cows and brought them to the designated area.

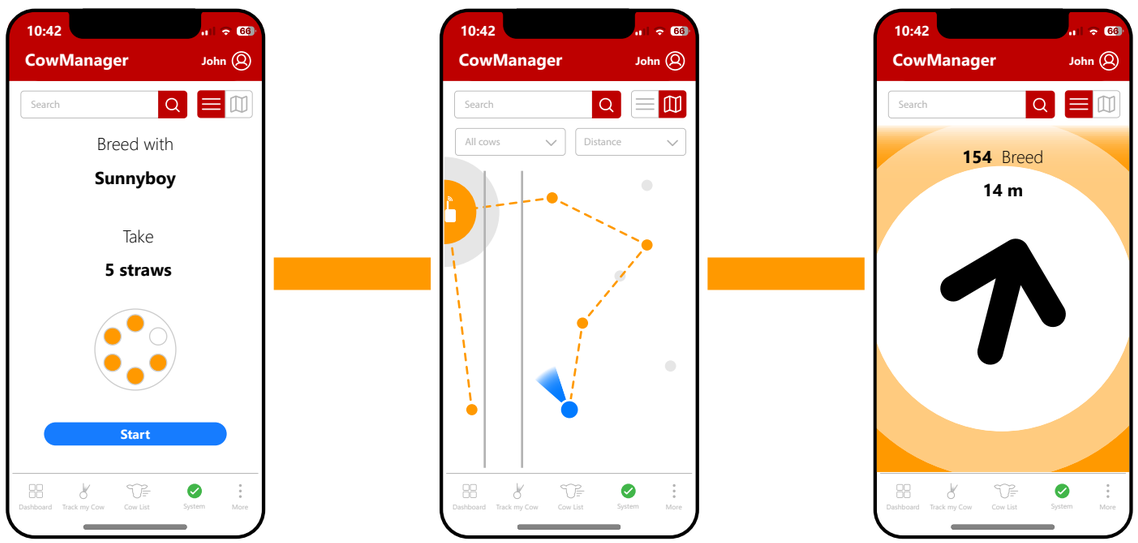


Figure 35 Snapshots of the interface showing the use case of an optimised route and for fetching cows.

5.3 Conclusion

This chapter combined insights from literature and my own studies to conceptualise, design, and prototype components for a comprehensive localisation solution, divided into the technology and user aspects.

The technology aspect focused primarily on developing a prototype for the navigation phase. The goal was to create a technological solution capable of determining the position of a tag device with an accuracy of less than 5 metres. Initial testing of Channel Sounding was necessary to evaluate its performance. Subsequently, the concept of using a smartphone as a mobile router was introduced and simulated using Python, showing promising results. The developed prototype successfully demonstrated the capability to achieve an average accuracy of 2 metres, meeting the evaluation criteria for high accuracy while maintaining a cost-effective approach by integrating the solution with the existing infrastructure.

Conversely, the user aspect aimed to enhance work engagement through an intuitive user interface. By implementing personalised profiles that provide direct feedback on cow locating tasks, incorporating leaderboards, and offering digital rewards, the fundamental needs of competence, recognition, and purpose were effectively addressed. Furthermore, interactive tutorials were integrated to train employees, optimising their use of the localisation solution.

The interface design was structured around the three phases of localisation—Uncovering, Navigating, and Identifying—each tailored to clearly communicate the certainty and accuracy of the estimated cow locations. The Uncovering phase showed a fan-like visualisation to indicate direction without precise location certainty. In the Navigating phase, an arrow symbolised that the exact location was known. Transitioning to the Identifying phase, the arrow disappears prompting users to visually search for a blinking sensor, minimising identification errors and speeding up the process intuitively. Additionally, two overviews—a list and a map—were developed, offering users flexibility based on their preference, environment, and specific use-case scenarios.

Two distinct use cases were developed to further enrich the interface, providing specific guidance in scenarios such as optimised route planning for cow insemination and efficient cow fetching using LEDs. These features were designed not only to enhance user comprehension, particularly for those with low literacy levels, but also to improve operational efficiency and task clarity.

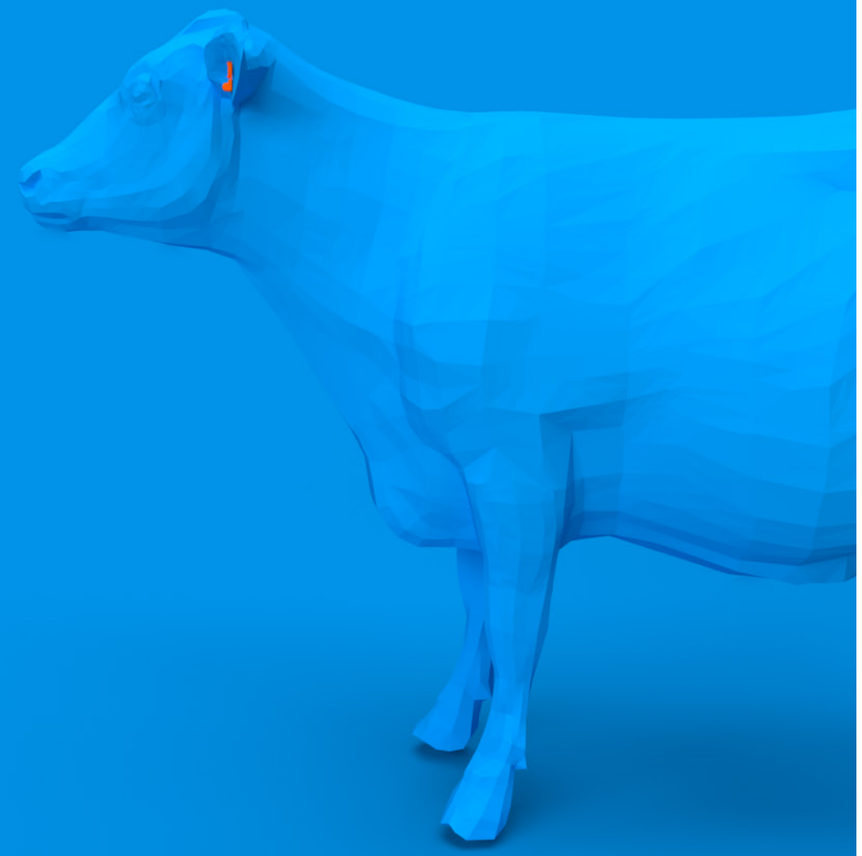
The final step addressed in the next Chapter involved integrating the technological advancements with the user-centric interface to deliver a comprehensive cow localisation solution adaptable to diverse environments while prioritising user needs and preferences. This integration ensures the solution's feasibility, viability, and desirability in practical agricultural settings.

Chapter 6

Integration

6.1 Localisation as a Funnel
6.2 Annotated User Interface
6.3 System Overview
6.4 Stakeholder Integration
6.5 Solution Validation

In this chapter, the concepts, designs, and insights from all previous chapters were integrated to deliver a comprehensive cow localisation solution. First, the solution was visualised as a funnel encompassing the three phases of localisation. Subsequently, a detailed user interface was annotated to illustrate its features. Following this, the user interface and funnel were merged with a general flowchart to visualise the integration of technology and user aspects. Finally, the impact on each stakeholder was discussed, and the plan of requirements was validated.



6.1 Localisation as a Funnel

The entire localisation process developed in this project could be conceptualised as a funnel, integrating the three phases of uncovering, navigating, and identifying. Each phase uses a different method and technology to locate a cow, each with a varying range and accuracy as described in Chapter 5. This concept builds upon the foundational elements outlined in Section 4.7.2, where the localisation process is divided into the distinct phases.

During the uncovering phase, users are provided with a rough direction to the cow, based on the last known router connection to initiate the localisation process. This phase acts as the starting point for narrowing down the search area, setting the stage for more precise guidance in subsequent phases. Without it, users would have to cross the entire farm, searching for a signal to establish a Channel Sounding connection between the cow and the phone.

Transitioning into the navigation phase, the localisation funnel narrows further, offering increasingly accurate guidance towards the target cow. This phase, explored in Section 5.1.2 and demonstrated to be effective in Section 5.1.4, uses the novel Channel Sounding distance-measuring technology of Bluetooth to provide precise directional guidance. This enables users to navigate with high accuracy through the farm environment. Without this phase, users can only locate a cow with an accuracy of 100 metres, as limited by the uncovering phase. Additionally, they would need to start searching for a blinking LED from at most 100 metres away, making cow identification challenging.

The final phase of the localisation funnel is identification. Here, users are equipped with tools to recognise the target cow, completing the localisation process. The visual cue of the blinking LED, and an intuitive interface aid users in identifying the target cow among the herd, ensuring accurate and efficient localisation.

By combining the rough direction provided in the uncovering phase, the accurate guidance of the navigation phase, and the precise recognition of the identifying phase, the localisation funnel captures users at any given location, guiding them towards the target cow with increasing accuracy. This holistic approach balances and optimises efficiency and accuracy in the entire process of cow localisation. Moreover, it ensures that the localisation solution meets the requirement for high accuracy and a long detection distance.

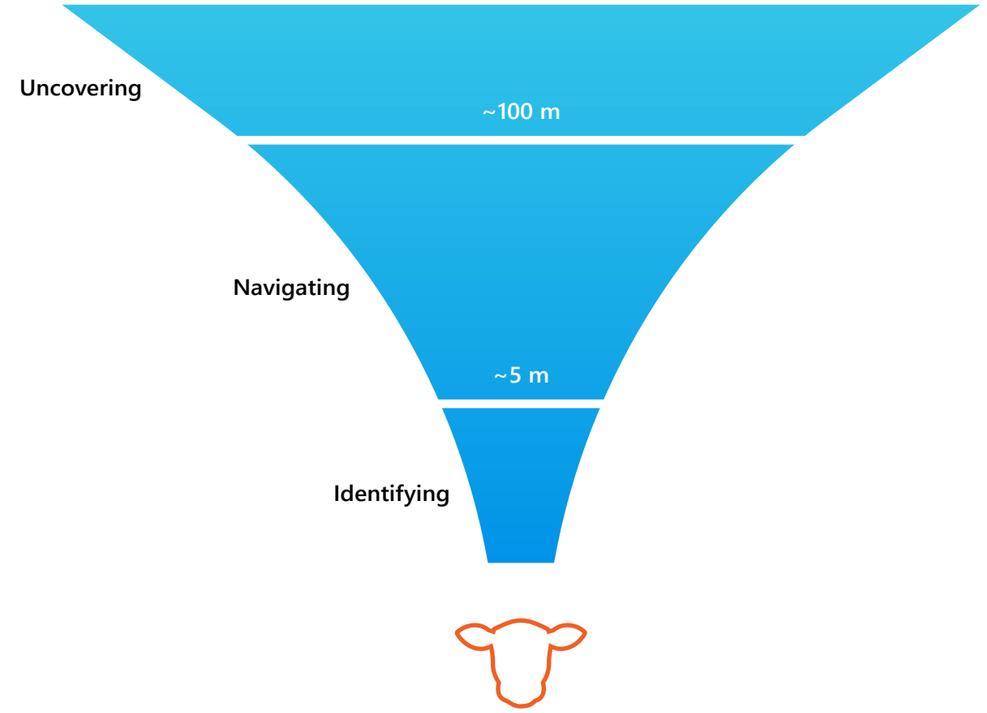


Figure 36 The accuracy of the three localisation phases combined form a funnel towards the cow.

6.2 Annotated User Interface

This section explains the user interface used to display an overview of all cows that need to be located and shows the visual steps presented while in the process of locating a single cow. All features of the interface are iteratively designed based on interviews and tests with farmers and employees of CowManager as described in Sections 4.2 and 5.2.2. The interface aims to intuitively assist users in locating cows as seamlessly as possible.

Upon launching the app, users are presented with a list of cows to locate. This list serves as a central hub, allowing users to easily identify and select the cow they intend to find, or opt for the algorithm to choose the optimised path to follow as explored in Section 5.2.3. Each entry in the list shows minimal but essential information about the cow, such as its identification number, the action to perform, and approximate distance to the cow.

For users preferring a visual representation of cow locations, the app offers a map view option. This feature overlays cow locations on a minimalistic map of the farm, providing users with a spatial understanding of where each cow, and they themselves, are located. Users can toggle between the list and map views based on their preferences and situational needs.

The app includes a personal profile section, where users can view and manage their account information. This feature allows users to track their performance over time, enhancing user engagement and providing a sense of belonging and competence.

To assist users in locating individual cows, the interface provides a step-by-step guide. This intuitive process breaks down the localisation task into the three distinct phases, ensuring a smooth and efficient workflow. Each phase is accompanied by its own visualisations, being transparent to the user of the location's accuracy, aiding the user in understanding the system when a challenge occurs.

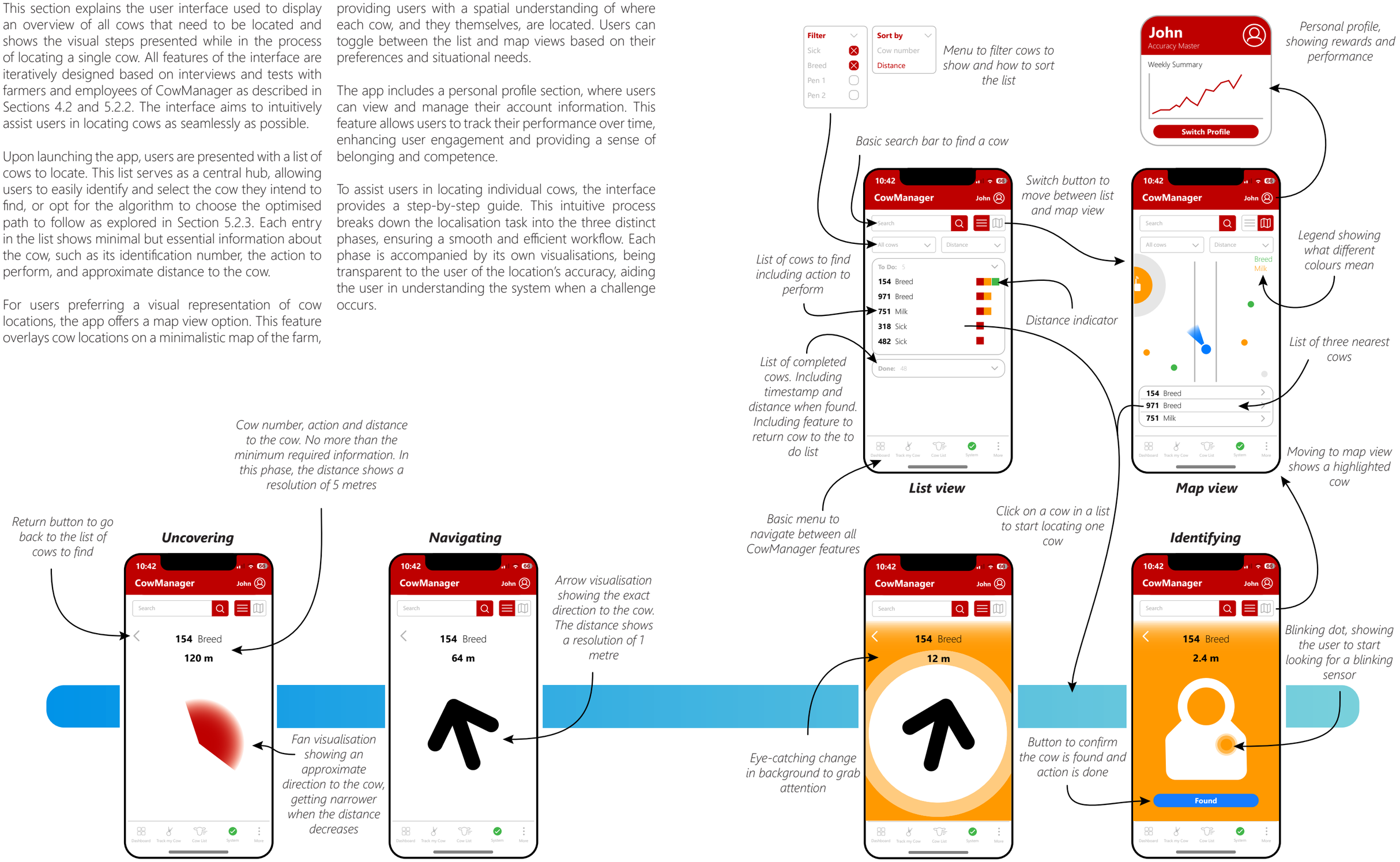


Figure 37 Annotated interface, showing all features of localisation and how this is visualised.

6.3 System Overview

This section integrates the systematic aspect of the technology and the user aspect, offering a complete overview of how the cow localisation system functions from both perspectives as shown in Figure 38.

Behind the user interface, the trilateration process determines the exact location of a cow, as explained in Section 5.1.2. Trilateration relies on measuring distances from at least three known beacons to the tag device worn by the cow. However, instead of deploying additional beacons, the system uses the user's smartphone to serve as a mobile beacon. By integrating the trilateration data and GPS data from the routers and the smartphone, the system achieves precise location estimations. This approach optimises costs as it only accurately locates cows near the user while ensuring efficient cow localisation across the farm as the user moves around.

The user's interaction with the interface is based on data flows behind the scenes, ensuring seamless operation and accurate cow localisation. The raw localisation data is processed and integrated in real-time by the smartphone, enabling the interface to provide timely and relevant information to the user. This dynamic data flow ensures that the interface remains responsive to changes in cow locations and user interactions, delivering an optimal user experience from start to finish. The data flowchart in Figure 38 provides a general overview; a detailed flowchart of the entire system can be found in Appendix G.

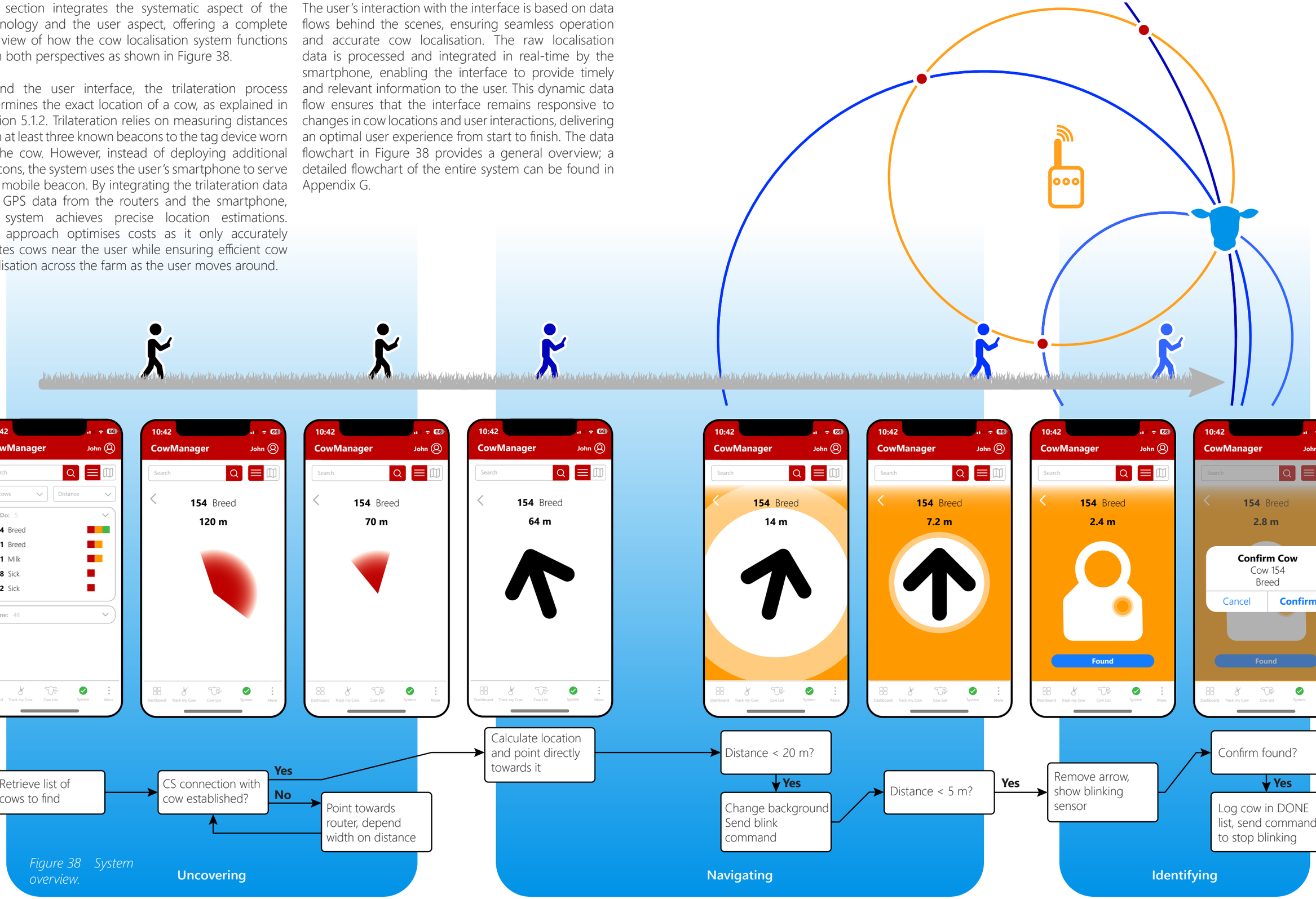


Figure 38 System overview.

6.4 Stakeholder Integration

The development and implementation of the localisation solution introduces significant changes and impacts for a wide range of stakeholders. Each group will experience various shifts in their roles, processes, and interactions.

Agis Innovation Centre is responsible for the technical development and optimisation of the localisation system. Extensive field tests and technical support are crucial to ensure the system's robustness and address any issues during deployment.

CowManager plays a critical role in integrating the localisation solution into their existing product ecosystem. They will update the microprocessor in sensors and routers and ensure the integration of GPS sensors in the routers, leveraging the pre-existing design that includes a GPS socket. This involves updating software interfaces and providing training and support to farmers. CowManager must also decide on the pricing strategy for the localisation service, which, despite requiring an additional €0.50 per sensor and router for the new chip, remains cost-effective due to the minimal need for new beacons. Marketing strategies will highlight the new features and benefits of the integrated system to attract more customers.

Suppliers and factories will experience minimal changes. A different, newer microprocessor will be sourced from suppliers, while the manufacturing of sensors and routers will remain largely the same with slight updates to the PCB in sensors and the addition of a GPS sensor in the routers.

Farmers will benefit significantly from the localisation solution. It simplifies the process of locating cows, saving time and effort. The user-friendly interface and intuitive design will make it easy to adopt and integrate into daily routines. This technology provides valuable data, enhancing decision-making and overall farm management. The cost-effectiveness of the solution, integrating with existing infrastructure and requiring minimal new investment, will be a significant advantage.

Farm employees, particularly those with limited education or language barriers, will experience a more streamlined and intuitive workflow. The intuitive design and training modules will enable them to use the system effectively, enhancing their sense of competence and recognition. Gamification elements, such as rewards and leaderboards, can further motivate and engage employees.

Cows will benefit indirectly through improved management practices. Quick and accurate localisation means timely health interventions and better overall care. The reduced stress and handling associated with traditional methods of locating and managing cows can lead to better animal welfare.

Society will benefit from advancements in agricultural technology as they contribute to more efficient and sustainable farming practices. Better animal welfare practices can lead to improved food quality and safety, addressing consumer concerns about livestock management and care.

Inseminators and veterinarians will find their jobs significantly streamlined. The optimised route feature ensures that inseminators can complete their tasks within the critical time window, enhancing the success rate of inseminations. Veterinarians will benefit from quick access to any cow needing medical attention, improving response times and outcomes for animal health interventions.

Governments and animal welfare organisations will observe improved compliance with animal welfare standards due to the precise management capabilities provided by the localisation solution. The system's detailed data collection and reporting capabilities provide clear and accurate records of cow management practices, making inspections more straightforward and effective.

The localisation solution brings significant changes and benefits across stakeholders. Agis Innovation Centre oversees technical development and testing, ensuring system reliability. CowManager integrates the solution into their ecosystem, updating hardware and software while strategising pricing and marketing. Suppliers and factories adapt with minimal changes. Farmers benefit from better cow management, while employees find the system intuitive, making it easy to locate cows. Cows benefit from improved care, and society gains from sustainable farming practices. Inseminators and veterinarians experience streamlined workflows, and governments benefit from improved compliance monitoring. Overall, the solution enhances efficiency, sustainability, and animal welfare in agriculture.

6.5 Solution Validation

During the entire project, all decisions were guided by the vision of empowering farmers to care for their cows as if they were in a petting zoo, using an intuitive localisation solution. To achieve this, the technology needed to facilitate a localisation system that farmers could interact with effortlessly. This overarching vision was broken down into empirical components, each individually evaluated and documented in a continually updated plan of requirements, detailed in Appendix H. Here, several key requirements that needed extra explanation are discussed.

A critical requirement was that the solution must be able to locate at least 80 cows per day. This figure was based on the needs of large farms housing approximately 5000 cows. In this project, the capability to locate a single tag was thoroughly tested and proven effective. While the same localisation method would apply to multiple cows, the system would need to incorporate a smart algorithm to determine the order in which cows are located. Current Channel Sounding technology lacks this feature, but discussions with CowManager developers suggested that such a solution could indeed work for multiple cows.

Another essential aspect was ensuring that maintenance could be easily handled by the farmers themselves. When sensors run out of battery or routers break, farmers should be able to replace them without difficulty. Since the solution uses the same hardware as the current infrastructure of sensors and routers, it ensures that farmers can maintain the system with ease, leveraging their existing knowledge and experience.

The development of the phone attachment boards was also a significant consideration. Given that only one or two employees typically locate cows simultaneously on a farm, only a few attachment boards are necessary. These boards should be produced in small batches. Additionally, is anticipated that future smartphones will integrate Channel Sounding, which would render the attachment boards unnecessary. However, due to the uncertainty of when this integration will occur, producing the attachment boards on a small scale is the logical approach.

Regarding the sensors, it was imperative that they did not become significantly heavier. The only hardware change involved replacing the microprocessor with a newer version, which is slightly larger but adds less than one gram to the sensor's weight.

The user device also needed to be smaller than the current FMC device. The existing device's directional antenna made it large and bulky. The new solution, though still requiring an attachment board, does away with the bulky directional antenna, resulting in a device no larger than a smartphone.

Installation time was another key factor. Because the new solution integrates seamlessly with the existing infrastructure of sensors and routers, the installation process does not require additional steps or time, maintaining the same ease and efficiency as the current system.

Additionally, some requirements depended on the choice of smartphone used by the farmers or their employees. As farmers prefer their employees to use their own phones for tasks, the durability of the solution—such as its waterproofness and resistance to drops—varies with the chosen phone. This variability means that some requirements can only be met if the employees' phones meet specific durability standards.

Throughout the project, my focus was on developing an intuitive cow localisation solution that empowers farmers to manage their herds effortlessly, similar to a petting zoo experience. Key requirements were carefully addressed, ensuring practicality and effectiveness. From enabling daily tracking of 80 cows on large farms to simplifying maintenance with existing infrastructure, each aspect was carefully designed to enhance efficiency and meet the users' needs and preferences.

Chapter 7

Conclusion

7.1 Conclusion and Discussion
7.2 Roadmap
7.3 Recommendations
7.4 Reflection

This chapter begins with the conclusion and discussion regarding the proposed cow localisation solution. Additionally, a roadmap for further development was created to ensure the solution reaches the market by 2025. My recommendations are also listed. The thesis concludes with my personal reflection on the project.



7.1 Conclusion and Discussion

This thesis aimed to investigate the research question: "How can a localisation solution be designed and integrated with the existing ear sensor to optimise user experience and efficiently locate cows, considering the diverse needs and preferences of farmers?"

The project was divided into two primary aspects: the technological aspect and the user aspect, focussing on optimising development for both before integration. Extensive technical research had already been conducted on tag localisation in the literature, primarily focusing on optimising accuracy. However, in farm environments, localisation solutions needed to consider four key technological evaluation criteria: accuracy, cost, battery life, and detection distance. Additionally, a novel distance measurement technology had been identified which had not yet been applied in any (localisation) solution. The technology and evaluation criteria revealed a gap that this project aimed to fill.

As a result, a technology oriented localisation solution was designed and prototyped which effectively meets the established evaluation criteria. Firstly, it achieves an accuracy of 2 metres through the use of Channel Sounding, the new distance measuring technology. Secondly, the solution is cost-effective, costing less than €1 per sensor by integrating the solution with the existing infrastructure and employing smartphones as mobile beacons, reducing the need for numerous expensive, static beacons. Channel Sounding also ensures prolonged battery life compared to Ultra-Wideband solutions, further optimised through variable update frequencies based on user-cow proximity. By using a variable update frequency, the solution can be as power-efficient as the current Find My Cow solution. Lastly, the solution meets the requirement for extended detection distances by using three phases of localisation, guiding users from afar by knowing the router in proximity to the cow, with increasing precision as they approach the cow.

Furthermore, the literature on the user aspect highlighted that large farms often employ workers with limited literacy, frequently migrant workers with diverse cultural backgrounds and language barriers. Therefore, the solution needed to be intuitive. Additionally, studies revealed that these workers often exhibit low work engagement, treating their tasks more like factory work than traditional farm labour. Consequently, enhancing work engagement became a crucial criterion for this thesis, particularly in the context of locating cows, an area with limited existing data.

Therefore, I conducted a study on work engagement for the specific task of cow localisation. The study revealed that users felt the fundamental needs of competence and recognition were lacking. Addressing these needs with a user interface enhances work engagement. According to the literature, timely feedback and features of gamification enhance these fundamental needs. In practice, developing personal profiles enables this by providing personal feedback and tracking work performance. Additionally, personal profiles allow the system to give personal rewards, gamifying the task and enhancing recognition. Competence is also enhanced using interactive tutorials to teach users how to optimally use the localisation solution, further fulfilling the need for competence.

Finally, the user interface (UI) had to be designed to be intuitive. The UI features three distinct visualisations corresponding to different phases of the cow localisation process: uncovering, navigating, and identifying, represented by a fan, an arrow, and a blinking LED respectively. These intuitive visual cues further enhance the engagement of low-literacy employees by effectively guiding them through the localisation process. The design of these features was developed iteratively with continuous feedback from farmers and CowManager employees.

In conclusion, the project successfully integrates technology and user engagement to create a user interface that intuitively connects users to the localisation technology. This enhancement improves efficiency in cow location and overall user experience on the farm. The solution advances beyond existing literature by optimising for the four evaluation criteria of accuracy, cost, battery lifetime, and detection distance, using the novel distance measurement technology that had never been integrated before. Furthermore, new knowledge was developed to uncover the fundamental needs of farm workers for the specific task of cow localisation. By addressing these basic needs, work engagement was designed to be improved. Integrating the user aspect and the technology aspect resulted in a comprehensive cow localisation solution that is efficient and optimises the user experience.

Feasibility

The feasibility of the cow localisation system has been thoroughly validated through field tests and iterative design processes. The system leverages new but cheap components, such as a microprocessor capable of Channel Sounding and a GPS module, to ensure precise localisation. The proof of concept, discussed in Chapter 5, demonstrates its effectiveness in real-world conditions, consistently maintaining accuracy within a 2-metre range. The integration of Channel Sounding enables

precise distance measurements, thereby enhancing the system's reliability and accuracy.

In practical terms, the design also limits the need for additional infrastructure by using existing smartphones as mobile beacons and enhancing routers with GPS capabilities. This builds upon CowManager's prior groundwork. However, given that Channel Sounding is unavailable in smartphones for now, the creation of an external antenna similar to the current Find My Cow device becomes imperative for rapid deployment. In essence, while minimal modifications from the manufacturer are needed, comprehensive development by the innovation team is crucial for ensuring seamless integration.

Viability

The localisation solution, which integrates the new Channel Sounding enabled chip, offers a promising economic perspective with an additional cost of just €0.50 per sensor and €10 per router. This integration seamlessly fits into the existing infrastructure, eliminating the need for significant new investments. Consequently, it becomes accessible for various farming operations, saving both time and enhancing farm management efficiency. Investing in this solution results in substantial cost savings on fertility hormones, which cost up to $700 (~€650) per sensor, making the €0.50 cost for the localisation solution remarkably economical.

This innovative solution shows the first use of Channel Sounding technology in cow localisation. While still in development, this technology shows significant potential for improvement. Moreover, from the user perspective, this solution stands out for its user-centred design in the interface. Unlike competitors that focused solely on productivity and conveying maximum information, this interface prioritises intuitiveness. Such a design aspect is deemed crucial for the viability of this cow localisation solution, considering the needs and preferences of its users.

Desirability

CowManager is currently in the process of developing a new mobile application, in which the designed UI is already desired to be integrated. This app boasts an enhanced interface and improved integration with data systems. Moreover, both farmers and CowManager employees have long stressed the importance of a robust localisation solution.

Such a solution, they argue, is essential for efficient cow management. It facilitates timely interventions on health alerts and optimises routing through a user-friendly interface. This not only enhances operational efficiency but also significantly improves animal welfare and productivity. Furthermore, the benefits extend beyond the farm, promoting societal advantages like better food quality and transparent farming practices.

The interest among farmers in this solution is clear. They are drawn to its cost-effectiveness compared to alternatives and are wary of reliability issues encountered with other market options. Tailored to seamlessly align with their workflow, the solution appeals to both investing farmers and their employees tasked with its implementation.

Limitations and Future Research

While the project uncovered various opportunities to improve the efficiency of the cow locating process, the implementation focused primarily on the technology aspect of the navigation phase. This decision was made to ensure that the project remained manageable within its scope while still delivering tangible improvements. Future research is recommended on optimising the other components.

One limitation of the proof of concept was its design focused on locating only one tag. While it is assumed that the solution can be scaled up, the technical implications of this scalability were not thoroughly explored. This limitation highlights the necessity for additional research and development in this area, particularly concerning the compatibility of the solution with multiple tags.

Embracing new technology inevitably entails a learning curve, and despite efforts to ensure a user-friendly interface, some users may require additional training and support. Moreover, reliance on smartphones could present challenges for those lacking access to modern devices or reliable internet connections. Although hands-on tutorials were recognised as potentially beneficial, none were developed or tested with the target user group. It is recommended to conduct full-scale testing of the solution on a farm to observe how the target group interacts with the UI and assess its intuitiveness.

The last limitation is the dependancy on the mobile beacon. Without it, the entire localisation solution fails. If for any reason, the Channel Sounding feature does not work mobily, the cow cannot be located. Additionally, the location of the phone has to be accurately known at all time to locate the cow accurately as well. Currently a smartphone is able to determine its location indoors, however this has its limitations as a result of the environment. Future research has to be done to improve this location indoors.

7.2 Roadmap

The timeframe for bringing the solution to the market is short. Therefore, a roadmap has been developed to outline the necessary developments to achieve this. This roadmap aligns with CowManager's plan to introduce the next generation sensor to the market in 2025, which will include the localisation solution. The roadmap integrates technological advancements and user-centric design, as discussed in previous chapters, to ensure successful deployment and adoption. It outlines a comprehensive plan for development, integration, testing, and launch.

In the Prototype Enhancement phase (Q3 and Q4 2024), the hardware, algorithms, and user interface have to be optimised and validated to create a robust system that can be tested on a full-scale farm.
Moving to System Integration (Q1 2025), the optimised solution must be integrated into the CowManager ecosystem. Hereafter, an initial test can be conducted on a single farm to validate functionality and gather feedback for further improvement.
In the Field Testing phase (Q2 2025), the system is tested in various environments to ensure versatility and reliability. Multiple pilot tests are conducted on farms with different conditions to assess adaptability and performance. Feedback from these pilots informs further refinement of technology and user interface.
Finally, in the Market Launch phase (Q3 2025), the complete localisation solution is officially introduced to the market. Training materials have to be developed to facilitate smooth adoption by farmers. At last, the solution must be transferred to CowManager for sales and support operations.

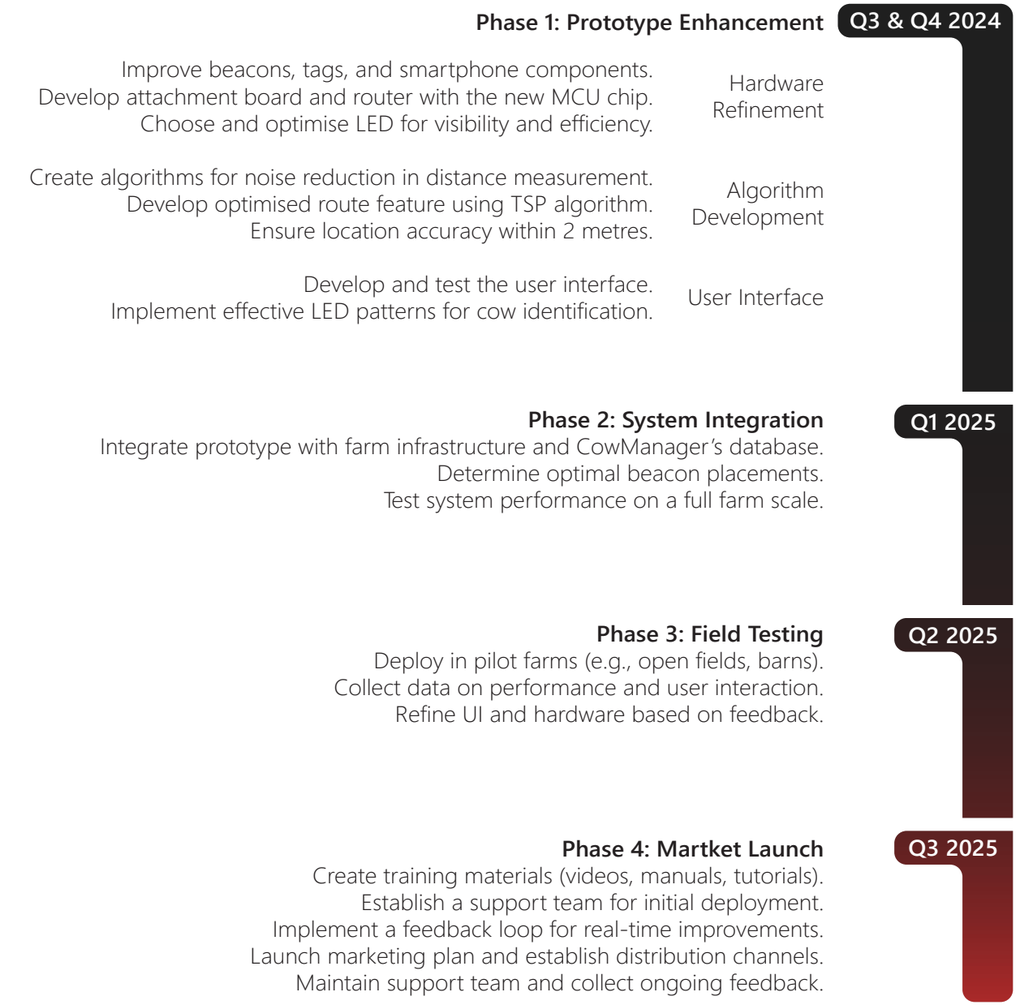


Figure 39 Roadmap with all required steps for the solution to be brought to the market in 2025.

7.3 Recommendations

In addition to the roadmap, several recommendations must be addressed to fully optimise the system. There are five recommendations for the technology aspect and three recommendations for the user aspect.

7.3.1 Technology Aspect

1. Optimise Update Frequency

It currently takes approximately 5 seconds to determine the location of a cow using the default settings of the development board. If 80 cows need to be located, it would take 5 x 80 = 400 seconds to find all cows. This also means that the location of a single cow is updated only once every 400 seconds, which is too long since cows can wander off. Therefore, it is recommended that the update time is variable, depending on the distance between the user and the cow. If a cow is far away, the location does not need to be updated frequently. This results in an inverse linear relationship where a higher distance results in a lower update frequency. Additionally, minimising the time of a single measurement will reduce both the time and power consumption.

2. Enhance Phone Location Accuracy

Optimise the location of the phone using Channel Sounding between static routers of known locations. Fuse the phone's GPS data with distance measurements of its own location to improve the indoor (and outdoor) location service of the phone, enabling it to be used as an accurate router. Indoors, the phone's GPS works but not optimally. Since the phone is used as a beacon, knowing its precise location is crucial to determine the location of the cow. By fusing GPS with a trilateration method between the phone and the routers, the phone's location service can be enhanced.

3. Algorithm Optimisation

The current Channel Sounding measurements using the development boards used default algorithms. It is recommended to research the noise to develop an algorithm that improves the distance measurements.

4. Power Consumption Measurement

There is little data available on the power consumption of a Channel Sounding event. Measurements from Silicon Labs provided a solid indication, but actual measurements are needed to determine the precise power consumption for the entire event of one measurement.

5. Minimise Consecutive Measurements

The number of consecutive measurements should be minimised to save time and power use. After optimising the algorithms, it is recommended to conduct another test to determine the minimum number of consecutive measurements required to locate the cow with the needed accuracy.

7.3.2 User Aspect

1. Quantitative Study on Work Engagement

Conduct a quantitative study on work engagement in the context of cow localisation. Define the low literacy levels and develop and test with them. The method used in this study is promising for creating the required knowledge in the context of cow localisation and work engagement. However, due to the limited number of responses, it is recommended to use the same method but find better ways to encourage participation. Afterwards, evaluate the levels of work engagement on a farm in the context of cow localisation to determine more accurate, averaged values.

2. Full-Scale Testing

As recommended in the roadmap and limitations, a full-scale test should be conducted. This test has two goals: testing the technology on a large scale with more than one cow to locate simultaneously, and evaluating the user interface for its intuitiveness. Observing the behaviour of workers during the cow localisation task can achieve this.

3. Automated Cow Selection

The preparation part of cow localisation takes a lot of time. Farmer interviews revealed that the choice to select a cow is based entirely on numerical thresholds. To improve efficiency, it is recommended that the system automatically selects cows based on adjustable thresholds set by the farmer. Additionally, the system should run 24/7, adding cows to the list as needed, rather than the farmer adding cows only once per day. This approach allows cows to be found and treated earlier. A summary of the list of cows to locate should be provided to the farmer for a good overview of farm operations. Furthermore, a shorter list of cows with uncertain conditions should be generated, requiring the farmer's attention once per day. This list should be significantly shorter than the current list, reducing the time spent on tasks that can largely be automated.

7.4 Reflection

The initial design problem was developed in collaboration with Agis to create a graduation opportunity for me. However, this meant that the validity and magnitude of the problem first had to be evaluated with farmers. Fortunately, cow localisation proved to be a significant issue, making a new and improved solution already highly desirable for farmers.

The project was strategically divided into two main areas: the technological side, tasked with developing the proof of concept, and the user side, focused on creating a seamless connection between users and the technology. This approach allowed for a comprehensive exploration of both aspects, identifying and addressing knowledge gaps from existing literature along the way. I am glad that I quickly split the project into these aspects to ensure the development of a solution that is not only technology-driven, as that is my strength. I believe that I have grown in developing from a user perspective, which has significantly strengthened the overall cow localisation solution. Now, the solution not only "just works," but it works in the way that users prefer.

However, throughout this project, my main focus has still been on developing a technological proof of concept, specifically the navigation phase within the broader context of cow localisation. A considerable amount of time was spent programming the smartphone application to display visually appealing elements, such as the arrow visualisation. In hindsight, I believe I sometimes devoted more time to these aspects than was necessary, which limited the time available for other, more critical tasks.

Additionally, conducting the study on work engagement was challenging due to the low response rate from farm workers. I later learned that the literacy levels of many farm workers were so low that even a seemingly simple questionnaire was too difficult for them to complete. Despite this, I believe valuable insights were still gathered from the study. However, I would have preferred to have significantly more responses to enhance the validity of the study.

Furthermore, due to the complexity of the technology and the lack of participants, the entire localisation solution could not be tested on a full scale. To achieve this, a number of new sensors would need to be created, and the entire system would have to be developed from both an algorithmic standpoint and a user interface perspective. This was beyond the scope of the project, but it also means that a comprehensive user test is lacking, which is certainly necessary.

This project has been an invaluable learning experience. It challenged me to step out of my comfort zone and consider user-centric design principles, which I believe have significantly enhanced the final solution. While there were difficulties, such as the usual struggles during programming and prototyping, and the technical limitations of the project scope, I am proud of the progress made and the insights gained. Moving forward, I am confident that this project has laid a solid foundation for further development and optimisation of the cow localisation solution.

Looking beyond the immediate application of cow localisation, there are numerous scenarios where knowing the locations of cows is essential. One such application is virtual fencing, where cows are kept within virtual boundaries, requiring the system to continuously track their locations. Additionally, climate control in barns is becoming increasingly important. The sensors can monitor the condition of individual cows as well as groups, enabling the creation of maps that show the states of cows in specific locations. For instance, a temperature map of the barn could help identify areas that require more or less heat, thereby optimising climate control in specific areas.

Reflecting on this experience, I am very grateful for the opportunity provided by Agis. As the first Industrial Design Engineer to work at this company, it was initially challenging to find my place. However, over time, my strengths became apparent, and I found my position within the company, allowing me to leverage my skills to their full potential. There was also a wealth of knowledge within the team from which I could learn. Lastly, I would like to thank my colleagues at the Agis Innovation Centre and CowManager for their support, which enabled me to develop and design a solution that has excited the entire company.

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Appendices

A. Market Analysis
B. Technology Comparison
C. Channel Sounding vs Time-of-Flight
D. Stakeholder Analysis
E. Work Engagement Study
F. Vision Development
G. Data and System Flowchart
H. Plan of Requirements
I. Original Project Brief

A. Market Analysis

The table below displays all found data and parameters on competitors and companies providing localisation solutions for other markets.

Company	Localisation system	Accuracy	Scalability	Cost	Error rate	Speed of use	Location refresh rate	Batterylife	Installation time	User experience	Beacons	Notes	Source
Cowmanager	Sortgate + signal strength	0.5m-400m	H	L	L	M	0.3 sec	<10 years	L	L	No	Find direction and walk towards it, receiving higher signal strength	CowManager
Smartbow	UWB Trilateration	0.5m-10m	H	H	M	M	6 sec	<2 years	H	H	Yes	Check location on live map, write it down and blindly walk towards location	Smartbow
Nedap	RFID + UWB Trilateration + GPS + cameras with computer vision	0.5m-50m	H	H	L	M	5 sec	<10 years	H	H	Yes	Differences for long and short range localisation systems. Combined to create position estimation	Nedap
IBO	UWB Trilateration	0.5m-10m	H	H	M	H	seconds	<4 years	H	H	Yes	Location live on map	Ibo
GEA	UWB Trilateration	0.5m-10m	H	H	M	H	1 sec	<4 years	H	H	Yes	Location on live map	Gea
Digitanimal	GPS	5m outside	H	H	L	M	30 sec	<1 year	L	M	No	Location on live map but slow updates	Digitanimal
DeLaval	UWB Trilateration	0.5m-10m	H	H	M	M	2.2 sec	<10 years	H	M	Yes	Location on live map	DeLaval
CattleEye	Camera computer vision	0m	L	L	L	L	hours	-	L	H	No	Detects when cow walks past camera	CattleEye
DeLaval	Ferrite rod	0m	L	L	L	L	hours	-	L	M	No	Farmer has to almost touch RFID tag to identify	DeLaval
Apple	Bluetooth + UWB	0.1m-inf m	H	M	L	H	2 min (depends on iphones in area)	<1 year	L	H	Yes	Beacons are Iphones, not stationary but nice in use	Apple
Centrak	RFID	3m-10m	H	M	H	M	30 sec	<2 year	H	H	Yes	Estimation live on map	CenTrak
Centrak	Gen2IR + WIFI + BLE + UWB Trilateration	0.5m-10m	H	H	M	H	1.5 sec	<2 year	H	H	Yes	Location live on map	CenTrak
-	GPS	5m outside	H	M	M	H	1 sec	-	L	H	No	Needs outdoor line of sight with satelites (which are the beacons)	Wikipedia
Mapsted	AI + (WIFI + BLE + gyro + map constraints + magno + GPS + predictive motion + accelero + cellular)	1m-5m	H	L	L	H	0.03 sec	-	L	H	No	Uses only mobile phone, using ML and all possible sensors in the phone	Mapsted
Oxts	UWB Trilateration + IMU	0.035m	M	H	L	H	0.05 sec	<80 days	H	H	Yes	Used for single car testing	Oxts
Quuppa	BLE AoA Triangulation	0.1m-10m	H	M	M	M	0.02 sec	<10 years	H	M	Yes	Bluetooth AoA beacons need very precice placement, live location on map	Quuppa
Stanley Healthcare	UltraSound in room discovery	3m-10m	H	M	M	M	variable	<2 years	M	M	No	Uses wifi acces to transmit location found by ultrasoon sensor	FCCID
Sewio	UWB Trilateration	0.5m-10m	H	H	L	H	0.1 sec - 10 sec	< 5 years	H	H	Yes	Location live on map	Sewio
Sick	RFID / visual ID	0m	L	L	L	L	hours	-	L	M	No	Detects when sensor passes through	SICK
Signify	LED guidance	1m-5m	H	M	M	H	seconds	-	M	H	Yes	Lights send signals, picked up by phone camera to determine location live on map	Signify
Totem compass	GNSS and mesh network		H	L	M	H	seconds	72 hours	L	H	N	Creates mesh network to communicate GNSS location	Totem

B. Technology Comparison

The table below shows the technologies that were found from the competitors and from literature. Each technology was evaluated based on the established evaluation criteria.

Output	Algorithm	Technology	Localisation system	Accuracy (m)	Range (m)	Beacons/ sensors	Cost	Battery impact	Note
Timestamp static location	Tag identification	Sortgate	Locate at timestamp + separate in 2 streams	0	0	Local receiver	M	L	Needs very short range between tag and sensor - separates cows in 2 streams/areas
		RFID	Locate at timestamp	0	0		L	L	Needs very short range between tag and sensor
		Ultrasound	Determine if sound can be heard	10	10		L	H	Noise interference
		Visual ID	Scan visual ID -> know location at timestamp	0	5		L	M	Dirty camera - Dirty tags - Needs very short range between tag and sensor
		Computer vision	ID and locate from image	0	5	No	M	H	Dirty camera - New training for every new cow
Live map	Internal movement	IMU	Derive relative location from starting point	1	inf		M	H	Measurement drifts over time
	Tag ranging	GPS	Location live on map / Trilateration possibilities	5	inf		L	H	Outside only - needs line of sight with satellites
		Bluetooth Channel sounding		1	100		L	M	Still under development by Bluetooth SIG
		Signal strength / RSSI / LQI		10	100	Beacons	M	M	Needs precise antenna orientation
		UWB Trilateration		1	50		H	H	Needs precise antenna orientation
		Bluetooth Triangulation		1	10		H	M	Needs precise antenna orientation

The established evaluation criteria were: accuracy, cost, battery lifetime and detection distance (range in the table above). By evaluating these criteria for each technology, a rank was established.

1. Channel Sounding
2. GPS
3. IMU
4. Signal Strength
5. UWB
6. Computer Vision
7. RFID
8. Sortgate
9. Ultra sound
10. Visual ID

Therefore, Channel Sounding was chosen as the technology to test and develop further with.

C. Channel Sounding vs Time-of-Flight

Time of flight distance measuring works by measuring the time it takes for a signal to travel between two devices. As it is known that the signal travels close to the speed of light, it can be determined what the distance is using the formula distance = velocity * time. However, when a medium with a higher density is encountered on the path of the signal, the signal is slowed down as the wavelength of the signal decreases. This means that the signal takes longer to travel between the two devices, resulting in a larger estimated distance.

In practice, the measured time of a signal is altered based on the properties of the measuring device. As the development board uses a microprocessor with a clock frequency up to 96 MHz, it means that every clock cycle takes 1/96*10^6 = 1*10^-8 = 10 nanoseconds. As radio waves travel at the speed of light in a vacuum (299.792.458 m/s) (Nasa, 2011), it means that a signal travels (d = v * t in which v is the speed of light and t is the time it takes the processor to cycle once) 3,12 meters every clock cycle in a perfect vacuum without any mediums in between.

Additionally, time of flight ranging is usually a two way ranging method which means that one device acts as an initiator and the other device acts as a reflector. The initiator sends a signal and starts measuring time. The reflector captures the signal and sends it back to the initiator. The initiator receives the signal and determines the time it took for the signal to return. This eliminates the need for both of the devices to have perfectly synchronised clocks which is hard to accomplish at nanosecond resolution. However, the reflector device is not a perfect mirror and takes time to send the signal back to the initiator, meaning that the signal takes even longer to return due to the processing speed of the reflector. As the environment of a farm has many (metal) obstacles and walls, it also means that signals get reflected in different directions, creating a multipath effect. A multipath occurs when a signal reaches the receiving antenna by multiple paths, resulting in interference (Esa, 2011).

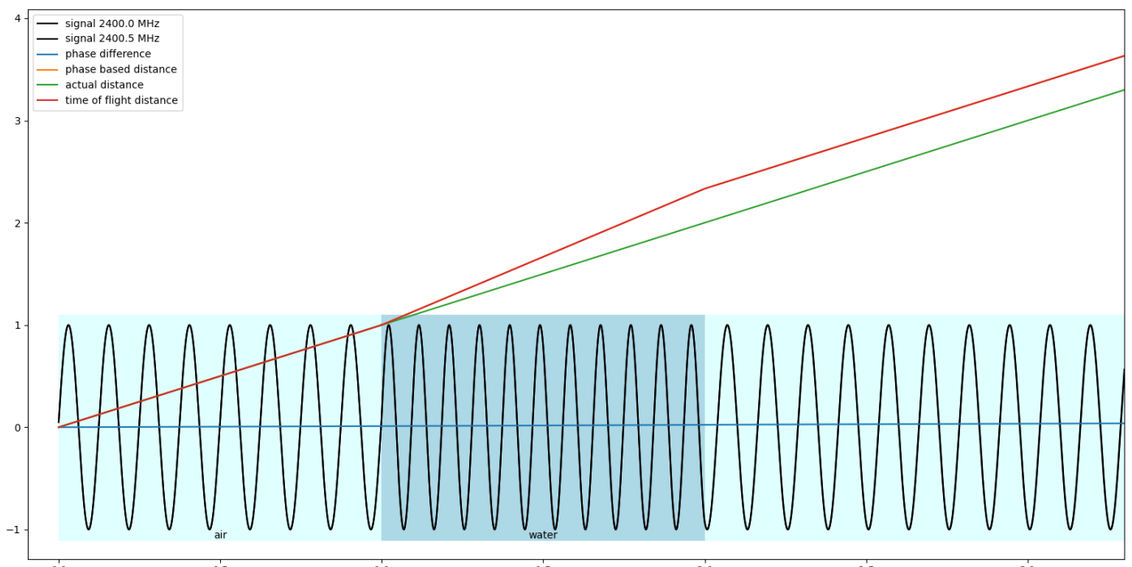
Considering all above, measuring distance using time of flight results in highly inaccurate distances that are greatly influenced by the environment and electronical limitations.

Channel sounding is an upcoming feature in Bluetooth Low Energy that is claimed to estimate distance with an accuracy of 10-30cm (Hillyard et al., 2023). It is a phase based ranging method that estimates distance between two devices by measuring phase difference between two signals between the two devices (Ólafsdóttir et al., 2017). The distance of a one way ranging method can be calculated by:

$$d = c / 2\pi * \Delta\Theta / \Delta f$$

In which c is the speed of light in m/s, $\Delta\Theta$ is the phase difference between the two signals at the receiving end and Δf is the difference in frequency of the two signals.

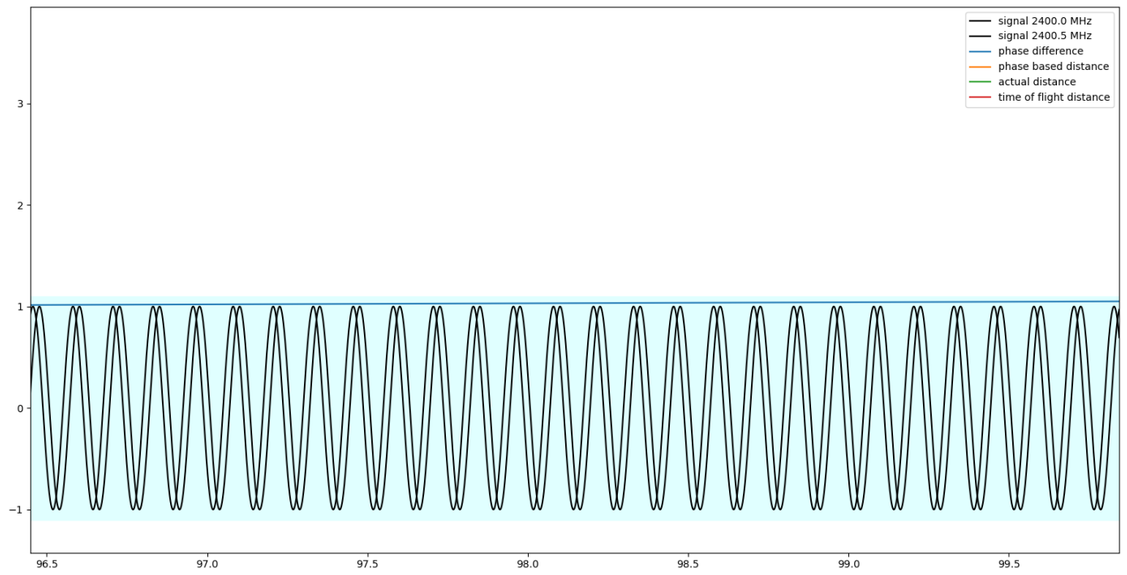
Phase based ranging also works as a two way ranging system. In this case the two devices act as an initiator and a reflector just like in the time of flight system.



The initiator sends a signal, knowing its frequency. The reflector uses its oscillator to match the incoming frequency and phase to perfectly reflect the signal back to the initiator. The initiator receives the signal back and measures the incoming phase of the signal. The initiator then sends a second signal with a slightly different frequency and measures the returned phase again. The formula as described above works the same, however the estimated distance is the distance of the whole trip, which is twice the to be determined distance.
However, just like with time of flight, the distance estimation of channel sounding is influenced by the environment if the signal has to pass through different mediums with higher densities. As discussed, the velocity of a signal decreases when it passes through a medium with a higher density. Since the frequency of a signal stays the same due to the transmitter, it means that the wavelength of a signal can decrease, resulting in a decrease in the speed of a signal through a medium. Due to the shorter wavelength, the phase difference between two signals increases faster than in a medium with a lower density. This means that the estimated distance increases when a signal passes through objects. The figures show how signals with slightly different frequencies can be used to determine range by measuring the phase difference between the two signals.

At a larger distance it become clear that the slight difference in the two frequencies create a increasing phase difference between the two signals.

However, channel sounding is known to handle multipaths well (Hillyard et al., 2023). This is achieved by sending signals with a lot of different frequencies that balance each other out, resolving ambiguities, and thus the presence of multipaths. Additionally, the devices can very accurately measure the phase of a signal. Phase(difference) is a number between 0 and 2pi (or 0 and 360 degrees). However the frequency of 2.4GHz is very fast. This means that every single wave of this frequency takes 0.4 nanoseconds. As the clock takes 10 nanoseconds to cycle, it is not near fast enough to keep up with this frequency. However, the frequency can be modulated down to MHz frequency without losing the phase. With a downsized frequency to 0.5 MHz, a signal takes 2500 nanoseconds to cycle. This means that a signal can be chopped into 250 parts. This results in a measurable phase resolution of 0.008 pi (or 1.44 degrees). Filling this in the formula as described above with a frequency difference of 4 MHz, we get an accuracy of 0.29 meters. This is 10 times more accurate than using the time of flight solution.



Power consumption

Data on the power consumption was found to compare Channel Sounding with UWB (Time-of-Flight). The data is as follows:

Technology	Phase	Time (ms)	Current
Channel Sounding	Sleep	71.80	4.16 uA
	Measurement	27.60	4.74 mA
Time of Flight	Sleep	89.89	24 uA
	Measurement	10.10	26.03 mA

(Sukumar, 2023)

In a timespan of 100ms, it means that Channel Sounding consumes 1.31 mA on average, while UWB using Time of Flight consumes 2.68 mA on average.

It can be concluded that CS consumes less than half of the energy than UWB. Additionally, the idle power consumption and the peak power is lower with CS. High peak power can damage batteries, reducing their lifetime significantly.

RSSI distance

RSSI is known to be used in distance measurements. To convert RSSI to distance, it first has to be calibrated by measuring the RSSI value at 1 metre. Afterwards, the following formula can be used to estimate the distance from RSSI:

d = 10^((RSSI_calibrated - RSSI) / 10n)

In which n is a constant between 2 and 4 that also has to be calibrated.

D. Stakeholder Analysis

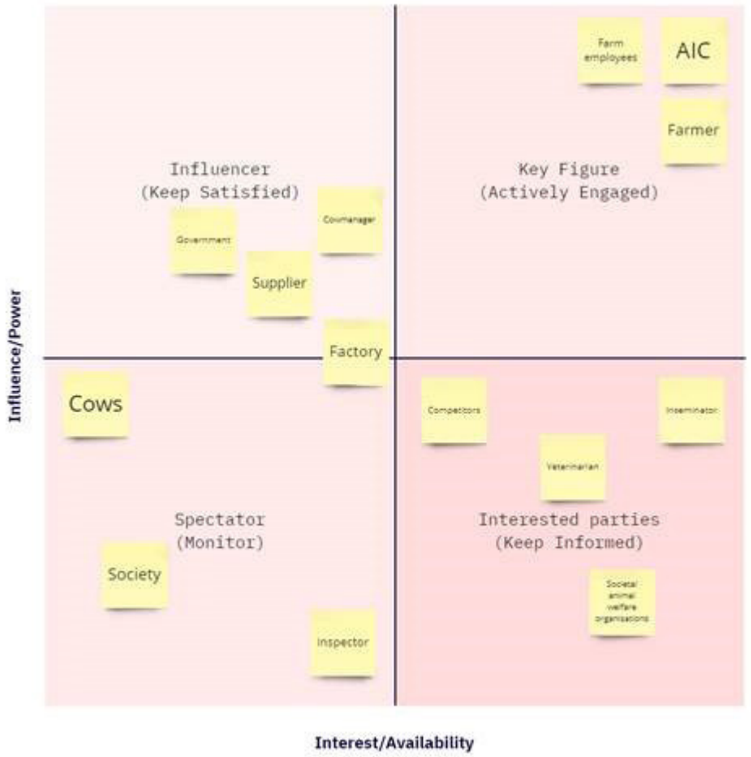
The stakeholders for this project were defined as followed:

1. Agis Innovation Centre
2. CowManager
3. Factory
4. Supplier
5. Government
6. Competitors
7. Farmers who are customers of CowManager
8. Farmers who are potentially customers of CowManager
9. Farm employees
10. Inseminator
11. Veterinarian
12. Inspector
13. Societal animal welfare organizations
14. Society
15. Cows

These stakeholders can be categorised as followed:

Stakeholders	Primary (Has direct influence on the project)	Secundary (Has indirect influence on the project)
Internal stakeholders (Involved in the project from within the company)	Agis Innovation centre	CowManager
External stakeholders (Involved in the project from outside the company)	Supplier Farmers Farm employees	Factory Cows
Interface stakeholders (Not involved in the project but has an interest in the project)	Government Competitors Inseminator Veterinarian Inspector	Societal animal welfare organisations Society

Placing the stakeholders in a grid to show their influence and interest results in the following grid:



E. Work Engagement Study

Working on a farm

6 Responses | 06:51 Average time to complete | Active Status

1. In which country do you work?

USA	1
Germany	3
New Zealand	1
The Netherlands	1
Other	0



2. How long have you been working at this company?

< 1 year	2
1 - 3 years	0
3 - 5 years	1
5 - 10 years	1
> 10 years	2



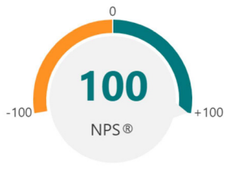
3. How long have you been working at farms in total?

< 1 year	0
1 - 3 years	1
3 - 5 years	0
5 - 10 years	1
> 10 years	4



4. How much do you like farm animals?

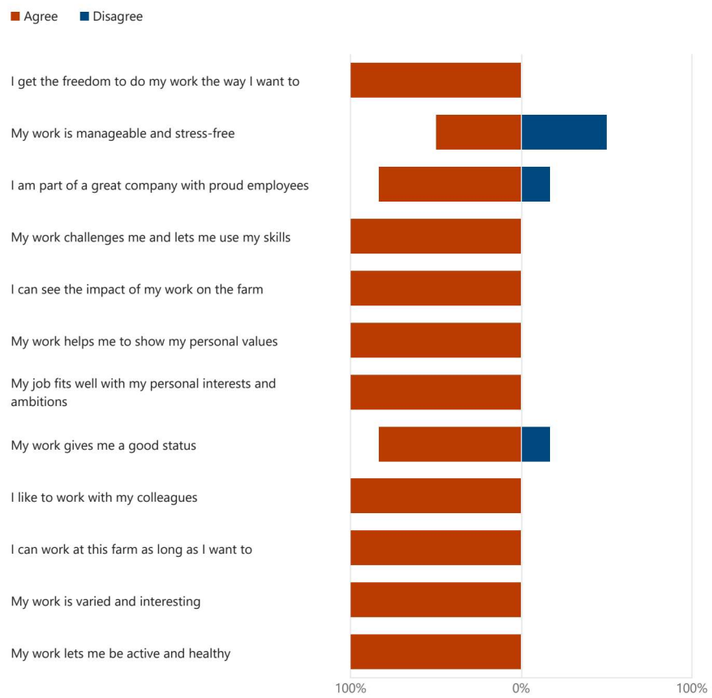
Promoters	6
Passives	0
Detractors	0



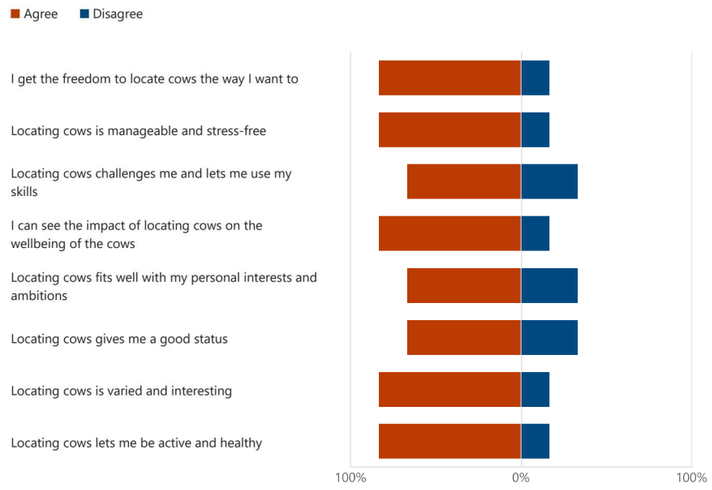
5. Do you use Find my Cow?

Yes	6
No	0





7. Statements of locating cows



F. Vision Development

To better understand the design direction of this project, a vision is created. The vision is created using the VIP method from Hekkert and Van Dijk (2017). This method consists of two phases; deconstructing the current product and designing a new product.

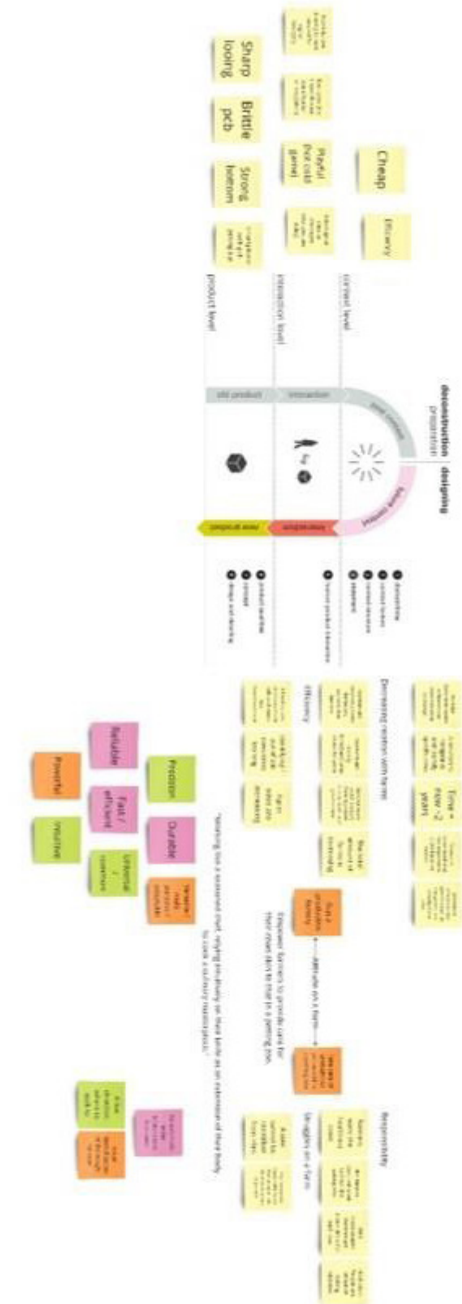
The deconstructing phase shows that the current product is a result of using features that were already implemented in the ear sensor while creating a product that is capable of much more than it is used for currently. The main touchpoint is a smartphone with a big external antenna. The phone is only used as a display to show the signal strength of a sensor, while there are many more unused features in a phone. The result is a cheap product that tries to be as efficient as possible. However, the interaction with the product is non intuitive and distracting, while the product itself looks sharp, brittle and unfinished.

From the interaction phase of the VIP method, it became clear that there are two contradicting quality clusters that are wished for on a farm. On one side, the farmer wants to run the farm like a productive factory. On the other side, the farmer wants to take care of their animals like you would in a petting zoo. These quality clusters are each opposites on the dimension called "Attitude on a farm".

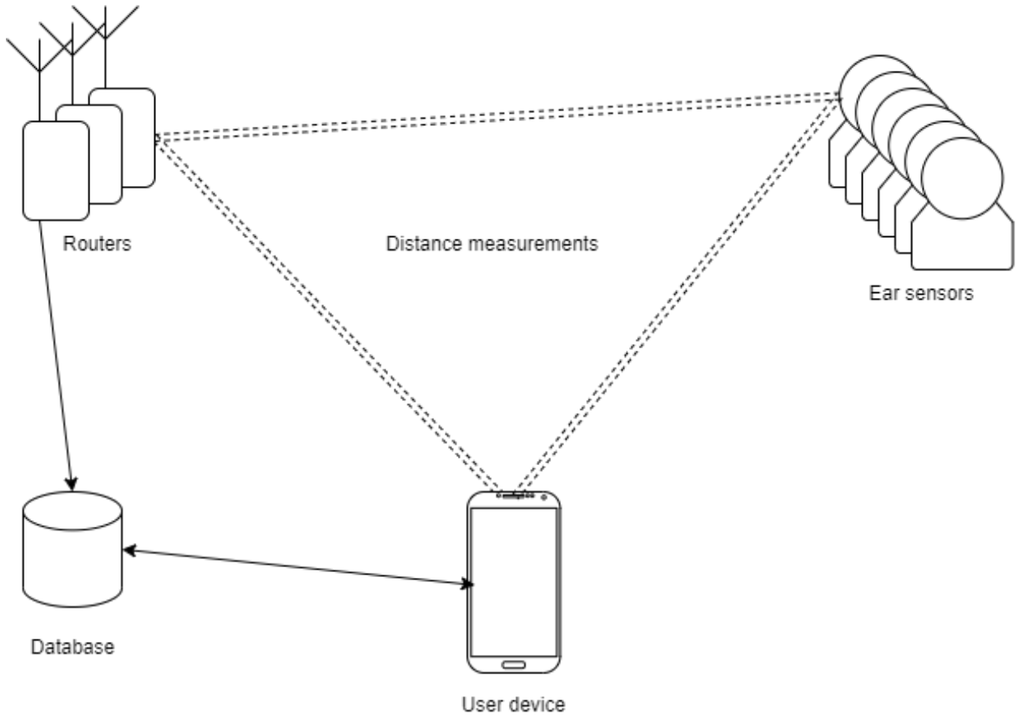
As a next step, a side of the dimension has to be chosen and a statement has to be made. As the world is moving towards a more sustainable and ethical way of treating farm animals, it is a logical step to steer away from running a farm like a productive factory. Therefore, the design statement for this project is:

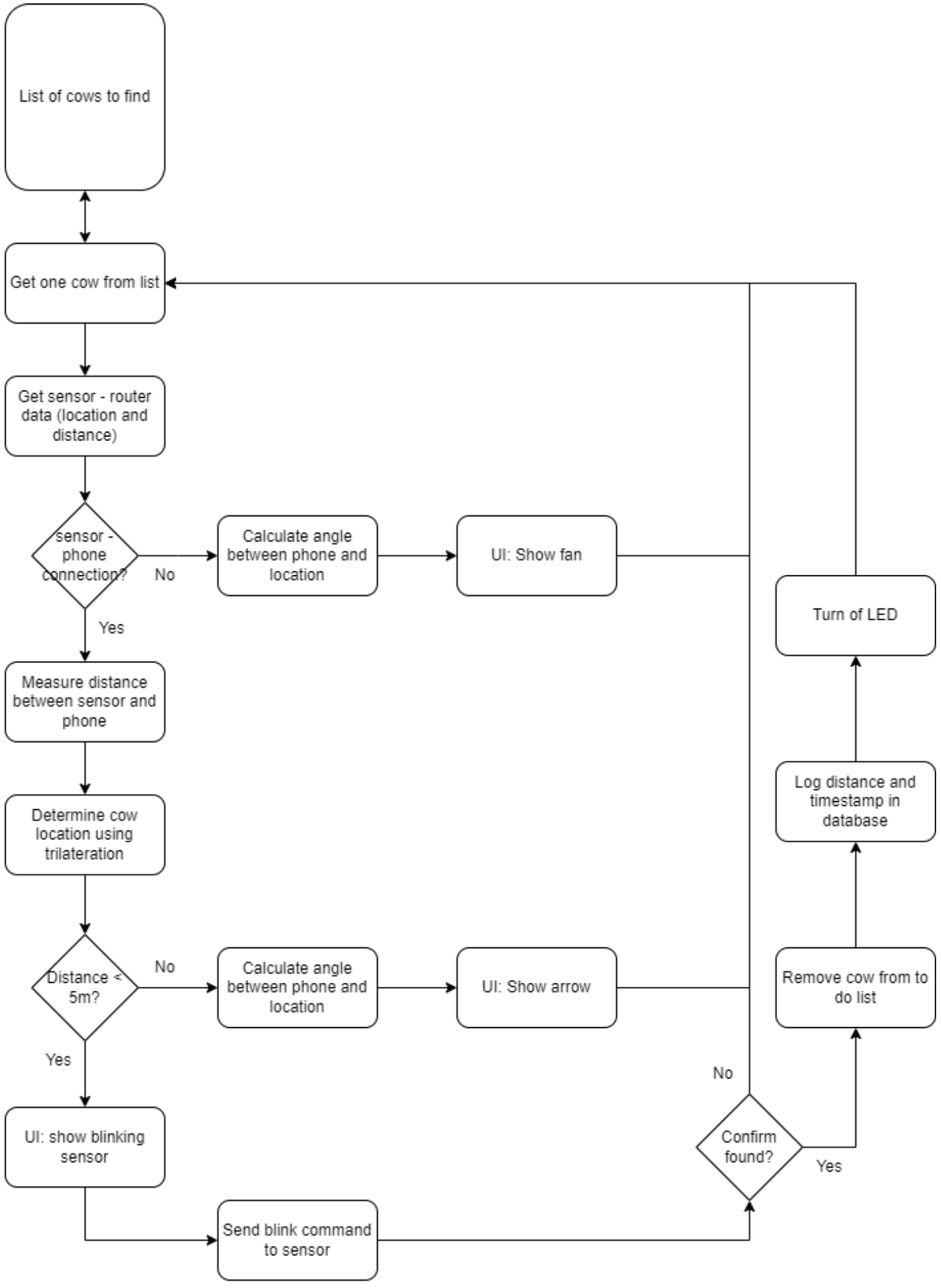
"Empower farmers to provide care for their cows akin to that in a petting zoo" in the context of locating cows.

An analogy that gives a better feeling to this vision is "Working like a seasoned chef, relying on their knife as an extension of their body to cook a culinary masterpiece". Product qualities for this analogy, and for a cow localisation solution are; precision, durable, versatile/multipurpose, reliable, fast/efficient, universal/common, powerful and intuitive.



G. Data and System Flowchart





H. Plan of Requirements

The plan of requirements was updated throughout the entire project. At last the requirements were validated as shown in the last column of the table.

#	Requirement	Source	Validated in section
1	**Performance**		
1.1	Solution must be able to locate cows faster than the current solution	Agis	4.7
1.2	Solution must be able to locate cows with an accuracy of at least 5 metres	Farmer interview	5.1.4
1.3	Solution must be able to guide a user to a cow from at least 100 metres away	Farmer interview	5.1.4
1.4	Solution must aid in identifying cows from 5 metres away	Farmer interview	5.2.2
1.5	Solution must be able to be dropped from at least 1.5 metres high	Farmer interview	Phone dependent
2	**Environment**		
2.1	Solution must work in -40 - 80 degrees Celsius	Agis	Phone dependent
2.2	Solution must work in rain and manure environments	Agis	Phone dependent
3	**Life in Service**		
3.1	Solution must not lower the battery life by more than 10%	Agis	2.6.3
3.2	Solution must be able to locate at least 80 cows per day	Farmer interviews	6.5
4	**Maintenance**		
4.1	Simple maintenance should be doable by the farmer	Agis	6.5
5	**Target Product Cost**		
5.1	production cost may not be higher than 20%	Agis	6.4
6	**Transport Before and During Use**		
6.1	Solution must be integrated with the existing infrastructure	Agis	5.1.2
6.2	Solution must provide wearable touchpoints	Farmer interview	4.7.3
7	**Quantity**		
7.1	Sensors and routers with localisation solution must be easily produced by the factory	Agis	6.4
7.2	Phone attachment board must be developed in small batches	Agis	6.5
8	**Size and Weight**		
8.1	Sensors may not become heavier	Agis	6.5
8.2	The user device must be smaller than the current FMC device	Agis	6.5
9	**Reliability**		
9.1	Solution must communicate the accuracy clearly	Literature	6.2
9.2	Solution may never guide the user to a wrong location	Farmer interview	5.1.4
10	**Installation and Use**		
10.1	Installation may not take longer than currently	Agis	6.5

I. Original Project Brief

Name student Ashraf Morra **Student number** 4,815,823

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Bringing farmers and cows together: Designing a solution to locate specific cows in real-time

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Agis Innovations is a farming innovator that focuses on measuring and predicting health of cows. They have developed an ear sensor (10 year battery life) for cows. It depends on a subscription which functionalities are included: health, fertility and/or nutrition. What makes Agis' ear sensor unique is its placement, resulting in more accurate and earlier health alerts. However, when a health alert occurs, the cow must be treated. Since a cow is hard to control, the farmer has to be brought to the cow. Therefore, the specific cow has to be located after which the farmer has to navigate to it. The bigger the farm (up to 10.000+ cows) the harder this task is. For the efficiency of the farm, the health and wellbeing of the cow, and the quality of its products, it is best to treat, and thus locate/navigate to the cow as soon as possible. Currently, locating cows is either not user friendly, or too expensive. The localization solution should be integrated with the ear sensors without significantly decreasing their battery life.
Key stakeholders are Agis themselves, as localization can be part of the health monitoring service. Then there are the farmers, their workers and veterinarians that want/have to run their farms efficiently while having healthy cows.
Consumers of cow products benefit from healthier cows as they produce higher quality products. Finally, the cows themselves benefit from being located fast as this improves their wellbeing and reduces the need for antibiotics and fertility hormones.

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introduction (continued): space for images



image / figure 1 Ear sensor

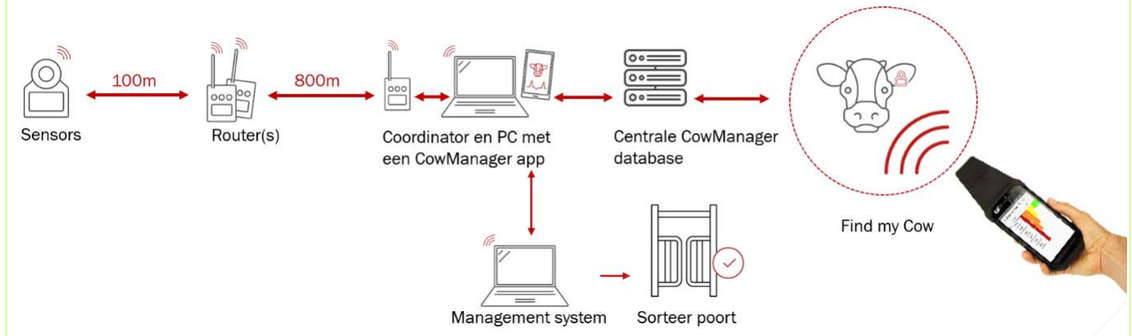


image / figure 2 Current way to locate cows

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The main research question is: How can a localization solution be designed and integrated with the existing ear sensor to optimize user experience and efficiently locate cows, considering the diverse needs and preferences of farmers?
By addressing this research question we can take a step towards a healthier and more ethical treatment of cows on farms. Locating and getting to sick cows faster prevents pain and reduces the need for antibiotics. The use of fertility hormones can be reduced by locating cows in heat within the 10 hour insemination window.
I expect to define the user experience that the localization solution should provide. Using the available technology in the ear sensor, I see an opportunity to integrate a localization solution without major investments.
In the scope of this project I will mainly look at bigger farms (around 5.000 cows) as it is more difficult to find cows efficiently. There are a lot of big farms that I can talk to, however they are mainly located in the US. The farms that I can visit have around 100-400 cows. The scope is limited to a solution that could be on the market in 2 years, as farming innovations move quickly.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design and integrate a smart solution to locate specific cows real time in any type of farm for farmers and their workers that have to physically get to cows as soon as possible.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

During the project I plan to do qualitative research on users (interviews, personas and customer journey maps), competitors and the existing ear sensor to get a deep understanding of the domain. Additionally, I plan to do literature research on state-of-the-art localization/positioning technologies and their uses. These researches will define the project's requirements to serve as a guide and validation aid during the conceptualization and prototyping phase. During the conceptualization phase, I plan on creating as many different ways of locating cows using fast-paced design methods like scamper and "how to .." . From the conceptualization phase, I will select the most promising concepts which will be prototyped and tested. This will be done using rapid prototyping technologies like Arduino's. These prototypes will be tested iteratively on a farm to determine the most promising technologies and concepts which will be combined into the final conceptual solution and a working prototype.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	20 Feb 2024
Mid-term evaluation	8 May 2024
Green light meeting	28 Jun 2024
Graduation ceremony	26 Jul 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

In my future career, I want to work in mechatronics or the IoT sector. Agis is a company that embodies both while rapidly innovating. I have a big passion for wireless technologies and using real-time data. The farming sector is relatively new to using IoT and data. Therefore there is a lot of innovation possible in this sector. This innovation is also required as the sector is changing rapidly due to regulations and former innovations.
Besides that, I want to improve the user experience on farms by providing an efficient way of working. Therefore, this project fits perfectly with my interests. I want to show my IoT and system design skills by developing physical working prototypes, by using Arduino's for example. But I also want to develop my skills in user experience by developing customer journeys and researching the touchpoints of a system. These touchpoints combine the technical solution with the to be designed user experience.
With this project, I want to prove for my future career that I am able to develop a user experience that is achieved by technology. As a personal ambition, I want to develop my competencies in rapid prototyping. I want to test a lot by prototyping instead of doing too much desk research as many wireless technologies act differently in barns.