Literature Review
Group 25

Prepared by:
Ntsako Phiri
Praise Samuel
Mukundi Mangena

Prepared for:
EEE4113F
Department of Electrical Engineering
University of Cape Town

May 25, 2025

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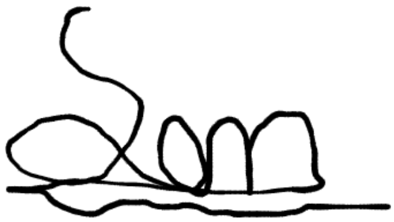

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Chapter 1

Introduction

Project Github : https://github.com/mukundimangena/EEE4113f

African penguins will be extinct by 2035 [1] .

Obviously that is only if no one cares enough to take the mantle into saving these precious species that you would rarely expect to be found in Africa. Their extinction is largely being caused by the depletion of their foodstocks such as sardines and anchovies to the large scale fishing industry around the southern African hemisphere.

Climate Change has also pushed the fish stocks from the shore into the deeper ocean forcing parents to travel longer leaving their young exposed to the elements.Urbanization has also played a crucial role in the depletion of the penguin colonies as it forces compression of the penguin colonies with predator territories.

In the sorrowful new of the plummeting of the numbers of these birds guardian angels Cape Nature , Bird-life South Africa and SANCOOB have joined hands into putting efforts to save this precious bird. This give hope into the potential future of the bird. These groups have largely invested in initiatives to find innovative solutions to reverse the extinction of these birds.

Christina Hagen, one of the scientists at these conservation firms has been working with the African penguin and looking at potential solutions to protect this bird. The shift in the fish stockpiles have caused migration of the penguins into areas that have a higher chance of survivability. However whenever the penguins move to a new area and form a colony they are always faced with a silent killer that can wipe a new colony in a single day. This is the notorious and most relentless hunter , the Honey Badger .It is one animal that can hunt the most venomous for breakfast. These a relentless predators are a massive challenge as they are incredibly smart and can crack any puzzle you put in front of them as long as there is food on the other side. Christina Hagen and her team figured out that they could help the penguins to migrate to areas with better food supply and hopefully they could grow their numbers to sustainability. They did this by erecting fencing and using their animal knowledge to call the penguins and they did come. however the relentless predator always fond ways to penetrate these perimeters to hunt down this defenseless and flightless bird. Christina and her team have been on a rat race as the hunter continuously breach their perimeters.

Christina and her team reached to us student engineers so we can help them devise a solution to keep these predators out of the perimeters of this colony. The first solution that cam up was an eye for an eye , you kill a penguin we kill a badger. This is however not the way it works we have to find methods to keep the badgers out of the colonies without causing harm or killing these predators. This was the genesis of our problem.

Noting that traditional methods have failed and there are great constraints to the possibility of this task we had to look at innovative ways to keep the badger out of the colony. In this report we explore methods that could be used to keep honey badgers out of the colonies taking into considerations the geographical limitations of salt water environments. In this task our Solution has to detect and Deter the predators causing zero harm to the predators , making sure that the solutions is portable weatherproof , maintenance free and taking into consideration the High caliber regulatory requirements for tackling such a task. After Detecting and deterring we are also looking at creating a user interface so that the conservationists can get the real time monitoring of the deployed systems.

In this report we are promising a solution that will not be about building AI powered scare-crows but creating an intelligent ecosystem guardian that promises 24/7 autonomous protection , real-time threat assessment , non-lethal deterrence and scalable solutions. In the long term we hope this solution will help in the recovery of the population of the african penguins.

Chapter 2

Problem Analysis

The core problem this project aims to address is the **protection of declining African penguin populations from predation, specifically by honey badgers, within their sensitive coastal colony environments.** This challenge requires a solution that is effective, non-harmful to both penguins and predators, and robust enough to operate in demanding geographical and regulatory conditions. The overarching goal is to contribute to wildlife conservation efforts through the application of technology.

2.1 D-School Initiated Activities & Empathy Building

The initial phase of this project, guided by the D-School, focuses on "designing the correct thing" by deeply understanding the problem space and user needs. This involves a structured Design Thinking process:

- **Empathize:** This stage will involve conducting research to develop a comprehensive understanding of the stakeholders, including conservationists, and the specific challenges faced by penguin colonies. This will likely involve direct engagement with these stakeholders to understand their current methods, frustrations, and desired outcomes concerning predator management and penguin safety. Key questions to explore will include "what motivates or discourages users (conservationists)?" and "where do they experience frustration?" with existing solutions or the lack thereof. Ethical considerations when interacting with people, such as clearly stating goals and ensuring anonymity if surveys are used, will be paramount.
- **Define:** Following the empathy phase, all research and observations will be combined to clearly define the users' (conservationists') problems and pinpoint unmet needs. This will involve synthesizing information to highlight opportunities for innovation, identify common pain points, and ultimately formulate a precise problem statement for the project.
- **Ideate:** With a well-defined problem, the team will engage in brainstorming to generate a wide range of creative, hardware-based solutions. This phase encourages "total freedom" where quantity of ideas initially supersedes quality, allowing for the sketching and sharing of many different concepts to address the identified unmet user needs.
- **Prototype:** Selected ideas will be transformed into tangible, tactile representations. These low-fidelity prototypes will allow the team to understand which components of their ideas work and which do not, and to begin weighing the impact versus feasibility of different approaches

through feedback.

- **Test:** Prototypes will be put before stakeholders (e.g., conservationists) for feedback. This iterative process will help verify if the proposed solution meets users' needs and improves their ability to protect the penguin colonies. Testing will be an ongoing activity throughout the implementation phase.

(This section describes the intended D-school process. It will be updated with the specifics of actual team activities as the project progresses.)

2.2 Design Choices and High-Level System Considerations

Based on the initial problem understanding (protecting penguin colonies from honey badgers in saltwater environments), several key design considerations and constraints emerge for the hardware-based solution:

- **Predator Specificity:** The solution must effectively deter honey badgers.
- **Non-Lethal Deterrence:** A critical requirement is that the deterrent mechanism must cause zero harm to the predators (and penguins).
- **Environmental Robustness:** The system must be weatherproof to withstand saltwater environments and durable.
- **Portability:** The solution needs to be portable for ease of deployment and relocation.
- **Low Maintenance:** The system should be designed to be as maintenance-free as possible.
- **Regulatory Compliance:** High-caliber regulatory requirements for wildlife conservation interventions must be met.
- **Real-time Monitoring:** A user interface is required for conservationists to get real-time monitoring of the deployed system.

While specific design concepts will emerge from the D-School's Ideate and Prototype phases, the overarching challenge involves finding an optimal balance between these requirements. For instance, different sensing technologies (e.g., thermal, visual, acoustic) and various non-lethal deterrents (e.g., light-based, sound-based, physical barriers activated on demand) will need to be explored and evaluated.

2.2.1 Rationale for Chosen Design: Approach

The D-School process, particularly the Prototyping and Testing phases, will be crucial in making informed design choices. The final design will be determined by:

- **Effectiveness:** How well does a concept, or a fusion of concepts, meet the primary goal of deterring honey badgers without harm?
- **Feasibility:** Can the concept be realistically implemented given technical constraints, cost, and the project timeline?

- **User Feedback:** How do stakeholders (conservationists) respond to the proposed solutions? Does it meet their operational needs and address their pain points?
- **Constraint Adherence:** Does the design satisfy all specified constraints (weatherproof, portable, low maintenance, regulatory)?

It is likely that the final solution will be an **iterative refinement of an initial concept or a fusion of the best aspects of multiple ideas** generated during brainstorming. For example, a highly effective but complex sensing mechanism might be combined with a simpler, robust deterrent if this combination offers the best overall performance and reliability. The literature review conducted after the problem statement definition will also heavily influence these choices by identifying existing technologies and their suitability.

2.2.2 Brief Description of Subsystems

The proposed hardware-based solution will be broken down into three primary individual subsystems, with each team member taking responsibility for one:

- **Sensing Subsystem:** This subsystem will be responsible for **detecting the presence of honey badgers** approaching or within the penguin colony perimeter, operating reliably in the challenging coastal environment.
- **Deterring Subsystem:** Upon receiving a trigger from the sensing subsystem, this subsystem will **activate a non-lethal deterrent mechanism** designed to effectively and harmlessly repel honey badgers from the protected area.
- **User Interface (UI) & Monitoring Subsystem:** This subsystem will enable **conservationists to monitor the system's status in real-time, receive alerts, and potentially configure system parameters**, ensuring they have visibility and control over the deployed protection measures.

Chapter 3

Literature Review

3.1 Introduction

Wildlife conflicts involving honey badgers(Mellivora capensis) have been a persistent issue when attempting to monitor and protect penguins. Predation is a significant threat to penguin populations, particularly in South African colonies where recent shifts in fish stocks have led to the establishment of new, more vulnerable colonies. Deterring predators successfully in a non-harmful way to predators and non-disruptive to non-target species has been sought after due to the way predators quickly become habituated when there is no non-lethal consequential deterrent used. This habituation makes the creation of sustainable, long-term solutions extremely difficult to mitigate in a non-harmful manner. While chemical deterrents, water jets, and electric fencing have shown limited success, acoustic deterrents are marketed as non-lethal alternatives but lack comprehensive evidence of efficacy. This review further provides valuable insights into developing more effective and sustainable systems for safeguarding penguin colonies by looking at numerous articles that explore the effectiveness of various repelling devices, alone and combined with other systems, in deterring predators(particularly badger activity) and protecting prey.

3.2 Existing Deterrent Systems

In-depth research on animal deterrent systems is discussed in this review of the literature, with a focus on different methods that have been used in order to protect prey or agriculture fields. This diverse range of studies aims to provide a comprehensive understanding of various non-lethal and lethal deterrent options to repel animals, along with the limitations associated with each approach.

3.2.1 Visual Repellents

Visual repellents include devices such as motion lights, LEDs, and strobe lights. These deterrents rely on visual stimuli in order to scare or blind animals. Mason [2] raised a critical point that visual repellents often have short-lived effects, as animals quickly become accustomed to the stimuli. These visual repellents tend to be more effective against birds than mammals. For example, strobe lights may deter coyotes but are ineffective against deers. Their effectiveness is strengthened when combined with other deterrents, such as acoustic devices or chemical repellents [1].

Effects of various light sources on nocturnal mammals

Nocturnal animals are notoriously sensitive to various types of light which can assist in mitigating the predator issue. One of the deterrents that Johnson [3] used was a light deterrent, which was used to reduce honey badger predation on beehives. The light deterrents were designed to exploit the honey badgers' aversion to well-lit areas, as [3] indicated that honey badgers avoided raiding hives in open, lit fields.

Motion Light Deterrents

[3] demonstrated how the light deterrents were highly effective in preventing honey badgers from accessing the hives, since none of the hives protected by light deterrents were successfully raided by honey badgers. These lights had 400 lumens and were attached to the hive posts at a height of 1.5 meters from the ground. The lights were triggered by motion within a 10-foot(3.048m) detection range and a 120° motion angle. The lights automatically turned off after 30 seconds if there was no further motion detected. The light deterrents were shown to have a '100% success rate' in preventing honey badger attacks, meaning that none of the hives protected by the light deterrents were damaged or disappeared, since light was a strong deterrent.

[3] stated light deterrents impacted the honey badgers to exhibit behaviors such as honey 'looking, scratching, and vocalizing' when they approached the bee hives. Although the honey badgers behaved in a defensive manner, they were not able to successfully reach the hives, as they were caught on camera traps that they were deterred by the lights. The light deterrents were particularly effective when properly installed, as improperly installed deterrents (in other conditions) led to longer visitation durations and more damage done by the badgers. Although the specific power consumption of the motion light deterrents used in the study is not explicitly mentioned in the document, this is a cost-effective light deterrent method which was highly effective in preventing honey badger attacks and reducing hive absconding rates.

Light Emitting Diode(LED) Deterrents

Lamani [4] integrated LED lights into the automatic solar PV powered and wind operated deterrent system developed to protect agricultural fields from birds and animals. Since reflectors were used to reflect natural light during the day, the LED deterrent was primarily used during the night to scare away animals, primarily birds, by creating a flashing light effect which discouraged the animals, thus preventing them from entering the fields. The LED light used was powered by the energy stored in a 12V, 9Ah battery, which was charged by a 36W solar panel during the day. The LED light was activated during the night using the stored energy of the battery. Battery testing revealed that the battery could be fully charged in 8 hours during the day, ensuring that the LED light would have enough power to operate throughout the night for 16 hours, which is energy efficient for deterring nocturnal animals. The field testing of the LED deterrent was conducted in a sorghum field over 12 days. The results showed that the LED deterrent, in combination with other deterrent methods, significantly reduced the presence of birds and animals in the field, especially during the night.

The use of light amplification by stimulated emission of radiation(laser) sensors has been an effective solution for detecting and repelling wild animals from livestock areas. [5] depicted how laser beams can successfully deter wildlife especially when integrated into a smart system that also uses acoustic and multicoloured LED deterrents. The multicoloured LEDs would deter the animals by flashing lights when the laser detected further movement in specific regions. These multicoloured were designed to distract and scare the animals, making them less likely to continue their approach towards the restricted areas, which was found to work extremely well in real-world conditions, effectively repelling animals such as elephants[5].

Strobe Lights

(Linhart et al, 1992) [6] detailed the use of strobe lights in an integrated electronic frightening device which combined strobe lights and warbling sirens significantly reduced coyote predation on sheep, with up to a 92.6% lamb losses reduction in certain areas.

The flashing strobe lights are generally stronger lights, coupled with the sirens, created an irregular and unpredictable stimulus that coyotes found difficult to habituate to, making them hesitant to approach the livestock area. While the strobe lights were effective on coyotes, another critical point was highlighted by [6]: the flashing lights' effect on other predators, specifically mountain lions, may not impact them as 'activity patterns of lions were only minimally affected by the devices'. Furthermore, the cost of individual strobe lights is an issue coupled with limited research available of strobe lights effects on badgers.

3.2.2 Water Jet Deterrents

Water jet devices use motion sensors to detect animal presence and then spray a jet of water, typically lasting 4 seconds, over a 90-degree arc. The water jet is intended to startle and physically deter animals from the area [7]. While water jets can reduce bait consumption, their deterrent effect is often mild as it is not heavily consequential towards the predators. Badgers are very persistent and may continue to visit the area despite the presence of the water jet, especially if the bait is highly desirable [7]. Water jets require a proper setup that has a reliable water supply, which can be challenging in rural or remote areas [7]. Water jets have been shown to reduce bait consumption by badgers, but the effect is relatively small compared to other deterrents (a 12% reduction compared to control plots). They do not significantly reduce overall animal activity in the area, suggesting that while they may deter feeding, they do not repel animals from the area entirely[7].

3.2.3 Chemical Repellents

Chemical repellents include substances that cause sensory irritation, mimic semi-chemicals (e.g., predator urine), or induce gastrointestinal malaise. These repellents are often applied directly to food sources or vegetation to deter consumption [2]. Chemical repellents are generally more effective against herbivores than carnivores or omnivores. For example, capsaicin-based repellents are effective against deer but not against carnivores like coyotes [2].Animals may become habituated to chemical repellents over time, especially if alternative food sources are scarce [2]. Some chemical repellents may have unintended effects on non-target species or humans, limiting their applicability in certain environments [2]. Chemical repellents can be effective in reducing consumption of treated food, but they rarely cause animals to abandon an area entirely. Their effectiveness is highly dependent on the availability of alternative food sources and the specific sensory sensitivities of the target species [2].

[8] in his research identified the use of Conditioned Taste Aversion(CTA) as a deterrent.CTA uses a non lethal poison aimed at causing illness and causes an intense aversion to the food flavor ,[8].He noted that CTA may successfully be effective at deterring eating behaviors but may not be effective at avoiding killing as the predators can find other positions on the target animal to kill.They mentioned that attacking and killing behaviors can continue even after an animal has successfully been conditioned using CTA. [8] Also discusses using scent marking techniques by using artificial odors to mark territories. This works for territorial animals such as wolves and coyotes , and by placing these scents on fencing, it could potentially reduce intrusions [8]. He however further argues that the effectiveness of artificial markers repelling predators is yet to be established.[8] highlights the issue of habituation of predators to the non lethal methodologies used to repel predators from their prey. He also notes that the motivation of lack of food pushes the animals to find ways to evade measure or customize to them. [8] discuses the use of animal armor.In this case a sheep collar was developed that a contained a non lethal dose of chemicals and this method was in effective for repelling coyotes.This study was done by [9]. They placed a variety of chemicals in collars of sheep and kid goats with collars containing chemical such as sodium cyanide which caused violent reactions in the coyotes however this didn't make the coyotes refrain from further attacks.[9] found out that 'coyotes that received a sublethal dose of chemical did not learn to avoid collars'.The coyotes did not learn to avoid the collar and those that did learn to avoid the collars still managed to kill the livestock by either throat or rear end attacks.[9] found out that, 'even strong repellents did not produce prey avoidance'.

[10] did an experiment to test the efficacy of chemical repellents on artificial tortoise nests created for testing. They placed quail eggs in an 6 to 8 cm hole in the ground together with Schwegler© a commercial grade chemical that is said to repel carnivores.The results showed a predation on the control nests on the first night but on the test site the depredation started taking place after the fourth day. [10] concludes that the chemicals used in this test are ineffective in protecting the simulated tortoise nest from predation.They give a reason of possibility of a ,'progressive loss of the repellents effectiveness as its concentration is reduced in the air over time[10].'

The studies above stack up evidence to the possibility of non lethal does of chemical repellents being ineffective at repelling predators from their prey.As [2] states, the effectiveness of non lethal chemical repellents are mostly useful to repel herbivores and not carnivores or omnivores. This is because of their gut system that is able to neutralize certain poisons.

3.2.4 Electric Fencing

Barriers have been developed for protection of humans and domestic animals since the medieval times this includes , The great wall of China , moats on medieval European castles[11].The advancement in technology has brought a more advanced method of barrier protection with electric fencing.

Electric fences deliver a mild electric shock to animals that come into contact with them. They are often used to exclude animals from specific areas, such as crop fields or farm buildings [2].The installation and maintenance of electric fences can be expensive, particularly for large areas such as penguin beaches. [2] note that Electric fences require regular maintenance to ensure they remain effective, which can be labor-intensive . Electric fencing has been shown to be effective in deterring animals such as deer and coyotes from entering protected areas. However, its effectiveness depends on proper installation and maintenance, and it may not be practical for all situations, particularly in urban environments [2].

[11] in his 1982 paper did some research on the effectiveness of electric fencing on sheep farms in Texas.They highlight the high expenses that are associated wit constructing an effective fencing system on a large scale farm.Though the very high cost of initial build they found out that after it is an effective method to protect their herd s against predation.[11] also highlights in his paper the effectiveness of different types of designs that will deter different sizes of predators from the location of the flock. Irregardless of the strong fencing boundary, their research was also not void of challenges. The fencing in their area of study was also destroyed by whitetail deer's that are not the target animal but opened up vulnerabilities to the fencing that opens up space for the predators.[11] also tested the effectiveness of low and high voltage electric fences. their study does not extensively show the effectiveness of the low voltage fencing however the study highlights that high voltage fencing has a high success rate. This is due to the very thick fur coating of the animals that will only receive a shock if the voltage they interacting with is high enough to penetrate its skin.They also noted the effectiveness of high voltage option being easier to work with in long fences.

In 1997 the Wildlife Damage Center in Sweden were trying to find the most effective electric fencing design.[12] wrote an article comparing four different types of fencing.This was after they had realized that the available fencing designs were effective on deterring larger predators from livestock and beehives but not against the lynx cat which could either slide underneath the fencing or jump over the fencing. [12] tested a lynx in the fencing enclosure to see which would be more effective to protect against it predating on livestock.[12] found that the sheep-net design was successful at keeping the lynx in the enclosure.The figure below shows the design that worked. [12] notes that this design is effective

Figure 3.1: Sheep-net design to enclose against the lynx

for protection against smaller and larger predators provided the fence is clear of vegetation.Clearing of vegetation is also noted by [11].

[13] designed a fault finding device in Sri-lanka .This was in in response to the 'time consuming works and additional workload to wildlife rangers to find faults on the protective electric fence',[13].This device was designed to be placed at 250m intervals on the electric fence.I contained a fault finding mechanism coupled with a GSM sim module that would send a message of the point of location to the rangers.The device is solar powered and checks for voltage on the fence collecting a number the number of pulses it gets. If it gets more than 30 pulses [13] it means there is a current flow but if there isn't then it checks for the voltage and if it is lower than 3000V then it would be too low and it send the rangers a message highlighting a possible failure and due to the geo-location capabilities of GSM

the rangers can go to the stretch that has the GSM module and check for possible shorts or faults.[14] in his research on a development of a fault finder he lists capabilities of good fault finder as ability to detect pulses , measure peak fence voltage , determine voltage polarity , determine peak current , determine peak current polarity.Fault detection technology could be also used to identify location of any intruders in a fenced area and trigger other protective systems to offer directed protective measure on the area of intrusion. solar powered fencing

Electric fencing is a viable non-lethal method for predator prevention.Electric fencing has,'effectively excluded or inhibited movements of coyotes, white-tailed deer, black bears , elk , **badgers** , and bison ',[15].Though these badgers are not honey badgers electric fencing could be a potential deterrent for honey-badgers provided the fencing is well designed and is void of any possible escape routes as these are incredibly intelligent animals.[16] advices to ensure that you fence is at least 61cm inside the ground to prevent badgers from digging underneath the hive.

3.2.5 Acoustic Deterrents

Acoustic deterrents have been explored as a non-lethal method for repelling badgers and other wildlife [8]. Sonic repellents use sounds associated with predators or physical distress to create discomfort, but badgers tend to habituate to these noises over time, reducing their effectiveness [17]. Bioacoustic methods, which play recorded distress calls from badgers, have shown more promise, as they require significantly more exposure before animals become desensitized. However, high-frequency ultrasonic deterrents have been found to be largely ineffective, as demonstrated in research by . While sound-based methods may provide temporary relief from badger intrusions, they are unlikely to serve as a long-term solution without additional control strategies, such as improved fencing or trapping.

The effectiveness of acoustic deterrents varies across species, with research indicating that distress calls are generally more effective than other sound-based methods. Bomford and O'Brien [17] examined the impact of distress calls, white noise, and ultrasonic devices on birds and mammals, concluding that distress calls—bioacoustics—were the most successful at repelling animals, though their effectiveness diminished with repeated exposure. Shivik and Martin [18] tested a radio-activated guard that used 30 different sounds to deter wolves from attacking livestock, demonstrating that varying the sound selection improved results. However, their study also emphasized that animals quickly habituate to repetitive sounds unless there is variation in frequency, intensity, and timing. This highlights a fundamental limitation of acoustic deterrents: while they can provide short-term protection, their long-term efficacy is restricted without continuous modifications to prevent habituation.

3.2.6 Lethal Predator Control Methods

Shooting is one of the lethal predator control methods used to protect endangered species. In Scotland, the shooting of mammals such as feral cats, stoats, and weasels—as advised by the BASC in the UK—is permitted to prevent the predation of endangered birds like the black grouse and water voles [19]. However, this method appears less effective when applied to honey badger populations. A study on controlled badger shooting highlights several key factors that hinder population reduction efforts[20]. Not all shots result in an immediate or clean kill, as some badgers escape after being wounded, potentially surviving with injuries or dying later from infections or starvation. The proportion of badgers that are hit but not recovered remains uncertain, as environmental signs like blood spots are not always reliable indicators of wounding [20]. Additionally, post-mortem analyses have revealed old firearm injuries in some badgers, suggesting that non-lethal shots are relatively common and that some individuals survive multiple shooting attempts [20]. The study identifies five possible outcomes of shooting: instantaneous death, death from secondary infection or starvation due to injury, non-fatal wounding with recovery, non-fatal wounding with persistent disability, and missed shots. While shooting may remove some badgers from an area, it is unclear how significantly this method reduces the overall population, as surviving individuals may adapt, and new badgers may move in to occupy vacated territories. The difficulty in retrieving wounded badgers further complicates efforts to accurately assess the effectiveness of shooting as a population control method, suggesting that its long-term impact remains uncertain [20].

An alternative method for managing badger populations is the use of cage traps [19][21]. Begg et al. [22] investigated the effectiveness of different management techniques on honey badger populations in their research. In Mana Pools National Park, they used cage traps (50x50x120 cm) made of weld mesh or metal, baited with fish, chicken, and other attractants, to reduce refuse bin raiding by honey badgers. Their results showed that the success rate was quite low due to the traps being non-selective, meaning the same animals could be recaptured multiple times, rendering the system redundant. Another drawback was that the traps required frequent monitoring, making the process labor-intensive [22]. However, this issue can be overcome through real-time remote monitoring [19]. Seward et al. [23], in their research on bear monitoring in the MPG Ranch, Montana, USA, implemented a bear cage trap fitted with remote door control and a camera system. This method 'saved an estimated US $\$6,580\$13,624$ in gas and staff hours during three months of trapping, had we physically checked traps once or twice daily, respectively' [23]. One major advantage of cage traps is their humane nature, as badgers tend to rest inside them rather than injure themselves while attempting to escape [22].

In contrast, steel foothold traps are far more lethal [21]. These mechanical devices are designed to capture an animal by clamping onto its limb when triggered. They typically consist of a pair of spring-loaded jaws that snap shut when the animal steps on a pressure-sensitive trigger plate, holding the animal in place until it is released or retrieved. Begg [24], in his study of the conflict between beekeepers and honey badgers in South Africa, highlighted the use of these traps by beekeepers to eradicate badgers that had been attacking their beehives. In 2000, 13 badgers were killed over a nine-month period, and many others were injured [24]. These traps, originally designed for larger animals, often cause death through blood loss, exhaustion, or trauma. Badgers that escape typically suffer severe injuries, such as loss of limb. While effective in reducing local honeybadger populations, these traps raise significant ethical concerns due to the suffering they inflict.

3.3 Conclusion

Protecting prey from predators requires a delicate balance, as removing predators entirely can disrupt the ecosystem, much like removing too many blocks from a Jenga tower, ultimately leading to collapse. While lethal methods are highly effective, they are neither sustainable nor advisable for maintaining a self-sustaining ecosystem.

This review examined various non-lethal predator deterrent methods used in different environments. Techniques such as Acoustic Deterrent Devices (ADDs) have proven successful in aquatic settings, though their effectiveness on land remains uncertain. Light-based deterrents, while promising, work best when combined with other technologies like sirens and ADDs. Additionally, innovative water-based deterrents have shown potential due to their immediate impact on predators.

Each deterrent method has its own strengths and limitations, and no single approach is universally effective. One of the greatest challenges in developing foolproof deterrents is the ability of predators to adapt and habituate to non-harmful deterrent measures. Given the limited research on penguin predators, this review explored a broad range of deterrents used to mitigate wildlife and agricultural conflicts, particularly in protecting penguin colonies from honey badgers.

Ultimately, the most effective solution lies in a strategic combination of non-lethal deterrents, tailored to the specific environment and predator behavior. By carefully weighing the pros and cons of each method, a more sustainable and adaptive approach can be developed to protect vulnerable species while maintaining ecological balance.

Chapter 4

Predator Sensing Subsystem

Prepared by PHRANN001

4.1 Introduction

The Predator Sensing Subsystem is a critical component of an automated time-sensitive deterrent system aimed at protecting penguin colonies from terrestrial predators, particularly honey badgers. This subsystem employs multiple sensor modalities to provide reliable early-warning detection of approaching threats while minimizing false positives that could disturb protected bird species. The system operates in the challenging coastal environment near Cape Town, South Africa, where it must operate reliably under varying weather conditions while maintaining low power consumption and minimal environmental impact. The subsystem integrates five distinct sensor types across two ESP32 processing units to create a robust, intelligent detection network.

4.2 Requirements and Specifications

4.2.1 User Requirements

Based on the challenges outlined by Christina Hagen, Pamela Isdell Fellow of Penguin Conservation at BirdLife South Africa, the following user requirements (UR) have been identified:

- **UR-1:** Detect predator presence (i.e, honey badgers) within a 360° perimeter around penguin colonies.
- **UR-2:**The system must minimise false positives to prevent predator habituation and reliably detect predators to not cause stress to non-target species.
- **UR-3:** The system must function effectively 24/7, under coastal environmental conditions (day/night, different weather).
- **UR-4:** The casing should be weatherproof and durable.
- **UR-5:** The system must operate on low power, suitable for solar power installations in remote locations.
- **UR-6:** The system should detect attempts to tamper with or bypass it, such as digging near a fence line.

- **UR-7:** The system must be relatively easy to install, move, and maintain with a minimal environmental footprint.
- **UR-8:** The system should be capable of logging detection events, including capturing visual evidence (images/video) for verification.
- **UR-9:** The system's data transmission for monitoring should be efficient, considering potentially limited internet connectivity (low data usage).
- **UR-10:** Be approved by CapeNature and not harm predators or non-target species.

4.2.2 Requirement Analysis

Based on the user requirements, the following functional requirements (FR) and specifications (SP) for the Sensing Subsystem are defined:

Table 4.1: Functional Requirements and Specifications for Predator Sensing Subsystem

FR ID & SP ID	Functional Requirement	Specification
FR-1 & SP-1	Detect motion within a configurable range and field of view.	Utilise RCWL-0516 (microwave radar) for wide-area motion detection (5–7 m range, 360°) & HC-SR501 (PIR) for heat-signature-based motion confirmation (3–7 m, <100°).
FR-2 & SP-2	Measure the distance to detected objects and identify approaching entities.	Dual-sensor verification (RCWL-0516 and HC-SR501). Employ HC-SR04 ultrasonic sensor to measure distances (2 cm to 4 m). Monitor for rapid decreases in distance or presence within a critical threshold (<1.5 m).
FR-3 & SP-3	Detect ground vibrations indicative of digging or heavy impact near the sensor unit.	Use SW420 vibration sensor to detect significant shocks or continuous vibration. Threshold to be adjustable.
FR-4 & SP-4	Capture still images or short video clips upon confirmed detection events.	ESP32-CAM module to capture images (VGA resolution) or short video (0.5–10 seconds) when triggered by the main controller. Store locally on an SD card and flag for transmission.
FR-5 & SP-5	Minimise power consumption during idle and active states.	ESP32 WROOM and ESP32-CAM to utilise deep sleep modes. Sensors to be power-cycled or put in low-power modes where possible, activated only upon initial trigger or periodic checks.
FR-6 & SP-6	Monitor ambient environmental conditions.	TMP102 sensor for temperature logging ($-40\,^{\circ}$C to $+125\,^{\circ}$C).
FR-7 & SP-7	Process integrated sensor data to make a reliable detection decision and trigger deterrent.	ESP32 V1 WROOM to execute sensor fusion logic. A confirmed threat involves a configurable combination of triggers. Output a trigger signal to the deterrent system. Log event.
FR-8 & SP-8	Operate from a 12V 1A supply, stepped down to 5V for components.	Utilise an efficient step-down DC-DC converter (>95% efficiency) to provide stable 5V.

Table 4.1 – continued from previous page

FR-9 & SP-9	Allow for adjustment of sensor sensitivity and detection logic parameters.	Firmware to support OTA updates or parameter changes via a communication channel (WiFi if periodically activated).
FR-10 & SP-10	Ensure components are housed appropriately for environmental protection and sensor function.	Main control units (ESP32 WROOM, ESP32-CAM body, converter, TMP102) fully enclosed. External sensors (RCWL-0516, HC-SR501 lens, HC-SR04 transducers, CAM lens) in weatherproof mounts ensuring operational exposure.

4.2.3 Acceptance Test Procedure (ATP)

An ATP is conducted to verify that the system meets the specified requirements. User Acceptance Testing (UAT) will be a key part, ensuring the system is fit for its intended purpose from the end-user's perspective. The Acceptance Criteria is:

Table 4.2: Acceptance Test Procedures (ATP)

AC ID	Description & Requirements
AC1	RCWL-0516 Motion Detection Test: Power the system. Move a human-sized object within a 7m radius around the sensor in different directions. >95% of test cases (UR1, FR1, FR2).
AC2	HC-SR501 Motion Confirmation Test: With the system powered, move a human hand (warm object) across the HC-SR501's field of view at 3-5m. (UR-1)
AC3	The SW420 sensor triggers upon a defined impact event (UR4, FR4).
AC4	Temperature readings from the TMP102 are within ±1°C of a calibrated reference thermometer (UR3, FR6).
AC5	The HC-SR04 accurately measures distances to solid objects within its operational range with ±5cm accuracy (UR5, FR3).
AC6	HC-SR04 Approach Detection Test: Have an object approach the HC-SR04 sensor from 4m towards 0.5m at a moderate speed (e.g., 0.5 m/s).
AC7	The ESP32-CAM captures a clear, identifiable image upon a valid trigger sequence (UR6, FR7, FR13).
AC8	The enclosure and external sensor housings prevent water ingress and dust accumulation after simulated environmental exposure (UR8, FR11).
AC9	The system successfully transmits alert data to a test server within Z seconds of a confirmed detection event (UR11, FR14).
AC10	Validate predator scenario by sequentially triggering multiple sensors as per defined fusion logic (i.e. RCWL-0516 detects motion, then HC-SR501 confirms, then HC-SR04 shows approach). (UR7, FR9, FR10).
AC11	Measure output voltage of the step-down converter that powers the 5V components. The system's average power consumption in standby and active modes meets the defined low-power budget (UR7, FR9, FR10).

4.3 Design Choices

This section discusses alternative components and methodologies considered for the subsystem, comparing them based on figures of merit such as cost, technical maturity, ease of implementation, reliability, power consumption, and accuracy.

4.3.1 Main Microcontroller

To meet the user requirements (UR-1: Reliability,UR-3:Longevity UR-5: Power efficiency) and functional requirements (FR-1–FR10) for a camera and sensing subsystem to monitor penguin predators, the microcontroller must support reliable image capture, low power consumption for remote deployment, and cost-effective scalability for multiple sensors. Two options were considered: the ESP32-WROOM-32 and the Microchip AVR-IoT WA (EV15R70A).

MCU	CPU	Wi-Fi	Active Current	GPIOs / ADC	Temp Accuracy	Cost (ZAR)
ESP32-WROOM-32	Dual-core 240 MHz	802.11 b/g/n	Tx: 115 mA, Rx: 50 mA	34 / 18	±0.5°C (ext.)	115–250
AVR-IoT WA (EV15R70A)	Single-core 20 MHz	802.11 b/g/n	Tx: 70 mA, Rx: 30 mA	22 / 8	±0.25°C (int.)	380–730

Table 4.3: Comparison of Microcontroller Options

Since the system requires reliable wireless connectivity and low power for long-term remote use, AVR-IoT WA is a more competitive choice since it has ultra-low processing as little 70mA. Although the AVR-IoT WA's built-in temperature and light sensors reduce complexity while offering accuracy, the need for external sensors in the ESP32 system is mitigated by its ample GPIO pins and compatibility with digital sensors, avoiding the need for external ADCs. T ESP32 Wroom 32 is a low cost, integrated Wi-Fi , dual-core processor, sufficient GPIOs. It is ideal for sensor scalability since it has 30 GPIO pins and communication tasks. ESP32's ADC converter is not accurate, which limited the choice of analog sensors or using external ADC which adds complexity to the system. **Decision**: The ESP32 WROOM DEVKIT is selected because it is the best balance of processing power for this application, integrated connectivity, low-power features, cost, and libraries availability, especially when paired with the ESP32-CAM for dedicated image handling and along the use of digital sensors. Additionally, the ESP32's wider availability and lower cost make it easier to replace(UR-7).

4.3.2 Camera Module

The camera must capture visual evidence for verification, balancing power, cost, and performance in remote areas (**UR-8**, **FR-4**, **UR-5**). The following table compares two camera options: ESP32-CAM OV2640 and Adafruit OV5640.

Camera	Resolution	Frame Rate	Power Consumption	Low-Light Performance	Cost
OV2640	2 MP (1632×1232)	15 fps (UXGA), 25–30 fps (VGA)	∼180mA(deep sleep 6mA)	Good with external IR	R160–300
OV5640	5 MP (2592×1944)	5 fps (QSXGA), 12 fps (VGA)	∼200–300 mW	Higher sensitivity (OmniBSI)	$10+

Table 4.4: Comparison of Camera Modules for Predator Sensing Subsystem

The OV2640 camera was chosen primarily for its cost-effectiveness and ability to handle both image processing and Wi-Fi connectivity since it comes with an integrated ESP32, which makes it a compact and efficient choice that seamlessly integrates with the main ESP32 WROOM controller in a distributed sensing system. While it offers lower image quality and resolution compared to the OV5640, the OV2640 is considered sufficient for basic verification tasks and real-time streaming, aligning with user requirements(UR-5, UR-7, UR-8, and UR-9). Furthermore, its compatibility with solar power and low bandwidth makes it ideal for low-power setups, addressing aspects of UR-8 and FR-4, and its compact size is beneficial for coastal deployments.

4.3.3 Design Choices and Methodology: Sensor Selection for Motion and Distance Detection Subsystem

To monitor penguin predators in a coastal environment, the subsystem requires reliable motion and distance detection to complement the camera system since visibility can be compromised in various weather conditons. The sensors must meet user requirements (UR-1: Detection, UR-2: Accuracy,UR-3: Longevity, UR-5: Power efficiency) and functional requirements (FR-1: Motion detection,FR-2: Distance Approximation, FR-6: Operation in various conditions). Three sensor categories were evaluated: wide area motion sensors, heat-based motion sensors, and ultrasonic distance sensors. The ESP32-WROOM-32, selected for its low cost, low power (10 µA in Deep Sleep), and 34 GPIO pins, provides ample interfacing capabilities for these sensors.

Wide Area Motion Sensor (Microwave Radar)

The RCWL-0516 is an affordable option for wide area motion detection application which does not it does not rely on visible or infrared light. It operates on Doppler radar principles and provides a broad detection angle of approximately 360°, making it suitable for basic motion sensing. However, it may suffer from false positives due to its simpler signal processing. In contrast, the LD2450 uses 24GHz mmWave radar and offers more precise multi-target tracking with better noise immunity. While it is significantly more expensive and has higher power consumption, it provides advanced features suitable for environments requiring high accuracy and reliability.

Table 4.5: Comparison of RCWL-0516 and LD2450 for Wide Area Motion Detection

Sensor	Technology	Detection Range	Detection Angle	Power Consumption	Cost (ZAR)
RCWL-0516	Doppler radar	4–7 m	∼360°	∼2–3 mA	ZAR 20–50
LD2450	24GHz mmWave radar	0.75–6 m	Multi-target tracking	∼10–20 mA	ZAR 150–300

Decision: The RCWL-0516 is selected as it is a provided component and offers a cost-effective and lower power solution for initial wide-area motion detection. Its tendency for false positives will be mitigated by fusion with other sensors i.e. the PIR and HC-SR04.

Heat-Based Motion Sensor (PIR) vs. IR Distance Sensor

The use of an accurate heat-based motion sensor is crucial since penguin predators are warm-blooded (i.e. badgers and leopards) in order to avoid environmental false triggers.

Sensor	Technology	Detection Range	Detection Angle	Power Consumption	Cost (ZAR)
HC-SR501 (PIR)	Passive Infrared	3–7 m	90–120°	65mA(∼50 µA (standby))	20–40
GP2Y0A21YKOF	Infrared Distance	1–8 m	Narrow beam	∼30 mA (active)	50–100

Table 4.6: Comparison of Heat-Based Motion Sensors

Decision Rationale: HC-SR501 PIR sensor detects motion via heat signatures but not distance in contrast to GP2Y0A21YK0F which enables precise distance calculations when interfaced with a microcontroller by providing analog output signal. It has faster response that than sensors that rely on sound wave propagation which ensures quicker detection. This supports FR-2 for measuring distances to approaching entities. However, HC-SR501 selected for its low cost, reliability in detecting warm-blooded animals(higher detection angle), and synergy with RCWL-0516 for reducing false positives (UR-2, FR-1, FR-7).

Ultrasonic Distance Sensor

The use of ulrasonic is implemented for distance detection and speed the object is approaching alert the system and user that there is an object in close proximity to the fence. The following are specifications for the ultrasonic sensors selected to enhance the subsystem:

Sensor	Technology	Range	Power Consumption	Environmental Resilience	Cost (ZAR)
HC-SR04	Ultrasonic	2 cm–4 m	∼15 mA(20mA (Max))	Requires housing	20–40
JSN-SR04T	Waterproof Ultrasonic	20 cm–6 m	∼20 mA	Waterproof	100–200

Table 4.7: Comparison of Ultrasonic Distance Sensors

Decision: Since ultrasonic sensors need external opening to detect, the need for adaquate is crucial when considering the coastal conditions which makes JSN-SR04T more appealing. Albeit, HC-SR04 has lower detection range, it is adequate for perimeter distance monitoring when appropriately housed and it is a low cost and less power consuming.

In addition to the sensor choices outlined, the integration of specific sensors serves crucial functions in addressing the unique challenges of protecting penguin colonies from honey badgers. An SW420 vibration sensor is used to detect ground movement, specifically targeting the digging behavior characteristic of honey badgers. This provides an early warning mechanism against attempts to bypass the system by digging near the fence line.

Furthermore, the system leverages temperature data from the TMP102 sensor to enhance the reliability of the PIR sensor in hotter conditions (30+ degrees Celsius). During such periods, the system can prioritize and only trigger an alert if both the RCWL-0516 and the HC-SR04 ultrasonic sensor detect dense movement, thus minimizing false positives caused by environmental factors(UR-2).

4.3.4 Enclosure Fabrication

Initially, the sensor housing design initially favored laser-cut perspex panels for their speed, precision, and cost-effectiveness in producing flat parts but faced challenges with fit accuracy, material availability, and limited 2.5D design flexibility. Consequently, PLA filament 3D printing was chosen for complex internal mounts and sensor housings due to its superior freedom in creating intricate geometries essential for precise component integration. While perspex offers good weather resistance suitable for coastal environments, PLA is less weatherproof and requires careful design or post-processing for durability; despite being slower and color-limited, 3D printing's versatility and customization outweighed these drawbacks, making it the optimal choice for the enclosure.

4.4 Submodule Design

The sensing subsystem integrates several modules to achieve its objectives.

4.4.1 Power Subsystem

- **Input**: 12V, 1A DC.
- **Regulation**: A step-down DC-DC converter (300W 9A Step Down Buck Module5-40V To 1.2-35V)efficiently converts 12V to 5V.

4.4.2 Main Control Unit (ESP32 V1 WROOM)

- **A state-based detection logic is applied for sensor fusion system**: Runs platform.io firmware to periodically read sensors, evaluate trigger conditions, manage power-saving modes (deep sleep), log data, and handle communication.
- **Interfaces**:
  - **I2C**: TMP102 (temperature)

- **Digital Inputs**: RCWL-0516 (motion out), HC-SR501 (PIR out), SW420 (vibration out).
- **Digital Input/Output**: HC-SR04 (Trig/Echo pins).
- **UART/SPI**: For serial debugging, programming, and potentially for communication with the ESP32-CAM if more than a simple trigger is needed.
- **Digital Output**: Trigger signal to ESP32-CAM.

- **Sensor Fusion Logic**:
  - RCWL-0516 provides initial motion alert.
  - Upon RCWL-0516 trigger, wake HC-SR501 (if in low power mode) and poll.
  - If HC-SR501 confirms motion (heat signature):
    1. Trigger HC-SR04 to measure distance.
    2. If distance < threshold_predator:
       (a) Send trigger to ESP32-CAM.
       (b) Log event (all sensor data, timestamp).
       (c) Transmit alert.
  - Continuously monitor SW420 for tampering/digging alerts.
  - Periodically log TMP102 data for environmental context.

4.4.3 Visual Verification Subsystem (ESP32-CAM with OV2640)

- **Function**: Dedicated to capturing images or short video clips.
- **Interface**: Receives a digital trigger signal from the main ESP32 WROOM.
- **Operation**: Upon trigger, wakes up (if in sleep mode), captures an image, saves it to an onboard microSD card, and/or transmits it via its own Wi-Fi (if configured, or signals main ESP32 that image is ready).
- **Power**: Can be put into deep sleep by the main ESP32 to save power and awakened via an external interrupt or timed wakeup.

4.4.4 Sensor Modules & Interfacing

The Predator Sensing Subsystem integrates multiple sensor modules with the ESP32 V1 WROOM main control unit and the ESP32-CAM visual verification unit. Figure 4.1 provides a block diagram overview of these interconnections.

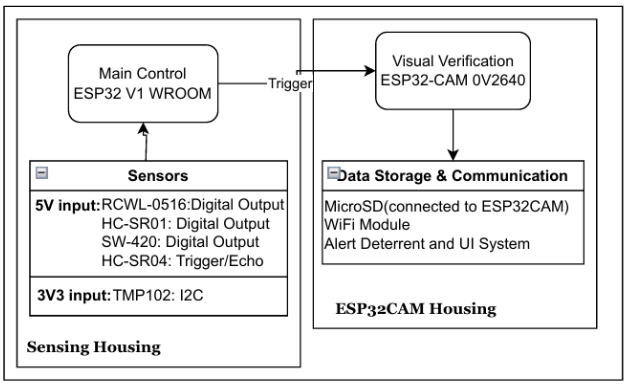


Figure 4.1: Block diagram of Sensing system

- **RCWL-0516**: Connect VCC (5V), GND, OUT (to ESP32 digital input).
- **HC-SR501**: Connect VCC (5V), GND, OUT (to ESP32 digital input). Adjust onboard potentiometers for sensitivity and delay.
- **HC-SR04**: Connect VCC (5V), GND, Trig (from ESP32 digital output), Echo (to ESP32 digital input). Distance calculation: Distance = $\frac{\text{Time\_Echo\_HIGH} \times \text{Speed\_of\_Sound}}{2}$.
- **SW420**: Connect VCC (5V), GND, DO (Digital Out to ESP32 digital input). Adjust onboard potentiometer for vibration sensitivity.
- **TMP102**: Connect VCC (3.3V from ESP32), GND, SCL (to ESP32 I2C SCL), SDA (to ESP32 I2C SDA).

4.4.5 Enclosure and Mounting

The main enclosure features a 3D-printed, two-part weatherproof housing with a lid and main compartment designed to protect sensors system while maintaining their operational functionality. It houses ESP32 WROOM, power subsystem, SW420 and TMP102 (for internal temp). The SW420 sensor is fitted flat to the base of the enclosure or a ground stake.Using TinkerCad, custom cylindrical mounts (attached to the external cutout for the HC-SR04 sensor) are designed to protect HC-SR04 transducers. The PIR sensor is also exposed through circular cutout and the RCWL-0516 motion sensor exposed through a rectangular cutout, but is protected by an IR-transparent plastic film covering the cutout. The ESP32Cam is enclosed in a dedicated 3D-printed case with power cable access with the ESP32-CAM lens looking through a small hole .

4.5 Results and Testing

The testing phase for the Predator Sensing Subsystem was crucial and followed a structured approach to validate its design and functionality against the user-defined requirements. An Acceptance Test Procedure (ATP) was conducted to verify that the system meets its specified functional requirements.

AC1: In this test, an object and a human within a 7m radius was around the RCWL-0516 motion sensor in different directions. The microcontroller LED was used to show a light indication when there is a high digital output. Results showed that the sensor can sense within ranges <5m which is lower than as expected, however it was accurately detecting presence in 360 degrees direction-**PASS**.

AC2: This test was conducted to evaluate the HC-SR501 sensor's ability to detect warm-blooded objects within its sensing range. A human hand was moved across the sensor's field of view at distances ranging from 3 to 7 meters, in accordance with UR1. The sensor's onboard sensitivity and time delay potentiometers were configured to their maximum settings to optimize detection accuracy and response time. A digital high output from the sensor triggered the microcontroller's onboard LED, providing a visual indication of successful motion detection-**PASS**.

AC3: In this test, the SW420 sensor triggers upon a defined impact event (such as a sharp tap on the enclosure and flat surface).The potentiometer was adjusted to highest sensitivity for maximum accuracy(UR4, FR4). The SW420 effectively detects significant vibrations as required for tamper/digging detection-**PASS**. Below are figures of the output from the sensors discussed in AC1-3.

AC4: The TMP102 was placed in an environment known temperatures and a warmer finger was placed on top the sensor to check the difference.The first subfigure of figure4.3 outputted an increase of 5 °C, which gradually decreased after removing the finger. Temperature readings from the TMP102 are within ±1°C of a calibrated reference thermometer (UR3, FR6) - **PASSED**.

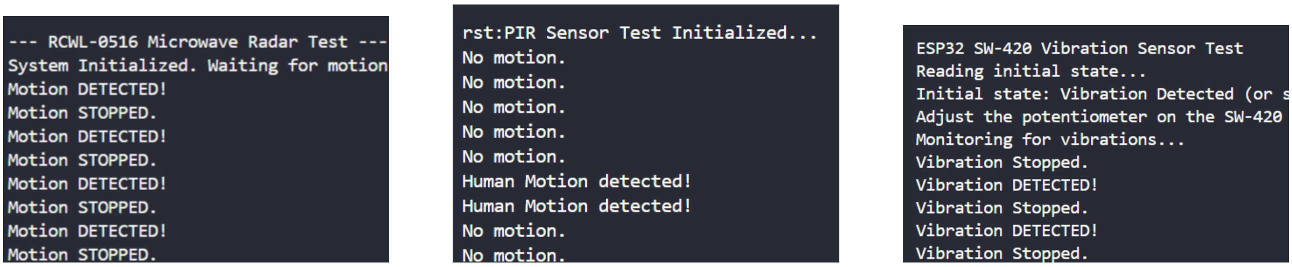


Figure 4.2: Sensor outputs from AC1–AC3 tests

AC5: In this test, a cup was placed at known distances (0-2m) from the HC-SR04 sensor. The results of system output/log were compared with actual distance ± 1-2cm accuracy (UR5, FR3) - **PASSED**.

AC6: The cup was moved(approached) the HC-SR04 sensor from 1.5m towards 2m at a moderate speed (<2m/s). The system correctly identifies an approaching object by checking the current time, distance and speed as it is moving away from/towards the sensor. This is done continuously checking the distance the object moved and tracking if the move is closer/further to determine whether the object is approaching and at what speed to estimate type of predator. This test verifies distance measurement, corresponding to FR-2 and contributing to UR-1 - **PASSED**.

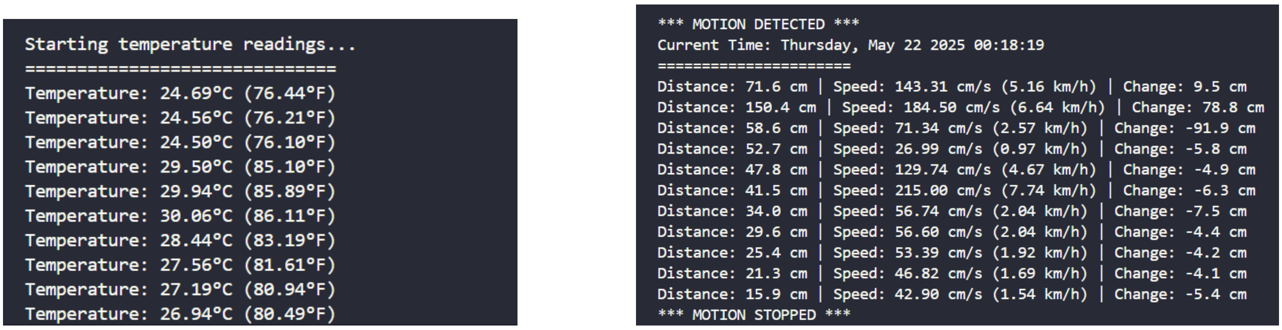


Figure 4.3: Sensor outputs from AC4–AC6 tests

AC7: A 'threat' condition was manually triggered in the ESP32 WROOM by using a warm cup to activate the HC-SR04 sensor to send a trigger signal to the ESP32-CAM. The ESP32-CAM successfully captured a clear, identifiable image upon the trigger event. A sample image is shown in Figure 4.3 - **PASSED**.

AC8: This test assesses the enclosure's integrity, corresponding to UR-4 (weatherproof and durable casing) and FR-10 (components housed appropriately for environmental protection). The 3D design incorporated overlapping sealing edges, integrated mounting points, and strategic component positioning to ensure all the components fitted into sensing subsystem while preventing water ingress and dust accumulation during coastal environmental exposure. However, cable exposure compromised the weatherproofing of the system- **FAIL**. Below are figures of camera images taken from ESP32Cam and 3D Sensing Subsystem Housing Design discussed in AC7-8.

AC9: The ESP32 was connected to Wi-Fi and monitored using the serial console to confirm successful initialization and time synchronization via NTP. Motion was simulated in front of the RCWL-0516 sensor, and the serial output verified that motion was detected and a timestamp was generated. Accessing the /data endpoint from a browser and curl returned the expected JSON with real-time motion status and the correct timestamp thus confirming the system worked system successfully transmits alert data to a test server of a confirmed detection event(UR11, FR14)-**PASS**.

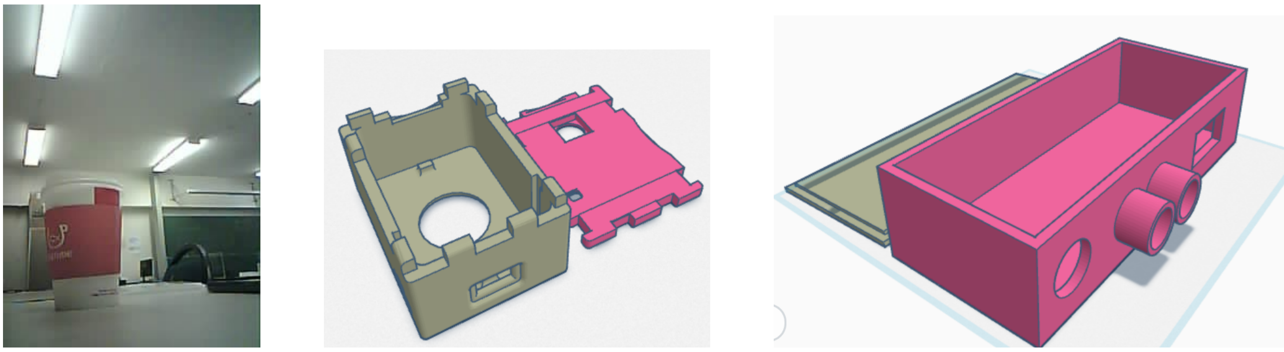


Figure 4.4: Left:Image captured from ESP32Cam(AC7), Center: ESP32Cam Case, Right: Sensing Subsystem Case(AC8)

AC10: This test was aimed at validating predator scenario by sequentially triggering multiple sensors as per defined fusion logic (i.e. RCWL-0516 detects motion, then HC-SR501 confirms, then HC-SR04 shows approach but TMP102 was not correctly reading) to meet UR7, FR9, FR10. ESP32 WROOM correctly processes the combined sensor inputs, the 'deterrent trigger' signal was activated - **PASS**.

AC11: In this test, the output voltage of the step-down converter was measured to ensure that it powers the 5V components. The system's average power consumption in standby and active modes meets the defined low-power budget (UR7, FR9, FR10)- **PASS**.

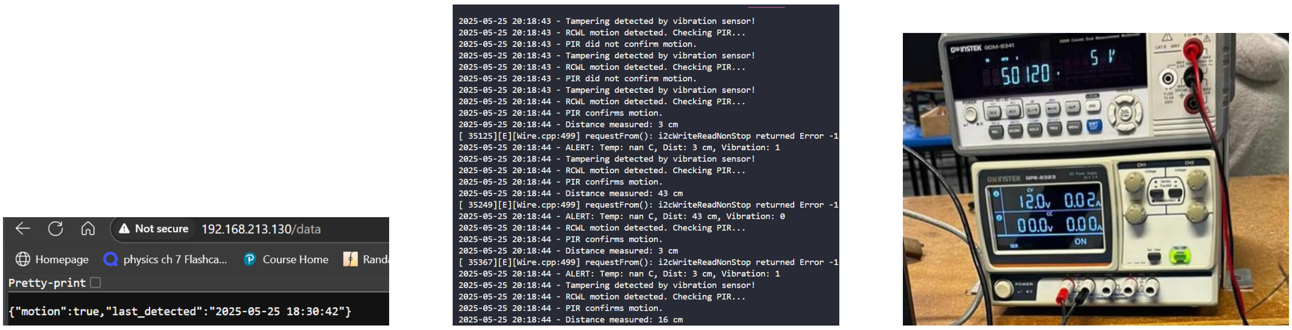


Figure 4.5: Voltage outputs from AC11 tests

4.6 Conclusions and Recommendations

The use of multiple sensors serve different primary functions. The HC-SR04 (Ultrasonic) is already designated for distance. Thus, the HC-SR501 is the clear choice for heat-based motion. It leverages a suite of diverse sensors, coordinated by ESP32 microcontrollers, to provide situational awareness. The ESP32-CAM will offer crucial visual verification, especially for nocturnal predators, while the ESP32 V1 WROOM will act as the central processing hub. The system is designed with a strong emphasis on non-harmful detection, minimal disturbance to non-target species (like penguins and other seabirds), low power consumption for potential solar operation, weather resistance, and ease of deployment in sensitive ecological areas. The data will inform a time-sensitive deterrent system designed to scare off predators without causing them harm.

Chapter 5

Predator Deterrence Subsystem

5.1 Introduction

The deterrence subsystem functions as the active defense mechanism within the predator management system, designed to physically repel intruding animals. It operates by receiving real-time data on predator positions from the sensing subsystem, which may utilize technologies such as PIR motion sensors, cameras, or radar modules. Upon receiving this input, the deterrence subsystem activates its components to repel the threat.

Central to this subsystem is the ESP32 microcontroller, which orchestrates the operation of deterrent devices. The ESP32 controls visual deterrents, such as flashing LED lights, and auditory deterrents, like speakers emitting predator-repelling sounds. These components are activated based on the processed data from the sensing subsystem, ensuring timely and appropriate responses to potential threats. The ESP32's capabilities in handling both input from sensors and output to deterrent devices make it an effective choice for such integrated systems.

This section provides a comprehensive overview of the deterrence subsystem's components and their interactions, highlighting the role of the ESP32 in integrating sensory input with responsive actions to enhance the system's effectiveness in predator deterrence.

5.2 User Requirements

The stakeholder, Dr Christina Hagen, a scientist and researcher with BirdLife South Africa, provided the team with the requirements for the overall system requirements. For the deterrent subsystem, the following requirements must be met.

- The deterrents cannot harm predators.
- Cannot disturb non-target species (especially penguins, terns and cormorants.
- The subsystem must be water and weather-proof.
- System must be easy to install and portable (with low footprint and no permanent damage where installed)
- The system must not be power intensive.
- Deterrent system must trigger only in presence of predators.

5.3 Requirements Analysis

Following these requirements, the functional requirements, design specifications, and acceptance test procedures of the system were formulated.

5.3.1 Functional Requirements

FR ID	Description
FR-01	Subsystem shall activate deterrents only in the presence of identified predator species, ensuring that no deterrent action is taken when non-target species are detected.
FR-02	Subsystem may only use non-lethal deterrent methods
FR-03	Subsystem must be housed in a waterproof, heat-resistant enclosure.
FR-04	Subsystem must use no more than 7.5 Watts during operation.
FR-05	The system shall be easy to deploy and relocate by one person.
FR-06	The system shall produce a stimulus that triggers an aversive response in target predators based on known behavioral studies.

Table 5.1: Functional Requirements of the Deterrence Subsystem

5.3.2 Design Specifications

From the given functional requirements, these specifications can be derived:

SP-ID	FR-ID	Specification Description
SP-01	FR-02, FR-06	The subsystem is a combination of acoustic (85 dB @ 0.1m) and light (500 lumens) deterrents.
SP-02	FR-03, FR-05	The enclosure is made of Perspex and measures 180 $\times$ 150 $\times$ 120 mm. (L x W x H)
SP-03	FR-04	Average power consumption: 5W during active operation, $<$ 1W in standby mode.
SP-04	FR-06	Operating frequency range: 2 kHz to 10 kHz
SP-05	FR-01	ESP32-powered with Wi-Fi and Bluetooth capabilities.

Table 5.2: Design Specifications and Their Corresponding Functional Requirements

5.3.3 Acceptance Testing Procedures

ATP ID	SP-ID	Testing Procedure	Pass Criteria
ATP-01	SP-01	Measure output of deterrent system with a calibrated sound level meter and light meter at 1m distance.	Sound $\leq$ 85 dB at 1m; light $\leq$ 500 lumens. No use of lethal mechanisms.
ATP-02	SP-02	Spray enclosure with water from a high pressure garden hose	No penetration of water, system stays fully operational
ATP-03	SP-02	1. Weigh the fully assembled system using a calibrated scale. 2. Measure the enclosure using calipers or a measuring tape. 3. Have a user attempt to carry it by hand over a flat 10-meter distance.	Weight $\leq$ 10 kg. External dimensions $\approx 180 \times 120 \times 150$ mm. Test user can carry the system comfortably and safely without dropping or needing a second person.
ATP-04	SP-03	Use a multimeter to measure real-time current and voltage draw in both active and standby modes.	Active mode: $\leq$ 5 W; Standby: $\leq$ 1 W.
ATP-05	SP-05	Simulate Wi-Fi detection signal using a test transmitter or local server and observe system response.	System successfully receives and processes data over Wi-Fi in $\leq$ 2 seconds. No packet loss or failure during repeated trials.
ATP-07	SP-04	Measure the frequency of the output of audio deterrent using a sound spectrum analyzer	Output frequency f: $2\,\text{kHz} < f < 20\,\text{kHz}$

5.3.4 Traceability Matrix

FR ID	Covering SP-ID(s)	Verifying ATP-ID(s)
FR-01	SP-05	ATP-05
FR-02	SP-01	ATP-01
FR-03	SP-02	ATP-02 ATP-03
FR-04	SP-03	ATP-04

Continued on next page

Table 5.3 – continued from previous page

FR ID	Covering SP-ID(s)	Verifying ATP-ID(s)
FR-05	SP-02	ATP-03
FR-06	SP-01 SP-04	ATP-01 ATP-07

Table 5.3: Requirements Traceability Matrix (ID Focused)

5.4 Design Choices

This section details the various choices considered when developing the solution for this subsystem

During our literature review, we identified several deterrent systems, including visual, audio, strobe, and electric fencing. Based on our requirement that deterrents must not harm predators, we narrowed our options to two main choices: electric fencing or a combination of light and audio deterrents.

Aspect	Electric Fences	Light/Audio Deterrents
Risk of Harm	Delivers a physical shock, violating non-lethal requirements.	Non-contact (light/sound), ensuring safety for all species.
Impact on Non-Target Species	Affects all animals, including protected species.	Can be tuned to target specific predators, reducing collateral impact.
Power Consumption	High (constant charge needed).	Low (event-triggered), ideal for energy-efficient systems.
Durability	Prone to corrosion (salt/moisture exposure).	Weatherproof (e.g., IP65), requiring less maintenance.
Deployment	Complex (posts, wiring, grounding).	Lightweight, portable, and easy to install.

Table 5.4: Comparison of Electric Fences vs. Light/Audio Deterrents

5.4.1 Micro-controller Selection

The ESP32, STM32F0, and Raspberry Pi were considered for this project. Their comparison is shown below.

Requirement	ESP32	STM32F0	Raspberry Pi (Zero 2 W)
Wireless Communication	Built-in Wi-Fi and Bluetooth	Requires external module	Built-in Wi-Fi and Bluetooth
Power Consumption	Moderate; deep sleep mode available (10 µA)	Very low; suitable for battery applications	High; not ideal for low-power scenarios
Processing Speed	Dual-core 240 MHz (Xtensa LX6)	Up to 48 MHz (ARM Cortex-M0)	Quad-core 1 GHz (Broadcom ARM Cortex-A53)
Cost	Low (R120)	Very low (R177)	Moderate (R400)

Table 5.5: Comparison of ESP32, STM32F0, and Raspberry Pi Zero 2 W for Project Requirements

The ESP32 offers the best overall balance of wireless connectivity, processing speed, and low power consumption, making it the most suitable choice for the project.

5.4.2 Enclosure Material

In order to meet the weatherproof and waterproof requirements, a suitable material must be chosen. This material must be durable, temperature-resistant, waterproof, lightweight, low-cost, readily available, and transparent. We compared Perspex (PMMA), HDPE (High-Density Polyethylene), and Fiberglass.

Metric	Perspex (PMMA)	HDPE	Fiberglass
Durability	Moderate (rigid but brittle)	High (flexible and tough)	Very high (strong and impact resistant)
Temperature Resistance	Moderate (–40°C to +80°C)	Good (–100°C to +120°C)	Excellent (–50°C to +150°C)
Waterproof	Yes	Yes	Yes
Lightweight	Light	Very light	Moderate
Low Cost	Moderate	Low	Moderate to High
Availability	Widely available	Widely available	Moderate availability
Transparency	Transparent (clear)	Opaque	Opaque

Table 5.6: Comparison of Materials Based on Key Project Metrics for the Enclosure

From Table 5.6, it is evident that Perspex is the most suitable material for the project due to its transparency, adequate durability, low cost, and lightweight attributes.

The enclosure is a compact box measuring 180 mm × 120 mm × 150 mm. It features interlocking 'teeth' along the edges, allowing all panels to fit securely together without the need for additional fasteners. The design was optimized specifically for laser cutting, ensuring precise cuts and ease of assembly.

5.4.3 Voltage Conversion

Our external power source is a 12V, 1A supply. However, our microcontroller can only be powered by a 5V source. Therefore, we must devise a way to convert this 12V supply to the required 5V for the microcontroller. We considered a linear voltage regulator, a buck converter, and a voltage divider.

Feature	**Buck Converter**	**Voltage Divider**	**Linear Voltage Regulator**
Efficiency	High (80–95%), low power loss	Very low, wastes significant power as heat	Moderate to low, dissipates excess voltage as heat
Output Voltage Stability	Stable output, regulated under varying load	Unstable, varies significantly with load	Stable, regulated voltage output
Complexity	More complex; requires inductor, diode, control circuitry	Very simple; typically just two resistors	Simple; integrated IC with few external components
Suitability for Powering	Ideal for powering active subsystems efficiently	Not suitable for powering loads; only for low-current voltage references	Suitable for powering subsystems with low to moderate current demands

Table 5.7: Comparison of Buck Converter, Voltage Divider, and Linear Voltage Regulator for 12V to 5V Conversion

From the comparison in Table 5.7, it is clear that a linear voltage regulator is the best fit for this application. Its stable, low-noise output voltage, simplicity, and sufficient efficiency for low to moderate currents make it the optimal choice for powering sensitive components such as microcontrollers and LEDs.

The LM317 voltage regulator module was selected because it is low-cost, includes an attached heat sink, and has a current capacity of approximately 1A. This capacity is sufficient for powering the microcontroller, as well as the LEDs and the buzzers in the light and audio deterrent systems, respectively.

5.4.4 Driver Circuits

The selection of a suitable driver circuit was essential for the LEDs and buzzers, which form the core of the light and audio deterrents. The driver circuit needed to enable these components to draw their required operating current while being controlled by a low-power signal from the microcontroller. Additionally, a fast switching speed was paramount for effective pattern generation.

Both logic-level MOSFET and BJT-based driver circuits were considered. The MOSFET-based circuit was chosen because, unlike BJTs, MOSFETs are voltage-driven. This characteristic allows for high power delivery to the components without drawing excessive current from the microcontroller's output pins. Furthermore, MOSFETs generally offer faster switching speeds compared to BJTs.

The VN0300L logic-level MOSFET was selected for this application. This specific model was chosen for its low cost, adequate current-handling capability, and compact size, particularly when compared to alternatives like the IRFZ44N.

5.4.5 Deterrent Patterns

Lighting Patterns

For the light deterrent system to be effective, patterns capable of invoking a fear response in predators were required. To achieve this, LED deterrent patterns should primarily emphasize high brightness, irregular flashing, and specific color wavelengths. Bright, intense flashes—potentially up to 500 lumens—can startle or disorient predators, especially when delivered in unpredictable sequences that prevent habituation. Additionally, using short-wavelength colors like blue or white light enhances the visual impact, as many predators are more sensitive to these hues. Together, these attributes simulate an unnatural or threatening stimulus, increasing the likelihood of triggering a fear or avoidance response.

Based on these criteria, several patterns were evaluated for their deterrent effectiveness:

LED Pattern	**Description**	**Effectiveness**
1, 1-2, 1-2-3	Sequential buildup of LEDs turning on	Low
LED Chaser	LEDs turn on in a chasing loop (e.g., 1→2→3→1...)	Moderate
OFF-AND-ON	All LEDs turn on and off together at regular intervals	Low
Flashing lights with increasing and decreasing speed	LEDs flash at variable rates (faster and slower)	High
Randomized Light	LEDs flash in a non-repeating, unpredictable pattern	High

Table 5.8: Comparison of LED Patterns by Deterrent Effectiveness

Based on this comparison (Table 5.8), the design incorporates the most effective patterns: randomized light, flashing lights with varying speeds, and the LED chaser. The lights will be white and blue, as research indicates these colors are particularly effective for deterring predators. These patterns will be implemented using firmware developed for the ESP32 microcontroller within the Arduino IDE.

Audio Patterns

Effective audio deterrent patterns should possess the following qualities:

- **Frequency Range:** 2 kHz to 20 kHz, to target predator hearing acuity while minimizing disturbance to non-target species like seabirds.
- **Pattern:** Irregular bursts of sound with unpredictable intervals and varying durations (e.g., 0.5–3 seconds).
- **Tone Type:** Sudden, startling tones or modulated siren-like patterns (e.g., rising and falling pitches).

Audio Pattern	**Description**	**Effectiveness**
Frequency Sweep	Sound sweeps continuously between low and high frequencies (e.g., 2 kHz to 20 kHz)	High
Off and On	Sound turns off and on at fixed intervals	Low
Heartbeat Mimicry	Repetitive low-frequency pulses mimicking a heartbeat	Moderate
Randomized Bursts	Irregular bursts of sound at varying frequencies and durations	High

Table 5.9: Comparison of Audio Patterns by Deterrent Effectiveness

The following audio patterns were compared, and their effectiveness was rated as indicated:

5.4.6 Final Design

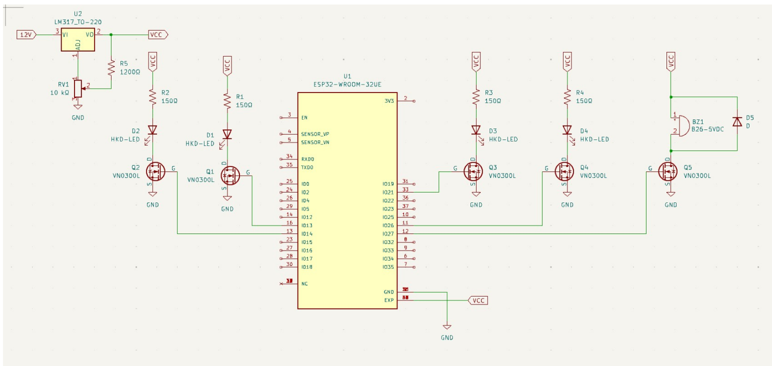


Figure 5.1: Final Schematic

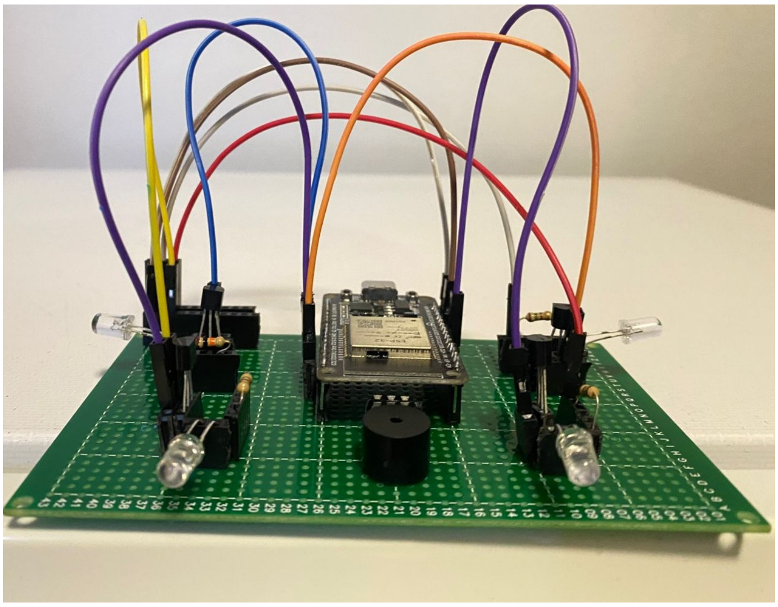


Figure 5.2: Physical Implementation

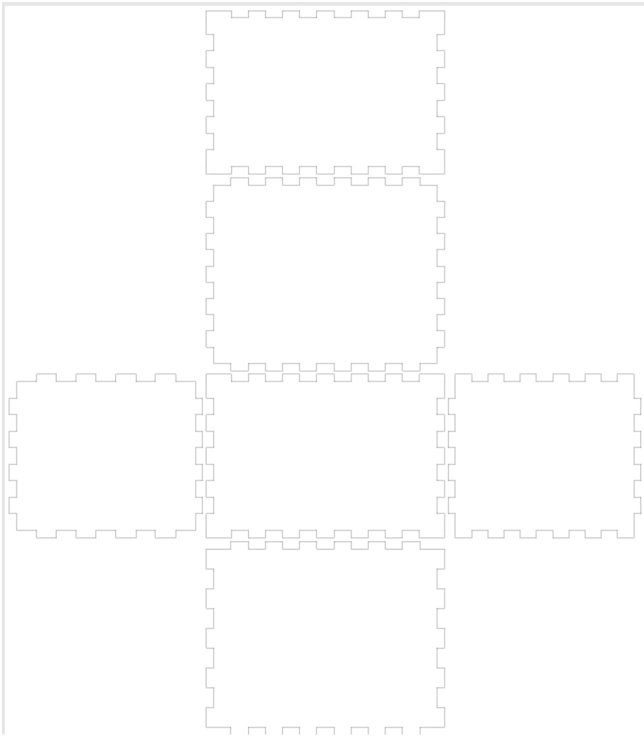


Figure 5.3: Final Enclosure Design

5.5 Testing

5.5.1 Driver Circuit Testing

The driver circuits were testing by using the ESP32 GPIO pins to periodically apply a gate signal to the MOSFET, while the circuit was powered by a 5V source. This was to ensure that all relevant components were working accordingly. The results are shown below.

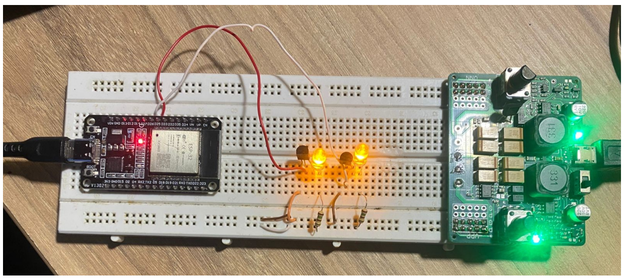


Figure 5.4: Driver Circuit on

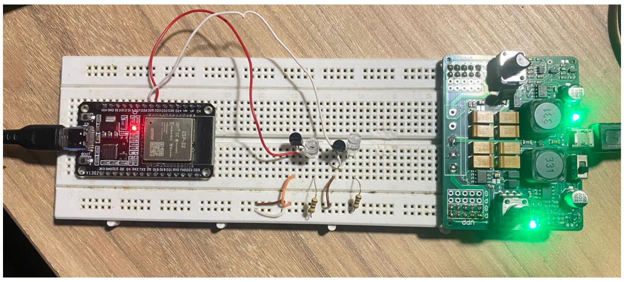


Figure 5.5: Driver circuit off

5.5.2 Power Consumption Test

When powered by a 5V source, the current drawn by the circuit both in active and standby mode is measured.

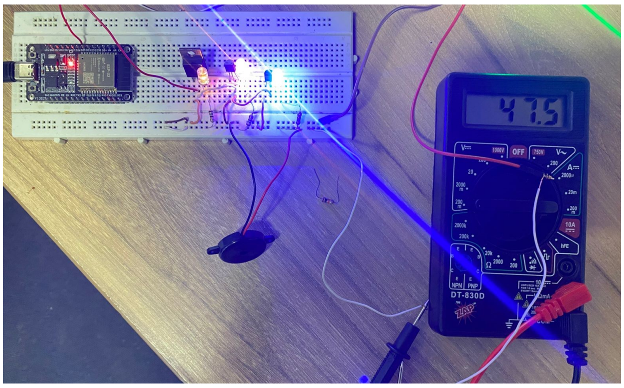


Figure 5.6: Current drawn during full operation

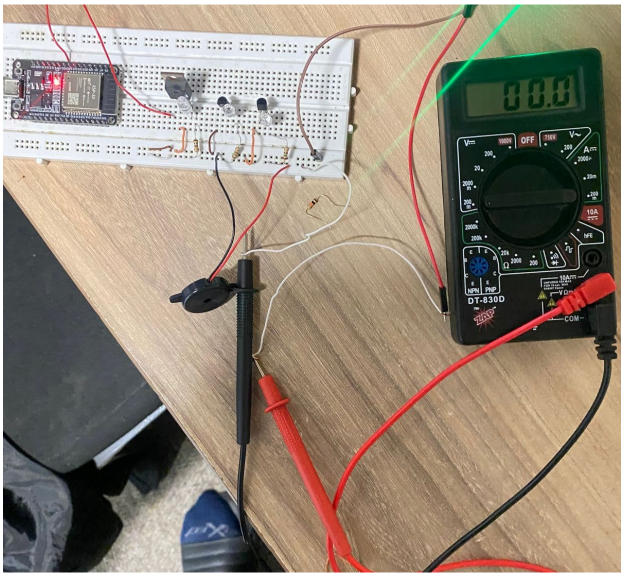


Figure 5.7: Current drawn in standby mode

5.5.3 ATP Consolidation Results

ATP ID	Description (Testing Procedure)	Pass/Fail
ATP-01	Measure output of deterrent system with a calibrated sound level meter and light meter at 0.1m distance.	Pass
ATP-02	Spray enclosure with water from a high pressure garden hose.	Pass
ATP-03	1. Weigh the fully assembled system using a calibrated scale. 2. Measure the enclosure using calipers or a measuring tape. 3. Have a user attempt to carry it by hand over a flat 10-meter distance.	Pass
ATP-04	Use a multimeter to measure real-time current and voltage draw in both active and standby modes.	Pass
ATP-05	Simulate Wi-Fi detection signal using a test transmitter or local server and observe system response.	Pass
ATP-07	Measure the frequency of the output of audio deterrent using a sound spectrum analyzer.	Pass

Table 5.10: ATP Consolidation Table

5.6 Conclusions

This section has detailed the design and validation of the predator deterrence subsystem, developed to humanely protect vulnerable wildlife as per requirements from BirdLife South Africa. The system, centered on an ESP32 microcontroller, employs non-lethal light and audio deterrents, selected over alternatives for their efficacy, target specificity, and low power consumption. Key design choices, including Perspex for a weather-proof enclosure, an LM317 for stable power conversion, MOSFET-driven circuits for efficient component control, and specific deterrent patterns, were systematically derived to meet the project's core objectives of portability, efficiency, and ethical operation.

The resulting design successfully translates user needs into a robust and practical engineering solution. Through a structured approach from requirements analysis to planned acceptance testing, the Predator Deterrence Subsystem is poised to offer a significant contribution to conservation efforts. Future work will involve comprehensive field testing to validate long-term durability and effectiveness, paving the way for potential refinements and broader deployment in protecting at-risk species.

Chapter 6

User Interface Design : Mukundi Mangena : MNGBLE005

Subsystem Github Link : https://github.com/mukundimangena/PenguinCo

6.1 Subsystem Introduction

The challenge of predation in the newly built penguin sanctuary is very prevalent. In this paper we have been looking at possible solutions to deter predators specifically penguins, baboons and leopards.These predators make it challenging to keep and grow a new colony of penguins.Despite the installation of security cameras and fences the predators keep devising ways to breach these securities.This means we required more intelligent methods to deter the predators.

IN chapters 1 and 2 we designed a detection and deterrent system that would probably be effective working by themselves , however despite these efforts this system lacks a realtime responsiveness and provision of actionable data that could be used to save the colonies and design better systems. There is a big need for a remotely accessible user interface that will provide colony managers with live alerts and data to help them manage .

In this subsystem there is a proposal of the development of a user interface dashboard that could potentially be used as a remote monitoring tool and a hub of control that will be added to the arsenal of the scientist to aid their predators deterrent efforts.This UI will provide real time alerts , system trigger logs,data visualization and offer remote access and control of the deterrent system that are available.

The goal of the user interface is to support the staff managing the colony to get actionable insights about the state of the colony in a timeous manner and make it as user friendly to allow for intuitiveness in the controls offered.This system will hopefully enhance the efficiency and effectiveness of penguin conservation measures being taken.

6.1.1 Requirement Analysis

The main goal of this subsystem is to develop a UI dashboard that empowers conservation scientists to monitor,control and analyse performance of a predator deterrent system designed to protect African penguin colonies. the system should be able to facilitate remote interactions with on-site deterrent hardware. It should provide real-time situational awareness and support long term ecological data collection.This section specifies criteria that is required for the acceptable features of the system. These acceptance tests will be used as design guidelines and points of reference in the design process of the system.The specifications should cover both functional and non-functional specifications so that the design of the UI is both functional and easy to use for a first time user.

Functional Requirements

FR ID	Functional Requirement
FUR-1	The user interface must display motion detection alerts, including zone location, timestamp, and triggered deterrent response.
FUR-2	The user interface must allow authorized users to remotely activate and deactivate the acoustic deterrent system for specific zones.
FUR-3	The system must maintain an event log of all predator detections and deterrent activations, accessible via the UI.
FUR-4	The interface must visualize colony zone-specific data using maps and graphs.
FUR-5	The user interface must provide access to historical data.
FUR-6	The UI must authenticate users through secure login credentials and restrict access to non-registered users.
FUR-7	The interface must support remote diagnostics by displaying the operational status of each sensor and deterrent device.
FUR-8	Users must be able to export system logs and zone activity reports as downloadable CSV or PDF files through the interface.
FUR-9	The UI must support live synchronization with the sensor and deterrent subsystems.
FUR-10	The interface must show battery health of the system
FUR-11	The interface must be designed with a clean, intuitive layout that accommodates both desktop and tablet-sized screens.

Table 6.1: Functional Requirements for the Predator Deterrent System UI Subsystem

Non-Functional Specifications

SP ID	Specification	FR ID	ATP ID
UIS-1	Human-Centered Design of User Interface	FUR-11	ATP-7
UIS-2	Remote Activation and Control Capability	FUR-2	ATP-2
UIS-3	Secure Login and Access Management	FUR-6	ATP-2
UIS-4	Real-Time Event Logging and Alerts	FUR-1, FUR-3	ATP-4
UIS-5	Data Visualization Tools	FUR-4, FUR-8	ATP-4

Table 6.2: Non Functional specifications and their associated FUR and Acceptance tests

Functional Specifications

Acceptance Tests

6.1.2 Design Process and Choices

[25] defines Human Centered design as, ‘A process and a set of techniques used to create new solutions for the world. Solutions include products, services, environments, organizations, and modes of interaction. The reason this process is called “human-centered” is because it starts with the people we are designing

SP ID	Specification	FR ID	ATP ID
UIS-1	Display real-time motion alerts to notify scientists of predator activity.	FUR-1	ATP-1
UIS-2	Log all system activities, sensor events, and deterrent activations in a system log.	FUR-3	ATP-2
UIS-3	Allow authorized users to activate or deactivate the deterrent system remotely.	FUR-2	ATP-3
UIS-4	Present graphical data (charts/graphs) of past predator events and deterrent usage.	FUR-4	ATP-4
UIS-5	Enable secure user login and restrict access to authorized personnel only.	FUR-6	ATP-5
UIS-6	Provide an option to download historical system logs and event data.	FUR-8	ATP-6
UIS-7	Provide easy navigation with clearly labeled menus and visual cues.	FUR-10	ATP-7

Table 6.3: Functional Specifications for the UI Subsystem

for.' The user interface was designed with the end user in mind therefore Human centered designed was implemented and considered in all the design processes of this system.

Technology Stack

There are various ways to develop a user interface, ranging from pre-built UI/UX frameworks such as WordPress to fully customized front-end development. For this project, the objective was to meet requirement FUR-11 6.1: to deliver a presentable, easy-to-use, and maintainable UI that can be easily understood and updated by future developers.

The first approach explored was building the UI using standard web technologies: HTML, CSS, and JavaScript. This method is well-established, widely supported, and has extensive online documentation. It provided full control over the interface and backend integration. However, it also required manually managing multiple files, which can slow development. Furthermore, JavaScript, being single-threaded and lacking standardization across environments, can lead to inconsistent performance.

A second approach involved using a more modern stack comprising React.js for the front end, TypeScript for type-safe development, and MongoDB for the database. React's modular structure allows for scalable and reusable components, while TypeScript enhances code reliability through static type checking. MongoDB, a flexible NoSQL solution, enables quick setup and is well-suited for lightweight deployment environments. This prototype offered several development advantages but added complexity and external dependencies.

The final design adopted a hybrid and pragmatic technology stack that balanced performance, simplicity, and ease of development. HTML and Tailwind CSS were used for the frontend to create a clean, responsive, and modern user interface. FastAPI was chosen for the backend due to its simplicity, speed, and ability to efficiently build RESTful APIs. SQLite was chosen in the earlier development phases however its lack of multi-threaded performance limited its performance .In the final prototype postgresSQL allowed for a better performance when querying the database from the local environment. JavaScript was employed to add interactivity and client-side logic to the application. This configuration

ATP ID	Test Procedure	Success Criteria
ATP-1	Simulate predator motion near the sensor. Check if alert is displayed on the UI in real-time.	Alert is shown with an accurate timestamp and location.
ATP-2	Trigger system events (e.g., motion detection, deterrent activation) and verify that logs are stored in the UI event log.	All events appear in the log with correct type, time, and status.
ATP-3	Log in as an authorized user and toggle the deterrent system on/off via the UI controls.	The deterrent activates/deactivates as expected, and status is updated live.
ATP-4	View the 'Event Analytics' section of the UI. Upload sample event data.	Graphs render correctly showing predator detection counts, deterrent activations, and trends.
ATP-5	Attempt login with correct and incorrect credentials. Try accessing data without login.	Access is only granted to authorized users. Unauthorized attempts are denied with a message.
ATP-6	Use the UI to download event logs in CSV format. Open and inspect file content.	File downloads successfully with readable, complete event data.
ATP-7	Navigate through the UI dashboard, menu buttons, and page transitions.	Navigation is intuitive with clear labeling. No broken links or layout issues.
ATP-8	Use date and event type filters on the historical data page. Submit filtered search.	Data table updates with filtered results. No irrelevant entries are shown.
ATP-9	Perform multiple UI actions in rapid succession (view alert, check log, download file).	UI responds to each action within 2 seconds with no lag or errors.
ATP-10	Navigate to the livestream feature of the application and start a livestream.	A livestream should show on your user Interface that is acccurate to your camera.

Table 6.4: Acceptance Test Procedures for the UI Subsystem

allowed for local development and testing without relying on external infrastructure. FastAPI manages backend operations and interacts with the database, while sensor data is transmitted via HTTP requests to update the UI in real time. In future iterations, the system will be deployed on a hosted server and integrated with the physical infrastructure, using FastAPI to receive and display live data from micro-controllers. This tech-stack allows the system to meet FUR-11.

Data Transfer Protocols

There are multiple ways to connect databases with physical micro-controllers on the ground.The detection and deterrent system uses a combination ESP32 and ESP-32 camera modules to control the physical systems. Therefore to successfully implement FUR-1 to FUR6 ,UIS-1 to UIs-3 the user interface requires a way to connect with these micro-controllers[MC] and remotely share data between the systems.

There are multiple solutions available to communicate from MC's to websites however a solution for this had to fit within the technology stack that was chosen.The first approach was using a direct database connection approach using ESP32 modules such as MySQL_Connector_Arduino that enables the MC to share information about the system by updating the database. The UI would in turn update its data dependent on the updated database information.

The second approach to solve the data transfer issues was using an HTTP REST API that would send a @POST request to the web server that will in then update the database through python Fast-API.This Approach enables an easier setup and implementation and can allow sending of data in JSON format that would allow for easier integration with a web-based UI solution.An example HTTPS POST request would look like below. This solution was chosen because of its ease of implementation , scalability and

```
POST /api/data
{
 "timestamp": "2025-05-22T13:45:00Z",
 "device_id": "penguin_cam_01",
 "event": "honey_badger_detected",
 "location": "nest_area_north"
}
// POST request to send data
```

Figure 6.1: Enter Caption

ease of testing.However it has to be over HTTPS to be secure this was not of much importance in the testing phase as the system was tested on a local machine.This ended up being the data transfer method of choice.

System Login and Security

A secure system is always required for a user interface of this type.The data shared on the system is sensitive as the moderators of the software would have their data present on the system and to ensure that the users that login to the system are registered users the login has to be robust.

HTTPS was considered for password and login protection.This method ensures secure data transmission and protect user credentials from interception.However an SSL certificate would have to be acquired and set up. This implementation would be best for when the system goes into production.

The second option was using a lightweight approach that uses a database that contains the user login information.The database would contain hashed passwords using a Hashing key , this way the user information would be protected and in the case of a system breach the personal information would still be protected.This password security method was implemented using python such as CryptContext that are lightweight but do a good job in securing user information in case of a database breach.

6.2 System Final Design

The final system that was designed is called PenguinCo which is a web-Based application that is designed using HTML and Tailwind.css with JavaScript for the responsiveness of the Website. The Backend uses a python Web framework FastAPi that allow for fast integration of web based application to have good functionality and support the backend.

User Login

The final user interface was designed as a webApp created using HTML and Tailwind.css for the front-end , it uses FastAPI for the backend interacting with a postgreSQL database.The User interface was designed to give a modern feel in its look following the [26] google's material guides . This design style was chosen to ensure that the end user experiences familiarity with other dashboard's they may have used before that follow [26]. These design decisions include the use of clearly marked sidebars , drop-down menus and cards to display important information about the system. The design principles for the system also followed Nielsen's design heuristics [27] which lays out do's and dont's of designing products. An example of how these heuristics were used is the in showing the battery status and intrusions data of the system as shown in the image below.

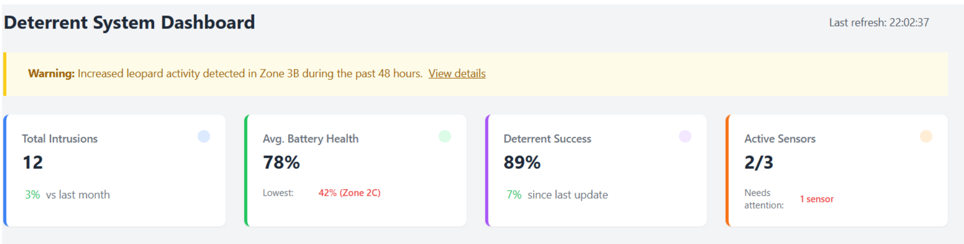


Figure 6.2: Example showing the implementation of Nielsen's design heuristic

The application was run on a local machine and saved the user information in an SQLite database. The user information was accessed by using a FastAPI protocol to authenticate users. To ensure that the users are informed whenever a wrong input is fed into the system the authenticator search in the database and if the username and password pair do not match then the user is notified of the failure to access the system.Functionality of the login page was tested and it was not possible to access the webpage data without the correct credentials. **This means that the ATP-5 was met** .

The system is split into 5 pages. A home page that will serve as a landing page for the users of the system , A live-feed page , this will allow the users to gain access to the different cameras around the vicinity of the the colony perimeters , a notifications tab which will contain the recent notifications of the system , a systems log which will be the most important as it will contain all the different components and data about the system. The page will also contains a settings page to enable control for the user and adding more users to the system and other system crucial settings.The combination of these pages make up the complete system.The functionality of the responsiveness was tested to meet **ATP-7 and ATP-9** which require the smooth functionality of all the buttons and feature of the system.

Data Visualization

The visualization of data tools were both simulated and real-time data. Simulating the data allowed us to have a proof of full concept and because the code is modularized adding more real-time data is a matter of updating the databases and the outputs of the system will change.To visualize the data the system uses a combination of JavaScript charting library Apex chart and a database updated from the micro-controllers. The charting function will give the UI a modern feel and a more intuitive way of seeing the data.Below are the example of a the system dashboard that uses a combination of pie charts

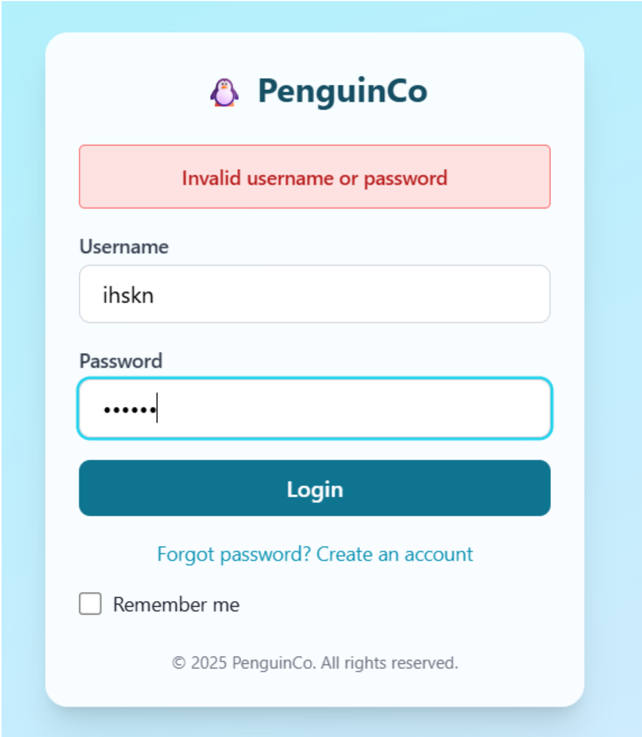
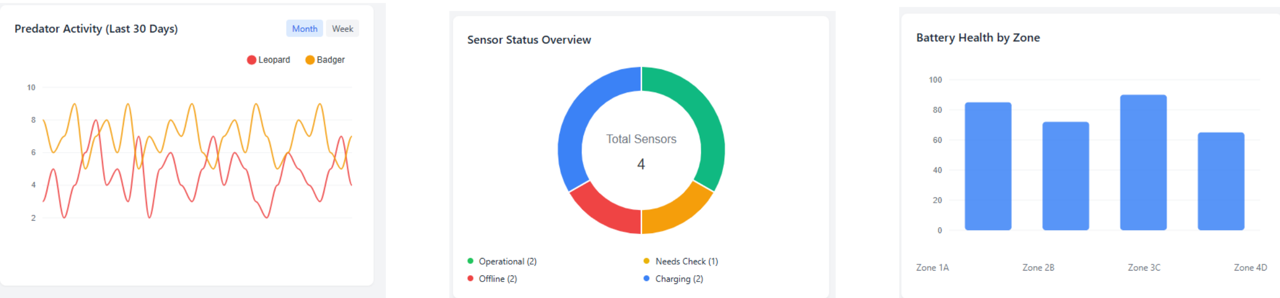


Figure 6.3: Login page password safety

, bar-graphs and line-graphs to represent the data in the back end of our system.



(a) Line Chart (b) Pie Chart (c) Bar Graph

Figure 6.4: Different Data presentation methods used in the UI

The system also features a Map feature that places virtual boundaries to give the user a view of the location of the colonies.This feature is very important as it gives a good perspective onto which sections may be facing more challenges and action may be taken.It is also important in the case that the colony grows and the system is extended into larger areas of land then this feature can be used to its maximum potential. This section of the UI was tested by **using ATP-4** that required the graphs to render data correctly. This ATP was met but not entirely because not all the Graphs show accurate depiction of real data but some show dummy data that is good for showing a good proof of concept.

Notifications

The system has multiple ways of notifying the user of intrusion or a deterrence of the system. Notifications are shown in the form of pop-up Notifications and full scale notifications. These were

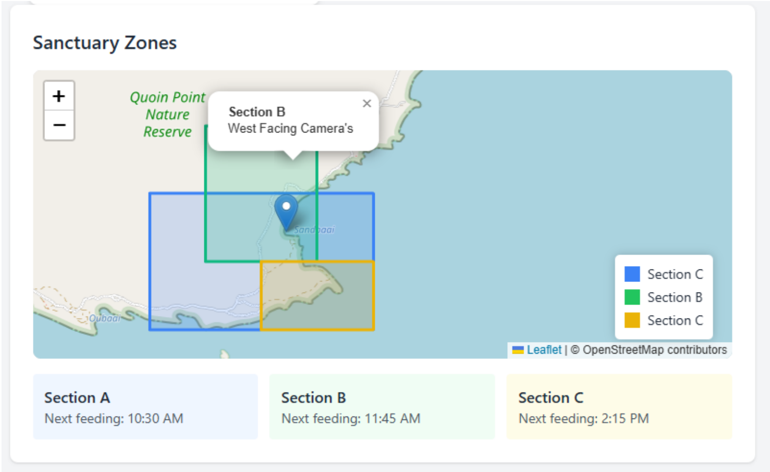


Figure 6.5: Map Showing the location of our sanctuaries

implemented by creating a database table that is updated by the systems that are on the field in case of an activity happening using a @POST decorator in the API. When the database is updated the system would then update its notifications as is in the database.

The web-app has a separate page for system notifications however smaller page real estate is taken on each page to show notifications as they are crucial to the updating the state of the system. The

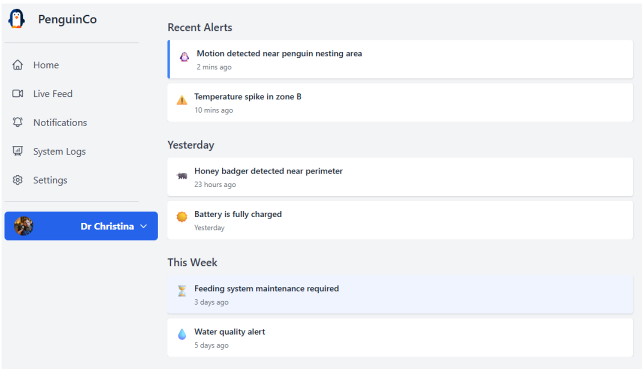


Figure 6.6: Notifications page

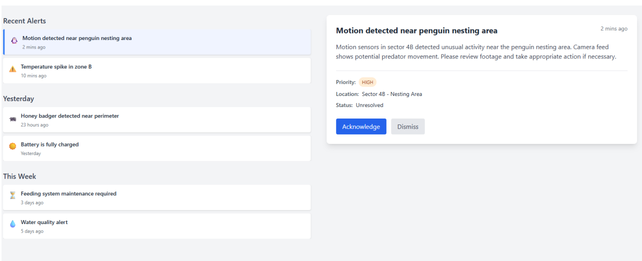
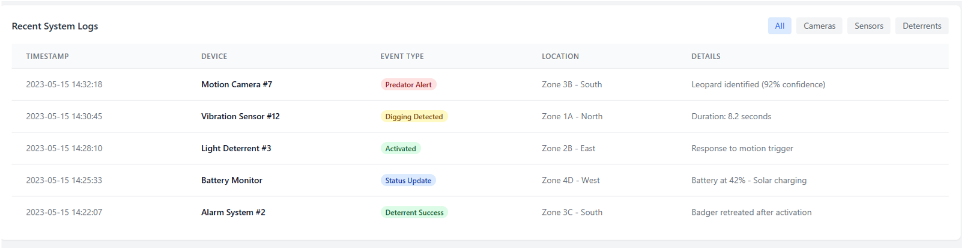


Figure 6.7: Full notifications showing

notifications section of the Application contains most of the functional requirements and specifications meaning its functionality is critical . The notifications were evaluated by using ATP-1 ,ATP-2 and ATP-6.Testing for these ATP is dependent on the correct functionality of the deterrent system. Testing for the functionality of the Notifications was achieved by setting an ESP32 to send notifications through


Recent System Logs

All Cameras Sensors Deterrents

TIMESTAMP	DEVICE	EVENT TYPE	LOCATION	DETAILS
2023-05-15 14:32:18	Motion Camera #7	Predator Alert	Zone 3B - South	Leopard identified (92% confidence)
2023-05-15 14:30:45	Vibration Sensor #12	Digging Detected	Zone 1A - North	Duration: 8.2 seconds
2023-05-15 14:28:10	Light Deterrent #3	Activated	Zone 2B - East	Response to motion trigger
2023-05-15 14:25:33	Battery Monitor	Status Update	Zone 4D - West	Battery at 42% - Solar charging
2023-05-15 14:22:07	Alarm System #2	Deterrent Success	Zone 3C - South	Badger retreated after activation

Figure 6.8: Trigger event notifications from the system

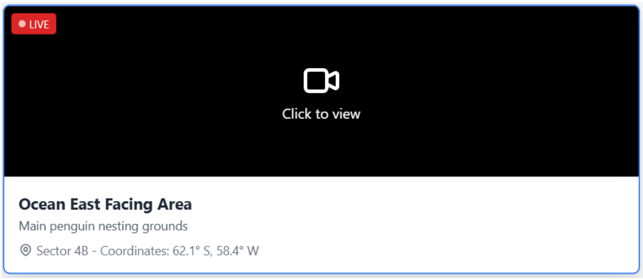


Figure 6.9: Live-stream Feed

the API endpoint at a 30 second interval. ATP1 and ATP-2 passed however ATP-6 did not pass as there was no feature that allowed for downloading data into a CSV format. This specification can be added as a feature in a future iteration of the application to complete the design iterative process.

Livestream

The site of the system has wifi and internet access available meaning video packets can be shared with the webBased system.To enable this livestream feature we use an ESP32 cam module and the motion JPEG over Https.This method captures JPEG frames and serves them via web server and the users would be able to view the stream in a web-browser. The ESP32-CAM's web server is then embedded in the html code to view the livestream in the website. This method works well however is not a suitable permanent solution this is because of the security issues that are exposed by HTTP and how slow it is to render images

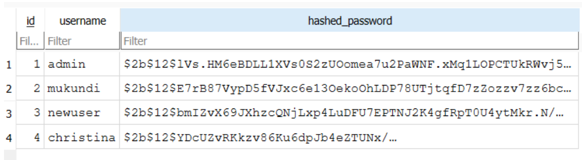
Databases choices and updating databases

The initial solution for databases was sqlite3 , this choice was made because of its seamless integration with fastAPI and how you can implement on the local machine with minimum setup requirements.However at a later development stage it became clear that it was not the best option due to its single-threaded feature .Mid-Development the system had to be migrated to a more capable PostgreSQL.There are 3 main tables in the Databases which is the user Table , notifications database and the sensorData table. The user database contains the login details of each of the system users.The database is secure since the information in the database hashes the user passwords. To update these tables fastAPi was used through its route decorators. It will update the users be either using the backend injection of the user data or through the UI login page to create an account.

The notifications database is updated by the data coming from the esp32 micro-controllers. These modules send text files that are processed using python fastapi services and the python module would

```
# create_user.py
from models import Base, User
from database import engine, SessionLocal
from auth import hash_password

Base.metadata.create_all(bind=engine)
db = SessionLocal()

# Add new users here
users_to_add = [
    {"username": "christina", "password": "Christina123"},

]

for user_data in users_to_add:
    if not db.query(User).filter(User.username == user_data["username"]).first():
        new_user = User(
            username=user_data["username"],
            hashed_password=hash_password(user_data["password"])
        )
        db.add(new_user)
        print(f"User {user_data['username']} created successfully")
    else:
        print(f"User {user_data['username']} already exists")

db.commit()
db.close()
```

(a) Adding user through FastAPI



	id	username	hashed_password
	Fil...	Filter	Filter
1	1	admin	$2b$12$lVs.HM6eBDLL1XVs0S2zUOomea7u2PaWNF.xMq1LOPCTUkRWvj5…
2	2	mukundi	$2b$12$E7rB87VypD5fVJxc6e13OekoOhLDP78UTjtqfD7zZozzv7zz6bc…
3	3	newuser	$2b$12$bmIZvX69JXhzcQNjLxp4LuDFU7EPTNJ2K4gfRpT0U4ytMkr.N/…
4	4	christina	$2b$12$YDcUZvRKkzv86Ku6dpJb4eZTUNx/…

(b) User Database example

then update the database with the data it has gotten from the **@post** route decorator file.Once the database is updated that webApp updates the notification tab with the updates.

6.3 Results and Recommendations

The goal for this subsystem is to give a toolset to the scientists to aid in their conservation attempts. Giving them enough toolsets to be able to visualize and get updates of what is transpiring at the vicinity of the penguin enclosures.The UI subsystem successfully implements most of the functional requirements mentioned in the table 6.1. Below is a table of ATP outputs that shows how this subsystem has met the system requirements.

6.3.1 Recommendations

Most system specifications are met with this design. The user interface functions as intended, giving scientists access to multiple features and displaying data intuitively. However, the system is not without limitations.

SQLite3 is challenging as a permanent solution , this is because it does not allow multi-thread execution. This means a @post and @get query to will not work if any of either are functioning . To solve this issue in the implementation we resolved to separating the database calls and setting database call timeouts. This enabled data access from the database however it still left some operations not functioning in real-time. A better solution would be using MYSQL or postgreSql which allow multi-threaded functionality.

The live-stream feature would benefit from a more capable camera. The ESP32-CAM is underpowered and lacks onboard memory, leading to significant display lag and no data retention.

To enhance security, the interface should implement an HTTPS certificate to protect transmitted data, including video streams, from interception by malicious actors.

Future iterations should include remote triggering functionality to give users full control and autonomy over the system.

6.4 Conclusion

Dissuading honey badgers is a challenging task. Many deterrent systems fail due to a lack of immediate impact on the predators. While combining detection and deterrence is necessary, it is not sufficient—making the user interface a crucial component.

PenguinCo, the developed UI, equips scientists and sanctuary caretakers with tools and insights to better understand and manage threats. By integrating the detection and deterrence subsystems and presenting relevant data clearly, this UI meaningfully supports conservation efforts and the broader goal of protecting endangered penguins.

ATP ID	Test Procedure	Result
ATP-1	Simulate predator motion near the sensor. Check if alert is displayed on the UI in real-time.	**Pass** : When motion is detected by the detection system it sends a json through a route decorator and the user interface updates to show activity on the UI in the form of notifications.
ATP-2	Trigger system events (e.g., motion detection, deterrent activation) and verify that logs are stored in the UI event log.	PASS : The database is updated when the detection system detects the presence of a badger.
ATP-3	Log in as an authorized user and toggle the deterrent system on/off via the UI controls.	Pass: The UI is inaccessible when using unkown login credentials. shown in image 6.3
ATP-4	View the 'Event Analytics' section of the UI. Upload sample event data.	Partial Pass : The graphs render correctly however the amount of data is not enough to create more meaningful graphs.Some of the graphs have dummy data.
ATP-5	Attempt login with correct and incorrect credentials. Try accessing data without login.	Access is only granted to authorized users. Unauthorized attempts are denied with a message.
ATP-6	Use the UI to download event logs in CSV format. Open and inspect file content.	Fail : The data download functionality failed. This feature could be added in a future iteration.
ATP-7	Navigate through the UI dashboard, menu buttons, and page transitions.	Pass: There is a clear flow between the different pages of the user interface and the design follows guidelines by [26]
ATP-8	Use date and event type filters on the historical data page. Submit filtered search.	Fail : The data filter function does not work however the data is presented in chronological format.
ATP-9	Perform multiple UI actions in rapid succession (view alert, check log, download file).	Pass : The UI functions as intended
ATP-10	Navigate to the livestream feature of the application and start a live stream.	Partial Pass : The livestream functionality works but the delay is so much that using pictures is a better solution.The camera probe also became erronous before further testing and testing of more possibilities.

Table 6.5: Acceptance Test Results

Chapter 7

Conclusions

The purpose of this project was to design and develop a functional, non-lethal system to protect endangered African penguin colonies from predators, particularly the highly adaptable honey badger. This report details the comprehensive approach taken, from understanding the problem to proposing a multi-faceted technological solution.

This report began with an extensive literature review6, which examined a wide array of existing deterrent systems, including visual, acoustic, chemical, and physical barriers. This review looked into the common challenge of predator habituation to non-lethal methods and the need for adaptive, integrated solutions. Following the literature review, the core of the project involved the design and prototyping of three interconnected subsystems.

The first subsystem was the **Predator Sensing Subsystem** 4 , which was developed to provide reliable, early-warning detection of approaching threats. It incorporates sensor fusion approach, integrating five distinct sensor types—microwave radar (RCWL-0516), Passive Infrared (HC-SR501), vibration (SW420), ultrasonic (HC-SR04), and temperature (TMP102)—processed by ESP32 microcontrollers. This multi-sensing strategy, coupled with an ESP32-CAM for visual verification, aims to minimize false positives and accurately identify predator presence while operating under challenging coastal conditions with low power requirements.

The **Predator Deterrence Subsystem** acts as the active defense mechanism, triggered by the sensing subsystem. It employs a combination of non-lethal visual (high-intensity flashing LEDs) and acoustic (variable frequency sounds) deterrents orchestrated by an ESP32 microcontroller. The design focused on creating unpredictable stimuli to reduce predator habituation, ensuring the deterrents are weatherproof, portable, power-efficient, and harmless to both predators and non-target species like penguins.

The **User Interface (UI) Subsystem**, 'PenguinCo' was developed as a web-based dashboard to provide conservation scientists with real-time monitoring, event logging, data visualization, and remote system status insights. This UI aims to enhance the efficiency of colony management by providing actionable data and a centralized hub for system interaction.

In summary, the project successfully achieved its goals by designing and demonstrating an integrated system comprising sensing, deterrence, and user interface components. This system offers a novel, humane, and technologically advanced approach to mitigating predator threats to African penguins, thereby contributing to their conservation. The modular design allows for future enhancements and adaptation to specific site requirements, providing a solid foundation for a practical and effective conservation tool.

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Graduate Attributes Table

	Graduate Attribute	**Description**
PHRANN001	GA 3	Sensing System4
	GA 7	D-School, Sensing System4
	GA 8	See Teams group meeting minutes
	GA 10	All submissions, activities including final report and presentation.

	Graduate Attribute	**Description**
MNGBLE005	GA 3	UI System
	GA 7	D-School, UI System
	GA 8	See Teams group meeting minutes
	GA 10	All submissions, activities including final report and presentation.

	Graduate Attribute	**Description**
SMLPRA001	GA 3	Deterrent System
	GA 7	D-School,Deterrent System
	GA 8	See Teams group meeting minutes
	GA 10	All submissions, activities including final report and presentation.