Group 27
Literature Review

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August 16, 2024

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Date

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Jake Wesselink

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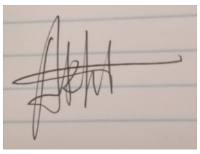

August 16, 2024

Akhtar Patel

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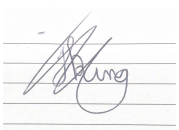

August 16, 2024

Josh King

Date

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Chapter 1

Introduction and Problem Analysis

What do you call a Hornbill in the Arctic?

-Lost!

1.1 Background

This project was launched with the aim to aid researchers from the University of Cape Town (UCT) in their quest to study the Southern Ground Hornbill in the Kruger National Park. As of 2018 these birds are listed as 'vulnerable' with a decreasing population per the International Union for Conservation of Nature [1]. This is due to ongoing habitat destruction and climate change affecting their breeding cycles and success rate.

These birds live in groups ranging from 5-10 individuals and display cooperative breeding habits meaning that a dominant breeding pair will be assisted by the other individuals in the group. Naturally, these birds make nests in the hollowed-out trunks of trees. Due to the limited number of adequate natural nest sites, researchers and conservationists have created artificial nest boxes as seen in figure 1.1.

Figure 1.1: Artificial Nest Box

Currently, only weight data is gathered for the chicks as they can be physically removed from the nests and manually weighed. However, to determine the effect of the changing climatic conditions on the health of the population, weight data of fully grown individuals is needed.

1.2 Problem Statement

Carrie Hickman, an ornithologist at UCT studying the Southern Ground Hornbill in the Kruger National Park for her Ph.D., requires a system to gather weight data on individual birds to determine how temperature and food availability are affecting the health and condition of the birds. The Southern Ground Hornbill is listed as an endangered species, and therefore this research is critical to their conservation.

1.3 Objectives

The objective of this project is to design a scale system that can accurately record the weights of the Hornbills while noting the time, day, individual bird, and temperature. This needs to be a system that is integrated into the existing nest boxes and can be fully autonomous as the researchers only visit the sites every few weeks. From these objectives, four subsystems were outlined, each to be completed by one of the group members involved.

1.4 System Requirements

The following general system requirements were outlined from interviews and discussions with Carrie Hickman, and the objectives and problem statement outlined above.

The system must be able to:

- Accurately record the weight of individual Ground Hornbills.
- Record the time, day, and temperature when weight readings are taken.
- Save this data for later wireless transmission to the researcher to ensure as little interference with the birds as possible.
- Operate on a battery system that can last for up to 1 week at a time.
- Function in the climatic conditions experienced in the Kruger National Park year-round.

1.5 Scope & Limitations

The project has the following scope:

- To aid in the research on the Southern Ground Horbill population in the Kruger National Park by recording accurate weight data of grown individuals.
- To do this by creating an autonomous scale, that can record and wirelessly transmit the data, while operating for a period of up to 1 week without human interference.

The project had the following limitations:

- A budget constraint of ZAR 2000, covering all aspects of the project.
- A time limitation resulting in the deadline for submission being 12 May 2024.

- A constraint as to which third-party suppliers were available to order components from and the time by which the order had to be completed.
- A constraint as to how the components required were to be ordered through UCT, resulting in a time constraint as components took weeks to be ordered and then arrive.
- The constraint in the gathering of information, as Microsoft Teams was used and relevant stakeholders would take days to reply, and access to the existing next boxes was unavailable due to the project being conducted in the Kruger National Park.

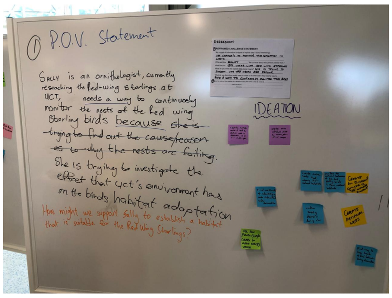
1.6 Report Outline

This report begins with Chapter 2, where the time spent at the Design School is discussed. Chapter 3 contains the literature review, which outlines the background information needed for each subsection to be fully conceptualized and then designed. Chapter 4 presents an in-depth explanation as to how the scale was designed and built, and then integrated into the existing nests. Chapter 5 goes on to detail the microcontroller operations, including the sensing, processing, and storage of data and identification of individual birds. The power subsystem is then described in Chapter 6, outlining the mechanisms required to ensure the system can last for the designated period of time while operating in the field. To complete the subsystems, Chapter 7 provides a detailed account of the Graphical User Interface that is to be used in conjunction with the scale system, increasing the efficiency and usability of the entire design and incorporating remote data retrieval functionality. Finally, Chapter 8 outlines the conclusion to the project, defining the recommendations for the improvements that should be made for the subsequent design iteration.

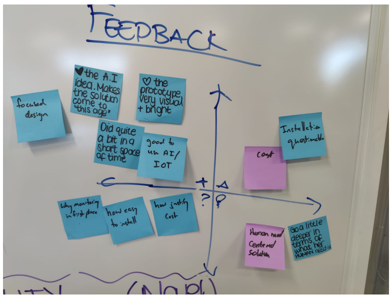
Chapter 2

Design School

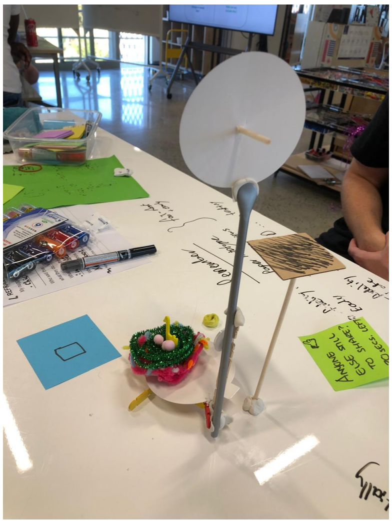
The first four Friday afternoons of the semester were spent at Design School where we learned the basic principles of a design project. We engaged in teams to complete weekly tasks. We engaged with stakeholders and heard their research tasks from which we deduced a problem statement. Using creativity to solve problems helped the team to engage to expand our horizons beyond the technicalities of engineering. The design thinking process led us through the steps of empathizing an idea, defining its potential, and ideating it in the weirdest most wonderful ways. The concepts of prototyping, testing, and implementation were then discussed at length to aid in the upcoming project. The time at the Design school was a great experience and a well-needed to jump-start the design project.



(a) The problem statement our group deduced.



(b) The feedback we got.



(c) The prototype we built.

Figure 2.1: Design considerations and prototype for the project.

Chapter 3

Literature Review

3.1 Introduction

Gathering accurate weight data on bird species is a task that has long since troubled ornithologists. This data is however essential for their research as it can provide a lot of information pertaining to the health of the individual, and the population at large if sufficiently many individuals are weighted in a population. This information may also give indications as to how the ever-changing climatic conditions are affecting the health of the species and the availability of the bird's food sources. This research could then help inform decisions around conservation efforts and habitat protection.

In the past, multiple techniques to identify and weigh individual birds in a population have been developed, all with advantages and limitations. The following will unpack some of the techniques that have been previously implemented to correctly identify individuals, as well as how their weight data has been collected. The techniques explored range from older more traditional approaches to new-age innovations that rely heavily on the advancement of technology and the benefits that come with it. For the newer novel solutions, techniques such as data transmission and storage, as well as power solutions and digital control will also be investigated. This is all to place the solution for the problem statement outlined above in the context of the project pitched by the Fitzpatrick Institute.

3.2 Individual Bird Identification Techniques

Ornithological research relies heavily on the ability to identify individual birds in a population to better understand movement patterns, mating habits, and general avian behaviour. To this end, Ornithologists have developed techniques to tag and monitor birds. With the advancement in technology, some of these techniques have become modernised while others have remained simple but effective. Techniques such as Radio Frequency Identification (RFID), GPS tracking and barcode tags with camera software used to recognise the codes have made data gathering of wild animals more effective at the cost of simplicity. Camera traps and visual tags, being the older forms of animal identification, are cost-effective and simpler solutions. The following aims to explore these different forms of animal tracking, with a focus on wild bird populations, outlining the potential benefits and pitfalls of each in the context of this research.

3.2.1 Camera Traps

Camera traps have become invaluable to wildlife documentation, especially for rare and elusive birds. Since their inception in the 1980s, automated camera traps have proved to be a useful tool in the conservation efforts of many ornithologists[2]. One of the primary applications is nest monitoring. This can yield information on predation rates and predator types, mating success rates, bird behaviours, and mating patterns. These camera traps have also been used to determine population size and stability. As outlined by O'Brien and Kinnaird, 'if it is possible to mark a subpopulation of birds (C), using collars or patagial wing bands for example, then camera traps can be used to estimate abundance (N) using mark-resighting models'[2, p.6]. When placed at feeding sites, these traps can also provide information on inter-species interactions and feeding behaviours.

The versatility of these camera traps is what sets it apart in wildlife research. They have been effectively used to monitor the shyest of animals, even in some of the most challenging environments (eg. tropical forests). According to O'Brien and Kinnaird, 'camera traps offer great potential for improving our understanding of terrestrial forest birds and moving research on rare and cryptic birds'[2, p.16].

Many considerations need to be met when selecting the type of camera trap. Trolliet et al. insist that 'characteristics such as trigger speed, detection zone, recovery time, night detection and battery consumption can vary greatly and have a significant impact on the types of data to be collected, such as the number of species detected and photographic rates' [3, p.3]. Improvements in night-vision and infrared cameras have enabled the documentation of nocturnal animals, as well as the nighttime behaviours of non-nocturnal animals [4]. Flash photography is usually not used due to the animals being scared by the flash, especially at night. These criteria must be considered when purchasing a camera for use based on the needs of the user. Trolliet et al. advise on the following being paid close attention to: picture resolution, camera cost, power availability, and battery consumption [3].

3.2.2 Visual Tagging

Tagging individual animals has become a common practice in most ornithological studies. The type of tag used varies greatly between different studies but the underlying principle of individual recognition remains constant. Types of tags used include RFID chips, GPS tracking chips, barcoded tags, coloured bracelets, and numbered tags. Each has its advantages and the type used must simply be the most compatible with the study's needs.

Coloured Bracelets and Numbered Tags

Coloured bracelets and numbered tags produce essentially the same outcome when it comes to the monitoring of bird species. In both, the individual has a personalized code that needs to be visible to the observer. Davis et al. conducted a study on novel tracking and reporting methods for studying large birds in urban landscapes using numbered livestock ear tags[5]. The study relied on third-party participation where residents of the city were encouraged to report sightings. The tag retention was determined by the number of sightings reported and calculated at 95% throughout the four-year study[5].

This form of tagging proved to be successful judged on the tag retention rate. Tags of this nature therefore provide a cheap and effective means to identify individual birds in a larger species. However, they require a monitoring system whereby sightings can be logged and recorded. This therefore could be used in conjunction with a camera trap system whereby photographs are taken of each bird that can then later be identified.

Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) technology, as introduced by Bridge et al., has transformed biological sciences by enabling the monitoring of individual animal activities in both field and controlled settings [6]. An RFID data-logging system allows researchers to track animals equipped with RFID tags wirelessly. It offers a customizable platform for a wide range of applications. The system operates through wireless communication between RFID tags and readers, emitting unique ID signals when stimulated by radio frequency transmissions. Its versatility enables adaptation to different research needs through hardware and software customization. As put by Bridge et al., 'RFID can be effectively employed in automated, remote sensing systems, with stationary readers that record specific animal activities, such as accessing a food source or nest'[6, p.2].

Bridge et al. outlines three real-world adaptations of an RFID system to monitor and gather data on bird populations. The first is a large-scale deployment to examine breeding behaviours in Wood Duck populations in America. Here 200 nest boxes were tagged with RFID systems to determine how females moved between nests during the mating/gestation periods. The second was an experiment to determine avian spatial cognition. Here birds were equipped with RFID chips uniquely linked to a certain bird feeder that would only open once they landed on it. The goal was to determine if the birds would return to the same feeder consistently. The third, similar to the first was a nest-box monitoring system to determine breeding birds' movement behaviours[6].

From this, it can be seen that RFID systems can be used for a variety of project types. They are a cost-effective solution to attaining the movement patterns of animal species[7]. A limitation of this system is that no footage is captured of the species being monitored, and if this were a requirement of the project, an RFID system would have to be used in conjunction with say a camera trap system.

Barcode Detection

Alarcón-Nieto et al. developed an automated barcode tracking system for behavioural studies in birds. In the study, two populations of birds in aviaries were fitted with barcodes attached to them through a small backpack strap. These populations were then monitored via a video camera and processing system that allowed for automatic identification [8]. These straps were designed carefully to ensure they caused the birds no harm yet allowed for the barcode to be visible at all times. Video analysis allowed the research group to monitor the birds' general behaviour throughout the 7-month study.

This study aimed to ascertain whether this form of tacking would be feasible in enclosed and urban habitats. Determining factors in this regard are barcode size, ensuring sufficient resolution to ensure accurate detection and recognition, and then camera factors such as lens distortion, depth of field, and shutter speed[8]. All of these factors determine the effectiveness of the research.

The backpack system proved to be a viable solution to identifying urban bird behaviours. The system was durable and with different camera set-ups, different data could be collected. According to Alarcón-Nieto et al., 'this system presents several advantages to more commonly-implemented method' [8, p.11], these most notably being, 'it is adaptable to different contexts and research questions, being possible to vary the temporal resolution (photos or video) and the area covered without requiring any additional markers to birds'[8, p.11].

Identifying individuals in a flock of birds will forever be a task that ornithologists will have to undertake. The systems discussed above demonstrate a few of the techniques that have been developed. The simpler tagging methods such as coloured bracelets and cattle tags offer a cheaper solution to the more complex solutions such as RFID chips and barcode backpacks that could be used to attain more complex behaviours with less human involvement but at the cost of complexity. All systems would benefit from having camera traps involved in the data-gathering process and some fully rely on it, making camera traps one of the most popular forms of bird surveillance. All in all, the choice of which system to use falls on the researcher's needs and technical abilities and this will guide them to the solution that works best for them.

3.3 Southern Ground Hornbill Behaviour

Wildlife and conservation research relies critically on obtaining behaviour traits and information. Insights into the behaviour of the Southern Ground Hornbills have been drawn from recent studies that have investigated their habitat utilization, activity patterns, and behaviours. This information can prove to be vital for the implementation of designs to aid conservationists.

3.3.1 Behavioural patterns and space usage of captive Hornbills

A study by Young delved into the behavioural patterns of captive Southern Ground Hornbills across different population groups in South Africa. Young studied "nine broad behavioural categories (namely perching, locomotion, object interaction, lying down, social interaction, preening, feeding, thermoregulation, and vocalising) of the captive ground hornbills" [9, p.97]. This was to assess the diurnal activity patterns, and space use, describe risk-taking behaviour, investigate the occurrence of behavioural syndromes in individuals, and more. Young noted that the most used spaces among the captive ground hornbills in the Johannesburg Zoo were "a Large perching platform and shade from a large tree" [9, p.71], "the nest box and a small riverine" [9, p.71] and "the boundary fence available for public interaction, entrance gate and food station" [9, p.71]. These findings were consistent across the different groups at the separate locations with similar types of spaces being used the most. Common behaviours of the Southern Ground Hornbill such as locomotion, feeding, and perching confirm the fundamental findings [10] but the observation highlighted a deviation from the bimodal activity patterns seen in their wild counterparts [10]. Noting a steady engagement in perching, locomotion, and object interaction throughout the day.

The study also revealed an intriguing variation in space use and risk-taking behaviours, hinting at the existence of unique personality traits among hornbills. Such findings underscore the complexity of their social dynamics and the importance of considering individual behavioural traits in conservation planning [9].

3.3.2 Habitat Usage and Fine-Scale Movements of Hornbills in the Lowveld Area

Zoghby studied the fine-scale movements and habitat use of Southern Ground Hornbills in the Lowveld area northeast of South Africa[11]. Zoghby explains a method for tagging adult Ground Hornbills, where the researchers used walk-in netted tunnel traps to capture adult Southern Ground Hornbills. Using a decoy bird model, and playing mating sounds, the researchers were able to attract birds inside the trap at which point the curtains of the trap were pulled shut. The captured birds were then fitted with a “solar-powered Argos/GPS PTT-100 transmitter (Microwave Telemetry Inc, Columbia) ”[11, p.20]. Zoghby states that “Subordinate adult males or sub-adults were fitted with a transmitter rather than the alpha pair because of their social importance to the group” [11, p.20] because the groups forage cohesively and remain together throughout the day. The study detailed that Ground Hornbill groups showed seasonal variations in movement distances. They traveled further per day during the summer breeding months, and in wet seasons successful breeding groups concentrated their foraging around nest sites. Ambient temperature affected hourly travel distances, these distances decreased markedly above 25 degrees. Zoghby underscored a preference for shaded habitats like Acacia-dominated woodland during the hotter parts of the day, noting that the loss of these types of vegetation could also be a cause of their decreasing numbers[11].

Zoghby provides valuable information of the ranging behaviour and habitat use, details a method for capturing and tagging adult hornbills, highlights seasonal movement patterns, and stresses the importance of habitat mosaics including large trees for shade and roosting [11].

Such research methods and patterns of habitat utilization offer insight into the behavioural aspects and environmental preferences of the Southern Ground Hornbill and more optimized locations, periods, and methods for weight data collection.

3.4 Current Weighing Techniques and Associated Features

Weighing birds on a scale involves a meticulous approach to ensure accuracy and minimize disturbance to the subjects. Various techniques have been developed to accommodate different bird species, sizes, and behavioural traits. Common methodologies include the use of precision balances, spring scales, or electronic weighing devices, each offering distinct advantages depending on the research objectives and environmental conditions. Furthermore, protocols for handling, restraining, and recording measurements play a crucial role in standardizing data collection procedures and facilitating comparative analyses across studies.

3.4.1 Electric Scales

Precision balances measure mass by balancing an unknown mass against a known quantity [12]. Spring scales use a coiled spring to measure weight and require a reading of a dial to determine the weight [12]. Electric scales use a force restoration mechanism as a digital counter of mass [12]. For the scope of this project, only electric scales are reviewed for their capability of reading out digital values of mass measurements that can be stored autonomously.

The most common force restoration mechanisms for electric scales are considered to be load cells. A load cell is a transducer that converts mechanical force to an electric signal [12]. Most common load cells used involve strain gauges which are comprised of fine wires arranged in a grid shape that react to change in their shape by adjusting its resistance. Researchers have widely used strain gauges in association with microcontrollers to record and store weight measurements in different industries.

Load cells rely on the principle of a Wheatstone bridge configuration employing strain gauges to accurately measure force or weight [12]. This setup is essential for compensating temperature effects and eliminating external force signals, ensuring precise measurements. Strain gauges play a pivotal role within the Wheatstone Bridge: when a load is applied, they undergo deformation, altering their resistance. Consequently, this resistance change creates an imbalance in the bridge, resulting in an output voltage directly proportional to the applied load. The load's application induces tension in some components and compression in others, leading to strain gauge deformation. Subsequently, the output voltage is transmitted through signal wires to a signal conditioner, which converts it into meaningful force values typically measured in kilograms. However, factors like temperature fluctuations, wire length variations, and strain gauge placement can introduce errors in measurements. To mitigate these errors, the load cells need to be calibrated by obtaining readings by placing known masses and subsequently generating an equation that will transform the electric signals into accurate mass measurements [12].

Wenderson proposed a multi-functional scale design where Arduino UNO R3 open-source electronic prototyping board was used to assemble the equipment for the multi-functional scale [13]. The HX711 24-bit converter and amplifier module were connected to an AEPH load cell - SPLT model coupled to an aluminium plate. This setup, along with the Data Logger Shield model RTC DS1307, allowed for precise weight measurements to be captured and recorded by the Arduino platform. The program developed in C++ language facilitated communication between the Arduino and the sensor modules, enabling the accurate measurement of weight using the HX711 module in conjunction with the load cell [13].

Kartika used a similar approach in the construction industry for designing a scale featuring an Arduino board and HX711 load cell sensors at its core [14]. This paper specifically emphasises the placements of the load cells to maximize the accuracy of weight readings. Load cells come in various shapes (circular, rectangular, t-shape, s-shape), and depending on the design specifications any can be chosen. The importance of choosing the shape is emphasised to ensure the accuracy of the reading as the exact position where a bird lands is not guaranteed.

From this, it is evident that electronic scales can be designed using simple load cells and integrating them with microcontrollers to measure and store mass parameters autonomously.

3.4.2 Automated Weighing Systems

Continuous recording of weight data for birds without causing disturbance necessitates the utilization of smart scales capable of autonomously capturing and storing valuable readings. Conventionally, researchers manually weigh birds by placing them on scales and recording the measurements [15], [16]. However, this approach poses risks to the birds' privacy and tranquillity. Additionally, monitoring large birds becomes challenging as capturing and placing them on scales can be difficult. Alternatively, it is common to see researchers disguise scales in nests [17], [18].

To address the challenges of stress-free, continuous monitoring, researchers have increasingly turned to innovative automated systems for tracking bird weights. These systems often integrate traditional methods with advancements in machine learning and 3D cameras. The incorporation of autonomous tare calibration is seen in various papers to ensure accuracy in weight measurements by updating the tare using an iteratively reweighted least squares method when the scale pan is empty [19]. To further increase accuracy artificial neural network algorithms amongst others are utilised for weight estimation from unstable values and generate a pattern of body weight estimations[19].

The 3D camera-based weighing system for broiler chickens seen in commercial production environments utilises a low-cost Kinect sensor to capture depth images of the birds[20]. A fully automatic system eliminates the need for them to voluntarily visit a platform weigher, offering a non-invasive and efficient weighing solution. Again, machine learning and image processing algorithms segment the depth images and extract weight descriptors, which are used to predict individual broiler weights using a Bayesian Artificial Neural Network [19], [20]. Tested with 48,000 individuals over 20 days, the system achieved an average relative mean error of 7.8% compared to reference weights obtained from a traditional platform weigher[20]. This innovative system shows promise for accurate and automated weight prediction in chicken farming, potentially enabling additional camera-based measurements such as activity analysis and health alerts in the wildlife bird research field.

3.5 Communication and Interfacing Technology for Wildlife Conservation

The application of communication and interfacing technology in wildlife conservation explored below aims to aid with the implementation and design of the design task outlined in the problem statement.

3.5.1 Zigbee Wireless Communication

Zigbee, an IEEE 802.15.4 standard for data communication, is recognised for its simplicity in implementation, cost-effectiveness, and low power consumption, rendering it a highly sought-after solution for wireless monitoring in remote regions[21]. Its infrastructure, consisting of a transmitter, receiver, and antennas, operates via Radio Frequency waves, functioning as the communication medium.

The efficacy of Zigbee devices lies in their ability to function on minimal power, thus sustaining operations for extended periods with small batteries, ideally suited for applications requiring prolonged, low-maintenance functionality[21]. This longevity is facilitated by the incorporation of a sleep mode across all devices, ensuring the conservation of power during periods of inactivity.

Utilizing Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as its communication protocol, Zigbee implements handshaking mechanisms alongside a series of acknowledgments, thereby guaranteeing reliable and secure data transmission. Notably, Zigbee boasts a range of 100 meters, operates across 16 channels, with a static bandwidth of 8MHz, and achieves a modest data rate of 250KBPS[22]. This technology is crucial for the system as it minimizes visual pollution, reduces the requirement for numerous wires, and allows devices to be spaced apart to ensure animal safety and maintain a neat appearance.

3.5.2 Emergence of Real-time Monitoring Approaches to Wildlife Conservation

Jake Wall et al. suggests a novel opportunitie for wildlife conservation and research with real-time tracking to “examine aspects of wildlife special activity and behaviour not possible with conventional tracking systems”[23, p.1]. Using these systems, Jake Wall et al. apply their wildlife tracking approaches to the monitoring of 94 African elephants “in the Samburu, Laikipia, Mt. Kenya, Chyulu Hills and

Mara ecosystems of Kenya and the Kruger-Limpopo ecosystem in South Africa."[23, p.3].In their study, Jake Wall et al. detail their cloud-based monitoring system including infrastructure, data collection, and customised software details.

The advancement of technologies especially in communication technology, miniaturization of electronics, and efficiency improvements have greatly expanded the potential use cases for technology systems in wildlife research. This has especially broadened the types of species the technology can be applied to, and improved the quality and quantity of data collected. Jake Wall et al. highlights the potential for Real-Time monitoring in the fields of wildlife conservation especially for at-risk wildlife. Jake Wall et al. explained that GPS tracking data collected from collars deployed on the elephants are telemetered using either a GSM (global system for mobile communications) or by Inmarsat Satellite Communication to a cloud-based server for data processing. Once a 'behavioural state of interest' [23, p.3] was identified, an alert was distributed to the researchers using methods such as e-mail and SMS (Short message service).

This study has highlighted how the continued advancement and expansion of communication networks have offered great opportunities to wildlife researchers to monitor and study wildlife to a much greater extent and provide them the ability to apply real-time tracking and monitoring systems to a variety of species [23].

3.5.3 GSM Based Notification Applications

Yasin et al. propose an automated irrigation system that uses an Arduino microcontroller with GSM (Global System for Mobile Communication) technology to allow remote monitoring and control of the system via SMS[24]. The irrigation system proposed can be equipped with sensors that measure the moisture in the soil. The microcontroller notifies the farmer automatically of system statuses and watering requests. The farmer can then send commands to the microcontroller to perform the necessary actions[24]. Yasin et al. propose using an "Arduino Mega 2560 microcontroller and a SIM900 GSM Shield'[24, p.2] for the automated irrigation system. Yasin et al. describe that "this system remotely controls the irrigation process by receiving commands via SMS and GSM network. There are not any special applications or hardware needed by mobile phones to be used in this system, and any mobile phone supporting the SMS service could be used for it'[24, p.6].

The proposed design by Yasin et al. can be modified and adapted for the use case of wildlife research specifically for the study of Southern Ground Hornbills. The hornbill groups in question are often located in remote areas specifically in the Lowveld area of South Africa where strong cellular network signals are not available and allow researchers who are often not technically inclined, to interface with a simple remote data collection system. SMS is a cheap, accessible, reliable, and power-efficient mode of communication that does not require high bandwidth or high signal strength and would be well suited to a remote monitoring and notification system. Such a system can be an asset for researchers on the ground who need to collect data from sensors that may not be easily accessible and can allow for a more efficient monitoring process [24].

3.6 System Power

Ensuring uninterrupted power is fundamental for the effective monitoring of avian activity. The selection of appropriate power sources is paramount to sustain continuous data collection and analysis. Among the options available, the LG RESU Prime battery system emerges as a notable candidate due to its exceptional efficiency and capacity[25]. The longevity of the LG RESU batteries is particularly noteworthy, withstanding numerous charge-discharge cycles while exhibiting minimal degradation, contingent upon proper enclosure and temperature regulation practices[25].

In a paper concerning an audio and video surveillance system for wildlife, Gula et al. incorporated a power system capable of supplying a commercial infrared camera and a microphone attached to an amplifier and recording device with power for up to 9 days at a time[26]. The system ran off a lead-acid battery with a storage capacity of 100Ah[26]. The drawback to this system however was its size, weighing in at 25kg. Modern advancements in battery storage capabilities as well as a small power requirement for the project will allow for the use of much smaller systems than described by Gula et al.

In tandem with battery systems, solar panels serve as a viable solution for remote power supply, albeit susceptible to efficiency diminishment caused by environmental factors such as dust and debris accumulation. Addressing this concern, engineers at Fraunhofer have developed an innovative self-cleaning mechanism leveraging a titanium oxide coating[27]. Under standard conditions, this coating demonstrates hydrophobic characteristics, effectively repelling water and preventing particulate adherence. Upon exposure to ultraviolet (UV) light, it transitions to a hydrophilic state, facilitating debris removal through water action. This dual functionality ensures consistent cleaning and sterilization of solar panel surfaces, thereby enhancing their longevity and sustaining optimal performance levels[27].

3.7 Conclusion

Efficiently obtaining reliable weight data on birds will forever be a task that ornithologists look to optimise. The challenge lies in that there is no one perfect solution. Each research group has its own specific set of criteria to which the solution has to be molded.

As seen, there are multiple avenues for researchers to take when deciding on how best to accomplish their desired tasks. From which type of individual bird identification system to use to how best to design a scale that can be easily controlled using a type of wireless system, there are multiple factors to take into account. Features such as cost, power consumption, ease of implementation and interfacing, as well as overall impact to the wildlife will need to be considered when making the final design choices.

This literature aimed to unpack some of these techniques in order to better gauge what solution may be necessary to accomplish the design task defined in the problem statement.

Chapter 4

Scale and Housing Subsystem

By: Jake Wesselink - WSSCAR008

4.1 Introduction

Accurate weight data is paramount to the understanding of the health, behaviour, and ecology of bird species in ornithological studies. In the context of this project, Carrie Hickman from the Fitzpatrick Institute at the University of Cape Town required a scale to accurately determine the weight of individual Southern Ground Hornbills. This subsection outlines the design and implementation of the unique requirements that the project entails. By achieving precise weight measurements while minimizing disturbance to the birds, this scale will play a pivotal role in Carrie's research efforts.

4.2 Requirements and Specifications

4.2.1 Requirements

Following a meeting with Carrie Hickman, the following requirements relevant to the Scale and Housing Subsection were outlined.

User Requirements

The system:

- Must accurately measure the weight of individual Hornbills that weigh between 3-5kg.
- Must be functional and accurate in the range of weather conditions and ambient temperatures relevant to the Kruger National Park.
- Must be able to be integrated into the existing artificial nests.
- Must operate without disrupting the natural behavior of the Hornbills and should be inconspicuous to avoid attracting the birds' attention.

Functional Requirements

The system:

- Must be able to withstand well over the weight of a single Hornbill to account for the extra force exerted during takeoff and landing and be small enough to ensure only one bird can fit on the perch at a time.
- Must output an analog voltage level between 0 and 3.1V to the ADC of the ESP32 Micro Controller as anything outside this range will cause damage.
- Must have a low power consumption to ensure a long operating time.
- Must be built out of weatherproof material to ensure a long lifespan.

4.2.2 System Specifications

The system:

- Must be able to weigh individual Hornbills to an accuracy of 1 gram.
- Must be able to withstand a total weight of three fully grown Ground Hornbills (15kg) to account for the extra weight during takeoff and landing and be no longer than 30 cm to ensure only one bird can sit on the perch at a time.
- Must output an analog voltage in the range of 0-3.1V, incorporating the necessary protection circuitry.
- Must be weather, rain, and dustproof and be able to operate in a temperature range from 5-40°C. Exposed components must have an IP65 [1] rating.
- Must be made out of wood and be positioned on top of the existing artificial nests. No components or fasteners may be exposed as this would present a safety hazard for the birds.
- Must be powered off +5V and -5V supply and have a low power consumption, drawing no more than 0.05A.

4.3 Acceptance Test Procedures (ATP's)

The following ATP's will be used to ensure that the scale designed to weigh the Ground Hornbills meets the established requirements and specifications listed above.

4.3.1 User Acceptance Tests (UAT)

1. **UAT1: Accuracy:** Must be accurate to within 1g.
    - **Test Case:** Measure the output weight from weighing known weights ranging from 1-5kg. Calculate the absolute difference between the recorded weight and the known weight.
    - **Acceptance Criteria:** The absolute difference is less than or equal to 1g.
2. **UAT2: Standard Deviation:**

[1] An IP65 rating signifies that an electronic device is dust-tight and protected against water jets from any direction.

- **Test Case:** Record multiple readings (N=50) of the same known weight using the ESP32 from the Micro Controller Subsection. Then calculate the standard deviation of the recorded weight measurements.
- **Acceptance Criteria:** 67% of data points must fall within 1 standard deviation of the mean.

Test conditions: The test for the above ATPs should be performed with weights of known mass accurate to 0.1g. The environment should be stable and controlled with an ambient temperature of around 22°C.

3. **UAT3: Temperature:** Must be able to operate in the temperature range specified: 5-40°C.
   - **Test Case:** Heat/cool the system using a hairdryer/refrigerator. While monitoring the temperature using a temperature sensor, monitor changes in the weight measurement of a known weight.
   - **Acceptance Criteria:** The scale must demonstrate no more than 0.01g/°Caccuracy shift.
   - **Test Conditions:** The climate must be set to the specified temperature levels. The environment must be otherwise stable.
4. **UAT4: Environment Compliant:** Must be made out of wood with no components without the required IP rating exposed, and be weatherproof to the necessary conditions.
   - **Test Case:** Simulate rain/dust by wetting/blowing dust at the scale.
   - **Acceptance Criteria:** The scale should function as normal, outputting expected values.

4.3.2 Unit Testing

1. **UT1: Robustness:** Must be able to withstand the full load capacity of 15kg (147.15N [2]) on both the housing and perch.
   - **Test Case:** Apply a load representing the hornbills' landing and takeoff movements.
   - **Acceptance Criteria:** The scale does not deform and the output does not exceed the maximum rated output.
2. **UT2: Protection Circuitry:** Must be functional over-voltage and reverse voltage protection circuitry.
   - **Test Case:** Apply a range of voltages from -3V to 5V while measuring the output voltage.
   - **Acceptance Criteria:** The output voltage remains zero or is positive and does not exceed 3.1V.
   - **Test Conditions:** Test the protection circuity in isolation away from the rest of the components to ensure safety should the circuits fail.

[2] 15kg*9.81m/s = 147.15N

3. **UT3: Power Supply and Power Usage:** Circuits must run off +5V and -5V supply.
    - **Test Case:** Supply the circuits with the needed +5V and -5V rails using a power supply.
    - **Acceptance Criteria:** Ensure the current drawn from the power supply is less than 0.05A.

4.4 Design Choices

4.4.1 Physical Integration into Next Boxes

According to Carrie Hickman, the ideal solution would involve the scale to either be situated on top or in front of the artificial nest boxes as the birds spend large portions of the day at their nest sights. The first design choice was therefore where to place the scale.

The nest boxes are built in such a way that there is space in the roof of the nest to allow for better insulation and temperature control. This would provide the ideal location to store electronic equipment from the other subsystems and allow for the scale to be seamlessly integrated into the nests. If the scale was placed in front of the nest, there would be wires running between the scale and the storage location of the other components which could potentially get damaged or interfere with the Hornbills. It was for this reason that a rooftop scale system was decided upon.

Next, a choice between a platform scale and a perch scale had to be made. In all of the images provided by Carrie Hickman, the Ground Hornbills were seen to be gripping the perch that they were standing on. Even if they were standing on the roof, they had their talons wrapped over the front lip. This led to the decision to design a perch rather than a flat platform because the birds would be more likely to stand on it. Further, a two load cell configuration was decided upon to eliminate moments cheated from torques affecting the weight reading due to the bird standing at different locations along the perch. This design would also provide greater horizontal support for when the birds land or take flight and protect from noise induced in the system as both ends of the perch will be fixed.

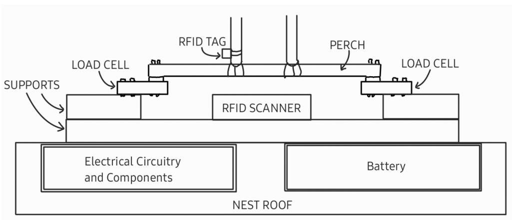


Figure 4.1: Initial Scale Design

4.4.2 Circuit Design and Component Selection

Load Cell and Amplifier

The first component selected was the load cell. Considering specification number 2, the scale needs to handle up to 3 times the max weight of the Hornbills. According to the information provided, these birds can weigh up to 5kg meaning that the scale would need to handle a total of 15kg. Seeing that this is a two load cell design, two 10kg load cells were selected. Load cells are most commonly used in conjunction with an HX711 IC, which is an amplifier and 24-bit ADC. However, for this project's scope, the decision was made to instead not use the HX711 and rather replicate some of its functions. Seeing that the ESP32 has two 12-bit ADCs, the replica circuit would need to function primarily as an amplifier because the load cell outputs a voltage differential too small to accurately detect the voltage level changes.

An instrumentational amplifier was selected as they are designed to amplify very small differential signals. They also have a higher Common-Mode Rejection Ratio (CMRR) compared to regular operational amplifiers and the ability to easily and precisely set the gain required through the use of an external resistor. Further, opp amps tend to have input off-set voltages, lower input impedances, and higher noise making them unsuitable for this task. The AD620 was the amplifier that best suited the needs of this project due to its low cost, low power consumption, and performance in the specifications discussed above. Tables detailing the components mentioned above are as follows:

Table 4.1: Load Cell Specifications

Parameter	**Value**
Rated Load	10 kg
Rated Output	1.0 ± 0.1 mV/V
Nonlinear	$\pm$0.05% F.S
Repeatability	0.05% F.S
Temperature Effect	0.003% F.S/°C
Temperature Range	-21 to 40°C
Operating Voltage	10V
IP rating	IP65

Table 4.2: AD620 Specifications

Parameter	**Value**
Gain	1 to 10,000
Power supply range	$\pm$2.3 V to $\pm$18 V
Max supply current	1.3 mA
Max input offset voltage	50 μV
Max input bias current	1.0 nA
100 dB min CMRR	100 dB
Bandwidth (G = 100)	120kHz
Settling time to 0.01	15 μs

The HX711 IC offers reverse polarity and over-voltage protection as part of its design, so without it, these protection circuits needed to be accounted for, designed, and implemented. This needs to be done to protect the ADC pin of the ESP32 from voltages outside its allowed input range (0-3.1V).

Protection Circuitry

Reverse polarity protection can be achieved with a single P-Channel Mosfet. When the Mosfet is supplied with a positive voltage, the gate-source voltage is kept low, keeping the device in an 'on' state and allowing current to flow through it. When the supply voltage is negative, the gate-source voltage becomes more positive, effectively reducing the current to zero and turning the device 'off'. The IRF9540 P-Channel Mosfet was selected for its low-on-state resistance, high switching speeds, and affordability.
Over-voltage protection was achieved through the use of two PNP transistors and a zener diode with the breakdown voltage equal to the maximum voltage that needed to be clipped (3.1V). Referring to figure 4.2, the basic working principle is that Q1 will conduct while the voltage is below the maximum allowed voltage while Q2 and the zener are both 'off'. When the voltage increases beyond the maximum allowed level, the zener will go into reverse breakdown and Q2 will conduct, turning Q1 off and stopping any voltage from reaching the load. This circuit was chosen for its simple design, the use of cheap, easily available components, and sufficient performance.

The circuits were built and tested in LT Spice as seen below.

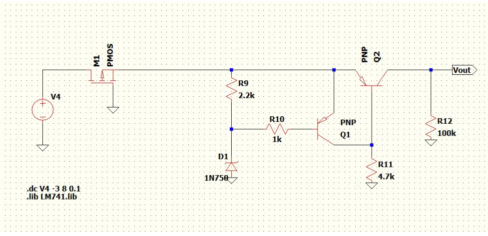


Figure 4.2: Protection Circuitry

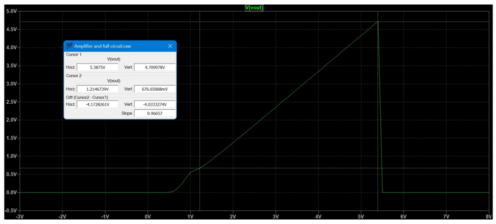


Figure 4.3: Protection Circuitry Simulation

As can be seen, the protection circuitry behaved as expected. Negative voltages are blocked proving that the negative voltage protection circuit involving the Mosfet works. The Zener used in the simulation has a reverse breakdown voltage of 4.7V because LT Spice did not have one with the required 3.1V. However, the circuit attenuated voltages over this level perfectly. When built physically, the correct zener will be used. There is a discontinuity from 0V to around 0.7V. This is due to the voltage drops across Mosfet and transistor and the minimum forward voltage required to turn them on. To account for this, the voltage differential caused by the expected load from the load cell should be amplified beyond 0.7V to ensure that this region of non-linearity does not affect the results.

4.4.3 Physical Design

The scale model can be seen below in Figures 4.4 with only a portion of the existing nest roof included. A force analysis was also completed on the perch to determine the shear forces and bending moments it would be subjected to. This can be seen in Figure 4.5.

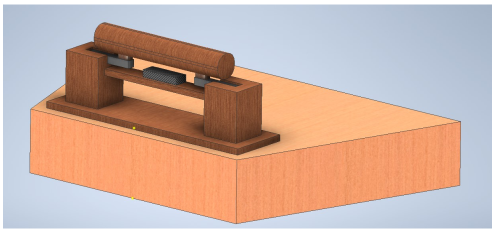


Figure 4.4: Scale Model

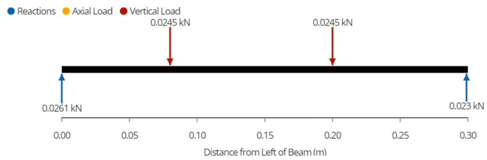


Figure 4.5: Load Analysis

A beam force analysis was needed to draw the Shear Force and Bending Moment diagrams. The forces exerted onto the beam from the bird are assumed to be half the weight of a grown Ground Hornbill[3]. The reaction forces were then calculated as shown in 4.5. The combined reaction force from the two load cells will always equal the loading force applied on the perch.

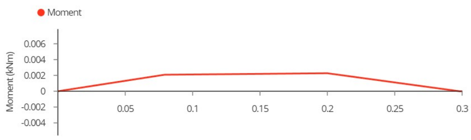


Figure 4.6: Bending Moment Diagram

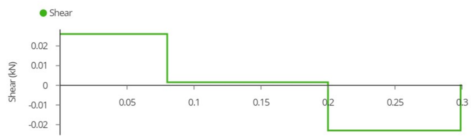


Figure 4.7: Shear Force Diagram

As seen in Figure 4.6, the maximum bending moment that the beam is subjected to under normal

[3] F(1)=F(2)=0.5*5kg*9.81m/s

loading is 2.27Nm with a maximum shear force of 26.1N seen in Figure 4.7. As the perch will be made out of a solid beam of wood, it will be able to withstand these loads.

4.4.4 Power Management and Cost Analysis

Table 4.3: Component Specifications

Name	**Quantity**	**Max Power Dissipation (W)**	**Cost p/u (R)**
BDD Electronic Load Cell 10KG	2		45.00
AD620 Instrumentation Amplifier	2	0.65	39.10
IRF9540 Mosfet	2	150	9.20
PN2907ABU PNP Transistor	4	0.625	6.51
3.3V Zener Diode	2	0.5	1.99
Total			R195.62

It should be noted that these are the maximum power ratings for the components. In the designed system, none of the components will be operated close to their maximum capacities, yielding a lower power consumption. Resistors are considered commonly available and therefore not included.

4.5 Prototype

4.5.1 Elecrical Circuitry

The full circuit design can be seen in Figure 4.8 below. The Load Cell and the AD620 amplifier are designed to be powered off +-5V, this being the only input from another subsection, namely the power subsection, needed. A filter was not included in the design as the filtering of data was covered in the Micro-controller Subsection in Chapter.

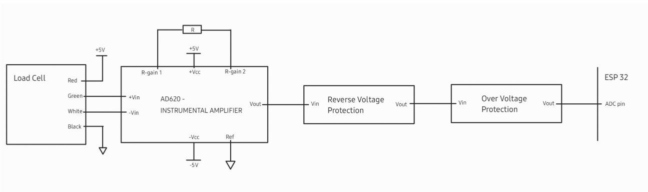


Figure 4.8: Electrical Circuitry Block Diagram

The load cell functions as a Wheatstone Bridge, thus powering it with a positive and negative rail results in the unloaded voltage differential seen by the output leads as zero. This is beneficial as this form of powering the device allows for a large voltage differential between the input terminals (10V in this case), and the ability to detect much smaller voltage differentials between the output leads, making the device more sensitive.

AD620 Gain Calculation

The formula to set the gain resistor for the AD620 is provided in the datasheet as:

$$Rg = \frac{49.4k}{G - 1} \tag{4.1}$$

To determine the gain 'G', first, the expected output voltage from each load cell had to be determined. The unloaded bias voltage of load cells used was 0.05mV and 0.07mV. This was low enough to not have to compensate for it by using the differential amplifier shown in Appendix A.1. The load cells were then loaded with the expected weight of 2.5kg (half the average weight of a Southern Ground Hornbill), and the output voltages were recorded as 4.1mV and 4.3mV.

Table 4.4: Table showing the resistor values used to set the required gain of the AD620.

Load Cell	Output V	Required Voltage	Gain Required	Resistor Used
1	4.1mV	2.5V	610	68Ω
2	4.3mV	2.5V	581	68Ω

4.5.2 Final Circuit

The Circuit as defined in Figure 4.8 was built and soldered onto vero-board to be used in testing.

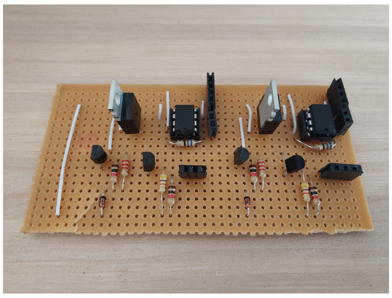


Figure 4.9: Electrical Circuitry

4.5.3 Scale Design

The scale was constructed out of wood to ensure it would be strong enough to withstand the high forces exerted during landing and takeoff. The design can be seen in Figures 4.10 below. There are blue 3D-printed protection caps to ensure that the load cells are protected. The files for which can be found in the git repository in Appendix A.3. This design is aimed to be integrated into the existing nest boxes. These boxes have space in their roofs to accommodate and store all the electrical equipment needed for this scale to function (see Figure 4.11). The birds by nature spend time perched at the nesting sites, this scale is designed to be a perch for a singular Horbill sitting above the nest box.

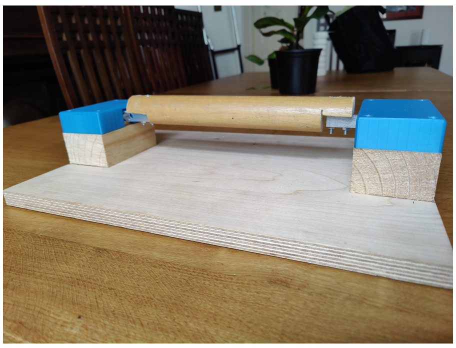


Figure 4.10: Scale Design

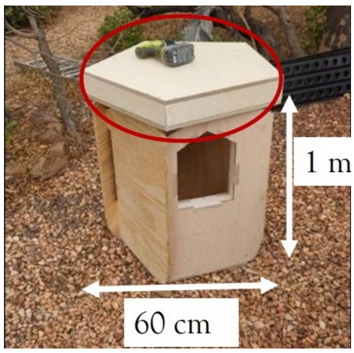


Figure 4.11: Existing Nests

4.6 Testing and Results

The testing process was divided into two sections: unit testing and full system testing.

4.6.1 Unit Testing

Reverse Voltage Testing

The Reverse Voltage Circuit was tested by applying a range of voltages directly to the isolated circuit and recording the output. The results can be seen in Figure 4.12.

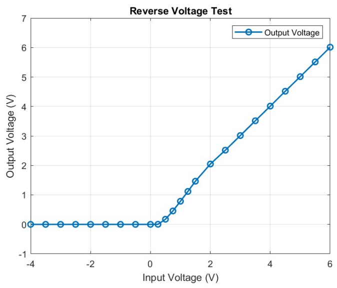


Figure 4.12: Graph Showing the Output Voltages from the Reverse Voltage Protection Circuit

As can be seen, the circuit can block negative voltages while linearly allowing positive voltages to pass through. The IRF9540N Mosfet used also has a low on-state resistance - Rds(on), of 0.2Ω which will result in a low loss in this circuit as the current output from the load cell will also be low. There is a region of nonlinearity up to 1V. To account for this, the expected output voltages corresponding to the expected weight of around 2.5kg should be amplified beyond this region.

Over Voltage Protection

The Over Voltage Protection circuit was also tested in isolation in a similar manner. The Results can be seen in Figure 4.13 below.

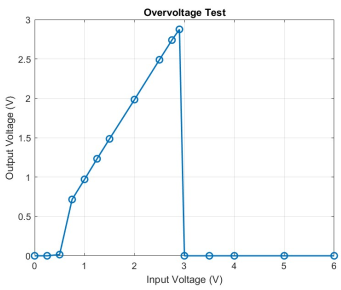


Figure 4.13: Graph Showing the Output Voltages from the Over Voltage Protection Circuit

This protection circuit is effectively rejecting voltages over 2.9V. This is slightly lower than expected with using a 3.3V reverse breakdown zener diode, however, this is preferential to ensure the safety of the Micro Controller's ADC. Again there is a region of non-linearity up to 1V input voltage due to the forward voltage drops of the transistors used. This is accounted for in the same manner defined above.

4.6.2 Full System Testing

Full system tests could now be conducted with the protection circuitry functioning as intended and the gain set on the AD620 amplifier. To do this, volumes of water were incrementally weighed and added to a large container. The output voltage from the circuit, as well as the ADC level, and output voltage of the ESP32, were recorded after each step. The scale used to measure the weight of the water had a sensitivity of 0.1g. Two data sets were collected for each weight increment, and the averages were taken to improve reliability. The plots of weight against output voltage can be seen below for each load cell.

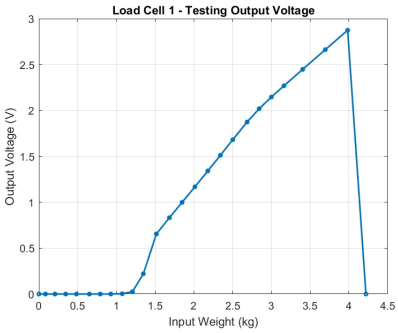


Figure 4.14: Load Cell 1

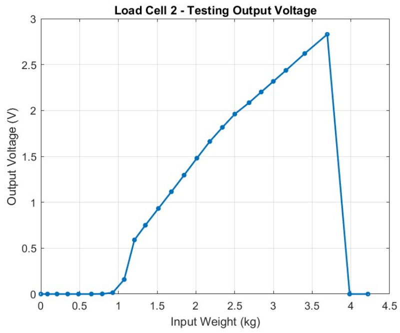


Figure 4.15: Load Cell 2

Line of Best Fit

From the data seen in Figures 4.15, 4.14, a line of best fit could be calculated using the data points that lay within the range of interest, 1.5kg - 3kg. Doing this would ensure the scale most accurately weighs Ground Hornbills between 3kg and 6kg. The lines of best fit can be seen plotted in Figure 4.16 below.

Figure 4.16: Lines of Best Fit Plotted for the Output Voltages Recorded

This line was then molded into an equation to predict the weight based on voltage output from the amplifier circuit.

$$Weight\_LC_1 = 1.0073 * V + 0.83008 \tag{4.2}$$

$$Weight\_LC_2 = 1.0978 * V + 0.40092 \tag{4.3}$$

Evalutating the Lines of Best Fit

To evaluate the accuracy of the Equations 4.2 and 4.3, the voltages recorded on the ESP32 were fed into the equations, and the output predicted weights recorded. The difference between these weights and the actual weights used were then plotted as a percentage of the actual weight. The plot can be seen in Figures 4.17 below.

Figure 4.17: Difference Between the Predicted Weight and the Actual Weight expressed as a percentage of the Actual Weight

From this, the average percentage error was calculated and found to be 0.8218% for Load Cell 1 and 1.8351% for Load Cell 2. At the expected weight of 2.5kg per load cell, this would lead to an error of 20.55g for Load Cell 1 and 45.88g for Load Cell 2, resulting in a combined error of 66.43g.

However, when performing a strictly numerical approach to determining the potential accuracy of the system, it would be possible to achieve a much higher accuracy. The 12-bit ADC has 4096 levels[4] available and can record voltages up to 3.1V meaning that each level corresponds to a 0.7mV[5] change in the input. The max weight that each of the load cells was able to weigh was 4kg which corresponded to a voltage of around 2.9V. Between 0-2.9V there are 3832 ADC levels implying that the accuracy could be 1.04g[6].

4.6.3 Evaluating the effect of Noise

The Gaussian distributions of the output voltages recorded on the ESP32 while manually inducing noise into the system by shaking the weight applied can be seen in figure 4.18 below. Load Cell 1 produced a standard deviation of 0.166, with 76% of the data points within the range. Load Cell 2 produced a standard deviation of 0.365, with 68% of the data points within the range.

4.6.4 Evaluating ATPS

4.7 Conclusion and Recommendations

4.7.1 Conclusion

This subsection successfully met most of its design requirements and specifications as seen in Section 4.6.4. It achieved a standard deviation within its acceptable range for a noisy signal, it did not deform

[4] $2^{12} = 4096$
[5] $0.7mV = 3.1V/4096levels$
[6] $1.04g = 4kg/3832levels$

Figure 4.18: Affect of Noise Inducted in the System

Test Number	Test Description	Evaluation
UAT1	Accurate to 1g	Fail
UAT2	Standard Deviation $\geq$ 0.67	Pass
UAT3	Operating Temperature: 5-40°C	Not Evaluated
UAT4	Environment Compliant	Not Evaluated
UT1	Withstands max load of 15kg	Pass
UT2	Protection Circuitry	Pass
UT3	Power Supply and Usage	Pass

Table 4.5: Summary of Test Resutss

or break when loaded with the maximum weight requirement. The protection circuitry worked as intended when powered from the defined voltage sources. As for the housing, this module was designed for easy integration into the existing nest boxes already in use in the field. With no modification required, this scale could be positioned on top of the nests in the orientation desired by Ornithological researchers. All the electronic equipment could easily be stored inside the roof of the nests to ensure that it causes no harm to the birds. UAT3 and UAT4 were not evaluated as they posed a genuine risk to the components in use. In the time available, damaging any of the equipment would have hindered this project's ability to produce a workable model. These tests should however be performed as outlined in section 6.3.2 before the system is deployed for field testing.

The main shortcoming of this design is that it was not able to practically achieve the desired accuracy of 1g. This was due to a combination of factors resulting in the models seen in equations 4.2 and 4.3 not producing the accuracy required in converting the voltage recorded to a weight reading. Remedies to improve this can be seen in section 6.7.2 below.

4.7.2 Recommendation

- Increase the gain of the AD620 to reduce the maximum weight input to 3kg, thus improving the accuracy by lowering the voltage steps of the ADC.
- Use perfect weights of known mass to calibrate the scale and evaluate the line of best fit, thus reducing error in the model.
- Use the average of more than just two experimental trials to evaluate the line of best fit, thus further reducing the error.
- Should the above fail, resort to using the HX711 IC as it contains a 24 bit ADC.

Chapter 5

Microcontroller and data-processing

This section was completed by Dylan Trowsdale - TRWDYL001

5.1 Introduction

This sub-module focuses on the micro-controller, sensing, and data processing module of the project. The primary objective of this sub-module is to accurately measure and record the weight data of the Adult Southern Ground Hornbills while minimizing the disturbance to their natural behavior and environment. The micro-controller will measure analog voltages from the scale module, filter, and process them into meaningful weight data. The sub-module will ensure that the weight measurements are only taken when a hornbill is on the scale and over a predefined weight threshold. By incorporating this trigger detection process, we can improve the efficiency of the ornithologists' research. In addition to the weight measurements, the sub-module will monitor temperature inside and outside the Hornbill's nests. Given the remote location of the research sites, the sub-module must be designed for low power consumption and battery operation. Furthermore, the micro-controller will be equipped with WiFi to facilitate data transmission and remote monitoring. The collected data will be stored on an external storage device to provide sufficient storage capacity for data collected between long intervals of site visits. The following sections will discuss the detailed design and implementation of the micro-controller, sensing, and data processing submodule.

UR1	The solution must measure weights of Southern Ground Hornbill
UR2	The solution needs to be able to operate for 1 week at a time without user intervention
UR3	The solution must be cost effective
UR4	The solution must function in the harsh environments and temperatures near the Kruger National park
UR5	The solution must measure the temperature of the nest and ambient environment
UR6	The solution should efficiently identify which bird is being weighed
UR7	The Solution should provide for easy data collection
UR8	Data should be stored and formatted in a useful way

Table 5.1: User Requirements

FR1	Micro controller needs to be able to accurately measure and process analog voltage inputs of each load cell of the scale
FR2	Micro controller Needs to be battery powered
FR3	The solution must have wireless communication
FR4	Entire sub-module must be integrated with the artificial nest such that it provides protection from the harsh environment and is hidden from the birds
FR5	Multiple temperature sensors are needed to measure temperature inside and outside the nest
FR6	Temperature sensors need to be accurate, durable and waterproof
FR7	Micro controller needs to interface with a RFID scanner to identify birds that are tagged with RFID tags
FR8	Micro controller needs a simple storage device to store sensor data for at least a week at a time

Table 5.2: Functional Requirements

SP01	Micro-controller needs at least 2 ADC input pins with a minimum resolution of 12 bits for Loadcell measurements
SP02	Micro-controller needs to have low power consumption and support battery operation for extended periods.
SP03	Micro-controller needs a low power mode or sleep mode for periods when it is not utilized
SP04	Micro-controller must have 802.11 WiFI capabilities for wireless communication and data transmission
SP05	Entire sub-module's components need to be housed in a weather-resistant enclosure to protect against environmental factors
SP06	Micro-controller needs to be able to operate above 45 degree ambient temperatures
SP07	Micro-controller needs to have sufficient processing capability, program memory and RAM to handle data processing, filtering, data storage, and wireless communication tasks
SP08	RFID scanner must be able to detect tagged birds from more than 6 cm
SP09	Micro-controller needs sufficient GPIO (General Purpose Input/Output) pins and sufficient digital, UART, SPI and I2c pins for sensor interfacing with future expandability if required
SP10	Solution must use an SD card to store data in a useful way.

Table 5.3: System Specifications

5.2 Requirements and Specifications

5.2.1 Requirements

User Requirements

Functional Requirements

5.2.2 System Specifications

From the User requirements, the system specifications have been defined:

5.3 Design Choices

5.3.1 Component choices

Due to the scope and limitations of the project only affordable and locally available products were considered.

Table 5.4: Key Features for micro-controller Comparison

Features	**ESP32-S3**	**ESP32-S3-1U**	**ESP32-C6–1**	**Arduino-Nano**
Prod ID	N16R8	N8R8	N8	Atmega328p
GPIO pins exp	37	37	24	14
ADC	2 12-bit ADC's	2 12-bit ADC's	1 12-bit ADC	1 10-bit ADC
802.11 WiFi	Yes	Yes (ext antenna)	Yes, WiFi 6	No
Operating Temp	-40 - 65	-40 - 65	-40 - 85	-40 - 85
Operating V	3.0 - 3.6 V	3.0 - 3.6 V	3.0 - 3.6 V	2.7 - 5 V
Core cnt & Clk F	2 cores 240 MHz	2 cores 240 MHz	1 core 160 MHz	1 core 16 MHz
SRAM	512KB	512KB	512KB	2KB
PSRAM	8MB	8MB	-	-
Flash	16 MB	8 MB		32 KB
Real Time Clock	Yes	Yes	No	No
Price	R204.70	R283.50	R170.10	R179.95
Store	Microrobotics	Digikey	Digikey	DIY Electronics

micro-controller

Multiple micro-controllers were considered based on the requirements and specifications set out.

Table 5.4 shows a detailed comparison of the considered micro-controllers. All the micro-controllers are affordable and available at stores locally. They are well-documented and can operate well above the required ambient operating temperature of 45 degrees. The Arduino Nano falls behind the ESP-32s with its processing power, lack of WiFi capability, lower resolution ADC, and fewer available GPIOs. The Esp32 dev boards have more than enough GPIO pins and programmable GPIOs, making it easy to program the necessary pins according to the desired protocol or function. The differences between the dev boards came down to the amount of RAM, the amount of flash storage, and, lastly, their WiFi capabilities. The Esp32-C6 dev board has only 512 KB of SRAM, whereas the S3 dev boards also have 8MB of PSRAM, so the S3 dev boards were preferred to the C6. Finally, The ESP32 S3 Dev Board—N16R8 was selected as it meets all the functional requirements, has the best specifications of the three ESP32 dev boards, and will not require an external antenna like the other S3 dev board, which would be an additional cost.

Temperature Sensing

In order to facilitate temperature sensing for the ambient environment as well as the nests, the temperature sensor is required to probe the desired location, which will not be near the micro-controller, since it will be positioned inside of a protective compartment of the artificial nest designed to house all the necessary electronic components by the scale and housing sub-module. The temperature sensors will need to be positioned or probed to measure the temperature of the required areas of the nest and the outside ambient environment. This requires some flexibility in the nature and choice of the sensors and requires that they be robust and water-resistant in their design. For this application, a stainless steel digital temperature sensing probe (DS18B20) and a digital temperature and humidity Sensor Module (SHTC3) were considered. These Temperature sensors have operating temperatures from -40 - 125 degrees, much higher than the operating temperature specification of 45 degrees. The stainless steel temperature probe has a flexible cable that is 1 meter long. This sensor design allows for

Features	HKD Digital Temp Probe (DS18B20	Digital Temp & Humidity Sensor (SHTC3)
Operating Temperature	-55 125	-40 125
Operating Voltage	3.0 5.5 V	3.3 5.0 V
Accuracy	0.5 degrees	0.2 degrees
Price	R27.00	R199.95
Store	Communica	DIY Electronics

Table 5.5: Key features for the Sensors Comparison

Table 5.6: Table showing the Cost analysis for the Sub-module

Component	Store	Quantity	Unit Price	Cost
ESP32 S3 Dev Board – N16R8	Microrobotics	1	R204.70	R204.70
HKD Digital Temp Probe (DS18B20	Communica	2	R27.00	R54.00
HKD I2C REAL TIME CLOCK- DS3231	Communica	1	R60.00	R60.00
125KHZ RDM6300 RFID MODULE	DIY Electronics	1	R149.95	R149.95
HKD RFID CARD 125KHZ (5PKT)	Communica	1	R35.01	R 35.01
RFID TAG 125KHZ	DIY Electronics	3	R9.95	R29.85
Total Cost				R533.51

a lot of flexibility in the exact positioning and desired sensing location. The SHTC3 breakout module can also be used with freedom in its placement but will require the correct cable lengths from the micro-controller board. The stainless steel temperature probe is completely waterproof and has a very robust design, which is required for this project. However, the SHTC3 sensing module does not have a completely water-resistant or robust design, which will not meet the requirements for this project. The stainless steel digital temperature sensing probe (DS18B20) has an accuracy of 0.5 degrees in the range of -10 - 85 degrees, which is well within the project's operating temperatures. The SHTC3 has an accuracy of 0.2 degrees, which is marginally better than the DS18B20.

Thus, the stainless steel digital temperature sensing probe (DS18B20) was selected for the temperature sensing of our project.

RFID reader and tags

Only passive RFID systems have been considered for the RFID detection system due to the limitations of the project and the limitations of RFID tags available for use with Wildlife, specifically for birds. The types of passive RFID systems are low-frequency RFID (125 - 134 KHz) and High-frequency RFID (13.56 MHz). Due to the budget constraint and limited availability of high-frequency RFID tags, especially in the context of use with Wildlife. Therefore, only low-frequency RFID systems were considered for the project's RFID detection application. The industry standard for low-frequency RFID scanners is the RDM6300 module, which is readily affordable and available at local stores. DIY Electronics had an RDM6300 module for R149.50. Due to stock shortages at other shops, this RFID reader module was selected for the design. Various low-frequency RFID tags were purchased to test and validate the RFID reader. Key tag RFID tags and RFID cards would be best for this purpose.

5.3.2 Cost Analysis

5.3.3 Prototype

Software Implementation

The ESP32 was programmed using PlatformIO, an open-source ecosystem for embedded systems development. PlatformIO was chosen for its cross-platform compatibility, integrated library manager, and IDE support, which facilitate efficient development and debugging. C++ was used for all the source code due to its compatibility, performance, and low-level control. C++ provides low-level memory manipulation, object-oriented programming, and performance optimization features. These are particularly useful for managing resources in an embedded system where processing and memory resources are constrained. Version control was used for the entirety of the software development process, and detailed documentation for the programs is available in the Group's GitLab repository:Link The software system is organized into several files based on functionality and purpose, including scale.cpp, filters.cpp, temperature.cpp, RFID.cpp, SD_card.cpp, and main.cpp. By encapsulating related functionality into separate files, the software implementation of the sub-module has promoted code modularity, reusability, readability, and collaboration. These practices allow for more efficient and maintainable code. Several techniques have been utilized to manage memory efficiently on the ESP32. Dynamically allocated memory allows the program to allocate memory at runtime based on its specific needs. This ensures that only the required memory is used, optimizing resource utilization. Additionally, implicit deletion is employed to deallocate memory no longer in use, preventing memory leaks and ensuring proper memory management. These efficient memory management techniques have optimized the program's memory usage to ensure the long-term stability and reliability of the system.

The Implementation for the entire software system is illustrated in a high-level flow diagram 5.1, which depicts the process flow of the code, decision points, and the overall logic of the sub-system's main code.

Hardware Implementation

The ESP32 was initially tested using a 'Hello World' LED blinking program, and it was discovered that the 5V-in pad and the RGB pad needed to be soldered on the board for their use. The prototype design for the temperature sensors, SD card, RFID module, and later, the more accurate real-time clock was implemented on a breadboard using jumper cables to connect to the pins of the ESP32 Microcontroller. The temperature sensors utilize the serial 1-wire protocol, which requires only one digital pin on the ESP32 for each sensor. Pin 4 and Pin 7 were selected for inside the nest and ambient temperature sensors, respectively. A 4.7K pull-up resistor is required between the GPIO Pins and VCC to connect the temperature sensors. The sensors' VCC line is connected to 3V3 on the ESP32 or 5V from the power module, the ground lead is connected to the common ground with the ESP32, and the data lines are connected to pins 4 and 7, respectively. The SD card, formatted as fat-32, utilizes the SPI protocol. The FAT32 formatting ensures compatibility with the ESP32 and allows for efficient file storage and retrieval. The SD card's CS pin is connected to Pin 10, the MOSI pin to Pin 11, the SCK pin to Pin 12, and the MISO pin to Pin 13. The SD card module's VCC pin is connected to the power module's 5V supply, and the ground pin is connected to the common ground. The RDM6300 RFID scanner's TX pin is connected to the ESP32's RX pin, which is pin 44 on the development board. The VCC and

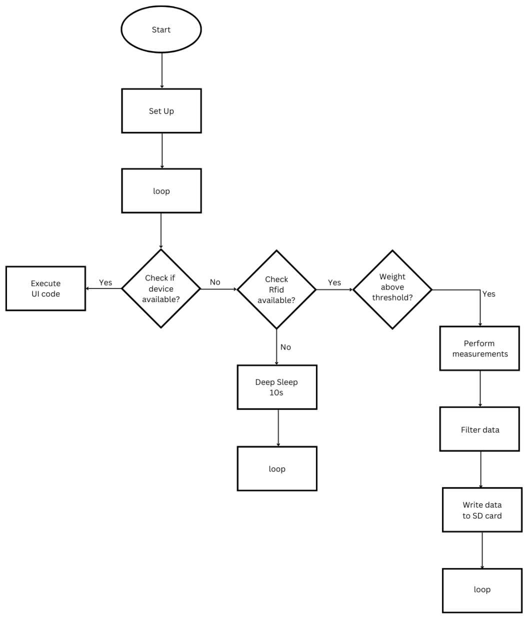


Figure 5.1: Software flow diagram

Figure 5.2: ESP32 - S3 and pin numbers

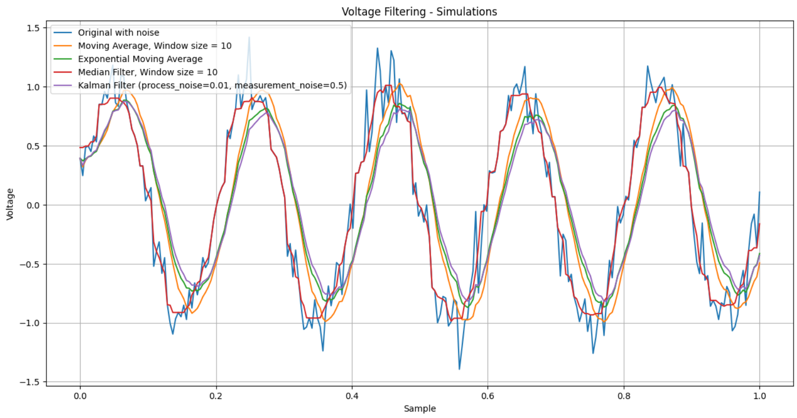


Figure 5.3: Filter Simulations

Ground pins of the RFID scanner are connected to the 5V supply from the power module and the common ground, respectively. The RFID scanner comes with an included antenna that connects to the antenna pins labeled on the board. For more detailed information about the components and their connections, please refer to the component datasheet.

Filtering

Different filter algorithms were considered to improve the reliability, precision, and robustness of ADC readings from the load cells. Moving Average: Smooths short-term fluctuations and noise by calculating the average value of a sliding window of data points. It helps remove high-frequency noise. Exponential Moving Average: This method assigns weights to recent data points and exponentially decreases weights for older points. It helps track gradual changes while being responsive to recent fluctuations. Median Filter: This filter selects the median value from a sliding window of data points. It is effective in removing outliers and extreme values. Kalman Filter: A recursive algorithm that provides an optimal estimate of the actual value based on noisy measurements and system dynamics. It reduces the impact of high-frequency noise and system variability.

The chosen filters aim to low-pass filter the ADC voltage to band-limit noise while allowing responsiveness to gradual changes. The filters were simulated in Python to verify functionality and will be evaluated with simulated 'real-world' data from the load cells. The simulations showed that all the

Test number	Test Description	Pass/Fail
AT01	ADC accuracy & Reliability within 1%	Pass
AT02	Power consumption less than 1.5W	Pass
AT03	WiFi connectivity to 10m	Pass
AT04	Environmental protection	TBC
AT05	Temperature sensing Accuracy and durability	Pass
AT06	Processing and Filtering data	Pass
AT07	Writing data to SD card	Pass
AT08	Reliable and Robust RFID detection with ranges more than 6cm	Fail

Table 5.7: Acceptance Tests

filters designed successfully filtered the noisy signal and recovered the signal of interest to varying degrees. However, to select the right filter for the design, they need to be evaluated and validated against simulated noisy 'Real-world' data from the loadcells.

5.4 Testing and Results

5.4.1 Acceptance Tests (ATs)

Acceptance Test Procedures (ATPs)

This section describes the testing procedures used to determine if the design meets the acceptance tests in table 7.4.

ATP01 - ADC accuracy and reliability

The Internal 12-bit ADC of the ESP-32 will be tested by measuring voltages from the load cells and comparing the measurements to the Keysight U3401A Digital multimeter available in the White lab. The testing methodology involves the following steps: Perform static tests on the load cells by progressively adding weight and measuring the output voltage using the Digital multimeter and the ESP32's ADC. Ensure the weight is kept as stable as possible before and during the measurement process to minimize process noise and isolate the ADC's performance. To achieve accurate and precise results, utilize Espressif's software characterization function to characterize the ESP32's ADC before each batch of measurements. For each ADC measurement, take 50 samples spaced by 50ms and use the average value as the final result. Repeat each weight measurement twice to ensure the repeatability and reliability of the tests.

ATP02 - Power consumption

The ESP32's power consumption will be measured during the ADC data collection and data processing phase, which is expected to be the system's highest power consumption state. The testing methodology involves setting the board up to perform ADC data collection and measuring the ESP32's current draw using the Keysight U3401A Digital multimeter available in the White lab. Record three current draw readings during the ADC collection and data processing phase and use the average current draw to calculate the power consumption based on the supply voltage.

ATP03 - WiFi connectivity and range

The WiFI connectivity and range of the ESP32 will be tested by making use of a simple web server that displays the current weight and temperature measurements. Set up the ESP32 and establish the network. Verify you can connect to the network from various distances with various devices. Verify that a connection can be established and maintained up to 10 meters away.

ATP04 - Environmental protection and robustness

ATP04 - To be confirmed, the housing needs to be tested in the field and in the environments that the system will be implemented in to assess this acceptance test.

ATP05 - Temperature sensor accuracy and robustness

The temperature sensors' performance and robustness will be tested by measuring the temperature of a controlled, air-conditioned environment and submerged in water to measure the temperature of cold, refrigerated water. Measure the recorded temperature three times and record the average. Compare the results with a separate calibrated thermometer.

ATP06, ATP07 - Processing, Filtering and writing data to the SD card

The designed filters will be tested, compared, and validated using simulated 'noisy' voltage readings from the scale. A known weight within the realistic range of Adult Southern Ground Hornbills was weighed. To simulate process noise (e.g., bird movement, jumping, wing flapping), a disturbed container of water was used to create a noisy reading. Perform 3 ADC measurement tests using the same process as the ADC testing, characterize the ADC, and collect 50 samples simultaneously from each Loadcell for each measurement. Write and save the 50 raw samples from each test to the SD card for analysis. Use the designed filters to evaluate their performance in processing and filtering the noisy voltage readings. Take an average of all the filtered readings and evaluate the best-performing filter.

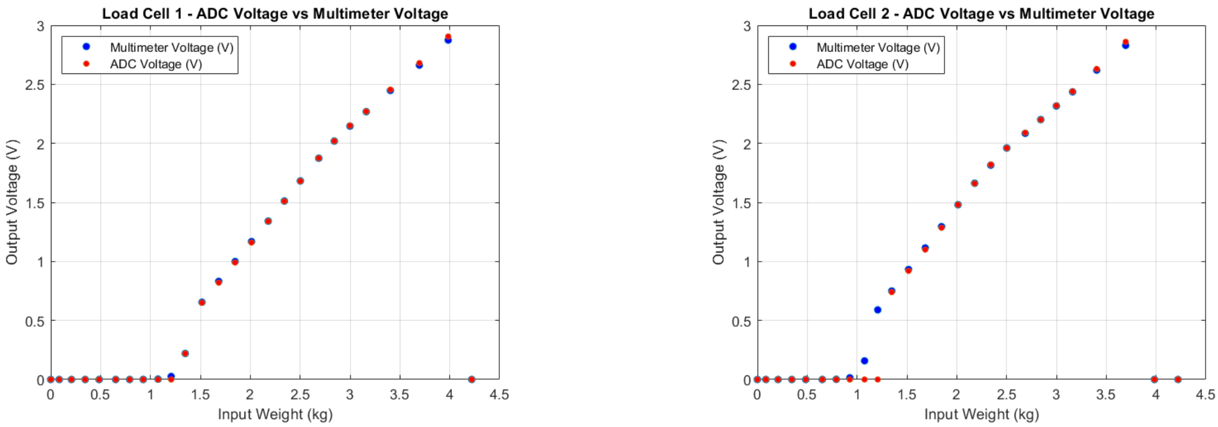
ATP08 - RFID detection

The detection range and performance of the RFID scanner will be tested using different types of RFID tags, including key tags and cards. The testing methodology involves the following steps: Gradually bring the tags closer to the scanner from a distance until successful detection is achieved and record the maximum detection range of each type of tag. Rotate the tags and approach the scanner from different angles to simulate non-ideal conditions and observe the scanners sensitivity to tag orientation noting the sensitivity and robustness of the scanners performance. The Micro-controller flickers an LED and prints the tag ID characters to the serial monitor upon successful detection.

5.4.2 Results

ATP01 - ADC performance

The tests conducted demonstrate that the ESP32's ADC performs well and within an acceptable level. The findings are displayed in 5.4a, 5.4b and 5.5.



(a) ADC voltage compared to Digital Multimeter for load cell 1

(b) ADC voltage compared to Digital Multimeter for load cell 2

Figure 5.4: Comparison of ADC voltage with Digital Multimeter

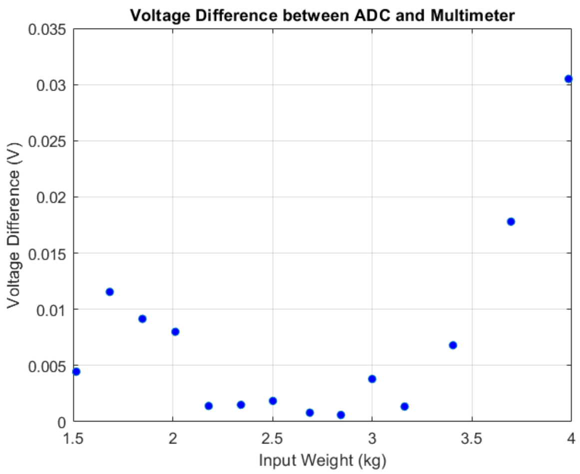


Figure 5.5: Voltage difference between the ADC and the Digital multimeter

The average difference between the ADC and the Digital Multimeter was very small (much less than 1%), except for the edge cases where the masses tested were on the edge of the detection region. The weights that corresponded to high differences were also toward the limits of the ADC. Even considering these edge cases, the maximum difference between the ADC voltages and the Multimeter was around 1%. The high errors can also be attributed to the effects of the undervoltage and overvoltage protection circuitry.

ATP02 - power consumption

The average current draw of the ESP32 was 225mA during this phase. Using a supply voltage of 5V, the observed power consumption is 1.125 W. This is within an acceptable range for the intended application considering that the data collection and filtering phase is a small proportion of the systems state.

ATP03 - WiFI performance

The ESP's WiFi network was able to be connected to with a laptop and cell-phone from over 10m away from the board even in a noisy lab environment with other WiFi networks present. At this distance the web server still operated as it should. This is an acceptable range for the use case of this project.

ATP05 - Temperature Sensor accuracy and robustness

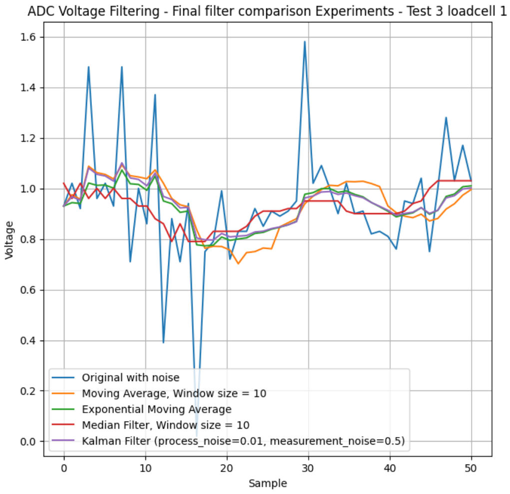
Due to equipment constraints, the sensors' accuracies could not be validated with a separate thermometer. However, in the controlled air-conditioned environment set to 24 degrees, the temperature sensors both had average measuremnts of 24.5 degrees. The sensors also both had an average of 5 degrees for the refrigerated water. Since the sensors both recorded cinsistent values as well as performing as expected measuring the ambient environment as well as the water, the performance was deemed acceptable for this project.

ATP06, ATP07 - Processing, Filtering and writing data to the SD card

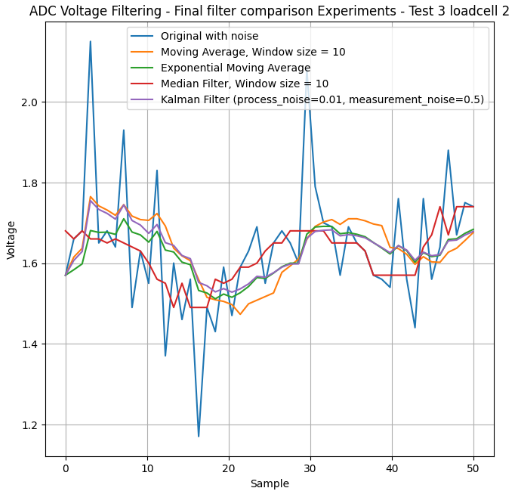
The tests were conducted to evaluate the processing, filtering and writing of data to the SD card. The designed filters were successfully evaluated and tested using the simulated noisy readings. The best-performing filter was the Median filter, and the second was the Exponential moving average filter. They recorded a weight of 3.961 and 3.968, respectively. These filters recorded a difference of 11 grams and 18 grams to the actual weight, respectively. This reading equates to less than 1% difference between the actual weight and, therefore, was deemed acceptable for this project.

ATP08 - RFID detection

. The tests revealed that the RFID scanner had a maximum detection range of approximately 4cm for the key tags and 3cm for cards. The average reliable detection range was between 3 and 3.5cm for the key tags and 2.5cm for the cards. The RFID scanner was found to be highly sensitive to the tag orientation and could not detect tags beyond 45 degrees. The tests highlight the limitations of the RFID scanner in terms of its detection range and detection reliability.



(a) Final Filter Evaluations Loadcell 1



(b) Final Filter Evaluations Loadcell 2

Figure 5.6: Comparison of Final Filter Evaluations

5.5 Conclusion and Recommendations

This sub-module has met most of its requirements and specifications in 7.4. A cost-effective and low-powered design could accurately measure and record weight data, monitor temperature sensors, process and filter, and store the data in a useful manner while providing WiFI connectivity for remote monitoring. However, the RFID detection system was not able to meet its specifications.

The detection system will need to be completely revisited to enhance the system design. The low-frequency RFID scanner does not offer the required range or robustness for use with wildlife as it requires near-perfect operation at the perfect distance and with the tags orientated in a specific manner. Thus, it is not recommended to be used in this design for efficient identification of the Southern Ground Hornbills. The ESP32's internal real-time clock (RTC) was found to be very difficult to use and to have severe clock drift over time. The main code loop's logic will also need to be evaluated and adjusted as the RFID scanner will not provide detection functionality as required. In order to collect useful data and to be able to synchronize the data with the camera setup that Carie currently uses, it is recommended to use a more accurate RTC (real-time clock) like the DS3231. After testing, the system was experimented with using a DS3231 RTC. The ESP32 was connected to a WiFi hotspot, and using NTP, the DS3231's time was set to the most accurate current time. Since it is battery operated, the DS3231 will keep the time for a long time with very high accuracy. This means the ESP32 can always use the most accurate time value when collecting and storing data.

Chapter 6

Power

By: Joshua King -KNGJOS007

6.1 Introduction

The power subsystem is pivotal in the design of an automated bird monitoring system, ensuring consistent and reliable power supply to essential devices over an extended period. To achieve this, a solar battery was made.

This system incorporates various measures to fulfil its objectives. These include two voltage regulators to maintain the correct voltage for different devices, along with safeguards such as overvoltage protection, reverse polarity protection, overcurrent protection and battery level monitoring. Additionally, a charge controller is implemented to ensure the battery is charged accurately and safely. .

6.2 Requirements and Specifications

6.2.1 Requirements

User Requirements

The system should:

- Provide power to all devices
- Be portable
- Be weatherproof
- Be bird-proof
- Have battery level monitoring
- Have relevant safety measures
- Work for an extended period without human intervention
- Be small and space efficient

Functional Requirements

The system:

- Should take radiant light and heat from the sun as input to the system
- Should output the correct voltage and power to the scale and micro-controller subsection components
- Should be weather and bird proof
- Should convert the radiant light into electricity
- Should power all devices even without sunlight for a minimum of 2 days
- Should adhere to battery safety standards

6.2.2 System Specifications

The system:

- Must be able to power all devices without sunlight for a minimum of two days
- Weigh less than 5grams
- Must be weather, rain and dust proof and be able to operate in a temperature range from 5-40°C. Exposed components must have an IP65 [1] rating.
- Must be able to give accurate voltage level feedback within 0.2v
- Must regulate 5 and 10 volts respectfully for an input range of 12-18v

Table 6.1: Device Specifications

Number	Device Name	Operating Voltage (V)	Maximum Current (A)	Max Power (W)
1	ESP32	+5.0	1.500	7.500
2	Weight Module	±5.0	0.300	1.500
3	GSM Module	+4.0	2.000	8.000
4	433Hz Receiver	+3.3	0.025	0.083
5	RFID Reader	+5.0	0.050	0.250
6	Temp Sensor	+5.0	0.008	0.040

6.3 Acceptance Test Procedures (ATP's)

The following ATP's will be used to ensure that the power subsection meets the established requirements and specifications listed above

[1] An IP65 rating signifies that an electronic device is dust-tight and protected against water jets from any direction.

6.3.1 User Acceptance Tests (UAT)

1. **UAT1: Output voltage:** Must deliver 5 and 10 volts.
   - **Test Case:** Use a voltage source to act as the solar panel, connect devices to the system and then measure the voltage across the terminals of each device.
   - **Acceptance Criteria:** The voltage should not deviate by more than 0.2v
2. **UAT2: Power without solar: Must deliver power to all devices without sunlight for a minimum of two days.**
   - **Test Case:** Charge the battery to full capacity, connect all devices and wait 2 days before measuring the voltage of all devices.
   - **Acceptance Criteria:** All devices should still be functioning optimally and voltages should still be 5 or 10 volts respectively
3. **UAT3: Temperature:** Must be able to operate in the temperature range specified: 5-40°C.
   - **Test Case:** Heat/Cool the system to the maximum and minimum temperature values and preform the same test for UAT1 and UAT2 again.
   - **Acceptance Criteria:** The results should be the same as above.
4. **UAT4: weather proof:**
   - **Test Case:** Use a hosepipe and dirt to simulate extreme conditions
   - **Acceptance Criteria:** The system should function as normal
5. **UAT4: Bird proof:** The Southern ground hornbill should not be able to damage the system
   - **Test Case:** Put food on top of the casing and let birds feed/peck.
   - **Acceptance Criteria:** The system should function as normal

6.3.2 Unit Testing

1. **UT1: Over Voltage:**
   - **Test Case:** Use a voltage source, set the value to 20v and then measure all devices voltage individually.
   - **Acceptance Criteria:** The voltages remain at their desired level between 20-12 volts input with a maximum deviation of 0.2v .
2. **UT1: Voltage regulators:**
   - **Test Case:** Using a voltage source vary the voltage between 12 and 18 volts, connect relevant devices and measure the voltage across the terminals .
   - **Acceptance Criteria:** The voltages should remain at 5 and 10 v respectfully with a maximum deviation of 0.2v

3. **UT2: Reverse Polarity:**
   - **Test Case:** Plug a device in the wrong way around and measure the voltage.
   - **Acceptance Criteria:** The voltage remains zero across the device.
4. **UT3: Over current:**
   - **Test Case:** Use voltage source, then plug in devices that draw 20 percent more current than the rating for each fuse and wait for 30 minutes.
   - **Acceptance Criteria:** All fuses should be popped within 30 minutes.

6.4 Design Choices

6.4.1 Voltage Regulator

Voltage regulators are essential components in electrical systems to maintain a stable voltage output despite fluctuations in the input voltage. This is especially import for the solar-battery as the intensity of the sun is never constant and hence the input voltage is always fluctuating. They ensure that sensitive electronic devices receive the required voltage levels, preventing damage and ensuring reliable operation.This is crucial for all devices but particularly the scale as it needs to make highly accurate weight readings. Without voltage regulators, variations in voltage could lead to malfunctioning or failure of electronic equipment, jeopardizing system performance and safety.

The LM317, LM2940 and LM1117 are all popular linear voltage regulators which were considered. The LM317 was the preferred choice due to its versatility, allowing for a wide range of output voltages with relatively higher output current capability compared to LM2940 and LM1117. Additionally, its ubiquity and low cost make it easily accessible for various projects

As seen in figure 1.1 below, a 10µF capacitor was used to stabilize the output voltage by filtering high-frequency noise and improving transient response, while the 100µF capacitor on the input side filters input voltage variations and reduces ripple, ensuring a stable and clean voltage supply to the regulator. These values strike a balance between filtering noise and maintaining good transient response or handling slower changes in input voltage. Moreover, the resistor values selected align with the formula, $V_{in} = (1.25)\left(\frac{R_2}{R_1}\right)$ to establish output voltages of 5 and 10 volts respectively.

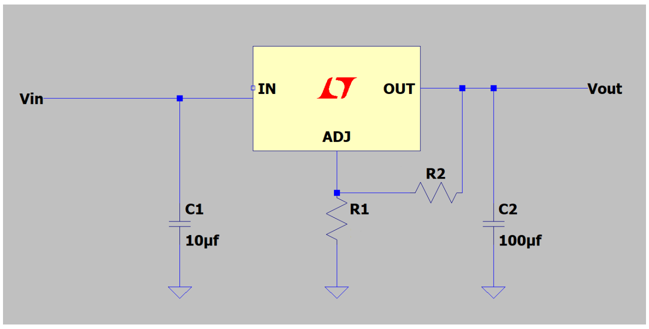


Figure 6.1: LM317 Voltage Regulator

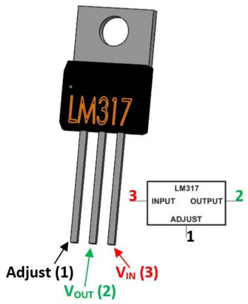


Figure 6.2: LM317

6.4.2 Negative Rails

For negative rails a voltage inverter IC and a voltage divider with an op-amp was looked at. Voltage inverter ICs offer simplicity, reducing design complexity and component count. On the other hand, a voltage divider with an op-amp was chosen as it provides more flexibility and control over the generated negative voltage. By adjusting resistor values and op-amp configurations, this method allows for precise regulation and adaptation to varying load conditions. Additionally the voltage divider op-amp had better the availability.Resistors R2 and R3 were selected according to the voltage divider formula depicted in Figure 1.7 to halve the input voltage, while R1 was chosen to stabilize the circuit and ensure proper current flow in the intended direction. Figure1.3 Shows how a 10v supply turns into a +-5v supply.

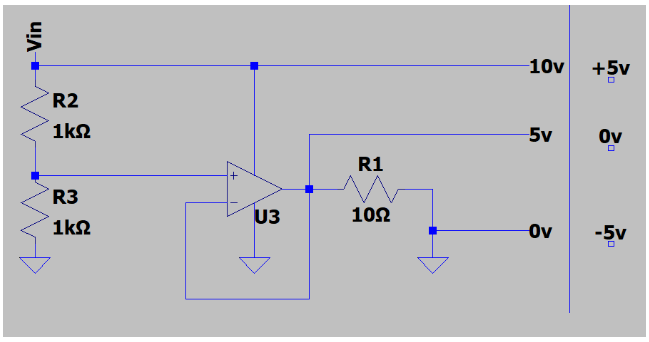


Figure 6.3: Voltage divider Op amp

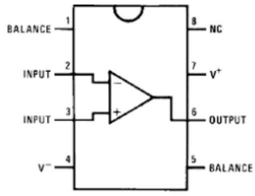


Figure 6.4: Cpamp connections

Polarity

For polarity safety, both a polarity detection IC and a basic diode setup were investigated. Despite the polarity detection IC yielding superior results with minimal wastage, the diode was selected for its ease of implementation and space efficiency. The voltage drop of the diode surprisingly helped regulate the correct output voltage.The diode can been seen in figure1.5 below.

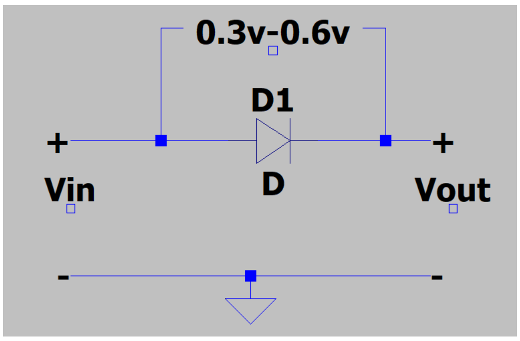


Figure 6.5: Diode

6.4.3 Battery level feedback

The micro-controller can only take 0-3.3v as input. Therefore the voltage across the battery terminals needed to be scaled. A simple voltage divider circuit was used to do this and large resistor values were chosen to limit the current going into the micro controller. Image 1.6 shows the derivations of the voltage divider resistor values. It was decided to use 3v as the max input to the micro-controller to avoid over voltage damage.

18v battery = when 18v = fully charged =100%

$$V_{out} = V_{in} \times (\frac{R2}{R2 + R1})$$

$3 = 18 \times (\frac{1000}{1000+5000})$ = 100%

$2.75 = 16.5 \times (\frac{1000}{1000+5000})$ = 75%

$2.5 = 15 \times (\frac{1000}{1000+5000})$ =50%

$2.25 = 13.5 \times (\frac{1000}{1000+5000})$ =25%

$2 = 12 \times (\frac{1000}{1000+5000})$ =0% (When the regulator stops working to regulate 10v)

Figure 6.6: Derivation of scaling factor

$$V_{out} = V_{in} \times (\frac{R2}{R2 + R1})$$

Figure 6.7: Voltage Divider Formula

6.4.4 Charge Controller

For the charge controller, the HKD lithium charge/discharge model and the XH-M603 were examined. Several models were available, but the system needed one that is inexpensive, compact, efficient and has the correct specifications. Therefore, it was decided that the XH-M603 controller was the best device to use. Additionally, the XH-M603 provides battery charge level feedback, valuable for comparing the Microcontroller results with those of the XH-M603. This board accepts input voltages ranging from 10 to 30 volts and outputs 12 to 24 volts with minimal loss. The primary function of the XH-M603 charge controller is to oversee the battery charging process. It is engineered to effectively control the electricity transfer from solar panels to batteries, ensuring efficient charging without the risk of overcharging or battery harm. The XH-M603, therefore, provides the system with all essential functions needed for effective operation and can be seen in Figure 1.8 below.

6.4.5 Battery

The options considered for the battery were Lithium-ion and Lead-acid. Lithium-ion batteries offer higher energy density, longer cycle life and lower maintenance requirements compared to lead-acid and are often preferred in solar battery applications. While lead-acid batteries may have lower upfront costs, the long-term benefits and performance of lithium-ion batteries make them the better choice for most solar energy storage needs. Therefore, a Lithium-ion battery was chosen based on this information.

The battery voltage and power requirements were selected to sustain uninterrupted operation of all devices listed in table 1.1 for 48 consecutive hours at maximum current, with the exception of the GSM module, which only requires power once a day for a brief duration (maximum of 1 minute). It was determined that two 9-volt batteries would be used in series to create an 18-volt battery. Although the voltage exceeds the required amount needed to power all devices, it suits the design of this specific

Figure 6.8: XH-M603

system, facilitating effective and consistent regulation of 5 and 10 volts, as well as accurate monitoring of battery levels across all possible combinations of battery charge and available solar energy.

Initially, the total power consumption for each device was calculated over two days, excluding the GSM module. The daily total is 9.373 watts, resulting in 18.746 watts over the span of two days.

Subsequently, the power demands of the GSM module were considered, resulting in 8 watts per day, summing up to 16 watts over two days.

Consequently, the combined power consumption for all devices over 48 hours was computed to be 34.746 watts. Finally, the total watt-hours were calculated to be $34.746 \times 48 = 1667$ Wh (rounded off).

With ampere-hours $= \frac{1667}{18} = 92.656$ Ah.

As a result, the battery rating should be 18 volts, 1667 watt-hours (92 Amperes per hour).

6.4.6 Solar Panels

Many solar panels are available with different ratings and prices. From figure 1.9 below we can see that the location of the solar battery(Kruger) receives high sunlight throughout the year.

To calculate the rating of the solar panel needed, considering factors such as panel efficiency, average sunlight hours per day and charging process inefficiencies. The formula is:

$$\begin{aligned}\text{Panel Rating (in Watts)} &= \frac{\text{Battery Capacity in Ah} \times \text{Battery Voltage in V} \times \text{Charging Efficiency}}{\text{Sunlight Hours per Day}} \\ &= \frac{(92.656\,\text{Ah}) \times (18\,\text{V}) \times (0.85)}{5\,\text{hours/day}}\end{aligned}$$

Plugging in provided values yields a Panel Rating of approximately 283.53 Watts. This means a solar panel with a rating of around 283.53 Watts is required to fully charge the 18V 92.656Ah battery, assuming 85 percent efficiency and 5 hours of sunlight daily.

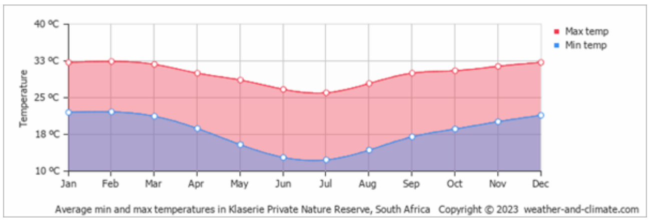


Figure 6.9: Average Temperature reading from Kruger region

6.5 Final Design

The high level overview can be seen in figure1.11 below and the actual circuitry can be seen in figure1.10 below.

Results and testing

6.6 Testing and Results

The testing process was divided into two sections: unit testing and full system testing.

6.6.1 Full system testing

Output voltage testing

All devices were connected to the circuit and left operating for 10 minutes and then the voltage across all terminals were measured and can be seen in figure 1.12a and 1.12b. This test was successful.

Power without solar testing

Tests for this could not be done as access to the battery was not available. however, using common formulas it was determined that the battery has enough capacity to power all devices in table 1.1 for 48 hours.

Temperature testing

The system was placed in the freezer and under a hairdryer until 5 degrees and 30 degrees respectfully(measured by a fairly accurate thermometer). Then a single devices was plugged in and it was seen that the device still functioned optimally. This test was successful.

Bird and weather proofing

These tests could not be conducted as access to the birds was not an option and the circuit could not be placed in the bird box with its weather proof container.

6.6.2 unit testing

Over voltage

The system was powered by 22 volts and devices were left to run for 10 minutes and then the voltage of the device terminals were measure and were found to be operating optimally with 5 and 10 volts respectfully and the connection to all devices can be seen in figure 1.13 below.

Voltage Regulator

The system was powered with a varying voltage from 12-18 volts and voltages across device terminals were measured. The test was successful with devices still operating optimally at 5 and 10 volts respectfully.

Reveres polarity

The system was powered in with normal operating voltage and a device was plugged in the wrong was around and the voltage across the terminals were measured. This test was successful as the voltage reading was negligible

Over current

The system was powered by optimal operating voltage and a device with around 20 percent more current than fuse1 was plugged in. After 3 minutes the fuse popped. This test was successful. The other fuses were not tested to prevent unwanted danger and to save costs.

6.7 Conclusion and Recommendations

6.7.1 Conclusion

In conclusion, the power subsystem for the automated bird monitoring system has been meticulously designed and thoroughly tested. Various measures ensure optimal performance and reliability. Through unit and full system testing, functionality has been validated, including output voltage, temperature resilience, overcurrent protection, voltage regulation, battery level monitoring and over voltage protection. While some tests like bird and weatherproofing were not feasible, the overall design ensures robustness to environmental challenges. With careful component selection, the power subsystem meets system requirements effectively.

6.7.2 Recommendation

- Test the battery level monitoring with the micro controller to see real results and compare with charge controller built in voltage reader.
- Use a veriboard or design a PCB for the circuit to reduce any losses, improve presentation, reduce danger and help with weather and bird proofing.
- To power more devices consider using a switching voltage regulator to ensure better stability
- Consider using MOSFET for polarity checking to reduce the voltage drop found using the diode.

6.7.3 Bill of Materials (BOM)

Component Name	**Quantity**	**Price (R)**
Resistors	10	1
LM317	2	20
Fuse & Casing	4	20
Capacitor	4	4
Diode	2	4
Op-Amp	1	10
Breadboard	1	80
Solar Panel	1	1000
Battery	2	300
	Total Price	**1439**

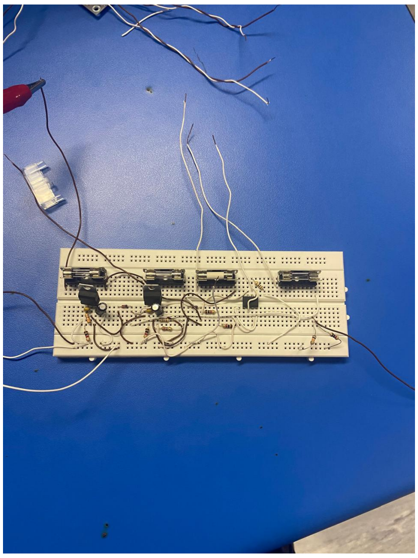


Figure 6.10: Circuit

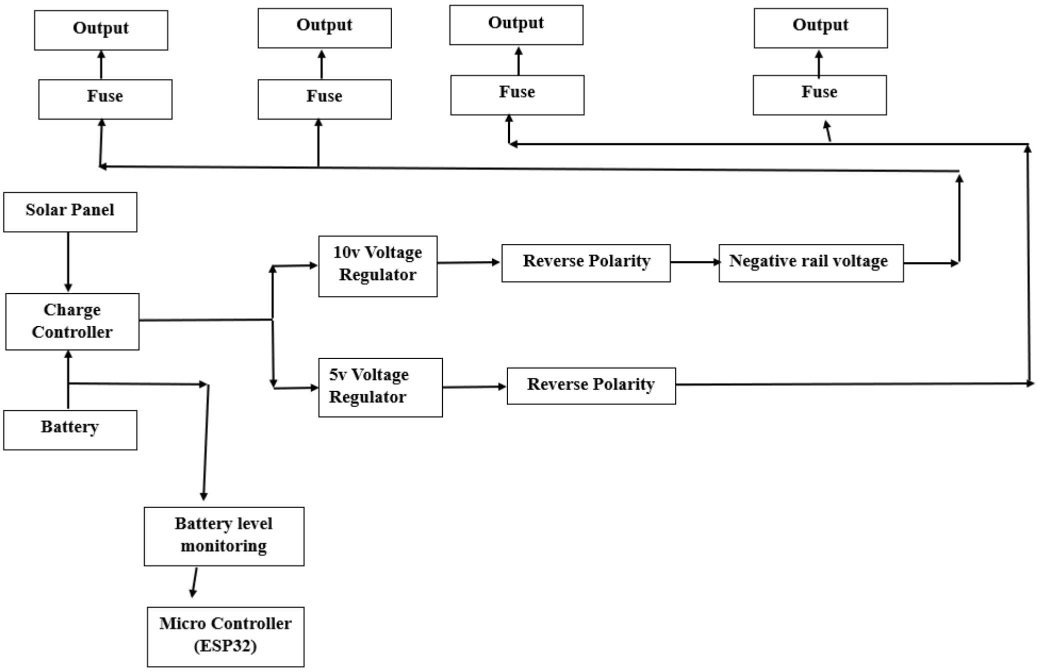


Figure 6.11: High level overview

(a) 10 volts with 12 volt input

(b) 5 volts with 12 volt input

Figure 6.12: Voltage testing

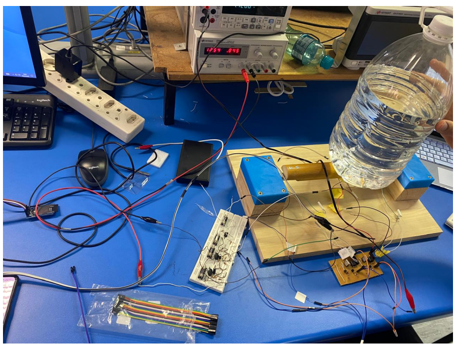


Figure 6.13: Fully operating whole system

Chapter 7

Communications and User interface

BY Akhtar Patel -PTLAKH001

7.1 Introduction

The aim of this project is to aid researchers in their research of Southern Ground Hornbills by designing a smart scale system that allows the researchers to capture meaningful data. This submodule forms a critical component of the smart scale project and aims to tie up the objectives of the other three subsections in a way that brings meaning and accessibility to the end user. This subsystem is designed to allow the end user to have seamless access to captured data and intuitive visualization of the data. At the core of this subsystem lies the objective of enabling end user to download data wirelessly from the smart scale eliminating the need for manual retrieval and enhancing data accessibility. Furthermore, the subsystem aims to provide end users with real-time visualization of stored data through an intuitive user interface, facilitating informed decision making and analysis. By prioritizing user-friendliness, data security and scalability, the subsystem endeavours to enhance the overall user experience and empower users with actionable insights derived from captured data.

7.2 Requirements and Specifications

7.2.1 Requirements

User Requirements

Requirement ID	Description
UR01	The user must be able to download the data accumulated by the system as a whole without disturbing the peace in the nest.
UR02	The solution has to account for data security, and only allow authorised personnel to access the data.
UR03	The solution must be cost-effective.
UR04	The system should be relatively easy to use and navigate around without technical expertise.
UR05	The solution must be interactive.
UR06	Data should be stored and formatted in a useful way that the user will be able to make meaning of.
UR07	The system should be able to operate on a range of devices: laptop, phone, or tablet.

Table 7.1: User requirements

Functional Requirements

Requirement ID	Description
FR01	The form of communication between the system and user must be wireless.
FRO2	The system must be secure.
FR02	The system must have a user interface.
FR03	The user must be able to download data saved on the system to his local storage.
FR04	The system must be fast and reliable.
FR04	The user must be able to view real-time measurements on the user interface.
FR05	The user must be able to visualize the data collected in a meaningful way.
FR06	The system should be scalable to an increasing number of RFID tags.

Table 7.2: Functional Requirements

7.2.2 System Specifications

From the User requirements, the system specifications have been defined:

7.3 Design Choices

Design choices were made based on the knowledge gained from the literature review in conjunction with stakeholder engagement. The design process is divided into 4 separate sections that coincide.

Requirement ID	Description
SP01	User needs to communicate with the system from a minimum distance of 2 meters.
SP02	The system must have a password to access data.
SP03	The system must be able to load and operate within 2 seconds.
SP04	The system must be able to download data file within 5 seconds.
SP05	The system must be able to view real-time reading of weight corresponding to the RFID.
SP06	The system must be able to view real-time reading of temperature.
SP07	The system must represent collected data in a graphical form.
SP08	The system should be able to cater for changes in the data collected.
SP09	The system must allow the user to interact with graphical data.
SP010	The system should adapt to different screens without compromising ease of navigation.

Table 7.3: System specifications

1. Wireless communication method.
2. Security protocol.
3. Data storage
4. User interface platform.
5. User interface architecture.

7.3.1 Wireless communication methods

The literature review extensively describes various Wireless communication methods that have previously been implemented by researchers in the field. Four methods were taken into consideration and the method best suited for the scope of the project was selected.

1. station mode (wifi) .
2. Bluetooth low energy.
3. Access point mode.
4. LoRa (long Range).

For this design system, the wireless communication method of choice is to configure the ESP32 in Access Point mode, which allows for the creation of an internal web server directly within the ESP32 device. Using this method, a device can easily connect to the ESP32 Access Point, allowing for seamless communication and data retrieval using the Hypertext Transfer Protocol (HTTP). This solution not only ensures smooth data exchange but also has the added benefit of supporting multiple users at the same time, without the need for an internet connection. This wireless communication method can also be seamlessly integrated into a web based user interface using HyperText Markup Language (HTML), enabling a user-friendly and versatile system design. Figure-5.3 shows the overview of how devices connect to the ESP32 Access Point.

7.3.2 Security protocol

The system is designed to only let authorised users to access the system, this is achieved by predefined password for the access point. The security protocol is tested in the ATP testing section and is proved to be robust only allowing users who know the password to access the server. In the initial design, a login page was integrated into the user interface dashboard to manage user authentication. However, it was later removed due to redundancy as Access Point authentication was deemed adequate for ensuring system security. Access Point authentication controls access to the system, eliminating the need for a separate login process. This streamlined approach maintains robust security measures while simplifying the user experience, ensuring seamless access to system functionalities.

7.3.3 Data storage

The user interface sub-module requires storage space on the ESP32 to store images, icons and source codes. The ESP32 module selected for this project is the ESP32-S3 and the reasoning behind this choice is elaborated in the micro-controller and data-processing sub-module. The ESP32 only has 16Mb on chip memory and to not overload the micro-controller the decision was made to add an SD card. The smallest available SD card was used, a 16GB (HKV HS-TFC1-16GB) and a HKD SD CARD READ/WRITE Module was used to integrate into the system. The SD card and the read/write module have temperature rating of 70 degrees making them compatible to integrate into the system.

7.3.4 Choice of User interface platform

The selected user interface platform for the subsystem leverages a web-based approach over a Python-based GUI. This decision was driven by the desire to capitalize on the styling capabilities of HTML and CSS, ensuring a visually appealing interface. Additionally, the use of chart.js enhances interactivity and facilitates data visualization, a key requirement for the subsystem. Ultimately, the web-based user interface was chosen for its intuitive nature and ability to deliver a more engaging user experience. Alternate design option was to use a tinker based python GUI.

7.3.5 User interface architecture

The user interface architecture revolves around a centralized home page linking to multiple HTML pages, each representing distinct sections or functionalities of the system, such as user profiles, data visualization, or settings. Navigation between these pages is facilitated through hyperlinks or buttons, ensuring users can easily access different parts of the system. This architecture was chosen for its scalability and flexibility, allowing for future expansion without disrupting the existing structure. Moreover, it promotes easy maintenance by isolating related functionalities in separate HTML pages, enabling updates or modifications to be made efficiently. Consistency in design and layout across all pages ensures a cohesive user experience, while modularity enhances code organization and flexibility in development. Overall, this architecture provides a robust foundation for the system's user interface, accommodating both current needs and future growth

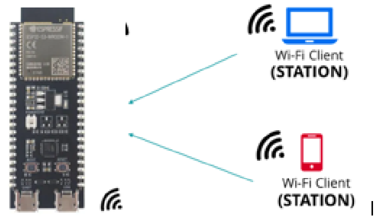


Figure 7.1: ESP32 acting as an access point

7.4 Prototype

The prototype section is divided into 2 modules the access point module in charge of creating an access point on the esp32 and a user interface module that deals with creating request and responses for the html code and the user interface module is also in charge of the html styling and designing.

7.4.1 Access Point

Based on the design choices made in the chapter above, a simple yet detailed system is created. The ESP32 is configured to operate as an access Point(AP) enabling it to establish its own wireless network. Devices connected to this access point are then able to send requests to the Esp32 based on the HTTP protocol, and receive appropriate responses from the ESP32. HTTP in conjunction with SPIFFS is used to download the raw data file which is in a .CSV format and is found on the ESP32s SD card.A series of HTML pages are used to structure the web based user interface for the end user to intuitively navigate through different functionalities of the system.

7.4.2 User Interface

At the core of the system architecture is a dashboard page which allows user to intuitively navigate through different functionalities of the system. Each functionality is encapsulated within its own HTML page.

1. Download stored data.
2. visualize stored data.
3. view power utility.
4. view real-real time measurement.

The navigation between the ‘dashboard’ page and other functionality pages is handled through JavaScript. When a user clicks on a button corresponding to a specific functionality the JavaScript function ’navigateTo()’ is invoked. This function determines the target page based on the user selection and redirects the browser accordingly using the ’window.location.href’ property.

CSS techniques including media queries, relative units, percentage sizing, flexbox layout, and the viewport meta tag are used to meet the system specification SP09. Media queries allow for custom styling based on devices screen width and orientation characteristics (phone, Laptop, Tablet). relative units and percentage sizing ensure elements adjust proportionally against each other. Flexbox layout provides centered alignment and dynamic spacing functionality. Each button encapsulating different

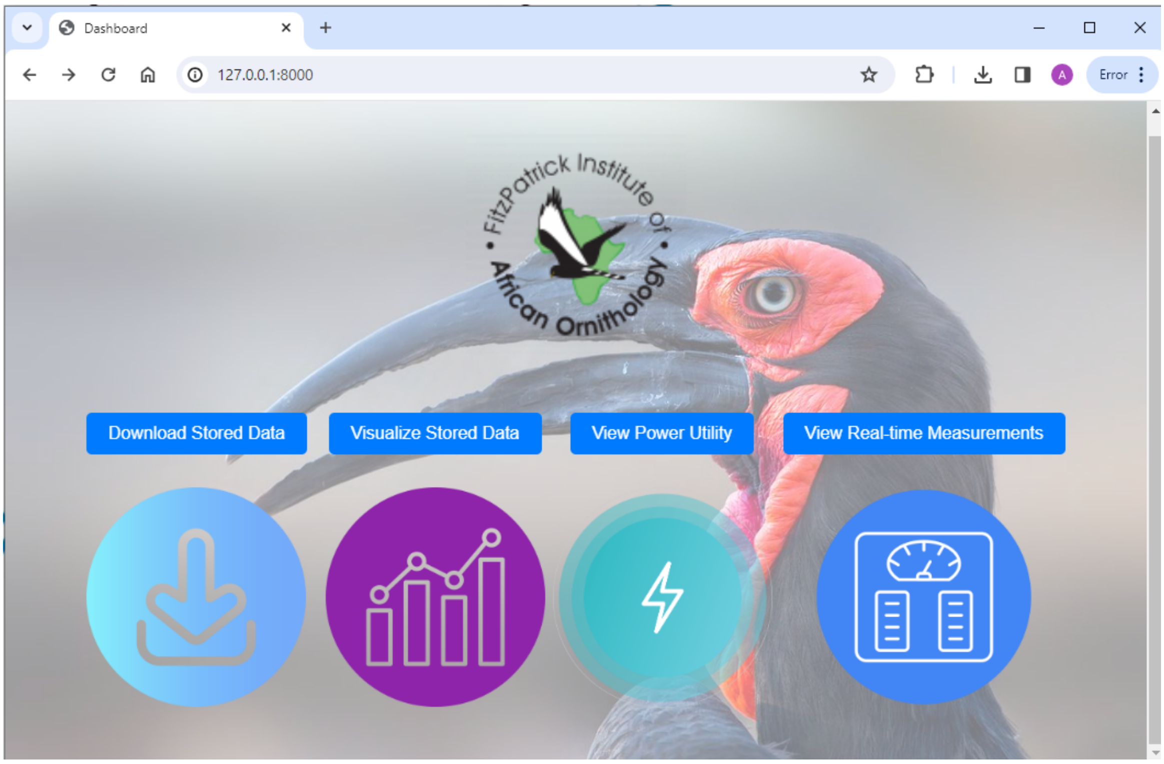


Figure 7.2: Dshboard page of user interface

functions is designed to have a self explanatory name, furthermore icons are added to make navigation easier. Together, these techniques create a user centric experience.

7.4.3 Data Visualization

The visualization HTML page has 2 subsystems.

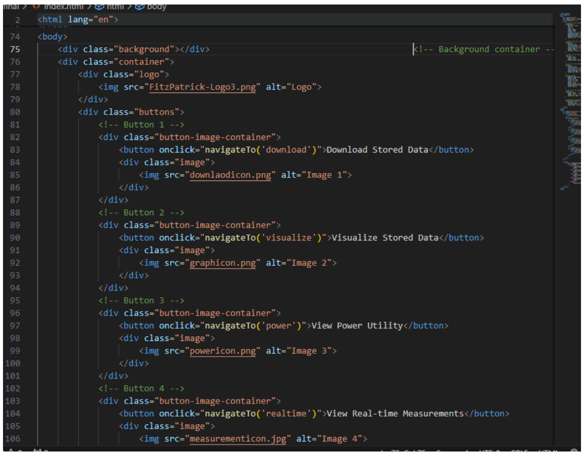
1. Parsing and preparing data.
2. Graphing prepared data.

Parsing and preparing data

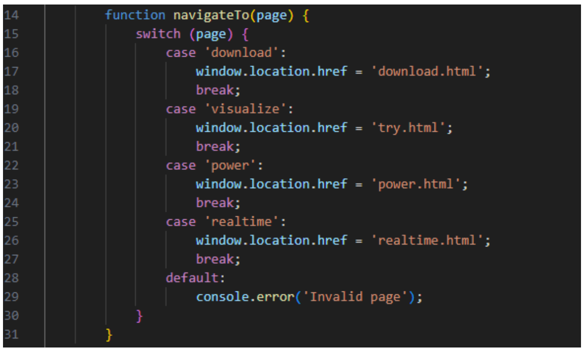
keeping in mind the entire smart scale system, there will be birds assigned to a unique RFID and their weights will be recorded alongside their associated RFID. This gives rise to the need to organize the data before running graphing code on it. The system is designed to fetch the CSV data using HTTP request and upon retrieval, it is transformed into text format for processing.Each line of the CSV data is split into individual rows, separated by newline characters. Within each row, the values corresponding to RFID, weight, and temperature are separated by semicolons. This parsing operation ensure that each data point is isolated and can be analysed individually.

The code proceeds to prepare the data based on the user requirements for visualization. It calculates average weights of all the weight recordings of each bird. The temperature averages were calculated at every 5 readings for a data set of 25, this is different to what the actual calculations would be in prototype deployment.

(NOTE : This was due to shortcomings of the entire scale system as it could not account for time,



(a) Code snippet showing onclick functionality used to navigate.



(b) Code snippet of NavigateTo() function redirecting to different pages.

Figure 7.3: Design considerations for different wireless communication methods

further details of this are elaborated in the micro-controllers recommendation chapter. The aim was to visualize daily temperature averages. The user-interface subsystem is designed using a modular architecture which allows for system updates, hence for future updates of the system would be simple.)

Utilizing JavaScript objects, the code accumulates weight and temperature values for each RFID tag while simultaneously keeping track of the number of measurements recorded. The code then structures the prepared data into datasets suitable for generating line charts and bar charts using Chart.js. These datasets are meticulously organized to include the necessary labels, data points and styling information, all which is required for the graphing subsystem.

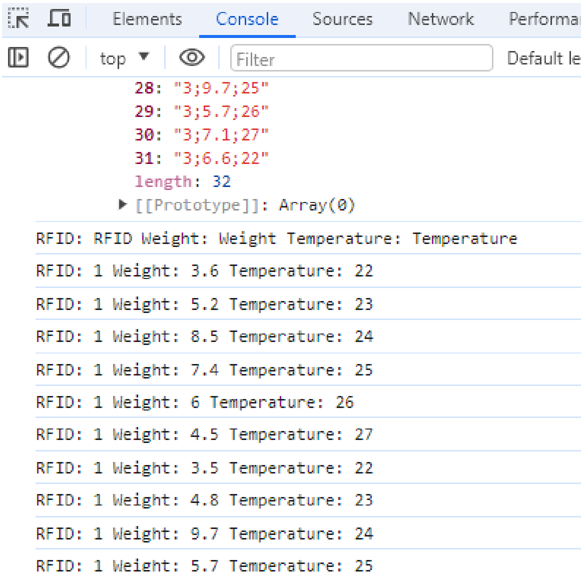
7.4.4 Graphing the data

The graphs were designed keeping in mind the user requirement to be able to interact with the data. Four key graphs were selected.

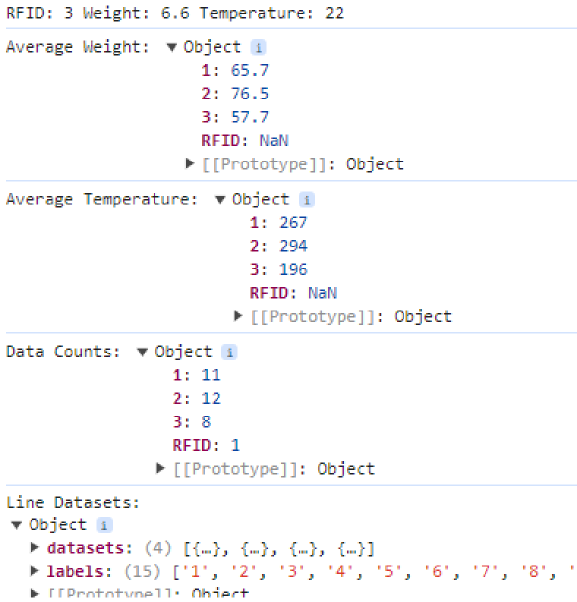
1. Line chart of weight recording of different birds(RFID) on the same axis .
2. Line chart of all temperature readings recorded.
3. Bar chart of average weight of each bird(RFID)
4. Bar chart of average temperatures.

The charts are designed with scalability in mind, based on the available number of RFID tagged birds meaning the system is currently tested with 3 RFIDs, however in the event where there are more RFIDS the charts will automatically adjust to an additional data set, this is achieved by dynamically plotting the graphs based on the outcome of the parsing and preparing function.

Furthermore the user can deselect a data set by simply clicking on the legend. To improve interactivity placing a cursor on each point or bar gives the value that point represents. A download button is also included to allow user to download graphs straight to their local workspace.



(a) Snippets from Console used for debugging and visualizing CSV file preparation



(b) snippet showing Java object created from a raw CSV file.

Figure 7.4: Snippet of Average calculation outcome.

Figure 7.5: An overview of the Visualize Data page.

Test number	Test Description	Pass/Fail
AT01	Wireless communication	Pass
AT02	System Security	Pass
AT03	Ease of navigation	Pass
AT04	Adaptability to different screen size	Pass
AT05	Download raw data file	Pass
AT06	Visualize collected data	Pass
AT07	interact with data	Pass
AT08	Download .JPEG files of graphs	Pass
AT09	View Real-time measurements	Pass

Table 7.4: Acceptance Tests

Real time measurements

The real time measurements page utilizes HTTP requests asynchronously communicate with the ESP32, upon recieve JSON response the HTML elements for temperature, weight, and rfid are updated. To ensure continuous updates from the ESP32 the function responsible for collecting the data every 5 seconds ensuring the displayed data remains current. Upon loading the web-page, the window.onload event handler initiates the updateSensorData() function, thus commencing the continuous update process. By leveraging these JavaScript functions, the webpage dynamically acquires and displays real-time sensor measurements from the ESP32 device, enhancing interactivity and responsiveness for the user.

7.5 Testing and Results

7.5.1 Acceptance Tests (ATs)

7.5.2 Acceptance Test Procedures (ATPs)

This section will elaborate on how different ATPs were tested.

7.5.3 Access point performance and security

The ATPs relating to system performance were tested by attempting to wirelessly connect to the Access Point from varying distances starting from the minimum distance specification of 2 meters and a maximum of 6 meters. System security is also tested in conjunction by inputting wrong password to the access point. Figure below shows the successful creation and connection to the access point and figure below shows a failed attempt to connect to the access point due to wrong password.

7.5.4 Ease of navigation and Adaptability

The system was easy to navigate around with the use of graphical icons depicting what each button does. The systems adaptability to different screen sizes was tested by opening the server on a laptop and a cellphone. further more the server window was adjusted from full screen to a quarter of the screen. The collection of figures below show the system adapting to different sizes and the different orientation of the system.

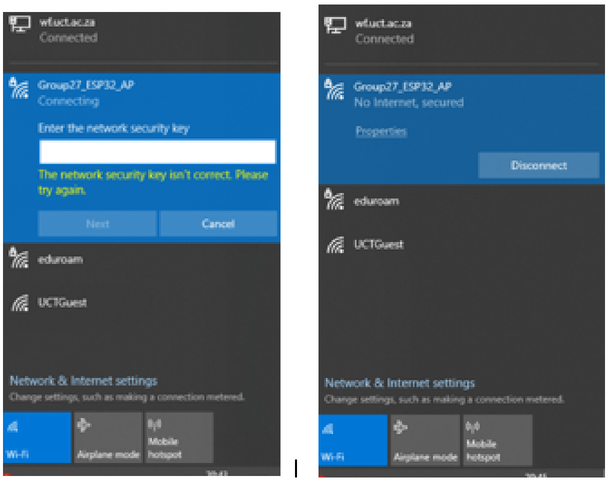


Figure 7.6: snippets showing a failed connection due to wrong password and a successful connection

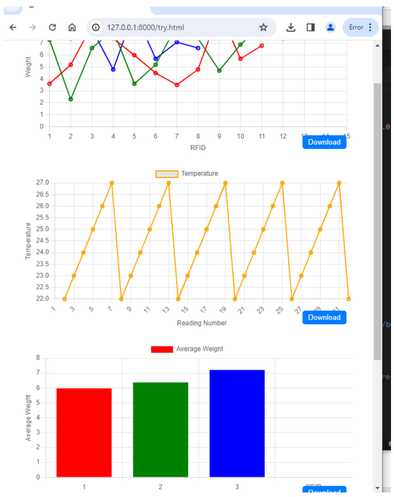


Figure 7.7: visualization adjusting to a horizontal narrow screen

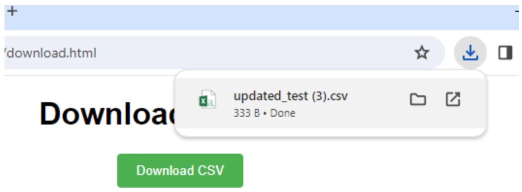
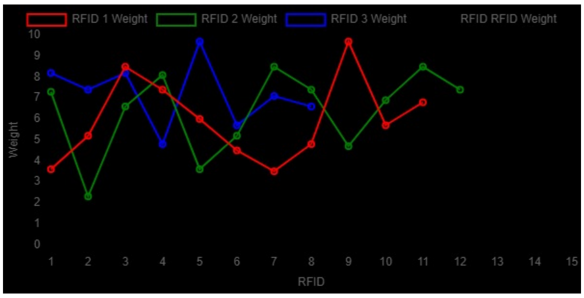
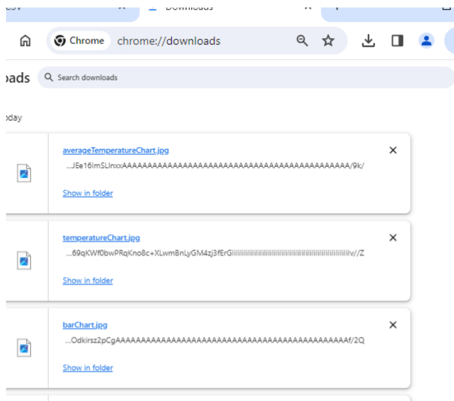


Figure 7.8: CSV file successfully downloaded to users local storage



(a) Downloaded .JPEG image of the weight line graph



(b) snippet of users download history showing files downloaded from ESP32 server.

Figure 7.9: Snippets of download functionality working

7.5.5 Download CSV file and graphs

The screenshots below show the csv file being downloaded on the users desktop. The Graphs also downloaded successfully however the background on the graphs was different to the one on the web server.

7.5.6 Interaction with visualized data

The system was successful in proving to be a user centric and interactive system as the user was able to select which graphs he would like to view by simple clicking on the legend bar. The snippets below also show what the page does when you place a cursor on a specific point.

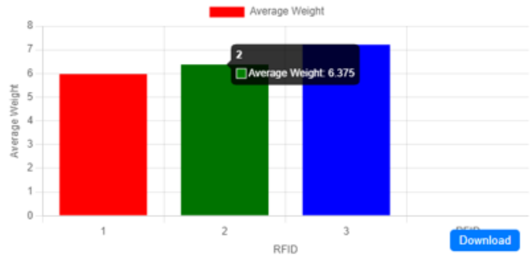
7.5.7 Real time measurements

The system was successfully able to show real time data of the recorded weight and temperature. This was tested by placing a 2 litre water bottle on the scale and taking a screenshot of the web-server output.

7.6 Conclusion and Recommendations

The system has successfully met all acceptance tests and fulfilled the initial design goals by providing a user-centric and intuitive interface for remote data visualization and download. However, certain

(a) User RFID 2 set of data.



(b) user being able to see the exact average weight of each RFID.

Figure 7.10: user interactions

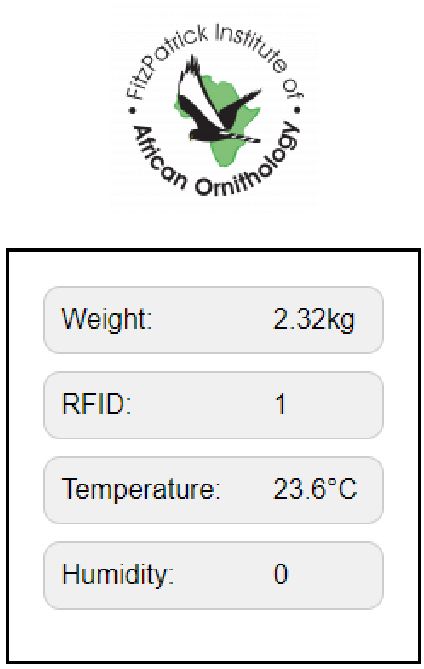


Figure 7.11: snippet showing real time data.

enhancements and additions are recommended for further improvement. Firstly, it's noted that the background color of the graph images is black, which may hinder data analysis. It's suggested to inspect and adjust the graph images to ensure better readability by selecting a more suitable background color. Additionally, the system would benefit from the inclusion of a clock feature to provide context and relevance to the data. Although originally planned, technical difficulties prevented its implementation. Revisiting this feature and integrating it into the system would enhance the overall functionality. The power utility page is identified as incomplete due to design choices made in the Power sub-module. However, the modular system architecture allows for flexibility in making system changes and upgrades. Implementing real-time measurement reading techniques similar to those used in other modules can help complete the power utility page. By adjusting requests and configuring the appropriate pins to receive power utility data, the page can be enhanced. Furthermore, it's recommended to add a local system component that runs on the user's device after retrieving the CSV file. This would allow users to visualize CSV data conveniently in their office environment. Implementing a Python script for this purpose offers flexibility for researchers to analyze data and add functionalities as needed.

In summary, while the system has achieved its primary objectives, incorporating these enhancements will further elevate its usability, functionality, and user experience.

The github link to the all source codes can be found here Visit my GitHub page

Chapter 8

Conclusions

8.0.1 Conclusion

In summary, the prototype design of the group's solution was able to meet most of the main requirements and specifications of the project, as demonstrated in the sub-modules evaluations. The solution provides a system that will allow Carrie to accurately record the weight of the Southern Ground Hornbills to a high degree of accuracy; although not within the accuracy specification that was required; the time of day and the temperatures of the ambient surrounding as well as the temperature inside the nests. The solution is able to operate in the remote test site locations and is able to operate on battery power for a week at a time. The solution also provides a simple and easy to use GUI that allows for remote data transfers. The proposed solution will increase Carrie's efficiency in her research.

8.1 Recommendations

The proposed solution did not meet its RFID detection and measurement accuracy specifications.

It is crucial to revisit the low-frequency RFID methodology in order to enhance the proposed detection system. This methodology, which is currently not functioning as required, necessitates a complete redesign to find a solution that will meet the specifications.

To improve the scale's accuracy and precision, it will be necessary to increase the gain of the OpAmp in the scale to reduce the maximum weight input to 3kg. This improves the accuracy by lowering the voltage steps of the ADC.

To further increase the scale's accuracy, better and more accurate masses should be used and tested to attain a more accurate loadcell characterization.

Furthermore, an HX711 IC can be resorted to as it has a 24-bit ADC and would allow much better accuracy and precision than the standard 12-bit ADC available on the ESP32.

Replacing the unreliable micro-controller's real-time clock with a more accurate external real-time clock, such as the DS3231, will significantly improve data synchronization between monitoring devices and provide more useful data.

Additional monitoring features, such as a battery level indicator from the power sub-module, can also easily be included.

A remote monitoring system can also be included such as a GSM800l which will allow the system to be able to provide feedback to the researchers if the system encounters any problems and also allow the researchers to send remote commands to the system. Considerations would obviously need to be made in regard to the availability of Cellular signal.

8.1.1 BOM

Component Name	**Quantity**	**Total Price (R)**
BDD Electronic Load Cell 10KG	2	R90.00
AD620 Instrumentation Amplifier	2	R80.00
IRF9540 Mosfet	2	R20.00
PN2907ABU PNP Transistor	4	R26.00
3.3V Zener Diode	2	R4.00
ESP32 S3 Dev Board – N16R8	1	R204.70
HKD Stainless Steel Digital Temperature Probe (DS18B20)	1	R54.00
HKD I2C REAL TIME CLOCK- DS3231	1	R60.00
125KHZ RDM6300 RFID MODULE	1	R149.95
HKD RFID CARD 125KHZ (5PKT)	1	R35.01
RFID TAG 125KHZ	1	R29.85
Resistors	10	R1.00
LM317	2	R20.00
Fuse & Casing	4	R20.00
Capacitor	4	R4.00
0.3V Diode	2	R4.00
Opamp	1	R10
Breadboard	1	R80.00
Solar Panel	1	R1000.00
Battery	2	R600.00
Total Price		**R2492.51**

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Appendix A

Appendix

A.1 Differential Amplifier

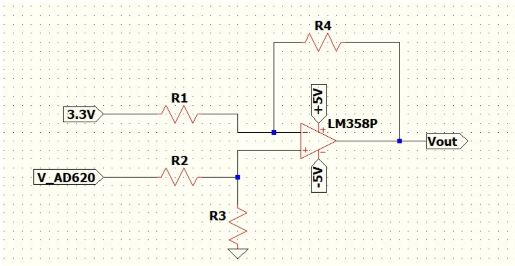

Figure A.1: Circuit Diagram of the Differential Voltage Amplifier

Should the bias voltage be non-negligible, this circuit may be used to nullify the unwanted effects. With R1 set equal to R2 and R3 set equal to R4, the gain of the amplifier can be set using the formula:

$Vout = \frac{R_3}{R_1} \cdot (V\_AD620 - 3.3V)$

A.2 Evidence of GAs Met

GA Requirement	Description
3	Engineering Design
7	Sustainability and Impact of Engineering Activity
8	Individual, Team and Multidisciplinary Working
10	Engineering Professionalism

Table A.1: GA Outlines

GA 8 was met though the use of Microsoft Teams, where all meetings and discussions concerning this project took place. The minutes can be found in this link to the teams channel: Link .

Chapter/Section	Contributors	GA Requirement
1.1	Jake	3, 10
1.2	Jake	3, 10
1.3	Jake	3, 10
1.4	Jake	3, 10
1.5	Jake	3, 10
1.6	Jake	3, 8, 10
2	All	7, 8, 10
3.1	Jake	3, 10
3.2	Jake	3, 10
3.3	Dylan	3, 10
3.4	Akter	3, 10
3.5	Josh, Dylan	3, 10
3.6	Josh, Jake	3, 10
3.7	Dylan	3, 10
4	Jake	3, 7, 8
5	Dylan	3, 7, 10
6	Josh	3, 7, 10
7	Akhtar	3, 7, 10
8	Dylan	3, 10
??	Dylan	3, 10

Table A.2: Table of Contributions

A.3 Git Repository

Here is a link to the git repository containing all of the code and files used in creating this project.