Weighing and Identification of Southern Ground Hornbills in the remote Greater Kruger

- Group 10 -

Prepared by:

Name	Student Number	Subsystem
Ashik John	JHNASH009	Scale Design
Msimamisi Lushaba	MWNMSI001	Power
Oliver Shaw	SHWOLI002	User Interface
Si Teng Wu	WXXSIT001	Process Control

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

July 3, 2024

Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this report from the work(s) of other people has been attributed, and has been cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as their own work or part thereof.

July 3, 2024

Ashik John

Date

July 3, 2024

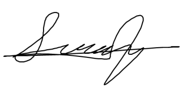
Msimamisi Lushaba

Date

July 3, 2024

Oliver Shaw

Date



July 3, 2024

Si Teng Wu

Date

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

In field ornithology the body mass of a bird is a very good indicator of the bird's health and being able to track changes in bird mass over time gives researchers a better understanding of the impacts the environment and the greater climate have on these bird species. Due to this it is crucial to be able to successfully and accurately weigh and record birds, especially endangered and at risk species. This gives researchers an insight into how species are adapting to the changing climate and to how to better aid species that are failing to adapt.

1.2 Problem Statement

Carrie Hickman, a PhD student studying Southern Ground Hornbills in the Greater Kruger, needs a way to gather and track accurate and reliable weight data that is correctly identified to specific birds because this data is vital in understanding the effects the environment is having on the Southern Ground Hornbill population.

1.3 Proposed Solution

The proposed solution to solve Carrie's problem was to design and develop an automated rooftop weighing scale. The system will automatically record a weight value as well as an identification number using RFID. The scale itself will take the dimensions of the roof into account to determine the optimal load cell arrangement to gather accurate data. The recorded data is calculated and stored by the central microcontroller. This data can then be accessed by the end-user on an application that communicates with the central microcontroller wirelessly through Bluetooth or Wi-Fi. This will allow for the wireless transfer of recorded weight data between the system placed in the tree and the user at the base of the tree.

1.4 Subsystem Breakdown

1.4.1 Power - MWNMSI001

The power supply system with a battery charger has two main parts: charging and supplying power. Solar panels charge the battery, controlled by a regulated battery charging module. A DC-DC converter regulates power for loads, with a rechargeable battery backup source for uninterrupted operation. The subsystem is designed to charge through solar panels when sunlight is available and use stored battery power when sunlight is limited, ensuring reliable and sustainable power supply.The subsystem also has battery level information for any diagnostics that may be deired.

1.4.2 Scale Design - JHNASH009

This subsystem includes the structural design of the weighing scale, and how it is optimised to improve the protection of circuitry, and installation to the nest box roof. Signal conditioning to improve reliable data recovery is also outlined in this subsystem. The system receives the weight of the bird and system power as inputs and then converts these inputs into a digital signal that can be read by the microprocessor for further processing.

1.4.3 Processing and Control - WXXSIT001

This subsystem involves designing a hardware solution and software for controlling the collection, processing, storage, and transmission of data, as well as an identification solution. It has been divided into the following sub-modules: Identification, Weight Processing, Storage, Transmission, System Control, and Power Saving Techniques. Through the use of a micro-controller module and various other hardware modules, this subsystem will be the 'brain' of the system and act as the central hub for data while the system is in the field. This subsystem will receive input data from the Scale and Power subsystems and provide output data to the Power and UI subsystem.

1.4.4 User Application - SHWOLI002

This subsystem deals with the design and development of a user application that allows for recorded weight data to be viewed and downloaded. It will receive a set of data from the Processing and Control Subsystem that includes data gathered by the Scale Design, Processing and Control and Power Subsystems. This being weight data, RFID number and battery percentage. The user application will visualise this data into a simple and striking user interface that is designed solely around the user adhering to usability design principles.

1.5 Scope & Limitations

This project attempts to tackle the EEE4113F Design theme for 2024, pertaining to wildlife conservation using technology. The relevant stakeholders include researchers from the Fitzpatrick Institute of Ornithology, specifically Carrie Hickman. The scope of design skills to use includes those developed at a final-year electrical engineering level, assessing various ECSA graduate attributes.

The project is therefore limited by the requirements of the ornithologists and their research, as well as the budget limit of R2000 prescribed by the EEE4113F course administration. The project duration is limited to a span of 12 weeks (one semester) and is to be completed in groups of 4, where each group member handles their own subsystem. The subsystem integration follows a black box approach, where each individual must make relevant design choices to arrive at a suitable solution. Other relevant limitations are determined through stakeholder engagement, and detailed later in this report.

1.6 Report Outline

The report consists of a comprehensive literature review examining existing solutions in wildlife conservation, and where possible, applications of smart weighing systems in ornithology. The literature review is followed by the detailed design process followed in each subsystem, including requirement analyses, ATP development and the design choices made to fulfil those ATPs. Lastly, the report concludes the 12-week design process and outlines the next steps to follow should the design be taken up for further development.

Chapter 2

Literature Review

2.1 Problem Statement

Carrie Hickman, a PhD student studying Southern Ground Hornbills in the Greater Kruger, needs a way to gather and track accurate and reliable weight data that is correctly identified to specific birds because this data is vital in understanding the effects the environment is having on the Southern Ground Hornbill population.

2.2 Introduction

The monitoring of wildlife behaviours and health metrics such as body weight play a crucial role in conservation efforts, especially for endangered species like the Southern Ground Hornbill. Accurate weight data helps researchers track population trends and identify relevant interventions for conservation. However, conventional weighing methods can be invasive and disruptive to wildlife habitats. To address this challenge, engineering students and ornithologists at the University of Cape Town are collaborating to develop non-invasive weighing scale systems tailored to the needs of various bird-monitoring projects.

Bird monitoring technologies have advanced significantly, offering new ways to collect data in ornithology and wildlife conservation. This review explores weighing techniques, scale design considerations, identification methods, power strategies, and data processing in bird monitoring. By examining these aspects, we aim to understand how these technologies can benefit the monitoring of adult Southern Ground Hornbills.

2.3 Existing Weighing Techniques in Practice

Examining existing applications offers valuable insights into the practical implementation and effectiveness of weighing scale technology in diverse contexts. Comparing these contexts to the Southern Ground Hornbill Project highlights potential modifications to existing technologies that may provide effective solutions in weighing adult Southern Ground Hornbills. Existing techniques for measuring mass, with a focus on wildlife conservation, and where possible, ornithology, will be considered in a chronological order to allow the reader to understand the evolution of techniques as well.

A study by Sibly and McCleery [10] in 1980 into designing a nest-balance for ground-nesting birds, was successfully used with herring gulls and barnacle geese. The scale comprised of an underground box containing the scale mechanism, based on a spring balance that adjusted a potentiometer spindle altering the analogue signal sent for data capture. The tray aboveground held the nest, and data was recorded every five minutes in a data-capturing house 200m away. The scales deployed in the field outputted linear responses over a 5kg range, with a standard deviation of 15g [10]. It should be noted that the mechanical system took up significant space and its underground application contrasts heavily with the nest boxes of the Southern Ground Hornbills in trees.

Tim and Anette Manolis [1] discuss the use of a hanging scale as opposed to the platform-based scales found in most other studies discussed in this section. They used a basic spring-loaded analogue scale, shown in 2.1, to which they hung a dried citrus fruit rind feeder of known weight. They were able to observe weights obtained to the nearest 0.5g. Although this is a significant resolution loss with respect to the weight of the house finches they were weighing, the method demonstrated recognisable patterns of weight gain and loss [1]. While the recording of measurements was manual, small spring scales offer the benefit of being relatively inexpensive and portable for short-term field projects. Albeit manual recording does not apply to the case of the Southern Ground Hornbill, it is relevant to explore low-cost applications in developing solutions.

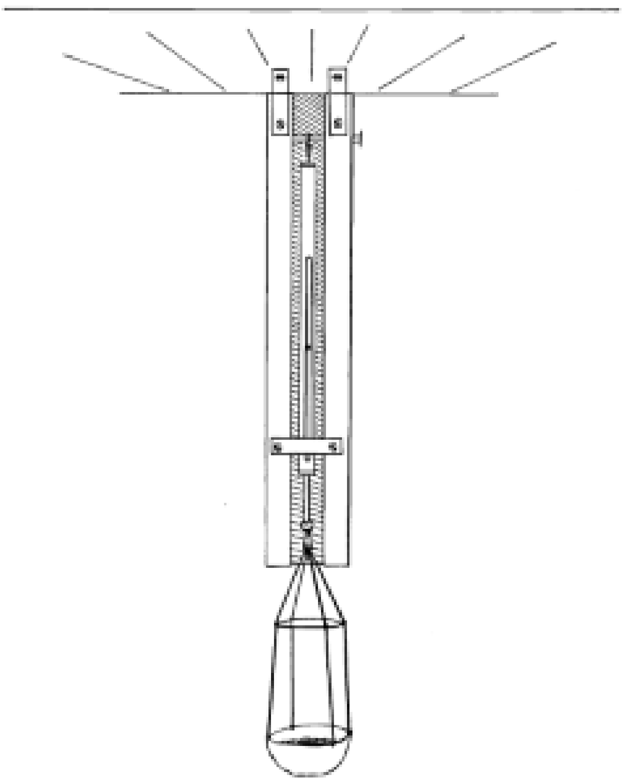


Figure 2.1: Hanging spring-scale use by Manolis [1]

Poole and Shoukimas [2] designed a perch scale that could easily be attached near the nests of Ospreys, shown in 2.2, with a focus on making the system compact, weatherproof, and relatively inexpensive. The scale was designed by incorporating a transducer into an artificial perch, along with batteries, an amplifier, and a recorder unit contained in a weatherproof ammunition box, allowing for remote weight measurements of birds landing on the perch. The scale was able to demonstrate accuracy within 2% of the actual weight on the perch, operating at a 0.5-5kg range [2]. The context of this application is highly relatable to that of the Southern Ground Hornbill, although the temperament of the different species towards foreign objects should be examined.

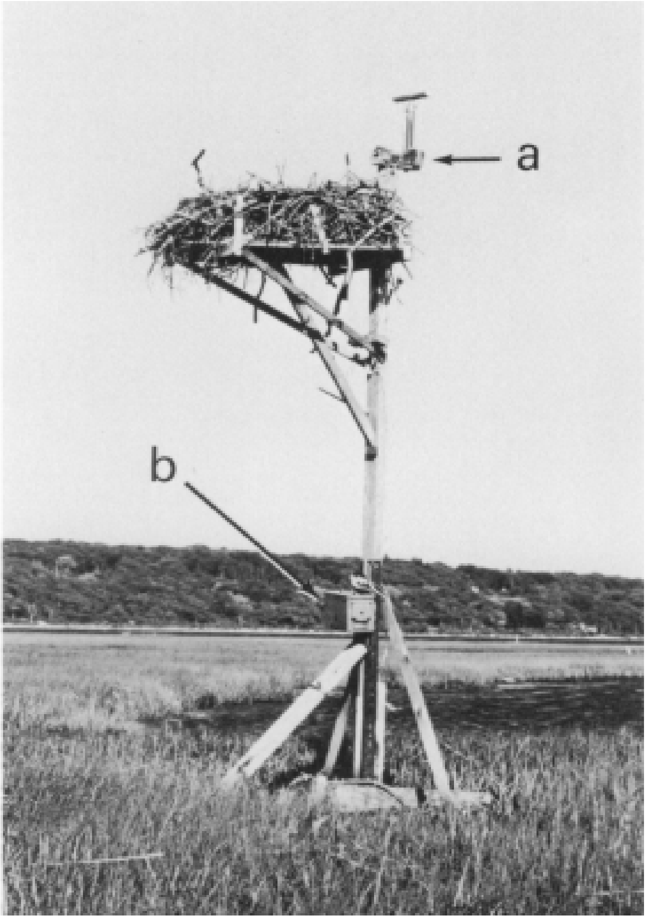


Figure 2.2: Perch scale on field used by Ospreys [2]

The team from University College Cork outline their development of a smart weighing scale for beehive monitoring [11]. They used a beam load cell connected in a half-wheatstone bridge configuration. This connection topology proved efficient for monitoring beehive weight, and testing results showed a linear relationship between the applied weight and the output voltage from the load cell. Important considerations in relating this application to bird monitoring, are the sedentary nature of beehives and the ability for the hives to be placed on the centre of the scale to be weighed.

Modern technologies have evolved to the point of suggesting that it may not actually be necessary to have birds rest on a conventional weighing scale to be able to obtain their body weight measurements.

Guglielmo et al. [12] outline their approach of using Quantitative Magnetic Resonance (QMR) to quantify fat, wet lean mass and total water mass in a scanned volume by utilizing the characteristic resonant frequency of hydrogen nuclei in different tissues. While QMR technology can be made field portable when transported in temperature-controlled containers [12], it requires capturing the birds and placing them in a scanner for a short period, which contrasts to the context of the Southern Ground Hornbills, in that they cannot be caught.

Mortensen, Lisouski and Ahrendt [3] developed a technique to predict the weight of broiler chickens using 3D computer vision technology. Many camera-based weighing algorithms operate on the assumption that there is a direct relationship between the volume that an object occupies and the mass of the object [3]. The results of the study showed a 7.8% average relative mean error. Although such technologies in their infancy may not provide the accuracy required by an ornithologist, it highlights how advanced back-end processing may offset limited equipment available on-field in bird monitoring applications. The system was successfully deployed in a poultry farm as shown in 2.3.

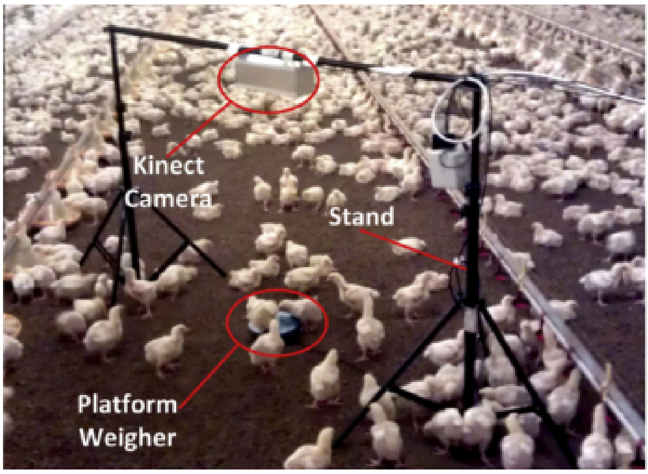


Figure 2.3: 3D vision system, along with a platform weigher to quantify error [3]

2.4 Design Considerations for Application Tailored Scales

Although there are various considerations when designing/selecting appropriate scales, the context of weight measurement in bird monitoring is atypical, and thus certain considerations would outweigh others. The most important considerations are common across the studies mentioned in the previous section and are discussed in further detail below.

2.4.1 Weight Capacity

Scales are designed to operate as expected within a certain weight range, and if exposed to weights outside of this range, the wieght can cause the system to fail or record inaccurate measurements. Designs may be modified to ensure that the scale is designed according to the expected weight. Poole and Shoukimas [2] mention that their design could be modified for smaller birds by increasing the gain of the amplifier circuit and using a transistor with a more flexible beam. A separate study on poultry weight measurement [13] outlines considerations to ensure that unnecessary weights do not end up on the scale, such as using a perch width that would limit the number of birds on it at a time and opting for a perch scale instead of a platform scale to avoid the accumulation of bird droppings.

2.4.2 Environmental Conditions

Based on the conditions of operation, components and housings may need to be chosen to withstand moisture, dust and other harsh circumstances. Sibly et al. [10] detail how wind turbulence and the moisture content of the nest affected weight readings. The issue of wind turbulence was accounted for by taking multiple readings and a control nest was used to evaluate the effect of moisture content. Poole et al. [2] ensured weatherproof design through various methods including zeroing the scale at a point that allowed for both positive and negative drift due to temperature, sealing strain gauges with weatherproof films and painting housings with reflective colours to reduce heat.

2.4.3 Bird Temperament and Behaviour

It is crucial to consider the natural behaviour of the birds and their acceptance of any design in their habitat. Haftorn [14] highlights the importance of being as non-invasive as possible with free-living birds as it may result in abnormal weight development. The same study mentions not being able to capture certain weights due to the birds not staying on the scale for long enough. Sibly et al. [10] were able to cater to the movement of birds on the scale by taking multiple readings and averaging them. Turner et al. [13] lowered the height of the perch in their poultry weighing scale, resulting in increased adoption of the perch by the chickens. While the ospreys in Poole et al.'s study readily adopted the foreign perches into their environment, the position of the bird on the perch affected the accuracy of the reading, which was accounted for by reducing the perch length. Muthoriq et al. [15] investigated the effect of object position on the reading error of weighing scales. It was concluded through static analysis that using a lever mechanism found in most mechanical weighing scales on top of the actual sensor/load cell pressure point can negate the error associated with the object position on the scale platform.

In wildlife monitoring, it provides value to track changes in weight for individuals, thus justifying the need for identification.

2.5 Identification Techniques Used in Ornithology

Understanding how a changing environment affects bird species is crucial for researchers aiming to help at-risk and endangered bird species [16]. This focus on halting biodiversity loss can be greatly aided by the use of marking [17]. To be able to study changes in the behaviour of these bird species and aid in conservation efforts it becomes necessary to track changes in individual birds. Traditionally, in ornithological research, coloured plastic or metal leg tags have been used. These tags are sometimes brightly coloured and have unique alphanumeric codes etched into the sides that allow for individual identification. However, advancements in technology have introduced alternative methods such as Radio-Frequency Identification (RFID) enabled leg rings and injectable tags. The use of this data can be divided into its use to track geographical changes which describe the movement and migration of these bird species, demographic data which looks into the survival rates and productivity and biological data which is concerned with the diet, body condition and genetic relationships [17]. The following is an exploration of the effectiveness, advantages, and limitations of these techniques used in ornithological research.

2.5.1 Leg Rings

Leg rings have been used extensively in ornithology to gain insights into the survival rates, breeding activities as well as other physiological and behavioural activities [17]. This method was first used by Hans Christian Cornelius Mortensen in 1899 and has since become the most important tool that researchers have to understand bird populations and the conservation of endangered bird species [18]. There have been many successful studies that utilised coloured or metal leg rings. For instance, a study conducted by Newton into the declines of farmland bird populations utilised colour leg rings to determine the survival rates of these birds. This study looked at various species of birds in Britain and leveraged several resources, such as the Breeding Bird Survey (BBS), a census on bird abundance showing year-by-year fluctuations [19]. The use of the ringing of these birds allowed Newton to compare periods of relative stability to periods of increase or decrease in population [19].

However, the limitations of these tags have been widely experienced by researchers through the years. Weimerskirch et al. [20] conducted a study of King Penguins but at the end of the study they were only able to retrieve 80% of the rings. Other studies have had better success rates of retrieved rings such as a study on Greenland White-fronted Geese fidelity by Wilson et al. which noted only one loss of leg ring of the over 700 birds that were ringed [21]. Beyond this, the technical limitation of leg rings is that they are difficult and labour-intensive to read and capture and for many species, this process includes the recapture of the birds to gather this data [22]. This has been seen to cause stress and has the possibility of inducing adverse physiological changes as seen in studies done by Wingfield et al. and Le Maho et al. [23], [24].

2.5.2 RFID-Enabled Devices

Technological advancements allowed for the development of RFID-enabled leg rings and injectable Passive Integrated Transponders (PIT) tags. An example of the design of these is shown in Figure 2.4.

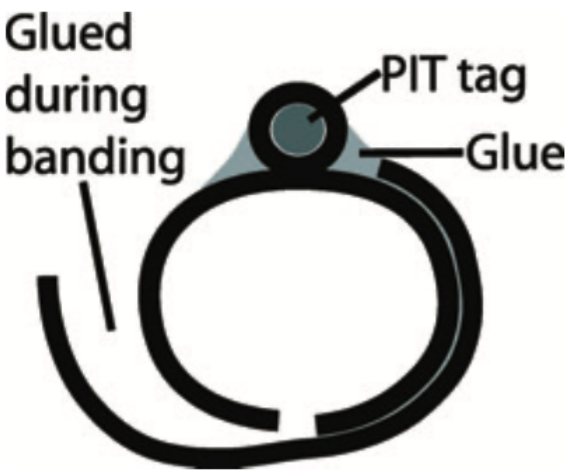


Figure 2.4: Cross-sectional drawing of an RFID leg ring [4]

These RFID-enabled devices led to researchers gaining the ability to track individual birds with unique identifiers, as well as allowing researchers to detect for the presence of a bird at a fixed location [25]. This furthered the insights that researchers could gain as they could gather mass amounts of data without needing to handle as well as recapture the birds for observation [25]. Due to this technological advancement, these observations could be linked to other recording devices such as automated weighing devices, triggers for cameras to capture video and photographs, and temperature sensors [25].

The use of these technologies in the field of ornithology has been around since 1992. A study by Becker & Wendeln [26] was one of the first studies that utilised RFID leg rings to gather location data of Common Terns in Germany. This study recorded the presence of the tagged Common Terns at two colonies, each of which was equipped with RFID antennae . Integrating RFID systems into nests allowed researchers to examine the relationship between body mass and breeding behaviour [25] such as in the study by Dittman and Becker [27], where the birds were weighed on concrete platforms with RFID systems that individually identified the bird to the corresponding weight. A further study by Freitag et al. [25] of the Wryneck added RFID technology to the nests to investigate their provisioning behaviour.

In all of the studies mentioned above, the use of RFID systems was vital in giving researchers reliable and automated recordings without much disturbance to the birds being studied [25]. Researchers have also been given new access to large amounts of data, such as a study by Boisvert and Sherry [28] which saw the recording of several hundred visits from a single bird in one day to an RFID-enabled feeder or a study on the colony-to-sea movements of penguins by Kerry et al. [29] which recorded the movements of 80 000 penguins in three months. Furthermore, these RFID-enabled devices allow for passive and long-term use that is usually longer than the lifespans of the birds being researched [25] and as the technology has advanced, the price has reduced exponentially allowing for the integration of these systems to be inexpensive due to new low-cost RFID solutions that can be integrated with various other sensing equipment such as scales [25]. An example of a system like this is described by Bridge and Botner, and shown in Figure 2.5, who developed a low-cost RFID device for use in ornithological research [4]. This system used a perch with integrated RFID antennae, as shown in Figure 2.6 and recorded over 8000 hours of usual human-only work in just six hours of fieldwork [4].

Figure 2.5: Photo of the completed circuit used by Bridge and Botner [4]

However, some limitations have been seen through the use of these RFID systems. Firstly, these systems require the birds to “repeatedly visit a discreet central location” and in close proximity to the RFID reader [25]. Another limitation is the potential for birds to be affected by the process of attaching the tag and gaining the required permit or license to attach these devices onto wild animals, however, due to the large number of studies that have utilised this technology, much more is known on the process and ensuring that it is done in a way that least affects the birds [25].

Figure 2.6: Black-capped Chickadee marked with an RFID Leg Ring and perching on Low-cost RFID Enabled wild bird feeder. Photo, courtesy K. J. McGowan

2.6 Power Supply and Generation Strategies

Previous power supply and generation technologies will be reviewed in order to address the problem statement and to understand the limits of current technologies in power supply and power generation for wild bird weighing and monitoring systems.

2.6.1 Power Supply with Replaceable Batteries

The use of replaceable batteries as a power source has been used in small-scale power supply modules. These power supply modules were portable but had a short lifespan [30]. This is a relevant study as it addresses a core aspect of the problem statement i.e. portability and longevity. This approach has been considered in contrast with energy scavenging techniques and was found to have higher power density but a relatively shorter lifespan [31].

2.6.2 Energy Scavenging: Photovoltaic Power Generation

A method for allowing the independent charging of power supply cells by use of photovoltaic panels has previously been used to design a monitoring system by Ruan Yue and Tang Ying [32]. It has particularly been used as an alternative to power supplies with replaceable power sources to increase the duration of operation of the power supply [33]. This technology has been used before in supplying reliable power in environmental IOT systems that require their sensors to be constantly active [34].

2.6.3 Energy Scavenging: Thermoelectric Power Generation

The usage of thermoelectric power generation is also explored in self-powered wildlife monitoring systems. It has been used by H. Zhang, X. Wu, Y. Pan, A. Azam, and Z. Zhang [35] to create a thermoelectric generator using a sheep's body temperature. The main applicatory idea from the above reference that relates to the problem statement, is the usage of varying temperatures to autonomously generate electrical energy.

2.6.4 Energy Scavenging: Piezoelectric Power Generation

The usage of vibration energy to produce electrical power has been used particularly in while bird monitoring by H. Zhang, X. Wu, Y. Pan, A. Azam, and Z. Zhang. When tested the power output was sufficient to power biological monitoring devices [35]. The exploration of such technologies has also yielded some bio-inspired variations as used by B. Wang, Z. Long, Y. Hong, Q. Pan, W. Lin, and Z. Yang in the design of a woodpecker-inspired piezoelectric power generator that uses impact energy to produce electrical power [36].

2.7 Power Conservation Techniques

In remote wilderness areas such as the Greater Kruger area, access to conventional power sources is scarce. The current utilization of power-saving strategies will be explored to better understand previous attempts at addressing such problem statements.

2.7.1 Sleep/Idle Modes as a Power-Saving Strategy

Using technology to vary the modes of system operation has been employed in systems of similar size and with similar power requirements. In a study by Shanq-Jang Ruan, Kun-Lin Tsai and Wen-Yew Liang [37] on handheld PDA systems, it was shown that an improvement of 16.9% in battery life efficiency can be obtained by including sleep and idle modes in the operation of the system. To optimize power usage, these modes reduce the activity in the system if there is no input being supplied. This approach was also advocated for in a study by Imran Ashraf, Federico Boccardi and Lester Ho [38] on developing similar technology for cellular networks where 10%-60% of the energy was saved. These networks are required to provide constant service for prolonged periods as similarly required by the power subsystem of the bird weight measurement system. In using such technology, D. Schmitt-Landsiedel et al. [39] noted an issue of current spikes during the switching of modes of operations in power supplies such as those mentioned by Kun-Lin Tsai and Wen-Yew Liang and Imran Ashraf, Federico Boccardi and Lester Ho. D. Schmitt-Landsiedel et al. used charge pumps to remedy the issue [39].

2.8 Data Acquisition

A common term used for the collection of data on wildlife is bio-logging. The increase in use of consumer mobile electronics ‘fueled the development of a multitude of inexpensive miniature sensors such as accelerometers, magnetometers, global positioning systems (GPS), and cameras’ [40]. These sensors are then used to develop small, lightweight, animal-borne units that can be used for the purpose of biologging and ‘can measure the physiology, behaviour, demographics, community interactions, and environment of instrumented subjects in the wild’ [40]. This section will explore various data acquisition and data processing techniques used in wildlife conservation and their relevance in the context of weighing and identifying Southern Ground Hornbills in the Greater Kruger.

Current trends see bio-loggers becoming smaller while using multiple sensors, machine learning, onboard processing, remote data retrieval and transmission technology [41]. This leads to the concept of Internet on Animals (IOA) which is the animal equivalent of Internet of Things (IOT) [41]. IOA is the use of connectivity to solve the main issues in bio-logging. A few notable issues with traditional biologgers which are shared in weighing and identifying Southern Ground Hornbills are runtime due to energy constraints and data retrieval.

Wild et al. [41] conducted a study proposing a new tracking device that uses WiFi technology as a solution for big data transmission. Field tests were conducted on a few different animals, one of which was semi-wild cockatiels that were in an outdoor aviary and results showed a successful collection of large data volumes over 3 consecutive days. Data was processed onboard the tracking device by a microcontroller in order to reduce data size and stored locally on flash memory using a FIFO (first in, first out) structure until a stable WiFi connection was established. Transferred data was either stored on local devices, webservers or cloud storage. Even though the aim and test conditions are not relatable to the context of the Southern Ground Hornbills, storage and data transmission techniques used by [41] are applicable.

Similar to [41], Del-Rio-Ruiz et al. [42] reflect the same idea of using IOT to develop a smart nest used to monitor the Great Tit bird species with the focus of identifying the birds and logging their movements in and out of the nest. They used RFID technology to identify the tagged birds upon landing in the nest. In contrast to Wild et al. [41], data is directly transmitted to the internet using GPRS upon collection, negating the need for large memory modules, since data is only stored temporarily before transmission. Their tests showed successful collection and transmission of data using RFID and GPRS in the field but since GPRS is used, it is less applicable to the Southern Ground Hornbills since cellular service is not reliable in the Greater Kruger [43].

Wild et al. [41] suggest that IOA is the current paradigm in bio-logging since it allows for remote/autonomous data retrieval therefore the overall IOA concept may be applicable within the context of the Southern Ground Hornbills since the Greater Kruger is remote and proves difficult retrieve data.

2.9 Data Processing

Dominguez-Morales et al. [44] state that processing data collected by the system onboard the device, known as edge-computing 'has several advantages, such as real-time analysis, low latency, security, and reduced data delivery'. In their work, Artificial Neural Networks (ANN) converted into Embedded Neural Networks (ENN) were used on data collected on horses before acquisition to increase accuracy and precision [44]. After testing on two different microcontrollers, Dominguez-Morales et al. [44] concluded that by processing data onboard with ENNs, they were able to achieve lower power usage due to decreased transmission times, decreased transmission rates and decreased computing time as well as lower flash memory usage after condensing data but at the cost of increased RAM memory usage [44]. Dominguez-Morales et al. [44] also concluded that using more powerful, larger ANNs in post-processing increased the accuracy of data but at the cost of transmission power. In summary, using ANNs in edge-computing could potentially save power and flash memory space at the cost of RAM memory space while using ANNs in post-processing could increase accuracy. Larios et al. [45] support the notion of edge-computing as they found in their study of weighing lesser kestrels, after 1 year of transmitting raw data, bandwidth consumption proved too high. To fix this, they began pre-processing data using ANNs for similar reasons to [44]. They also found that by implementing pre-processing and ANNs they were able to use the unstable weight data to create weight estimations instead of discarding it, producing more weight data. In addition, Wild et al. [41] also propose edge computing by using algorithms to process raw sensor data and condense it to reduce data size and save memory. However, Wild et al. [41] did not implement any ANN technology.

Although the Southern Ground Hornbills are very different to horses and much larger than lesser kestrels, such processing techniques may be useful since power and transmission bandwidth will be limited in the remote Greater Kruger. However, ANNs may not be as feasible now since training models require large datasets on the Southern Ground Hornbill which do not exist yet but it is a possible avenue to explore in future.

2.10 Data Storage

Data management will become more and more important as data continues to be collected, and more so when IOA systems such as GPS are used on multiple subjects [46]. This can result in huge data volumes that need to be organised, managed and processed. In order to do this correctly, Urbano et al. [46] proposes the use of Spatial Databases and Spatial Database Management Systems or Database Management Systems (DBMS). It is suggested that data will be transmitted to the database, and then processed and presented in a front-end for researchers to use. This is affirmed by Dominguez-Morales et al. [44], as they store their data on an SD card before transmitting it to a database. Urbano et al. [46] also suggest using cloud-based computing and cloud storage to store and manage the data. Wild et al. [41] further this by choosing to store their data on the tracking device until a connection is established, followed by transmission of the data to either a mobile device, webserver or cloud-based DBMS, depending on what the user preferred. This is very feasible within the context of the Southern Ground Hornbills since their data is used for research and also requires a place for data to be stored and used effectively.

2.11 Conclusion

This review of wild bird monitoring technologies highlights the continuous evolution and innovation in data collection methods for ornithology and wildlife conservation. The exploration of weighing techniques, scale design considerations, identification methods, power strategies, and data processing reveals the diverse approaches used to enhance monitoring practices. The integration of modern technologies, such as RFID tracking and artificial neural networks, demonstrates the potential for more efficient and accurate data collection. As technology continues to advance, there is a promising future for improving our understanding of bird behaviour and conservation efforts through innovative monitoring solutions.

Chapter 3

Scale Design

Prepared by Ashik John - JHNASH009

This chapter pertains to the physical design of the weighing scale, as well as the conditioning of the weight signal to be read by a microprocessor for further processing. The physical scale is central to the proposed solution, and effective design is critical in ensuring integration with other subsystems. The subsystem is intended to provide a rooftop platform upon which adult birds land. The force exerted by the weight of the birds must then be converted to an electrical signal by appropriate transducers, and then conditioned to be fed into an ADC. The design of the platform, housing, and signal conditioning circuitry must ensure that the enclosed electronics can produce reliable weight data, thus validating the full system design as a viable solution.

The following sections delve into the design objectives, design process followed, the subsequent testing of the proposed designs, and whether the results fulfil the intended objectives.

3.1 Requirement Analysis

The project objectives relevant to this section, as required by the end-user, are as follows:

- The scale should reliably measure the accurate weight of adult Ground Hornbills
- The scale should be durable enough for conditions in the Greater Kruger region
- The scale must naturally integrate into the environment and pose no danger to the birds

The above user requirements give rise to traceable functional specifications to be achieved in the scope of this chapter. Each specification has an associated Acceptance Test Procedure (ATP), shown in Table 3.1, that will be adhered to through the design process, and serve as a success metric for the final design.

No.	Description	ATP criteria
SP-1	Weight capacity of 20kg	Linear operation in the range of 0-20kg
SP-2	Consistent weight readings irrespective of bird position	Weight readings should be consistent across the platform
SP-3	Accuracy within 1% of actual weight	Test designed scale against known weights
SP-4	Electronics must be adequately protected from the exterior to avoid damage	Predictable functioning in all potential Greater Kruger environmental conditions
SP-5	The design should pose no harm to the birds	No exposed electronics or sharp edges capable of cutting the bird
SP-6	Birds must accept the scale in their nest area	Birds freely land on the scale

Table 3.1: Functional Specifications and associated ATP's

3.2 Structural Design

This section covers the process followed in designing the landing platform of the scale, and how appropriate load cells were chosen to ensure a sufficient weight range of operation. It delves into the placement and connection topology for the selected load cells to maximise accuracy and minimise the effect of object positioning. The design of the housing covers the protection of the system circuitry, as well as the scale's integration onto the roofs of existing artificial nest boxes.

3.2.1 Load Cell Configuration

The most common transducers used in modern digital weighing scales are load cells. Load cells typically consist of strain gauges arranged in either full or half Wheatstone Bridge configuration depending on the use case. The strain gauges are stuck to a deflective metal structure, thus changing the output voltage of the Wheatstone Bridge proportional to the deflection.

Weight Capacity

Load cells come with rated capacities; exceeding which may permanently damage the cell, resulting in unreliable data output. The maximum expected weight on the scale must therefore be quantified to choose an adequate load cell. It should also be noted that cells with higher capacities come with a trade-off of resolution and accuracy. The capacity should be selected such that the maximum expected weight on the scale leaves little headroom to improve resolution, and further minimised to reduce the full-scale error inherent to the cells for maximum accuracy.

An adult Ground Hornbill typically weighs 5kg, reaching a maximum of 6.5kg at full maturity and health. Considering the scale platform will be located on the rooftop of the nest, analysis of bird behaviour shows at most two birds on the platform at a time. It is therefore reasonable to assume a maximum stable load of 13kg. Furthermore, it is important to consider the peak loads exerted on the scale during the transient phases of take-off and landing. While it is not possible to obtain accurate data on these loads without field-testing, an alternative approach of including an appropriate safety factor in the rated capacity can account for the momentary, peak loads experienced during the transient phases. Assuming a limit case where two, typical adult birds take off/land at the same instant, we can apply a 2x safety factor to arrive at a maximum weight capacity of 20kg. This should provide adequate protection from over-loading while also ensuring accurate output signals.

Placement & Connection

Keeping the objectives of accuracy and reliability in mind, various connection topologies of the load cells can be considered. Many scales with relatively small platforms use a single, full-bridge beam load cell placed at the centre of the scale. The small platforms usually ensure centrally placed loads, leading to consistent data across multiple readings. The rooftops of the nest boxes are large pentagons, which allow significant space for the birds to move around. A centrally placed load cell would therefore provide unreliable data in the context of this project.

Alternatively, some platform scales use half-bridge compression load cells at the four corners of the platform, which are then connected in a full-bridge configuration. This topology has the benefit of improving the consistency of weight readings relative to its position and distributing the load to increase the maximum weight capacity. While this approach is closer to a viable solution, the limited local availability of these components suggests that the lowest weight capacity of this topology that can be implemented is 4 x 50 = 200kg. This sacrifices accuracy and resolution, and other avenues should be considered before resorting to this option.

The most promising approach that can be practically implemented within the constraints of this project, is therefore the use of 4 full-bridge beam load cells that would bring the cumulative weight rating to 20kg. This configuration affords increased accuracy of 4 individual full-bridge load cells, which are then connected in parallel to average the output signal, thereby accounting for a non-central load. The proposed connection can be seen in Figure 3.1, showing the 4 load cells, and how each load cell is connected to the base and platform to ensure deflection. The physical implementation and full CAD rendering can be found in the appendix of this report.

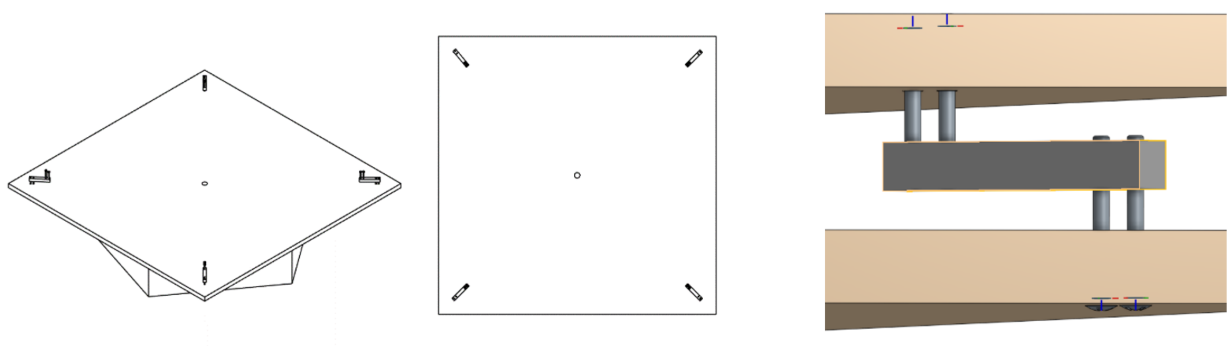


Figure 3.1: CAD rendering of Load cell placement and connection

3.2.2 Housing

Given that the Ground Hornbills are sensitive to foreign objects in their environment, it is critical to ensure that the scale is designed with materials that are both non-hazardous and familiar to the birds. The destructive nature of the Hornbills, coupled with the environmental conditions in the Greater Kruger region, necessitate a hidden, weatherproof area to store the scale's electronic circuitry.

Integration with Nest Box

The proposed solution is meant to seamlessly integrate with the nest boxes that are currently used by the researchers, as seen in Figure 3.2. Platform scales using multiple load cells must be designed such that the cells are placed equidistant from each other while maximising the platform area capable of producing a reliable signal. Drawing inspiration from a graduation hat, the scale is designed as a square platform with a base that fits onto the nest roof as a hat would fit on a graduate's head. The design of the base is shown in Figure 3.3, further serving as a compartment to store the scale circuitry. The full drawings inclusive of dimensions can be found in the appendix. The scale's design has the added benefit of easy installation, emulating a plug-and-play design. The body can be simply lifted off the nest for maintenance or fault-checking.

The scale is also fabricated with the same exterior plywood used to make the nest boxes, thus ensuring the birds' acceptance of the scale into their environment. The holes used to attach the load cells are counter-sunken to avoid the potential hazard of protruding bolt heads.

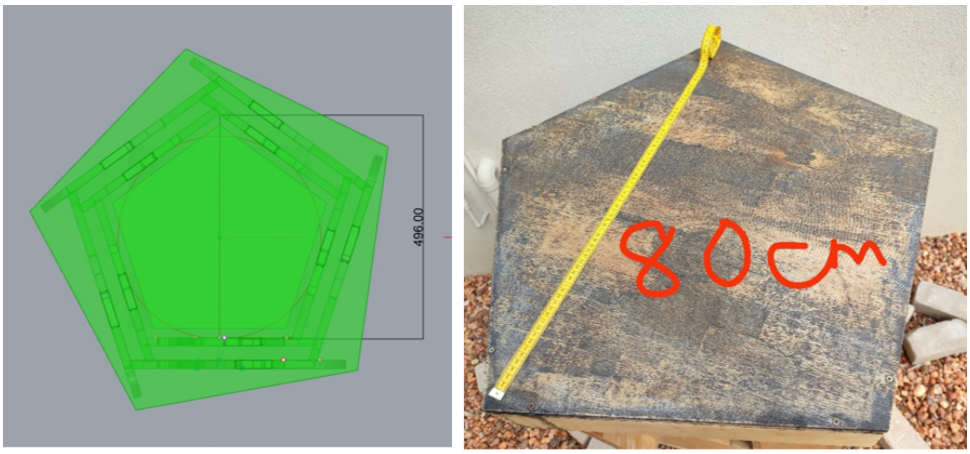


Figure 3.2: Nest Boxes used in-field

Protection of Internal Circuitry

To avoid the destruction of wiring and circuitry, the birds should only be exposed to the plywood platform. The base of the scale consists of a pentagonal brim designed to the dimensions of the nest roof for an exact fit, as in Figure 3.3. The brim has internal supports at the vertices to reinforce the walls and elevate the base from the roof, leaving an effective space large enough to store the scale circuitry and facilitate heat dissipation.

The wires connecting the load cells enter the compartment through a centrally located hole, where further connections with other subsystems are made. Once all wires are put through the hole, the hole can then be sealed using silicone to prevent any moisture from entering the electronics compartment. The wires on the top of the base are not exposed to the birds due to the top platform covering the load cells as in Figure 3.1. The extension points of the load cell connections are also covered in heat shrink to avoid short circuits. All circuitry is thus protected from both environmental conditions and the destructive nature of the Hornbills.

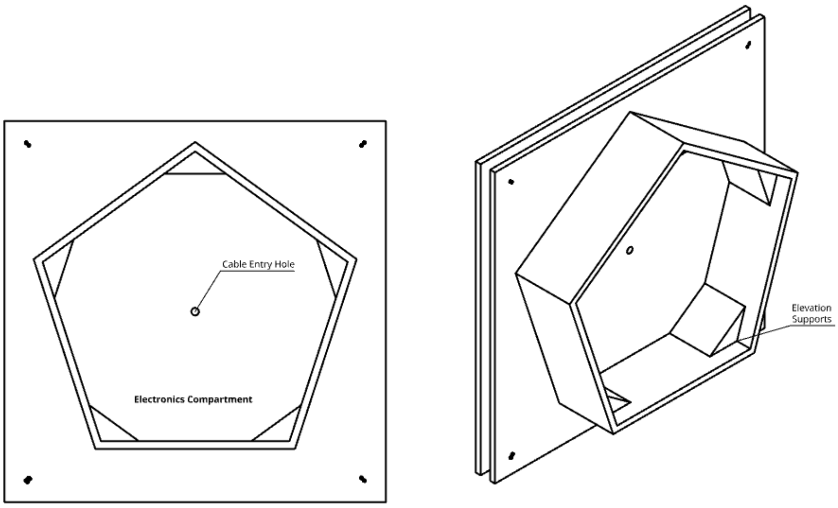


Figure 3.3: Bottom view of scale showing the electronics compartment

3.3 Signal Conditioning

While load cells are commonly used transducers for measuring the weight of objects, the raw output signal has inherent limitations which affect the performance of downstream systems such as the ADC or microcontroller. Load cell output is dependent on the excitation voltage supplied to the Wheatstone bridge, as well as the deflection of the beam, which provides a differential output voltage from the bridge.

The output voltage range is typically rated in mV/V of excitation voltage. Within the scope of this project, the largest power rail available from the power sub-system is 5V DC, and the selected load cells have an output rating of 1 mv/V of excitation. Priority was given to the weight capacity of the cells during the selection process, as most locally available cells had the same output rating. The maximum output of each load cell used would therefore be 5mV at the maximum weight capacity of 5kg per load cell. Once connected in the 4-cell parallel configuration, the 5mV output was then scaled to correspond to a weight range of 20kg.

Although the connection topology assists in reducing signal fluctuations, the relatively small output signal is prone to significant fluctuation as a result of noise. The signal is fed to an ADC to produce a digital signal that can be subsequently read by a microprocessor for further processing. Resolution and accuracy can be improved by choosing an ADC with a high bit-resolution, but the available quantisation levels cannot be effectively exploited with a signal in the range of a few millivolts.

The aforementioned problems therefore signal the need for noise filtering and signal amplification.

Amplification of sensor output is typically achieved through the use of an instrumentation amplifier such as the AD620 IC. This section covers the design process of an instrumentation amplifier and the bench-marking of its performance against the AD620 amplifier. Lastly, different modules used to convert the load cell output to a digital signal to be read by the microcontroller are compared against different metrics to select the solution most applicable to this project.

3.3.1 Instrumentation Amplifier Design

Considering that the amplified signal will be inputted to an ADC, the amplifier gain is chosen based on the operating range of the ADC. The ADS1232 module is a 24-bit ADC that has an input voltage range from -2.5V to 2.5V, used in this design thanks to its high resolution and comparatively low cost to other ADCs. To use the maximum input voltage range, the 5mV signal needs to be amplified by a gain of 500 V/V.

Theoretical Design

It may be immediately apparent that a single op-amp differential amplifier may be appropriate for this application, but there are limitations associated with such a design. The noise in the signal can be minimised by having an amplifier with a high Common Mode Rejection Ratio (CMMR) since the noise on the signal tends to be common to both differential inputs to the amplifier. Additionally, the amplifier needs to have a high input impedance to minimise the effects of loading on the weight-sensing circuit. It may be beneficial to introduce an additional buffer stage to improve the critical performance parameters mentioned above.

The suggested design schematic can be seen in Figure 3.4, where the first two op-amps U1 and U2 are inverting amplifiers that amplify each differential input, and U3 is a typical differential amplifier. The first two op-amps serve as the buffer stage to increase the input impedance. The use of multiple amplification stages improves the overall CMMR as each amplification further rejects the common mode signal present on each line.

The gain of the entire circuit can be derived to be

$$\mathrm{G} = \frac{R3}{R2} \cdot \frac{2R1 + Rg}{Rg}$$

By setting R2 = R3 = 1.2kΩ, resistor selection is simplified, with the remaining resistors chosen to achieve a gain closest to, but not exceeding the desired gain of 500 V/V. The final resistor values can be seen in Figure 3.4.

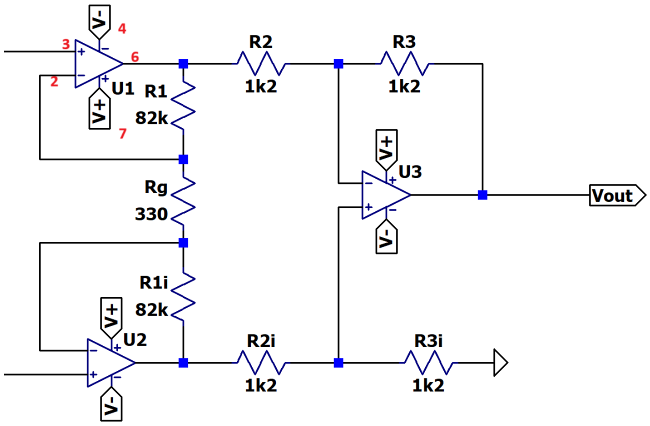
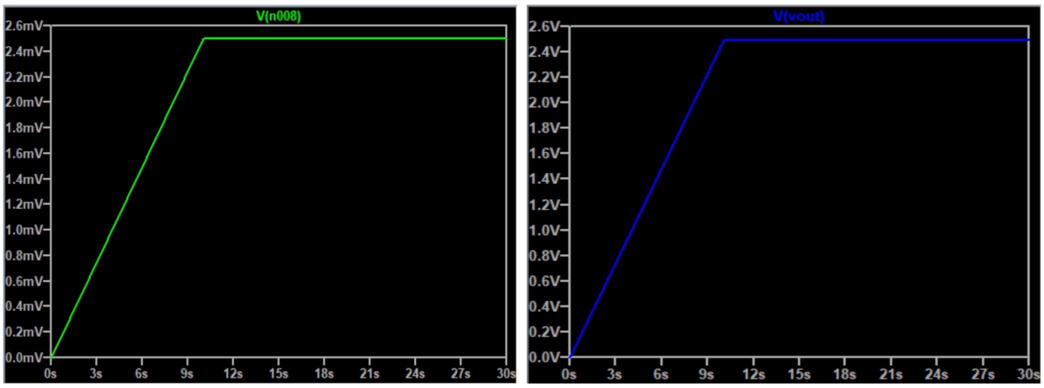


Figure 3.4: 3 Op-amp based Instrumentation Amplifier schematic

Simulation

To simulate the functioning of the 3 op-amp Instrumentation amplifier, a signal that resembles the expected values signal from a load cell needs to be inputted to the differential lines of the amplifier. As the input can take on any DC value ranging from 0 - 5mV, it is adequate to use a ramp signal in this range. The LTspice simulations of the amplifier, using ideal op-amps with $\pm$ 5V power, show expected performance in successfully amplifying the signal to 2.5V as shown in Figure 3.5.



(a) Input signal (b) Output Signal

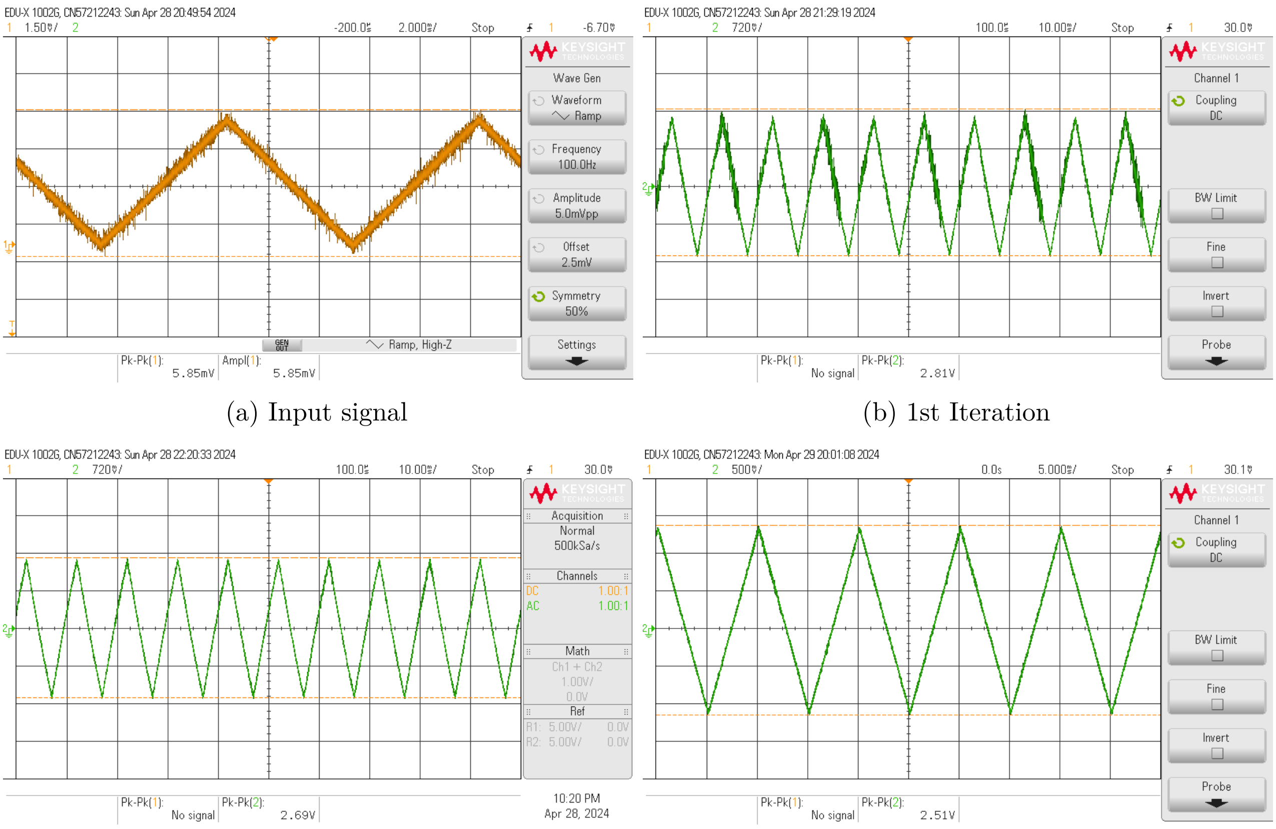
Figure 3.5: Simulated amplifier performance

Practical Implementation

Practical implementation involves the selection of op-amps with near-ideal ratings. To minimise the costs associated with the amplifier design, the available chip selection was reduced to those stocked in the university lab. TL071 op-amps were chosen due to it being a FET input chip that has better input impedance, CMMR and noise handling capabilities than a BJT input op-amp.

A 100Hz triangular wave was used as the input with a peak-to-peak value of 5mV. Generating a small signal introduced noise, providing an appropriate load cell signal representation as in Figure 3.6a.

The design was put through various iterations, whose individual improvements can be seen from Figure 3.6b through Figure 3.6d. The first iteration saw a noisy output that was amplified to 2.81V. The second iteration then attempted to attenuate output noise by adding decoupling capacitors to the op-amp power supplies, achieving minimal noise and a peak voltage of 2.69V, which was closer to the desired output of 2.5V. The final iteration replaced the 5% tolerance resistors with 1% tolerance resistors which stabilised the amplified voltage to 2.51V. The overall design is successful when bench-marked against an AD620 instrumentation IC, exhibiting similar performance without the laser-trimmed accuracy of the resistors present in a single chip.



(a) Input signal

(b) 1st Iteration

(c) 2nd Iteration

(d) 3rd Iteration

Figure 3.6: Tested performance across various iterations

3.3.2 Comparison to existing solutions

Although the design of the 3 op-amp amplifier yielded promising amplification performance, there are other factors which must be taken into consideration when choosing the most suitable signal conditioning solution.

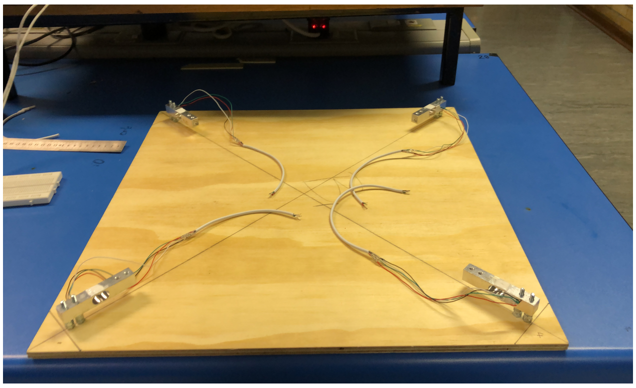
Three potential solutions have been compared in Table 3.2 to produce a reliable digital signal against relevant metrics. Analysis of the potential solutions shows the HX711 module to be the best option against all metrics. The on-board ADC on the HX711, also 24-bit, significantly reduces the relative cost of the module as the external ADS1232 chip is not required. The HX711 is also the most commonly used solution and is well-documented across online forums, with existing code libraries making it easy to implement in weighing applications. Additionally, the clear drawback of the previously designed amplifier is its power consumption due to the presence of 3 separate op-amps.

Solution	**Power consumption (mW)**	**Size** (cm^2)	**Cost** (R)
3 op-amp with ADC	45.3	70	150
AD620 IC with ADC	7.75	20	182.85
HX711 amplification module	7.5	6	51.75

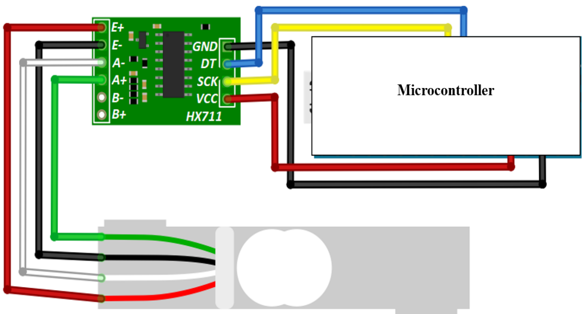
Table 3.2: Comparison of potential signal conditioning solutions

3.4 Testing & Results

A final prototype consisting of a flat base and landing platform was constructed for testing purposes, with signal conditioning carried out using the HX711 amplification module to provide a digital signal to the microcontroller. The paralleled load cell connection operates similarly to how a single load cell would, and can thus be connected directly to the HX711 as shown in Figure 3.7b. The output accuracy of the scale was tested against known weights, and finally, the relevant ATP compliance tests outlined in Section 3.1 were carried out.



(a) Load cells on base before being paralleled



(b) HX711 Connection for signal conditioning

Figure 3.7: Final Design Prototype connection scheme

3.4.1 Centre Accuracy

To test the best-case accuracy of the scale, a centrally located mass can be used, placed at position 0 of Figure 3.8a. The central location of the load ensures that the weight is evenly distributed across all the load cells, minimising the need for parallel averaging of each load cell's signal.

3 masses were weighed on a kitchen scale, which was rated to handle up to a 2.5kg load. The prototype scale was calibrated to the kitchen scale, and multiple readings were taken to compare to the known weights. The results of this test and the associated error of each mass can be seen in Table 3.3.

The 975g mass was used for calibration and it is therefore expected to produce the most accurate reading. Load cell errors are rated proportional to the full-scale output. The load cells used in this prototype have an error rating of ±0.15mV/V, corresponding to a 15% error. The theoretical assumption that using multiple load cells improves accuracy has therefore been proven since the measured errors are well below 15%. A likely cause of the increase in error with weight may be the non-linear deflection of the platform relative to the object's weight.

Actual Weight (g)	**Average Measurement (g)**	**Error (%)**
442	442.279	0.063%
975	974.818	0.018%
2425	2421.117	0.16%

Table 3.3: Best-case error for different known weights

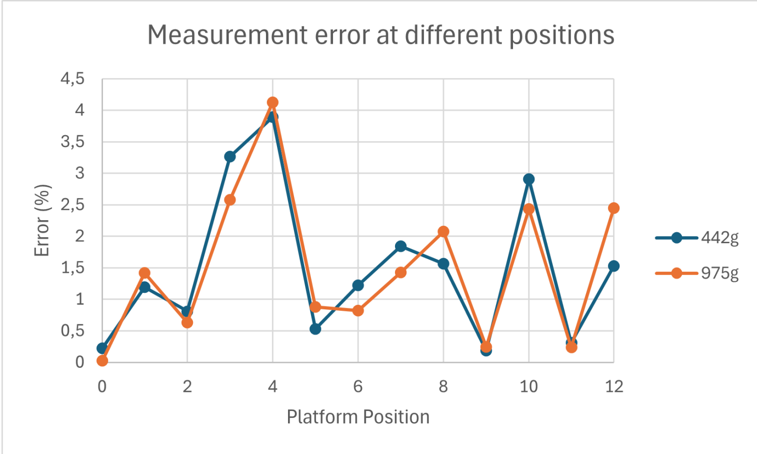
3.4.2 Effect of Object position

To understand the effects of object position on accuracy, known weights were placed at different positions as shown in Figure3.8a. The associated error at each position is plotted for both masses used is plotted in 3.8b. As expected, the highest accuracy is at the centre of the platform.

Positions 1-4 show the errors associated with the points closest to each load cell. It is interesting to note that the error varies significantly at each load cell, indicating that the load cells are inherently mismatched, regardless of having the same capacity and being ordered from the same supplier. This indication is further reinforced by the errors at positions between various load cells. Load cells at positions 1 and 2 seem to be closely matched, while the ones at positions 3 and 4 are closely matched. The errors between closely matched load cells (positions 9 and 11) are significantly lower than the errors between mismatched cells (positions 10 and 12).

This analysis suggests that in the case of 4 perfectly matched load cells, the effect of position becomes less apparent in the output weight, thus validating the design assumptions. This should however be confirmed through testing using load cells with lower tolerance ratings.

(a) Positions at which accuracy was tested



(b) Weight error at each position

Figure 3.8: Effect of Object position on Accuracy

3.4.3 ATP Compliance

There are limitations to testing all ATPs outlined in Table 3.1, associated with the scope of this project. Tests carried out to assess each ATP and potential improvements are elaborated on below.

SP-1: Linear operation in the range of 0-20kg

This ATP criterion can be tested by applying known weights in the range of 0-20kg and reading data that is within a reasonable margin. While existing known weights were limited to a range below 2.5kg due to the kitchen scale used, the readings did show a linear relationship in that range. While this shows adequate operation, this ATP should only be considered as passed once a weight range of at least 0-13kg has been applied, which is the maximum expected stable weight on the scale.

SP-2: Weight readings should be consistent across the platform

Deviation in readings across different positions has occurred, but the main contributing factor to this has been attributed to the mismatch between load cells. This assumption, once tested, should qualify the design to pass this ATP, by reading consistent value irrespective of position.

SP-3: Accuracy within 1% against known weights

The best-case accuracy is well within 1%, although there is a decrease in accuracy with an increase in weight. With the tested weight range, the ATP has been passed, but the full-scale range should be tested, and the plywood thickness of the platform should be increased to minimise board deflection if necessary.

SP-4 to Sp-6: Environmental durability and acceptance of birds

These criteria can only be adequately tested in-field and should form part of future tests before finalising the design. The existing design has however catered for these ATPs in hiding all electronics, and using familiar materials as outlined in Section 3.2.2.

3.5 Conclusion

The proposed scale for measuring the weight of adult Ground Hornbills has been designed and executed, considering factors like accuracy, durability, and integration with the environment. Through testing and adherence to derived Acceptance Test Procedures, the proposed solution has shown promising results in terms of reliability and functionality. The signal conditioning, housing design, and structural considerations have been carefully implemented to ensure the scale's effectiveness in real-world conditions, making it a potential solution for the intended application in the Greater Kruger region, with scope for improvements through higher accuracy load cells and a larger range of testing apparatus.

Chapter 4

Power Supply

Prepared by Msimamisi Lushaba - MWNMSI001

This power supply unit is a critical subsystem within the bigger system as it is responsible for providing the necessary power to sustain the operation of sensing, weighing, control and processing subsystems. In this design, ideas such as subsystem efficiency, ubiquity of parts, cost, robustness, reliability, and low energy consumption are echoed to ensure that a desirable yet feasible subsystem is designed. Furthermore, given the nature of the use case of this weighing system, considerations to ensure that the power subsystem has minimal impact on the natural environment and on the Southern Ground Hornbills which are being studied.

4.1 Requirement Analysis

Requirements

ID	Requirement
R01	Overall system must use low power.
R02	Power subsystem must supply power to all other subsystems.
R03	Power subsystem must use power harvesting to charge unit storage unit.
R04	Power supply must be able to supply power for a period of 2 weeks.
R05	The power storage unit must be replaceable.
R06	The power supply must be concealed and acceptable to the birds.
R07	Any excess heat generated by the power supply components must be dissipated safely.
R08	Power must be conserved when the system is unused.
R09	Have system diagnostic data available if possible.

Table 4.1: Power subsystem requirements

Specifications

ID	Specification	Develops
S01	Power subsystem storage has a 9V capacity.	R01
S02	Power subsystem provides an output of 5V at 60 mA.	R02
S03	Power subsystem provides an output of 3.3V at 250 mA.	R02
S04	Subsystem uses a 10V DC regulated solar charging module from 12V solar panels.	R03
S05	A rechargeable and replaceable battery must be used.	R04, R05

Table 4.2: Power subsystem specifications

ID	Specification	Develops
S06	Power subsystem components must fit within the dimensions of the scale housing.	R06
S07	Regulator ICs must use aluminium heat sinks to dissipate heat.	R07
S08	NPN BJTs must be used as logic switches to control voltage supply to subsystems.	R08
S09	A voltage divided battery voltage rail must be provided to indicate battery level.	R09

Table 4.3: Power subsystem specifications

Acceptance Test Procedures

ID	Acceptance Test Procedure	Tests	Acceptance Condition
ATP01	Visually inspect if the battery used is rated at 9V.	S01	Battery is rated at 9V.
ATP02	Connect the power supply module to a 9V input voltage and measure a 5V output voltage at $\approx$ 0.06A using a multimeter.	S02	Output voltage ranges from 4.25V to 5.75V and current is within the range of 0.51A and 0.69A.
ATP03	Connect the power supply module to a 9V input voltage and measure a 3.3V output voltage at $\approx$ 0.1A using a multimeter.	S03	Output voltage ranges from 3.1V to 3.5V and current is within the range of 0.1A and 0.15A.
ATP04	Connect charging circuit input voltage point to a 12V supply and use a multimeter to measure the regulated output charging voltage.	S04	Output voltage ranges from 9.5V to 10V.
ATP05	Visually inspect if the battery used is removable and labelled as rechargeable	S05	Battery is rechargeable and removable.
ATP06	User a ruler to measure the dimensions of the power supply board.	S06	Power supply subsystem board has length $\leq$ 10cm and breadth $\leq$ 10cm
ATP07	Visually inspect if the voltage regulator ICs have heat sinks.	S07	Voltage regulator ICs have heat sinks attached.
ATP08	Supply an input voltage of 5V to the Collector pin and 3.3V to the Base pin of the NPN BJT. Measure the voltage on the Emitter pin.	S08	The output voltage on the Emitter pin $\geq$ 4.8V.
ATP09	Supply input voltage to divider stage and measure the output voltage: a) when input voltage = 9V. b) when input voltage = 4.5V. c) when input voltage = 0V.	S09	a) The output voltage = 3V b) The output voltage = 1.5V c) The output voltage = 0V

Table 4.4: Power subsystem ATPs

Traceability Analysis

Requirement ID(s)	Specification ID(s)	Acceptance Test Procedure ID(s)
R01	S01	ATP01
R02	S02, S03	ATP02, ATP03
R03	S04	ATP04
R04	S05	ATP05
R05	S05	ATP05
R06	S06	ATP06
R07	S07	ATP07
R08	S08	ATP08
R09	S09	ATP09

Table 4.5: Traceability Matrix

4.2 Subsystem Design

4.2.1 High Level Design

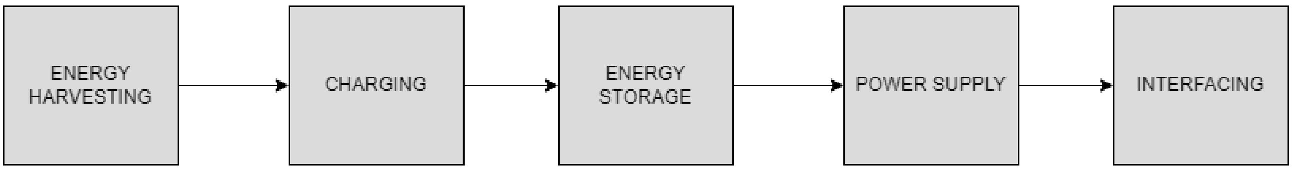


Figure 4.1: Subsystem level breakdown

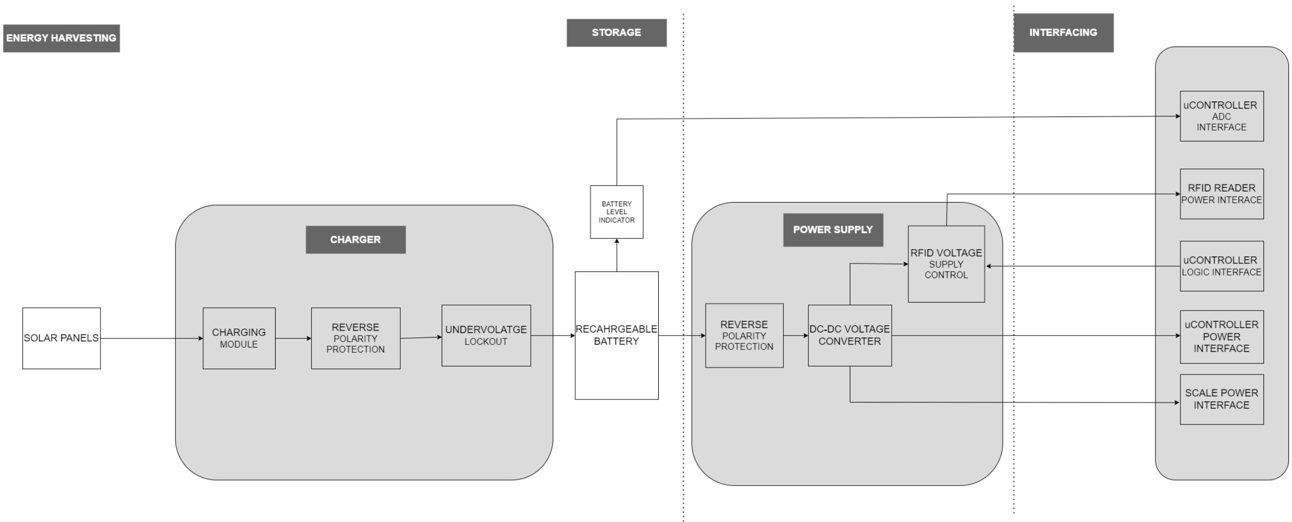


Figure 4.2: Module level breakdown

4.2.2 Design Decisions

Energy Storage

The initial consideration was on the capacity of our energy storage device. From the specifications of a 9V rechargeable and removable battery (S01, S06) the capacity and rechargeable nature were chosen according to the specifications. The main decision was with regards to the battery chemistry to be used, particularly the most common being the Lithium-ion battery and the Nickel–Metal Hydride battery. The choice of the Lithium-ion battery over the Nickel–Metal Hydride was based on the better performance presented by the Lithium-ion battery across the following criteria[47].

Criteria	Lithum-ion	Nickel–Metal Hydride
Affordability		✓
Operation at extreme temperatures	✓	
Charging Rate	✓	
Lifespan	✓	
High current discharge		✓

Table 4.6: Battery Selection

Energy Harvesting

The abundance of sunlight and the consistently sunny environment in the Greater Kruger area steered the energy harvesting method towards solar energy harvesting. This was also the most convenient method to minimise disturbance in the habitat of the Southern Ground Hornbills (which were portrayed to destroy an prevalent foreign structures by the principal stakeholder) by eliminating the need for mechanically moving parts required by wind and water based energy harvesting. Using the Global Solar Atlas photovoltaic power calculator (endorsed by World Bank Group, ESMAP and Solargis)[48], it was established that the available solar energy in the Greater Kruger Area is 0.004GWh/day which translates to 5.5kWh/m^2 per day. Since a 12V solar panel that can be found is 110mm x 110mm [49], the available energy can be derived to be $(5.5kWh/day \times 0.0121m^2 = 0.06655kWh/day) \approx 66.5Wh/day$. From a typical 9V Li-ion battery with a capaity of 880mAh[50], the energy requirement get one full 9V charge per day from a circuit with even 50% efficiency is $((1/0.5) \times (800mAh \times 9V/1000 = 14.4Wh/day)$ which is less than the available energy.

DC-DC Voltage Conversion/Regulation

This design decision aimed to provide an efficient solution for gaining the correct output voltage for each subsystem as per the specifications S02 and S03 as well as to produce correct battery charging voltages to meet specification S05. . The following considerations were made:

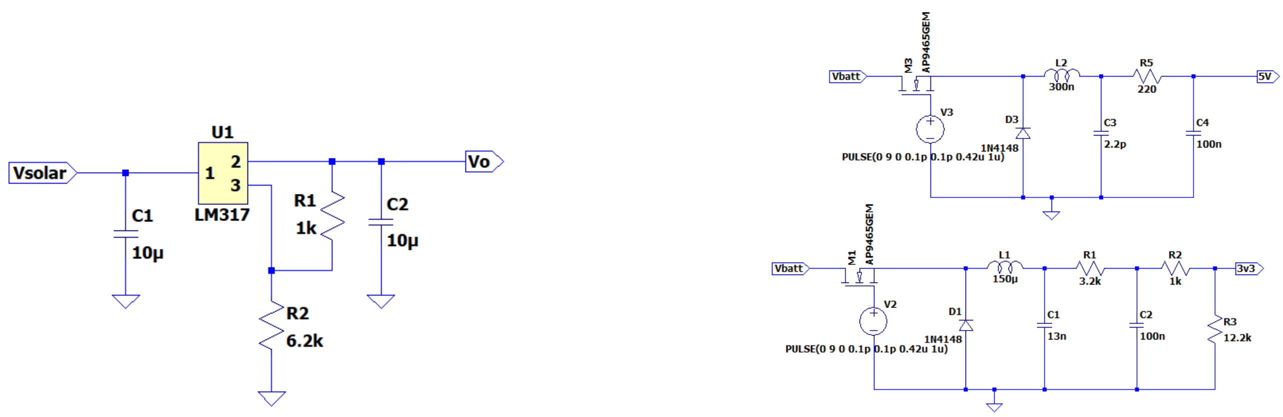
- Subsystems have high current requirements such as 250 mA through the use of WiFi during the data download phase in the the microcontroller.
- In a DC-DC Buck converter, current increases as voltage is reduced[51].

- The voltage conversion in DC-DC Buck converter requires an independent PWM switching signal which can be generated using a 555 timer at a constant input voltage
- Having increased current levels during the charging phase of the battery may results in increased heat levels which is undesirable for safe battery charging.
- Linear voltage regulators regulate voltages at constant and relatively lower current levels.
- Linear voltage regulators are less efficient when compared to Buck converters[52][53].

These considerations that led to the choice of the use of a linear voltage regulator in the charging module and a Buck converter in the power supply module were summarized as follows:

Use Case	**Consideration**	**DC-DC Buck Converter** (manually designed)	**Linear Voltage Regulator** (LM317)
Power supply	Subsystems have high current requirements	✓	
Power supply	Has constant input voltage from battery	✓	
Power supply	Limited voltage supply from battery	✓	
Battery charging	High current results in overheating		✓
Battery charging	Excess voltage from solar panels		✓

Table 4.7: Voltage regulation/conversion circuitry selection



(a) Charging circuit voltage regulator

(b) Power supply circuit buck converter

Figure 4.3: Voltage Conversion/Regulation circuitry

Protection Circuitry

- **Undervoltage lockout** : Since the intensity of the sun is variable, so is the linearly regulated battery charging voltage levels. When the charging voltage drops below a charging voltage value of ≈ 9.5V the charging port will be switched off. A IN4739A(due to its Vz = 9.1V)[54] Zener diode, PN2222A BJT and IN47[55] silicon diode combination circuit was used to achieve this behaviour.

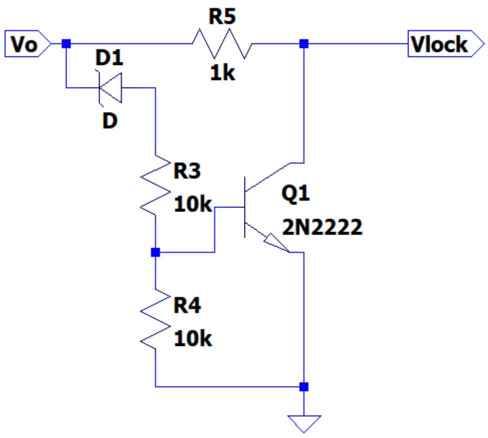


Figure 4.4: UVLO circuit

- **Reverse polarity protection** : The removable nature of the battery required the provision of reverse polarity protection in the case of inverted battery connection. A 1N4733A(due to its Vz = 5V)[54] Zener diode and BS17O P-MOSFET [56] combination was used as the switching and protection element to switch the circuit off in the case of reverse polarity. This was due to its ubiquity which implies easy replacement, fast mosfet switching time of 7ns and a zener breakdown voltage of 5V which ensures that the 9V battery will always be detected when connected in reverse polarity.

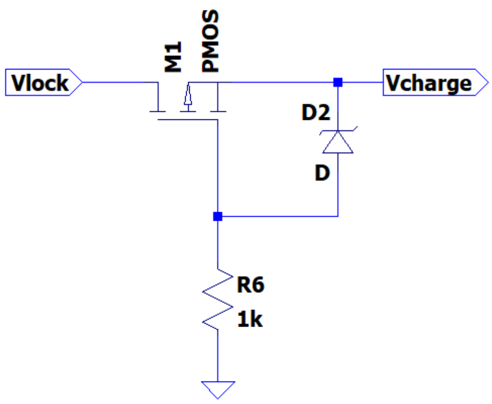


Figure 4.5: Reverse polarity protection circuit

System Sustainability

- **Power Conservation** : The power supply to the RFID reader modules is logically controlled by microcontroller to ensure it is switched off when unused. The logic switch interface to allow the switching of RFID reader modules was created using a PN2222A BJT and resistor combination circuit to allow for sufficiently high current to be drawn during operation.

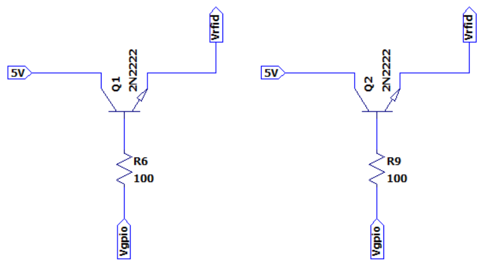


Figure 4.6: RFID voltage control power circuitry

- **Heat management** : Heat sinks were used on voltage regulation ICs to achieve specification S07.
- **Battery level monitoring** : a voltage divided battery volatge pin is available from the battery to the microcontroller to allow for the monitoring of the battery voltage and generation of battery level data as per specification S09. The voltage division is to ensure that volatge levels are within 0V and 3V as required by the input pin on the microcontroller ADC that accepts a maximum of 3.3V.

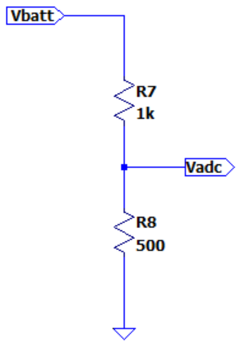


Figure 4.7: Subsystem level breakdown

Failure Management

The main goal to achieve failure management was using ubiquitous circuit components that are easy to acquire, easy to replace once damaged and unlikely to receive major upgrades in future thus requiring a major change in the subsystem if the component is damaged in future.

4.2.3 Final Design

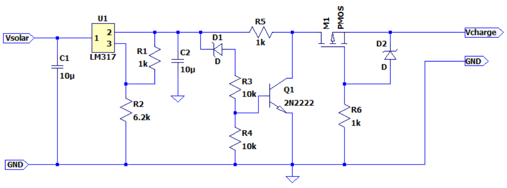


Figure 4.8: Battery Charger

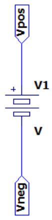


Figure 4.9: Battery

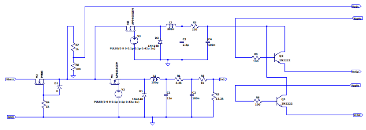


Figure 4.10: Power Supply

4.3 Subsystem Testing

4.3.1 Simulation

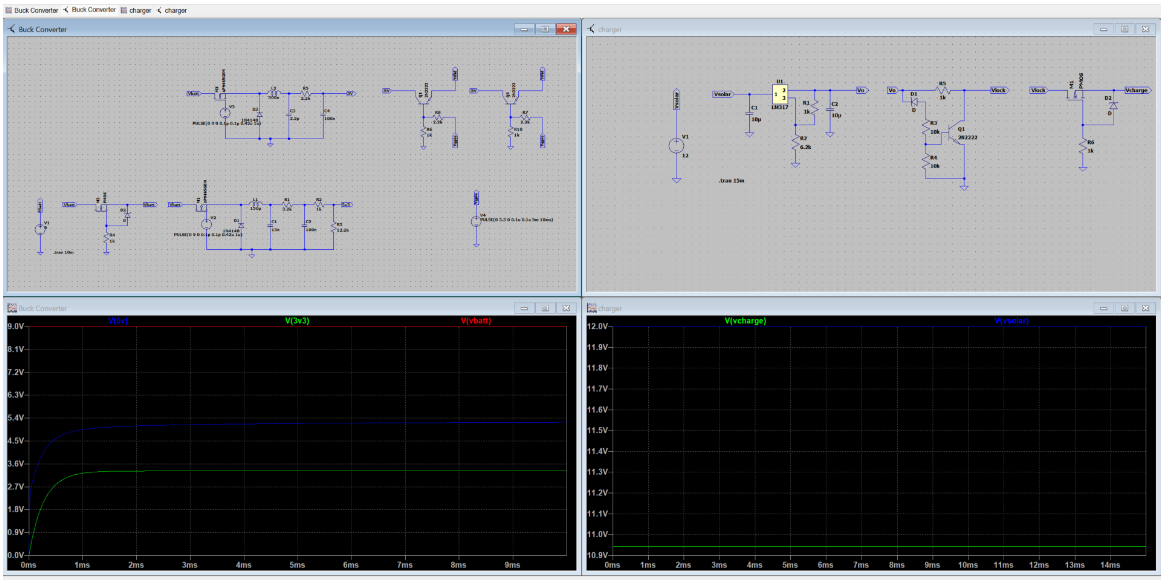


Figure 4.11: Battery Charger and Power Supply Simulation

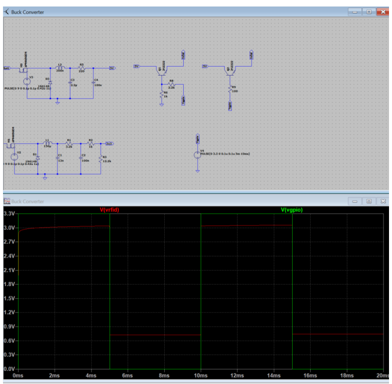


Figure 4.12: Battery Charger and Power Supply Simulation

4.3.2 Physical Testing

Results

Acceptance Test Procedure ID(s)	Result	Pass/Fail
ATP01	Battery rated at 9V.	Pass
ATP02	Output voltage was 5.2V	Pass
ATP03	Output voltage was 3.5V	Pass
ATP04	Charging voltage was 10.6V	Fail
ATP05	Battery removable and rechargeable.	Pass
ATP06	Board was 7cm x 6m	Pass
ATP07	Heat sinks were acquired	Pass
ATP08	Output voltage was 2.8V	Fail
ATP09	Output voltage values	Pass

Table 4.8: Test Results

Analysis of Testing Outcomes

Overall, the system demonstrates satisfactory performance in most areas, with notable exceptions in the charging voltage (ATP04) and output voltage (ATP08). These failures should be addressed to ensure the system meets all requirements and functions reliably in real-world conditions. It's important to note that the failure of ATP04 is not a critical issue, as charging will still occur, albeit potentially reducing the lifespan of the battery. Similarly, the failure of ATP08 reduces the control of the microcontroller over the switching of the RFID readers. However, there is a workaround available, which involves keeping the RFID readers on longer than intended, resulting in lower power conservation but preserving the main functionality of the subsystem. Despite these challenges, the system's overall performance remains promising, with most ATPs passing successfully, indicating its potential for successful implementation and operation.

4.4 Conclusion

The power subsystem was designed to be reliable given the harsh environment in the Greater Kruger and in the worst case, be as easy to fix as can be. Throughout the design process, factors such as subsystem efficiency, part availability, cost-effectiveness, robustness, reliability, and energy consumption were carefully considered to ensure the creation of a desirable and feasible subsystem. While the system generally performed as expected, there were minor accuracy caveats attributed to the use of passive components in the majority of the subsystem. This tradeoff was made to prioritize ubiquity, ease of replacement, and cost minimization over specialized circuitry. Additionally, special attention was given to ensure that the power subsystem has minimal impact on the natural environment and on the Southern Ground Hornbills. Overall, the design strikes a balance between functionality, practicality, and environmental considerations.

Chapter 5

Processing and Control

Prepared by Si Teng Wu - WXXSIT001

5.1 Introduction

This subsystem involves designing a hardware solution and software for controlling the collection, processing, storage, and transmission of data, as well as an identification solution. It has been divided into the following sub-modules: Identification, Weight Processing, Storage, Transmission, System Control, and Power Saving Techniques. Through the use of a micro-controller module and various other hardware modules, this subsystem will be the 'brain' of the system and act as the central hub for data while the system is in the field. This subsystem will receive input data from the Scale and Power subsystems and provide output data to the Power UI subsystem.

5.2 Requirements and Specifications

5.2.1 User Requirements

The stakeholder/user, Carrie Hickman, a PhD student at the Fitzpatrick Institute of African Ornithology, UCT, has provided the following user requirements that are relevant to this subsystem. These requirements were collected through stakeholder engagements on the EEE4113F Teams [57].

- The bird being weighed needs to be identified.
- The weight should be accurate to within a gram.
- There should be some way to collect data without climbing the tree.
- The data should be stored on an SD card as a backup.
- The system should last for two weeks.

5.2.2 Requirements Analysis

Using these user requirements, the following functional requirements (FR), specifications (SP), and Acceptance Test Procedures (ATP) were created. The specifications provide a standard for the subsystem, and the ATPs will be used to test the standards of the proposed solution.

FR ID	Functional Requirement
FR-1	Control the system using a micro-controller.
FR-2	Use a suitable identification technique on the bird as it is being weighed.
FR-3	Collect diagnostic battery data.
FR-4	Collect the weight data.
FR-5	Develop a weight processing algorithm that can process the weight data.
FR-6	Store the data on local, non-volatile and removable storage.
FR-7	Transmit the data wirelessly from the nest to the user's device on the ground.
FR-8	Use power saving techniques to limit the use of power.

Table 5.1: Functional Requirements of the subsystem

SP ID	Specification	FR ID	ATP ID
SP-1	Use the ESP32 S3 Dev Module operating at 3.3V and <250mA.	FR-1	ATP-1
SP-2	Use the RDM6300 125kHz RFID module operating at 5V <50mA.	FR-2	ATP-2
SP-3	The RFID must detect PIT tags at a minimum distance of 5cm and use the GPIO pins to switch on/off.	FR-2	ATP-3
SP-4	Activate RFID only when the weight detected exceeds 2.2 kg.	FR-2, FR-8	ATP-4
SP-5	Use the ADC to read the normalised battery level (0-3.0V) and calculate it as a percentage.	FR-3	ATP-5
SP-6	Read the HX711 using I2C every 10 seconds.	FR-4, FR-8	ATP-6
SP-7	Implement a suitable filtering technique (normal average, moving average, exponential average, or median filter) to process the weight data.	FR-4	ATP-7
SP-8	Utilize a micro SD card module connected via SPI to store data in a text file format <weight,ID,battery%>.	FR-6	ATP-8
SP-9	Implement a web server over WiFi to transmit data.	FR-7	ATP-9
SP-10	Utilize deep sleep mode to minimize power consumption whenever possible.	FR-8	ATP-10
SP-11	Use a 433MHz remote transmitter and receiver to start the WiFi when necessary.	FR-7, FR-8	ATP-11

Table 5.2: System Specifications and associated FRs and ATPs

ATP ID	Test Procedure	Success Criteria
ATP-1	Setup a power supply at 3.3V connect the 3.3V and GND pins on the ESP32 S3 (MCU). Flash the code Test_ESP32S3_Power.ino and observe the current draw and onboard LED.	The ESP32 S3's red LED is on and the current draw is <250mA.
ATP-2	Setup a power supply at 5.0V and connect the 5V and GND of the RDM6300. Observe the current draw and onboard LED.	The LED is on and the current draw is <50mA.
ATP-3	Connect the Tx pin of the RDM6300 to MCU pin 4 and flash Read_RFID.ino. Power both modules (ATP-1,2), and connect the MCU to a PC. Bring an RFID tag close to the antenna and observe the serial console. Measure the maximum distance of detection.	Distance >= 5cm.
ATP-4	Connect the RFID module, HX711, and micro SD module to the MCU (ATP-1,3,6,8). Flash Final.ino, hover a tag above the RFID antenna and place a 2 kg and 5 kg weight, separately.	The console only outputs 'Weight detected' and reads RFID when using 5kgs.
ATP-5	Connect the power supply to MCU pin 7 and flash PollingADC-BATT.ino. Change the voltage to 0V, 1V, 2V, 3V and observe the console.	Console outputs 0, 33, 66, 100% at respective levels.
ATP-6	Setup a power supply at 5V and connect the HX711 5V and GND pin to the supply and DAT and CLK to MCU pin 8 and 9, respectively. Flash WeighingScale.ino, place a weight on the scale and observe the serial console.	Console shows weight data.
ATP-7	Run the filtering techniques on clean, noisy and bad data, and compare performance.	<5% error on clean and noisy data; <10% error on bad data.
ATP-8	Setup a power supply at 5V and connect the 5V and GND of the micro SD card module. Connect pins CS, MOSI, SCK, MISO to MCU pins 10, 11, 12, 13, respectively. Flash SDTest.ino and press reset on the ESP32S3. Remove the SD card and check its contents.	Test.txt is present with 'Hello World!'.
ATP-9	Connect the remote module to the MCU (ATP-1,11) and extend the antenna on the remote. Flash WifiSend.ino, press button B on the remote, connect to 'ESP32-Access-Point', using password '123456789' on a user device and run the python script GetrRequest.py.	A text file is downloaded with 'Hello World!'.
ATP-10	Connect the remote module to the MCU (ATP-1,11) and extend the antenna on the remote. Flash Sleep.ino, press button B on the remote and observe the serial console.	ESP32 resets every 10 seconds, prints 'Awake!', after waking from button.
ATP-11	Setup a power supply at 5V and connect the 5V and GND pins. Connect a voltage divider using a 4.7k and 12k resistor to GND from pin D0. Connect the output of the voltage divider to MCU pin 6. Power the MCU (ATP-1) and flash WiFiSend.ino. Press the button B and check on a user device for WiFi networks.	'ESP32-Access-Point' is present on WiFi networks.

Table 5.3: Acceptance Test Procedures

5.3 Design Choices

5.3.1 Micro-controller

This subsystems needs a micro-controller to act as the central processing unit. There are various options on the market, but the design of a module to interface with a micro-controller IC is not within the scope of this project so the decision was made to use a off-the-shelf micro-controller kit/dev module. The Raspberry Pi Pico W, ESP32 series and Arduino Nano dev boards were considered. The cost, availability, features and to a lesser extent, software support, were considered when the decision was made. In terms of features, WiFi, flash storage, communication peripherals, deep sleep mode and clock speed were considered.

Micro-controller	Price	WiFi	Flash	SPI,I2C,UART	Sleep	Clock Speed
Pi Pico W	R150.00	Yes	2MB	Yes	Yes	133MHz
ESP32 S3	R178.00	Yes	16MB	Yes	Yes	240MHz
Arduino Nano	R200.00	No	32kB	Yes	Yes	16MHz

Table 5.4: Comparison of Micro-controllers [5][6][7]

It was decided, based on the results shown in Table 5.4, that the ESP32 S3 Devkit C was the most suitable choice for this design. The price is in the middle of the options, but has all the features, 16MB of flash, allowing for more space for instructions, and the highest clock speed, allowing for faster processing. The Pi Pico could have been a viable option, but lacks in flash space and clock speed compared to the ESP32 S3. The Arduino Nano AT328P does not have onboard WiFi so it would not be a viable option.

In terms of choosing the ESP32 S3, it was a trivial decision based off of flash, price and avaialblity. The ESP32 prices ranged from R150 to R240, approximately, but the S3 boasts the best features at a mid range price. It was also in stock and available. Finally, the ESP32 S3 has many software libraries and interfaces with Arduino IDE.

5.3.2 Identification

The identification options were limited. The user is currently able to identify the birds using a camera trap (visually) and by bird calls (acoustically). Due to the violent nature of the Southern Ground Hornbill, introducing hardware elements outside of the housing would be dangerous for both the hardware and the bird, so an external camera was not a viable solution. Recording of the birds while weighing the is possible, but this poses two problems. The storage space required to store audio files would be much than just text based data and more importantly, there is no guarantee that the bird will do its call when its is being weighed. The RFID solution was then proposed to the stakeholder, who agreed that its would be possible to tag the birds when they are young [57]. RFID would allow for the birds to be consistently identified when they are weighed, uses low storage to store the ID, and can be done without exposing hardware to the external environments or the birds.

There are three possible types of RFID that could be used. Low frequency (LF), high frequency

(HF) and ultra-high frequency (UHF). The power consumption, size, range and availability of Passive Integrated Transponders (PIT) tags for animals were considered for the decision.

Frequency	**Operational Range**	**Power Consumption**	**PIT Tag Availability**
LF (125-135kHz)	Up to 20 cm	Low (0.25W)	Common (125kHz or 134.2kHz)
HF (13.56MHz)	Up to 20 cm	Slightly higher	Rare for animal PIT tags
UHF (868-928MHz)	Up to 3 m	Significant	Limited availability

Table 5.5: Comparison of RFID Frequencies [8]

As shown in Table 5.5, the most suitable solution for a low power design would be LF RFID, as it uses the lowest power consumption and has the most readily available supply of animal PIT tags. For this design, an 125kHz RFID reader module, RDM6300, was chosen and common proximity tags were used to demonstrate and test the effectiveness of the RFID reader.

5.3.3 RFID Wiring and Control

Having chosen the RDM6300, and ESP32 S3, a challenge arose as to how to connect these modules effectively. The platform for the scale will be approximately $1m^2$. Assuming the antennas for RDM6300 are designed to be 25cmx25cm squares in a future iteration, that would require 16 antennas to cover the surface of the scale. Due to the limited number of UART peripherals on the ESP32 S3, a choice needed to be made on how to effectively have 16 antennas and one input for the ESP32. The following choices were considered:

- Uses a multiplexer (MUX) for the antennas and a single RDM6300 module.
- Uses a MUX for 16 RDM6300 modules with individual antennas.
- Uses 16 RDM6300 modules and programmatically switch them on/off.

The first option was rejected as the antennas are tuned to 125kHz with specific Inductance-Resistance-Capacitance (LRC) values. A MUX between the antennas and the module may cause parasitics that would change the resonance frequency of the antennas.

Both the second and third options are viable solutions, but the last solution was chosen. The ESP32 S3 has an abundance of GPIO pins and by turning each module on one at a time, this limits the peak current draw for the system, and ensures that no modules are drawing power while idle, waiting for their turn on the MUX. This also removes the need for an extra component, decreasing complexity. The Tx pin of all 16 modules would be connected to a single ESP32 Rx pin (pin 4). For this design, 3 modules were tested instead of 16 due to cost constraints.

5.3.4 WiFi vs Bluetooth

WiFi and Bluetooth were considered for the transmission of data from the device in the nest to the users device on the ground. It is expected that the trees for the nest can be up to 30m in the air and the device will be housed inside a wooden box, on top of a nest, on top of a tree, therefore line of sight will not be available. The following factors were considered: Power consumption, max one-way data rate and nominal range.

Technology	Power Consumption (mA)	Data Rate (Mb/s)	Range (m)
WiFi	100-350	31.4	100
Bluetooth	1-35	0.732	10

Table 5.6: Comparison of Wireless Technologies [9]

It is evident from Table 5.6 that WiFi is the only solution, albeit more power hungry, that can reach the ranges required for this design. It is also noted that these ranges were tested in line of sight conditions, further cementing that WiFi is the better option.

5.3.5 Power Saving Considerations

These power saving choices were made in order to address the two week duration requested by the stakeholder. This subsystem will contain the majority of the electronics used in the entire system, so it is very important to save power whenever possible. The following choices and their reasons were made:

Component	Decision	Reason
RFID	Control the power for the RFID modules	Removes their power consumption completely when not being used.
RFID	Only use RFID when weight is above 2.2kgs	Ensures RFID is used only when a potential adult has landed.
Collection	Takes a single reading and waits for bird to leave before taking another	Ensures that a single bird will not be weighed and identified constantly when it is on the scale.
WiFi	Introduce a remote transmitter receiver that is used to start the WiFi download process	As the user only visits the nest fortnightly, the WiFi, which consumes the most power, will be off until the user manually turns it on.
WiFi	Turn off the WiFi if no one has connected after 30 seconds	Ensures the WiFi isn't left on if the user mis-clicks the remote.
Sleep	The ESP32 will sleep and wake every 10 seconds to take a sample reading or wake upon remote trigger for WiFi	Ensures that the ESP32 will draw minimum power while idling.

Table 5.7: Power Saving Decisions

5.3.6 Long Term Storage Solutions

The data collected during the period of a fortnight needs to be stored in some form of non-volatile storage until the data can be transmitted. They are 3 options for this: using the ESP32 S3's 16 MB of onboard flash, adding an EEPROM chip or using a micro SD card module. According to the user, the storage should be removable as well and its was explicitly specified that an SD card should be used as a form of back-up storage [57]. Taking this into account, no further considerations were made and the decision to use a micro SD card module was made. The smallest SD card available, 16GB, was chosen.

5.4 System Design

5.4.1 Block Diagram and System Control Flowchart

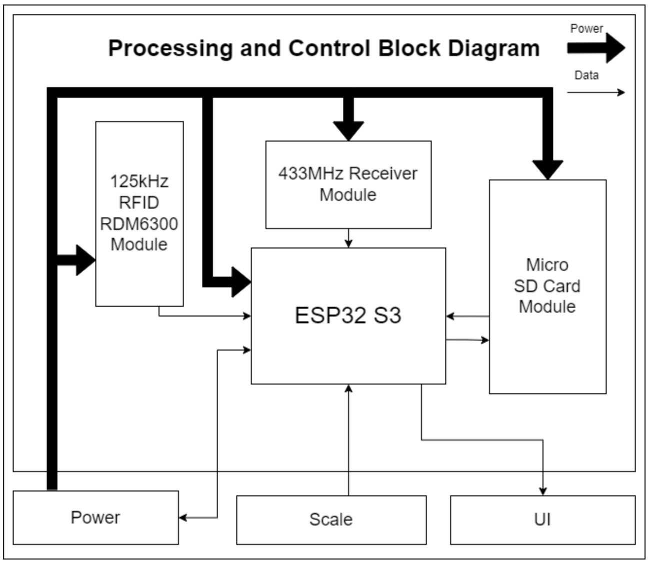


Figure 5.1: Block Diagram

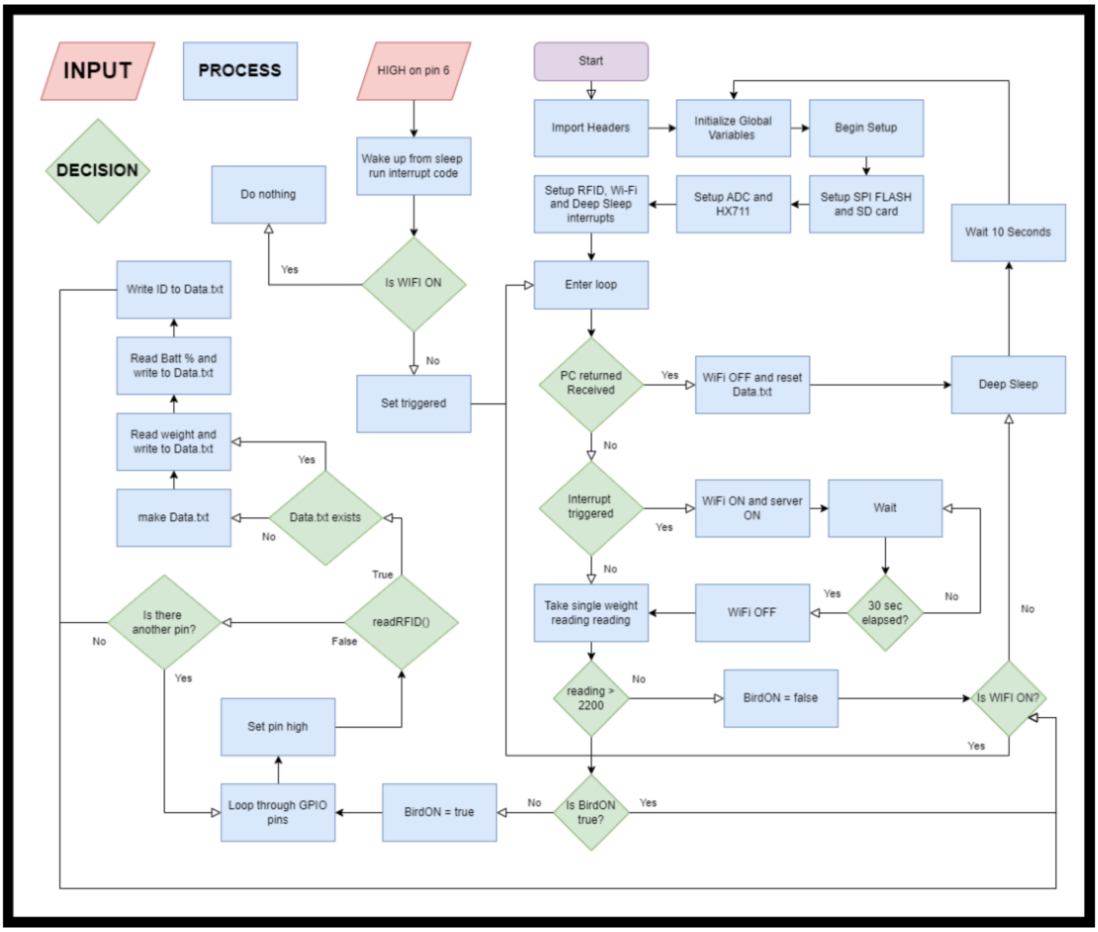


Figure 5.2: System Control Flowchart

A detailed console output illustrating the control sequence outline in Figure **??**, can be found in Appendix A.3.3

5.4.2 Circuit Diagram

The hardware was built on a breadboard and linked using jumper wires. Pictures can be found in Appendix A.3.4.

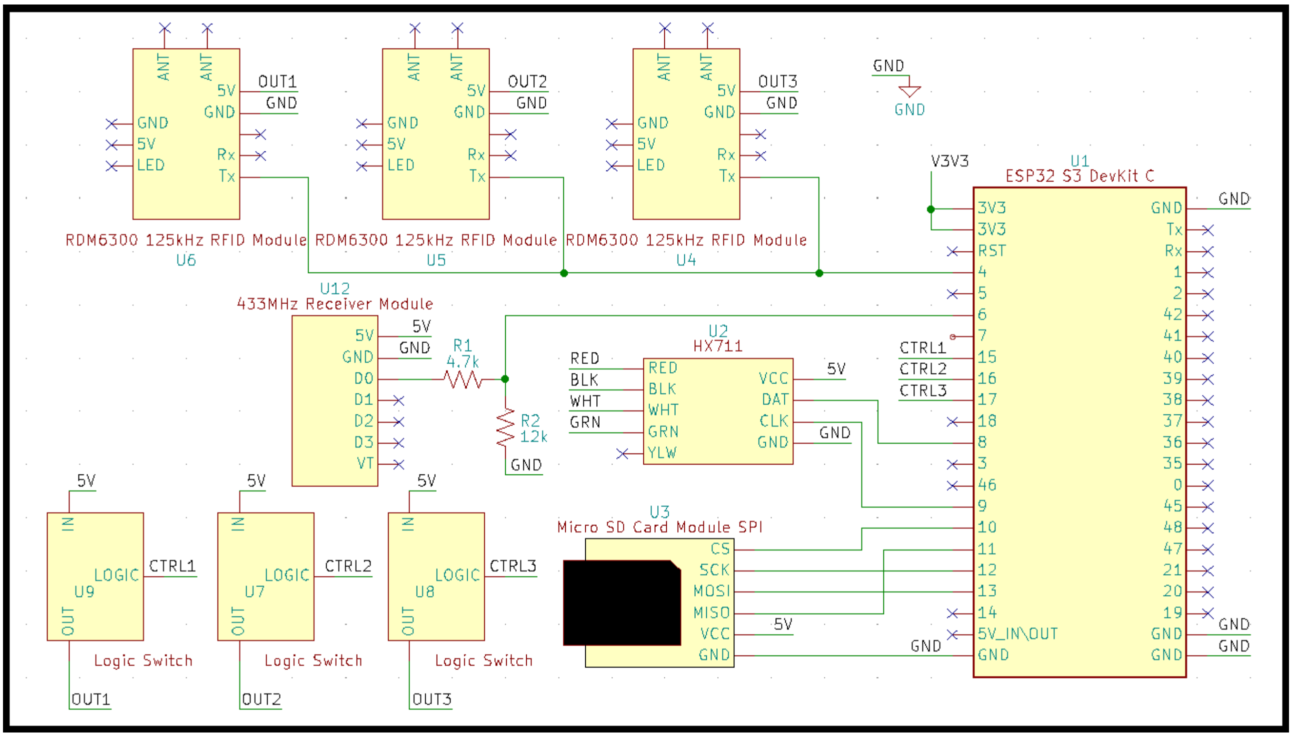


Figure 5.3: Circuit Diagram

5.4.3 Used Libraries

The following libraries are not part of the stand C libraries or standard Arduino libraries, but were used in the final code. Shown in Table 5.8.

Header File	Description	Author
HX711.h	Used to interface with the HX711	Bogdan Necula [58]
AsyncTCP.h	Base library for ESPAsyncWebServer.h	me-no-dev et al. [59]
ESPAsyncWebServer.h	Allows the creation of Asynchronous Web Servers	me-no-dev et al. [60]

Table 5.8: External Libraries

5.4.4 Custom RFID Reading

The RDM6300 is a well known 125kHz RFID module. It was decided to write custom code needed to interface with the UART, gather the serial data, perform various validations and produce an ID consistently. The following methods were made:

Function	Description	Return Type
clearSerialBuffer()	Clears the input serial buffer	void
isAlphanumeric(String str)	Checks if `str` is alphanumeric and contains no null characters	bool, True if valid
check()	Extracts the first 12 bits from ID, uses `isAlphanumeric()`, and compares the ID to an array of known birds	uint8_t, 0 if bird found, 1 if not found, 2 if ID is invalid
readRFID()	Clears the buffer, after a short delay, reads serial data until a string has 15 characters, runs `check()`, and prints if the ID is a bird or not	bool, True when Bird found

Table 5.9: RFID Function Descriptions

The code in Table 5.9 can be found in Appendix A.3.1

5.4.5 Weight Processing Results

Four weight processing techniques will be investigated: Average, Moving Average, Exponential Average and Median Filter. Average is a reduction and will produce a final result, but the rest are smoothing algorithms so an average and a median will be used to reduce the signals to a final value. Three sets of data based on a 4880g weight will be used for testing which was obtained using the readvalue() function from the actual scale. Clean data, noisy Data and bad Data were obtained by not disturbing, lightly tapping, and violently thumping the weight, respectively. The raw waveforms can be found in Appendix A.3.2, however for testing, a 50 sample portion within the 'step' is used as the scale only reads after a trigger threshold. It is also assumed, as a simplification, that once the bird is on the weight it will stay there for a long time. Figure 5.4 shows the raw signal after portioning, note that all graphs are set to the same limits to better see the effects. All code can be found under main/Data Analysis on the GitHub.

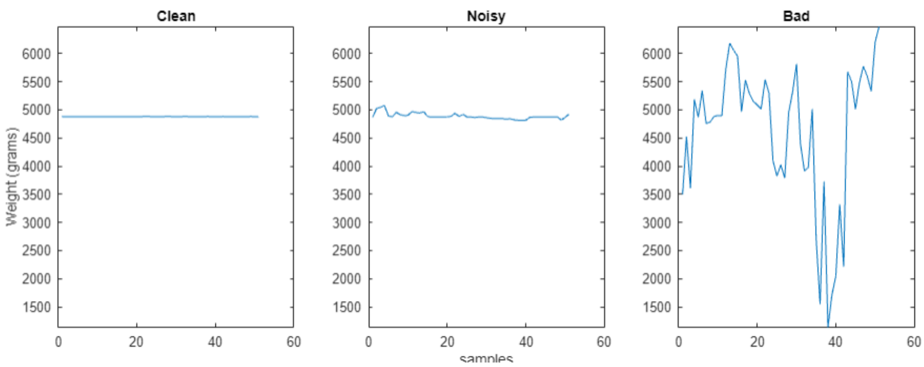


Figure 5.4: 50 samples of Raw Data

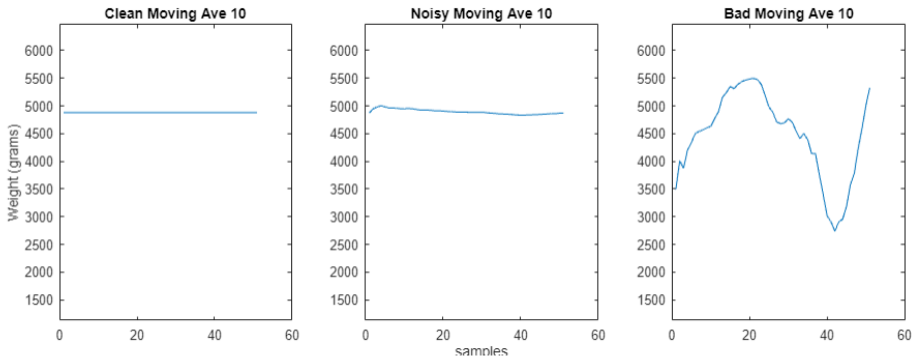


Figure 5.5: Moving Average at 10 sample filtering gap

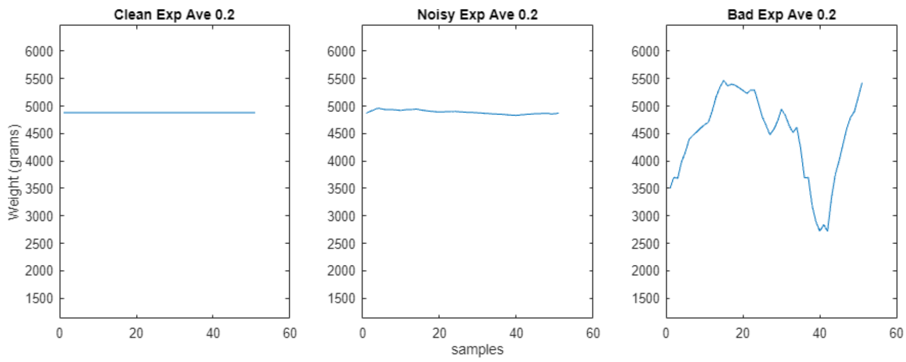


Figure 5.6: Exponential Moving Average at alpha = 0.2

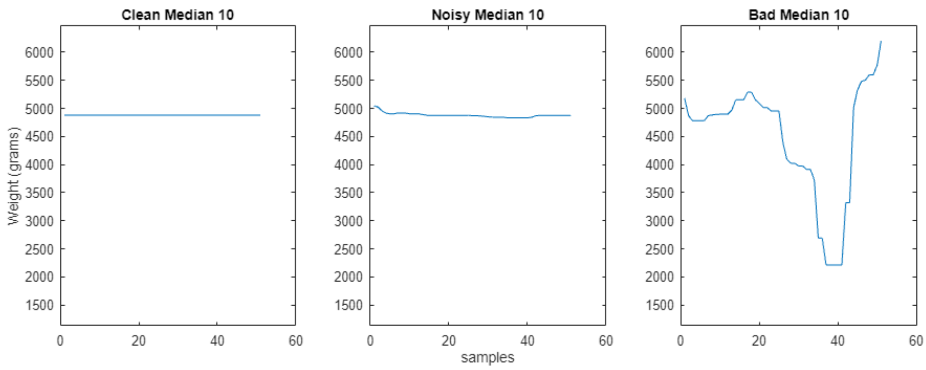


Figure 5.7: Median Filter at 10 sample filtering gap

	Clean (%)	**Noisy (%)**	**Bad (%)**
Average	0.000959980	0.164421761	5.337903322
Median	0.000200204	0.145573770	1.822099590

Table 5.10: Average and Median Reduction Percentage Error before Filter

Smoothing Alg.	Clean (%)	Noisy (%)	Bad (%)
Moving Average	0.000721414	0.111590287	5.829597848
Exp Average	0.000827435	0.111066583	5.445617314
Median Filter	0.000959981	0.164421761	5.337903323

Table 5.11: Percentage Error after Filter using Median Reduction

It can be seen from Table 5.10 that the median reduction provides the best results in the clean and bad data, but in Table 5.11, the exponential moving filter followed by a median reduction, showed the best results for noisy data.

5.5 ATP Results

ATP ID	Results	Pass/Fail
ATP-1	ESP32 S3 consumed 248 mA at 3.3V	Pass
ATP-2	RDM6300 consumed 27mA at 5V	Pass
ATP-3	Distance was <2cm	Failed
ATP-4	No output observered for 2 kgs but 'Weight Detected' at 5 kgs	Pass
ATP-5	All expected values outputted	Pass
ATP-6	Given a weight of 4880g, read approximately 4880g	Pass
ATP-7	All techniques were able to get <0.001% for clean data, <2% for noisy data and <6% for bad Data	Pass
ATP-8	File exists and contains 'Hello World!'	Pass
ATP-9	File downloaded and contains 'Hello World!'	Pass
ATP-10	Console resets and prints Awake! or resets every 10 seconds	Pass
ATP-11	Upon pressing 'B', 'ESP32-Access-Point' appeared on the Available WiFi Networks	Pass

Table 5.12: ATP Results

5.6 Conclusions and Recommendations

The Processing and Control subsystem contains the central processing unit of the entire system and acts as a central hub for data while in the field. In this iteration, weight data and RFID data was successfully collected, stored in a micro SD card and upon an external remote button press, transmitted to the user device via WiFi. Weight processing techniques were investigated and it was found that the a median reduction without filtering works best on clean data or very bad data, but a median reduction after an exponential moving average filter preforms best for noisy data. Most of the ATPs were passed except for the RFID range. Improving the range may be possible by redesigning the antenna but this is out of the scope of this iteration. In future, designing a full build using the investigated algorithms and a custom antenna would be highly recommended.

Chapter 6

User Application

Prepared by Oliver Shaw - SHWOLI002

6.1 Introduction

This section discusses the design, development, and testing process of the user application. The user application serves as the primary point of contact between the end user and the entire system. Its main function is to ensure that the system remains autonomous, and the user does not need to interact with it to view, gather, or record the sensor data collected by the system. To achieve this, we had to choose a data transfer method that would allow for fast and high-quality transfers without affecting the existing environment. The user application also needed to maintain a clean and user-friendly interface that displayed all necessary information without compromising the layout and format that aligns with design principles.

This section explores the various methods of transferring data collected by other subsystems. The collected data pertains to the weight of birds along with their RFID. Additionally, the battery percentage is the last piece of data that is sent to this subsystem from the other subsystems.

Moreover, we discuss the functional and non-functional specifications and testing procedures that ensure that the subsystem meets the requirements of the stakeholders and maintains its integrity.

6.2 Requirement Analysis

The section on Acceptance Test Procedures examines the fundamental requirements of the subsystem and expands these to determine both the functional and non-functional specifications of data transmission and the user application. It outlines specific acceptance criteria for each specification, which is used to evaluate the subsystem and ensure that it meets the required standards. This evaluation is crucial in delivering a functional and useful system to the stakeholders.

6.2.1 Functional Requirements

FR ID	Functional Requirement
UAR-1	Data transfer must not impact the existing environment.
UAR-2	Data must be accessible from the base of the tree.
UAR-3	Data transfer must be power efficient.
UAR-4	Data must be retrievable at any time.
UAR-5	Develop a GUI for the bird weighing system.
UAR-6	User Application must display all data gathered by the sensors.
UAR-7	User Application must allow for easy and quick data access.
UAR-8	User Application must ensure authorized access only.
UAR-9	User Application must allow the user to download the full dataset.
UAR-10	User Application must be user friendly and visually appealing.
UAR-11	User Application must be developed to ensure changes can easily be made to the system.

Table 6.1: Functional Requirements of the User Application Subsystem

6.2.2 Non-Functional Specifications

SP ID	Specification	FR ID	ATP ID
UAS-1	Human Centred Design of User Application.	UAR-9	ATP-1
UAS-2	Performance.	UAR-7	ATP-2
UAS-3	Code Maintainability.	UAR-11	ATP-3
UAS-4	Data Transfer.	UAR-1, UAR-3	ATP-4

Table 6.2: User Application Subsystem Non-Functional Specifications and associated UARs and ATPs

6.2.3 Functional Specifications

SP ID	Specification	FR ID	ATP ID
UAS-5	Authorized user access only.	UAR-8	ATP-5
UAS-6	Data Transfer range of more than 20 metre.	UAR-2	ATP-6
UAS-7	Connection must be possible at any time.	UAR-4	ATP-7
UAS-8	Recorded bird weight data must be visually available.	UAR-6	ATP-8
UAS-9	Alternative Data Visualisation.	UAR-6	ATP-9
UAS-10	Battery Data monitoring.	UAR-6	ATP-10

Table 6.3: User Application Subsystem Functional Specifications and associated UARs and ATPs

6.2.4 Acceptance Test Procedures

ATP ID	Test Procedure	Success Criteria
ATP-1	The User Application follows good design principles and has an understandable flow throughout. A group of users of varying understanding of the application will use and rate the experience.	The User Application must be easy to use with or without experience and the group of users must grade the applications design a PASS.
ATP-2	The User Application will be connected to the host server and the data will be loaded across automatically. This is timed to determine the performance.	The time for the user application to load must be less than 5 seconds.
ATP-3	Code will be reviewed to ensure it allows for future developers to add code easily for new functions and alter the current function.	Code is neatly presented and well commented.
ATP-4	The system will be reviewed with regards to the environment to ensure that the impact of engineering is minimised and the habitats of the birds is preserved.	The subsystem does not impact the environment negatively at all.
ATP-5	Two new users will try and access the server, one of which is an authorized user and the other is unauthorized.	Only the user that had authorized access is able to connect to the system.
ATP-6	The user will be positioned at a distance greater than 20 metres from the system.	The user is able to connect to the server and access the data.
ATP-7	The system will be accessed over a period of an hour at even intervals of 10 minutes to ensure that access is available at any time.	The system grants access at each of the 6 attempts.
ATP-8	The User Application will be tested by following the logical path of user and ensure that the bird weight data is visible and accessible.	The bird weight data is accessible and visible.
ATP-9	The User Application will be tested by following the logical path of the user and ensure that the user is able to view an alternative version of the data.	The bird weight data is visible in an alternative form.
ATP-10	The User Application will be tested by following the logical path of the user and ensure that the user is able to view information on the battery percentage.	The battery percentage is clearly visible to the user.

Table 6.4: User Application Acceptance Test Procedures

6.3 Design Choices

6.3.1 Type of Application

In order to decide on the platform for hosting the application, two options were considered - browser-based or locally installed. The choice was determined by the conditions in which the system was to be used, specifically in the Kruger National Park, which is located at a considerable distance from the nearest inhabitants. The system needed to be accessed on any device that the user had with them when they arrived at the tree to collect data. Based on these requirements, it was decided that a web application would be a better choice than an application that is stored locally on the device. This is because a web-hosted application can be accessed from any device that has access to the host of the server, while a device-centric approach would require the application to be downloaded onto the device before use. Additionally, the lack of general connectivity in the Kruger National Park makes a web application a more practical solution.

6.3.2 Data Transfer and Communication Method

Various methods of data transfer were considered for the Southern Ground Hornbill monitoring system. Initially, a wired solution was proposed to connect the system at the top of the tree to the base where the user could manually plug in and collect the data. However, this design raised issues because the birds tend to attack wires that look like snakes, and unfamiliar electronics near their nests can disturb them.

Therefore, we decided to explore wireless transmission options, including Wi-Fi, Bluetooth, and Long Range (LoRa) technologies. At the same time, we were deciding on the board that would control the entire system, and we chose the ESP32-S3 system on a chip microcontroller. Due to budget constraints, LoRa was not considered as it would require additional transceivers, while the ESP32-S3 can handle two types of wireless transfer without additional components, namely, 2.4 GHz Wi-Fi (802.11 b/g/n) and Bluetooth LE 5.0.

Although Bluetooth LE 5.0 offers power-saving potential and a good range, many examples of using it on the ESP32-S3 have struggled to achieve the desired range using low power. This requires increasing the power used to establish a reliable and secure connection. Therefore, we opted for Wi-Fi as the communication method because it offers several user-oriented benefits.

For example, Wi-Fi allows users to create access control by having a password on the Wi-Fi connection instead of requiring a unique password each time they access the application, streamlining the data access process. Additionally, any user on any device can connect to the ESP32-S3 to collect data if they know the Wi-Fi password. This is important in the field as if the user's device has a dead battery the application can be accessed from another device. Furthermore, Wi-Fi provides high bandwidth, fast, and reliable data transmission, ensuring a seamless user experience with a focus on the user's experience.

6.3.3 Styling and Appearance Framework

There are many options available to style and format HTML web applications. Frameworks such as Bootstrap offer a broad range of styling options, but they require significant storage space. Lightweight alternatives, such as Skeleton, Concise CSS or Base, are available but they may not offer as many features as Bootstrap. To keep the user application lightweight, a basic approach was taken, which involved creating separate HTML, CSS, and JavaScript code. This approach resulted in a streamlined and easy-to-use user interface, with functionality as the main objective.

6.3.4 User Interface Design

The user interface is a crucial aspect of the user interface subsystem. It should be designed while keeping in mind the needs of the user with respect to functionality and availability of information. Additionally, the information presented through the user interface should follow important design principles that prioritize the user's experience.

The user application must follow a set of golden rules to ensure that the system is centered around the user. Firstly, consistency is crucial within the application to enable users to comprehend the system easily. In our application, we will use a consistent layout of fonts, colors, and design to guarantee that our application adheres to this principle and provides users with an experience that makes sense. The application's flow should feel natural to the user, which is essential to ensure the application's success. It must be human-centered and reflect the real world.

To echo the process of data accessibility and reduce the need to input data, we have made a choice to avoid requiring a login before accessing the web page and data. Instead, the Landing page will have buttons that lead the user directly to the most critical information at the first stage of contact. This is an important part of the system because it utilizes the requirement that a connection with the ESP32-S3 must be made before accessing the page. The user will be required to enter a password to establish a Wi-Fi connection, eliminating the need for a separate and unnecessary login screen.

The application should be designed to be user-friendly for everyone, regardless of their level of understanding or experience with the system. This means that the interface should have clear and prominent action buttons with bright colours that attract the user's attention to the most important parts of the interface. The interface should also be designed to present the user with a limited number of choices at any given time, as the more options presented to the user, the more time they will take to make a decision. Therefore, the interface will present a maximum of two choices at any given time, and these choices will be defined with concise and effective language that guides the user without overwhelming them with decisions.

In order to provide an optimal user experience, the system provides direct and dynamic feedback for every user decision. This means that the user's actions will either lead to a new page displaying the information they were seeking, or dynamic on-screen animations will provide visual feedback to the user. This ensures that the user feels that the system is working to their advantage and that all the information they need is readily available.

The journey of the user through the application should be well-organized, and the actions performed by the user must lead to closure. This can be achieved by designing the application in such a way that from the very first Landing page to the end of the user's journey, there is a sense of completeness, and the information they are seeking is easily accessible.

It is crucial to consider potential failures while designing user experiences. The design flow should aim to prevent errors by providing clear instructions to users about the consequences of their actions and also include ways for users to undo any mistakes they may make. This can be achieved by adding return buttons on pages that come after the Landing page and ensuring clear and concise design decisions on each page.

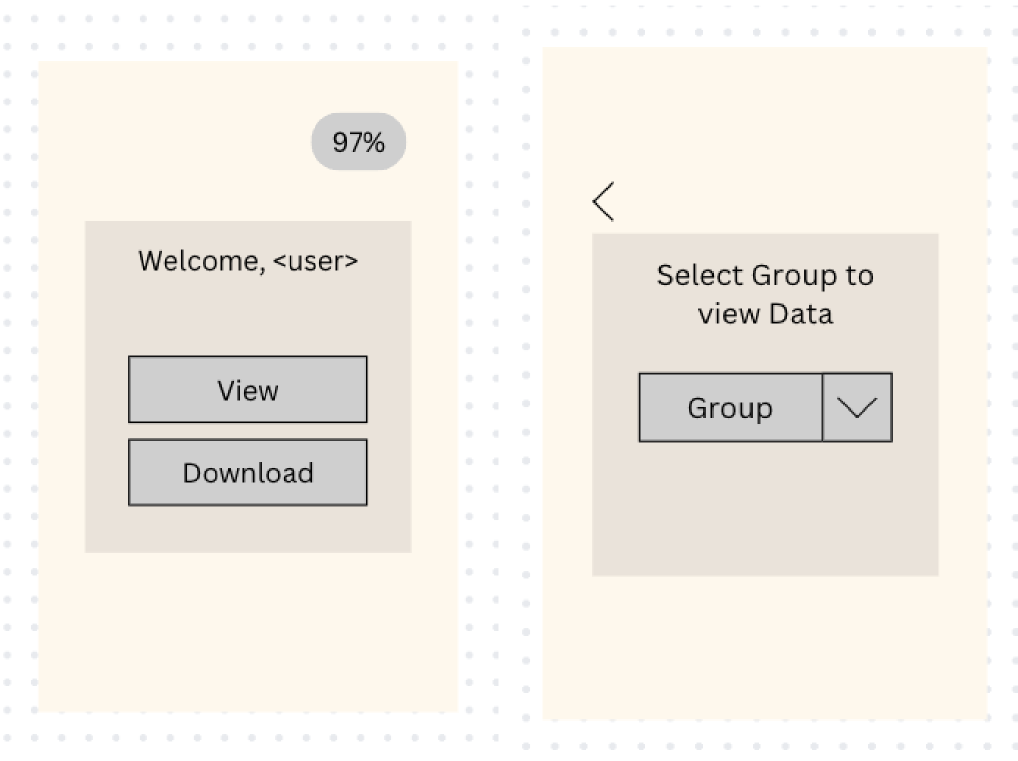
The entire system should prioritize giving users control and ensuring that the application is user-friendly, with quick and easy decision-making that avoids frustration. These decisions should follow a logical flow that imitates human interaction. To achieve this, all necessary data should be presented to the user from the first page to ensure efficiency throughout the system.

6.4 Final Design

6.4.1 User Interface

After taking the design principles into account as well as the users requirements for the system and the system requirements that ensure a solution is created that meets the stakeholders requirements a design of the proposed solution can be created. To do this effectively it was useful to create a set of user scenarios or use cases. From these use cases it is then much easier to design the solution to ensure that the user, no matter their intention in entering the application, is able to access the data easily and that the system is responsive to these requests.

Below are the Landing Page (a) and the Group Selection Page (b). These design follow the aforementioned design principles that ensure the application is centred around the user. To make sure of this the design was kept simple and consistent throughout. Offering the user a small and defined number of options at each stage. The final design will offer a more diverse colour difference between the background and the buttons that require action. The headings of each page will also be presented in a bright colour to direct the user. This is important as it lets the user know what action is required from them. With these elements together it will be able to provide a completely seamless and easy-to-use system.



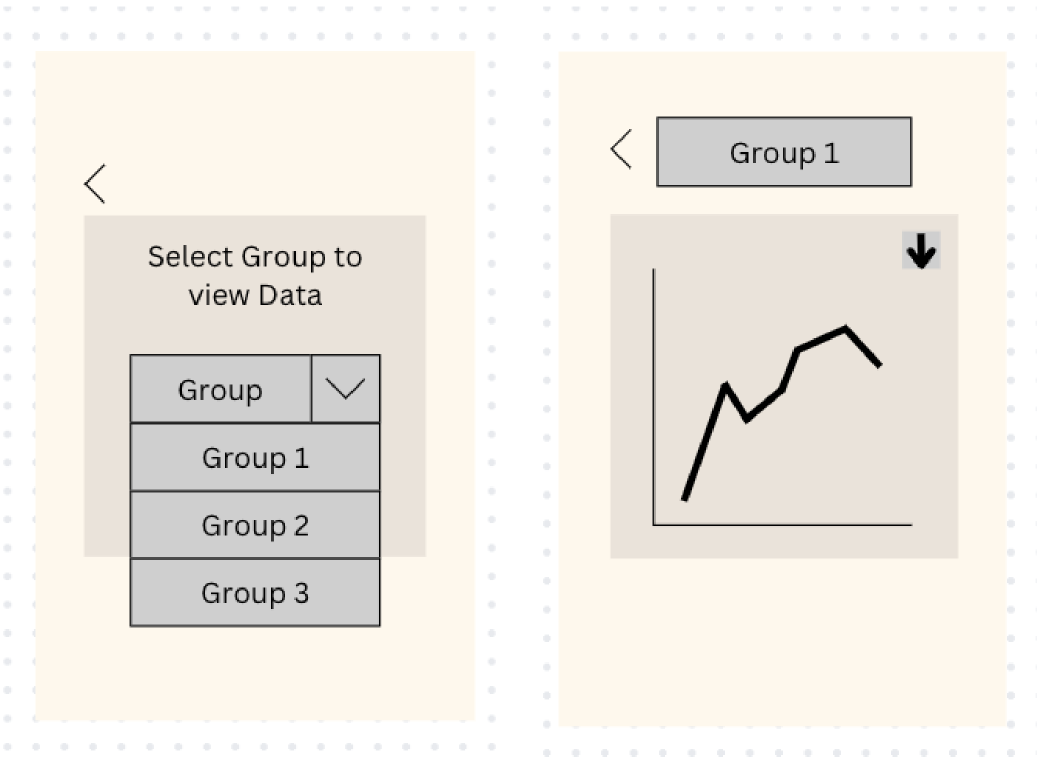
(a) Landing Page

(b) Group Selection Page

Figure 6.1: User Flow from Landing Page to Group Selection Page

The Group Selection Page shows the user only one action button that when pressed will show a drop down menu. This is important as it doesn't overload the user with options and the button is presented near the centre of the screen. This was important because the user must be able to clearly see the action button but beyond this the time it takes a user to take action depends on the distance between their cursor/ finger and the button. So by placing this in the middle of the page we are able to place it close to any other location on the screen.

The drop down menu is shown below alongside the Graph Page that visually displays the sensor data that has been collected by the system. The Group Selection Page drop down menu offers simply labeled groups of data that correspond to the weight data of a specific bird. This weight data has multiple values depending on the number of times the bird has been successfully weighed. The data that the system receives does not have any time stamps and therefore the data, when visualised into a line graph, sets regular intervals between the data points regardless of the period of time that may have elapsed between them. This allows us to display the weight data in a very clear manner and is shown below.



(a) Drop Down Menu (b) Graph Page

Figure 6.2: User Flow from Selection Page to Graph Page

6.4.2 Application Type

The decision was to create a Web Application. This is achieved by creating separate HTML, CSS and JavaScript code that deal with the elements of the web page, the styling and appearance of those elements as well as deal with any actions that the user takes.

6.4.3 Graphing and Downloadable Data

In order to achieve graphs within HTML, the choice to implement ApexCharts was made. ApexCharts is a JavaScript library that allows graphs to be created within the HTML page. It also allows users to download the information from the same page that displays the graph. This was an important decision as it means that the user does not have to revert to the Landing Page in order to download the data.

6.5 Results and Testing

6.5.1 Data Transfer and Communication

This process is vital to the security of the system. It ensures that only users with authorized access are able to access the system and sensor data. This is done by having a password protected Wi-Fi network hosted by the ESP32-S3.

The testing procedure was a basic set up of three devices, one that had previously been connected to the server, one device that had never been connected but had been provided with the user credentials, and finally a device with no user credentials.

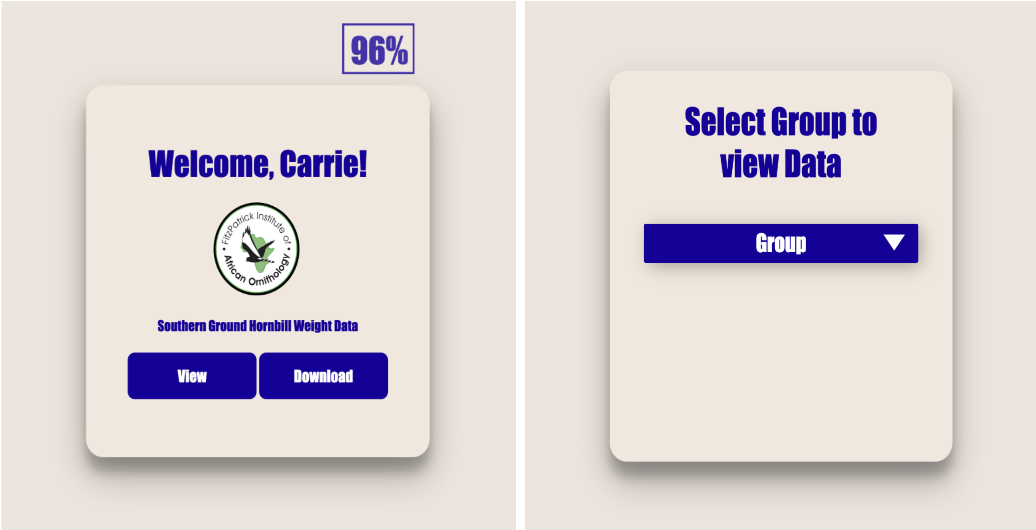
Device Number	User Credentials	Successful Connection?
1	Full credentials and previously connected to the system	Yes.
2	Full credentials but previously not connected.	Yes.
3	No credentials.	No.

Table 6.5: Authorized Access Control Results

The testing confirmed that the system does not allow access to unauthorized users.

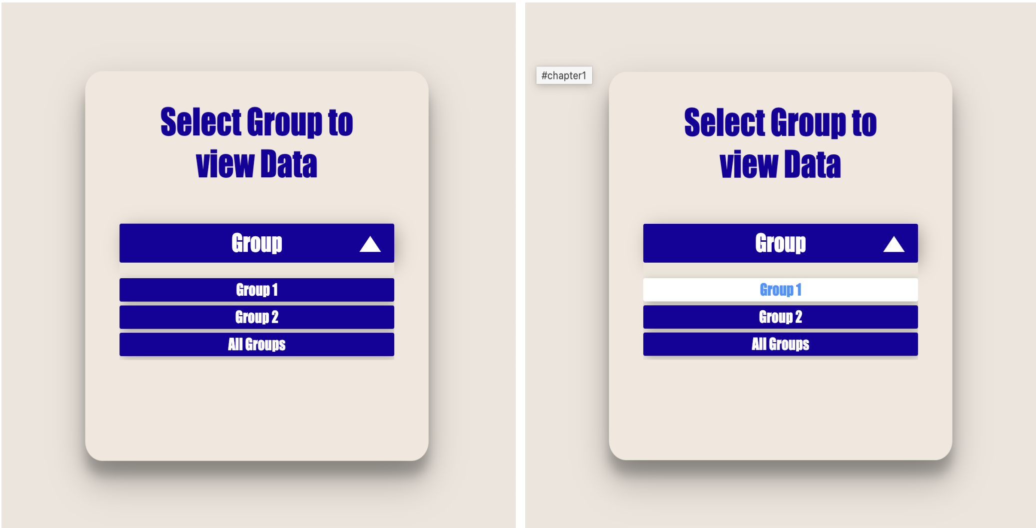
6.5.2 User Interface

The User Interface was testing to ensure that the flow from the Landing Page to the user's end destination are familiar and streamlined. The size of the container that is used automatically adjusts to the device on which the user is accessing the application. Below the flow from the Landing Page to the Group Selection Page is shown. The drop down menu gives the user options of which set of data to view, as well as an option to view all the data sets presented. The colour of the buttons change when they are hovered over when being used on a system with a cursor or for mobile operation when the button is clicked it clearly and dynamically changes to ensure the user is can be confident to know what action they have taken.



(a) Landing Page (b) Group Selection Page

Figure 6.3: User Flow from Landing Page to Group Selection Page



(a) Drop Down Menu (b) Hover Effect

Figure 6.4: Group Selection Page Design Details

Once the user has selected a group of data the data will be presented in a graph as shown in the figure below. This gives the user access to a direct visualised version of the data the system has collected. There is also an option on this screen to download the data in SVG, PNG or CSV format. This allows the user to be at the end of the user journey from the Landing Page with the intention of viewing the data, but now they are able to utilise the full capabilities of the application and simply download the information from this final page of their journey.

Figure 6.5: Graph Page showing Download Options

To determine the overall usability of the application a group of 5 users were selected that ranged from very inexperienced with computer systems all the way to university students studying computer science. These participants were asked to give a pass or fail grade to each stage of the user application section by section. The application was divided into the Landing Page, Group Selection Page and the Data Visualisation and Recording Page. These were all evaluated and each section was given a passing grade for each of the subsections of the application. After the test had been completed participants were asked to grade the application on a scale from 0 to 10, where 0 represented a completely unusable design and 10 represented a design that felt natural and easy to use. The range of responses was between a 7 and 9. The mean of the results was a 7.9 which was taken as a successful user review.

6.6 Acceptance Test Procedure Results

ATP ID	Test Procedure	Success Criteria	Result
ATP-1	The User Application follows good design principles and has an understandable flow throughout. A group of users of varying understanding of the application will use and rate the experience.	The User Application must be easy to use with or without experience and the group of users must grade the applications design a PASS.	**PASS.** The user testing resulted in each section of the application being given a passing grade. And the application as a whole was rated a 7.9/10.
ATP-2	The User Application will be connected to the host server and the data will be loaded across automatically. This is timed to determine the performance.	The time for the user application to load must be less than 5 seconds.	**PASS.** The time taken for the application to load was timed and the outcome was an average of 4.4 seconds.
ATP-3	Code will be reviewed to ensure it allows for future developers to add code easily for new functions and alter the current function.	Code is neatly presented and well commented.	**PASS.** The code is well presented and has consistent commenting throughout but could be neater and more concisely coded.
ATP-4	The system will be reviewed with regards to the environment to ensure that the impact of engineering is minimised and the habitats of the birds is preserved.	The subsystem does not impact the environment negatively at all.	**PASS.** The system does not make any changes to the habitat and environment around the system.
ATP-5	Two new users will try and access the server, one of which is an authorized user and the other is unauthorized.	Only the user that had authorized access is able to connect to the system.	**PASS.** The test was completed using three use cases and access was only granted to authorized users.
ATP-6	The user will be positioned at a distance greater than 20 metres from the system.	The user is able to connect to the server and access the data.	**PASS.** The system can comfortably achieve a distance of 20 metres from the system. The max distance was not determined.
ATP-7	The system will be accessed over a period of an hour at even intervals of 10 minutes to ensure that access is available at any time.	The system grants access at each of the 6 attempts.	**PASS.** The system was able to be accessed by an authorized user over a period of one hour. Six attempts to gather the data were made, and each attempt was successful.
ATP-8	The User Application will be tested by following the logical path of user and ensure that the bird weight data is visible and accessible.	The bird weight data is accessible and visible.	**PASS.** The bird weight data was easily accessible and visualised by a graph.
ATP-9	The User Application will be tested by following the logical path of the user and ensure that the user is able to view an alternative version of the data.	The bird weight data is visible in an alternative form.	**FAIL.** An attempt to stack the user graphs of the different groups of data was not successful.
ATP-10	The User Application will be tested by following the logical path of the user and ensure that the user is able to view information on the battery percentage.	The battery percentage is clearly visible to the user.	**PASS.** The battery data is visible to the user on the Landing Page.

Table 6.6: User Application Acceptance Test Procedure Results

6.7 Conclusion

The User Application subsystem dealt with the design and development of the user interface as well as the web based HTML, CSS and JavaScript code that make up the web application, its styling and appearance as well as the handling of any user interactions. The performance of this subsystem was a success. The entire design process focused heavily on user centric design principles ensuring the the design of the user interface as well as the functionality of the application itself follow a logical flow that mimics the real world and human interactions. This provides a simple and easy-to-understand user experience that gives the user consistency within the system that ensures they feel comfortable using the application. Beyond this the subsystem ensured that the natural environment surrounding by utilising a wireless communication method, namely Wi-Fi, that allowed for a large enough range while offering user authentication through the unique Wi-Fi password that is required before access is granted. This ensures the system maintains authorized access only. The web application was compiled using HTML, CSS and JavaScript which ensured the footprint was small and didn't take any additional storage from the main system that remained efficient and had good performance from the user end. The most vital part of the subsystem was ensuring the availability of the weighing sensor data, which was achieved by using ApexCharts in order to display a visually appealing graph that allows for the graphed data to be downloaded. As a whole this subsystem was well graded when put through user testing.

Chapter 7

Conclusions

The purpose of this project is to develop an automated, reliable method for gathering and tracking accurate weight data, correctly identified to specific Southern Ground Hornbills in the Greater Kruger region. This data is essential for understanding the impacts of the environment on the Southern Ground Hornbill population, aiding in monitoring their health, assessing their adaptation to changing climates, and informing conservation efforts for this endangered species. The proposed system integrates several subsystems designed to meet the demands of accuracy, durability, and environmental integration. It entails an automated rooftop weighing scale that records weight and identification via RFID, designed to fit roof dimensions and incorporate a reliable power supply. Additionally, it features a central microcontroller for storing and wirelessly sharing data, along with a user interface application for convenient access to the shared data.

The scale subsystem has undergone iterative design and execution, incorporating signal conditioning, housing design, and structural considerations to ensure reliability in real-world conditions. While showing promise in reliability and functionality, there is room for improvement through the use of higher accuracy load cells and expanded testing apparatus.

The power subsystem was crafted with reliability in mind, accounting for harsh environmental conditions and prioritizing ease of repair, robustness and affordability. Though minor accuracy concerns were noted due to component tolerances, the subsystem strikes a balance between functionality, practicality, and environmental impact.

In the Processing and Control subsystem, the central processing unit effectively manages weight and RFID data collection and transmission, employing specific data processing techniques to handle various data conditions. While certain aspects like RFID range may require future refinement, the overall design lays a foundation for further optimization.

The User Application subsystem ensures a seamless user experience through intuitive interface design and efficient web-based application development. By focusing on user-centric principles and environmental considerations, the subsystem provides authorized access and presents data in a visually appealing manner while maintaining system efficiency.

Collectively, these subsystems form a comprehensive solution poised to address the challenges of measuring Ground Hornbill weight in the Greater Kruger region, with potential for ongoing enhancements and optimization.

Bibliography

[1] T. Manoils and A. Manolis, "A simple technique for weighing birds at feeders without recapture," *North American Bird Bander*, vol. 6, no. 3, p. 4, 2024.

[2] A. Poole, "A scale for weighing birds at habitual perches," *Journal of Field Ornithology*, vol. 53, no. 4, pp. 409–414, 1982.

[3] A. K. Mortensen, P. Lisouski, and P. Ahrendt, "Weight prediction of broiler chickens using 3d computer vision," *Computers and Electronics in Agriculture*, vol. 123, pp. 319–326, 2016.

[4] E. S. Bridge and D. N. Bonter, "A low-cost radio frequency identification device for ornithological research," *Journal of Field Ornithology*, vol. 82, pp. 52–59, 2011.

[5] Arduino, "ATmega328P Arduino Compatible Nano V3 Improved Version — pishop.co.za," https://www.pishop.co.za/store/arduino-boards/geekcreit-atmega328p-arduino-compatible-nano-v3-improved-version, 2024, [Accessed 12-05-2024].

[6] MicroRobotics, "ESP32 S3 Dev Board - 16MB Flash, 8MB PSRAM — robotics.org.za," https://www.robotics.org.za/ESP32-S3-N16R8?search=esp32, 2024, [Accessed 12-05-2024].

[7] PiShop, "Raspberry Pi Pico WH with pre-soldered headers — pishop.co.za," https://www.pishop.co.za/store/raspberry-pi-boards/raspberry-pi-pico-wh-with-pre-soldered-headers, 2024, [Accessed 12-05-2024].

[8] B. Fennani, H. Hamam, and A. O. Dahmane, "Rfid overview," in *ICM 2011 Proceeding*, 2011, pp. 1–5.

[9] E. Ferro and F. Potorti, "Bluetooth and wi-fi wireless protocols: a survey and a comparison," *IEEE Wireless Communications*, vol. 12, no. 1, pp. 12–26, 2005.

[10] R. M. Sibly and R. H. McCleery, "A balance for weighing ground-nesting birds," *Journal of Applied Ecology*, vol. 17, no. 2, pp. 323–327, 1980. [Online]. Available: http://www.jstor.org/stable/2402328

[11] D. W. Fitzgerald, F. E. Murphy, W. M. Wright, P. M. Whelan, and E. M. Popovici, "Design and development of a smart weighing scale for beehive monitoring," in *2015 26th Irish signals and systems conference (ISSC)*. IEEE, 2015, pp. 1–6.

[12] C. G. Guglielmo, L. P. McGuire, A. R. Gerson, and C. L. Seewagen, "Simple, rapid, and non-invasive measurement of fat, lean, and total water masses of live birds using quantitative magnetic resonance," *Journal of Ornithology*, vol. 152, pp. 75–85, 2011.

[13] M. Turner, P. Gurney, J. Crowther, and J. Sharp, "An automatic weighing system for poultry," *Journal of Agricultural Engineering Research*, vol. 29, no. 1, pp. 17–24, 1984.

[14] S. Haftorn, "Seasonal and diurnal body weight variations in titmice, based on analyses of individual birds," *The Wilson Bulletin*, pp. 217–235, 1989.

[15] E. Muthoriq, A. Hariyanto, Z. Abidin, and M. Bur, "The effect of object position on reading error on weighing scale," in *2018 International Conference on Applied Engineering (ICAE)*. IEEE, 2018, pp. 1–5.

[16] B. E. Reichert, C. E. Cattau, R. J. F. Jr., W. L. Kendall, and W. M. Kitchens, "Extreme weather and experience influence reproduction in an endangered bird," *Ecology*, vol. 93, pp. 2580–2589, 12 2012. [Online]. Available: https://doi.org/10.1890/12-0233.1

[17] G. Q. A. Anderson and R. E. Green, "The value of ringing for bird conservation," *Ringing & Migration*, vol. 24, pp. 205–212, 1 2009, doi: 10.1080/03078698.2009.9674393. [Online]. Available: https://doi.org/10.1080/03078698.2009.9674393

[18] S. R. Baillie, R. A. Robinson, J. A. Clark, and C. P. F. Redfern, "From individuals to flyways: The future of marking birds for conservation," *Ringing & Migration*, vol. 24, pp. 155–161, 1 2009, doi: 10.1080/03078698.2009.9674386. [Online]. Available: https://doi.org/10.1080/03078698.2009.9674386

[19] I. Newton, "The recent declines of farmland bird populations in britain: an appraisal of causal factors and conservation actions," *Ibis*, vol. 146, pp. 579–600, 10 2004. [Online]. Available: https://doi.org/10.1111/j.1474-919X.2004.00375.x

[20] H. WEIMERSKIRCH, J. C. STAHL, and P. JOUVENTIN, "The breeding biology and population dynamics of king penguins aptenodytes patagonica on the crozet islands," *Ibis*, vol. 134, pp. 107–117, 4 1992. [Online]. Available: https://doi.org/10.1111/j.1474-919X.1992.tb08387.x

[21] H. J. Wilson, D. W. Norriss, A. Walsh, A. D. Fox, and D. A. Stroud, "Winter site fidelity in greenland white-fronted geese anser albifrons flavirostris, implications for conservation and management," *Ardea*, vol. 79, pp. 287–294, 1991.

[22] M. Gauthier-Clerc and Y. L. Maho, "Beyond bird marking with rings," *Ardea*, vol. 89, pp. 221–230, 2001.

[23] Y. L. Maho, H. Karmann, D. Briot, Y. Handrich, J.-P. Robin, E. Mioskowski, Y. Cherel, and J. Farni, "Stress in birds due to routine handling and a technique to avoid it," *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, vol. 263, pp. R775–R781, 1992.

[24] J. C. Wingfield, J. P. Smith, and D. S. Farner, "Endocrine responses of white-crowned sparrows to environmental stress," *The Condor*, vol. 84, pp. 399–409, 1982.

[25] D. N. Bonter and E. S. Bridge, "Applications of radio frequency identification (rfid) in ornithological research: a review," *Journal of Field Ornithology*, vol. 82, pp. 1–10, 2011.

[26] P. H. Becker and H. Wendeln, "A new application for transponders in population ecology of the common tern," *The Condor*, vol. 99, pp. 534–538, 1997.

[27] T. Dittmann and P. H. Becker, "Sex, age, experience and condition as factors affecting arrival date in prospecting common terns, sterna hirundo," *Animal Behaviour*, vol. 65, pp. 981–986, 2003.

[28] M. J. Boisvert and D. F. Sherry, "A system for the automated recording of feeding behavior and body weight," *Physiology & Behavior*, vol. 71, pp. 147–151, 2000. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0031938400003176

[29] K. KERRY, J. CLARKE, and G. ELSE, "The use of an automated weighing and recording system for the study of the biology of adelie penguins (pygoscelis adeliae)(14th symposium on polar biology)," vol. 6. National Institute of Polar Research, 1993, pp. 62–75.

[30] K. B. Newbery and C. Southwell, "An automated camera system for remote monitoring in polar environments," *Cold Regions Science and Technology*, vol. 55, pp. 47–51, 06 2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0165232X08000864

[31] *Powering wireless sensor nodes: Primary batteries versus energy harvesting*, 2009 IEEE Instrumentation and Measurement Technology Conference. IEEE, 07 2009.

[32] H. Zhang, X. Wu, Y. Pan, A. Azam, and Z. Zhang, "A novel vibration energy harvester based on eccentric semicircular rotor for self-powered applications in wildlife monitoring," *Energy Conversion and Management*, vol. 247, p. 114674, 11 2021. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0196890421008505

[33] B. Wang, Z. Long, Y. Hong, Q. Pan, W. Lin, and Z. Yang, "Woodpecker-mimic two-layer band energy harvester with a piezoelectric array for powering wrist-worn wearables," *Nano Energy*, vol. 89, p. 106385, 11 2021.

[34] F. Wu, C. Rüdiger, and M. Yuce, "Real-time performance of a self-powered environmental iot sensor network system," *Sensors*, vol. 17, p. 282, 02 2017.

[35] *A water quality monitoring system based on wireless sensor network & solar power supply*. IEEE. [Online]. Available: https://ieeexplore.ieee.org/document/6011777

[36] M. M. M. Nadzri, "Design issues and considerations for hardware implementation of wildlife surveillance system: A review," *Journal of Tomography System and Sensor Application*, vol. 4, p. 82–94, 11 2021. [Online]. Available: http://www.tssa.my/index.php/jtssa/article/view/173/76

[37] *A study on battery life tradeoff between deep sleep and sleep modes of an actual PDA*. [Online]. Available: https://ieeexplore.ieee.org/document/4582875

[38] I. Ashraf, F. Boccardi, and L. Ho, "Sleep mode techniques for small cell deployments," *IEEE Communications Magazine*, vol. 49, pp. 72–79, 08 2011.

[39] D. Schmitt-Landsiedel, M. Eireiner, J. Berthold, G. Georgakos, S. Henzler, D. Schmitt-Landsiedel, M. Eireiner, J. Berthold, G. Georgakos, and S. Henzler, "Activation technique for sleep-transistor circuits for reduced power supply noise," in *2006 Proceedings of the 32nd European Solid-State Circuits Conference*, 2006, pp. 102–105.

[40] C. C. Wilmers, B. Nickel, C. M. Bryce, J. A. Smith, R. E. Wheat, and V. Yovovich, "The golden age of bio-logging: how animal-borne sensors are advancing the frontiers of ecology," *Ecology*, vol. 96, no. 7, pp. 1741–1753, 2015. [Online]. Available: https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/14-1401.1

[41] T. A. Wild, M. Wikelski, S. Tyndel, G. Alarcón-Nieto, B. C. Klump, L. M. Aplin, M. Meboldt, and H. J. Williams, "Internet on animals: Wi-fi-enabled devices provide a solution for big data transmission in biologging," *Methods in Ecology and Evolution*, vol. 14, no. 1, pp. 87–102, 2023. [Online]. Available: https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.13798

[42] R. Del-Rio-Ruiz, J.-M. Lopez-Garde, J. Ruiz-de Garibay, and J. L. Macon, "Smart nests: Iot for ornithology," in *2018 Global Internet of Things Summit (GIoTS)*, 2018, pp. 1–6.

[43] K. N. Park, "Kruger park cell phone coverage map," Available at https://www.krugerpark.co.za/Maps_of_Kruger_Park-travel/cellphone-map-knp.html#:~:text=Mobile%20phone%20coverage%20in%20Kruger,some%20sizable%20gaps%20in%20between. (2024/03/16).

[44] J. P. Dominguez-Morales, L. Duran-Lopez, D. Gutierrez-Galan, A. Rios-Navarro, A. Linares-Barranco, and A. Jimenez-Fernandez, "Wildlife monitoring on the edge: A performance evaluation of embedded neural networks on microcontrollers for animal behavior classification," *Sensors*, vol. 21, no. 9, 2021. [Online]. Available: https://www.mdpi.com/1424-8220/21/9/2975

[45] D. F. Larios, C. Rodríguez, J. Barbancho, M. Baena, M. A. Leal, J. Marín, C. León, and J. Bustamante, "An automatic weighting system for wild animals based in an artificial neural network: How to weigh wild animals without causing stress," *Sensors*, vol. 13, no. 3, pp. 2862–2883, 2013. [Online]. Available: https://www.mdpi.com/1424-8220/13/3/2862

[46] F. Urbano, F. Cagnacci, C. Calenge, H. Dettki, A. Cameron, and M. Neteler, "Wildlife tracking data management: a new vision," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 365, no. 1550, pp. 2177–2185, 2010. [Online]. Available: https://royalsocietypublishing.org/doi/abs/10.1098/rstb.2010.0081

[47] Tycorun, "Comparing li-ion vs ni-mh battery which is better choice," Tycorun Batteries, 07 2022. [Online]. Available: https://www.tycorun.com/blogs/news/comparing-li-ion-vs-ni-mh-battery-which-is-better-choice#What_does_nimh_mean_on_a_battery

[48] "Global solar atlas," globalsolaratlas.info. [Online]. Available: https://globalsolaratlas.info/map?r=ZAF&c=-24.232564

[49] C. S. Africa, "Hkd solar cell 12v 150ma 1.8w," Communica South Africa. [Online]. Available: https://www.communica.co.za/products/hkd-solar-cell-12v-150ma-1-8w?variant=31932594356297&sfdr_ptcid=31591_617_668161165&sfdr_hash=3b433c98c08c134178670f050670da1d&gad_source=1

[50] "Beston 9v li-ion 800mah battery - outdoorphoto - south africa," Outdoorphoto. [Online]. Available: https://www.outdoorphoto.co.za/beston-9v-li-ion-800mah-battery#:~:text=Description-

[51] "Buck converters (step-down converter)," www.monolithicpower.com. [Online]. Available: https://www.monolithicpower.com/en/power-electronics/dc-dc-converters/buck-converters

[52] "Application note switching regulator ic series efficiency of buck converter." [Online]. Available: https://fscdn.rohm.com/en/products/databook/applinote/ic/power/switching_regulator/buck_converter_efficiency_app-e.pdf

[53] J. Teel, "Linear and switching voltage regulators – an introduction," PREDICTABLE DESIGNS, 11 2016. [Online]. Available: https://predictabledesigns.com/linear-and-switching-voltage-regulators-introduction/

[54] "N4728a to 1n4761a zener diodes." [Online]. Available: https://www.vishay.com/docs/85816/1n4728a.pdf

[55] Vishay, "Vishay general semiconductor general purpose plastic rectifier," 04 2020. [Online]. Available: https://www.vishay.com/docs/88503/1n4001.pdf

[56] "Popular mosfets frequently used in power electronics designs," Components101. [Online]. Available: https://components101.com/articles/popular-mosfets-frequently-used-in-power-electronics-designs

[57] EEE4113F 2024 - Stakeholder Engagement. All Carrie Hickman Posts. Microsoft Corporation. 12/05/2024. [Online]. Available: https://teams.microsoft.com/l/channel/19%3A16092253e43b43d0ae12e2f4b0cbdb59%40thread.tacv2/Stakeholder%20Engagement?groupId=d4192a4a-a750-48ea-bd8e-ee5cbd5776cb&tenantId=92454335-564e-4ccf-b0b0-24445b8c03f7&ngc=true

[58] B. Necula, "GitHub - bogde/HX711: An Arduino library to interface the Avia Semiconductor HX711 24-Bit Analog-to-Digital Converter (ADC) for Weight Scales. — github.com," https://github.com/bogde/HX711, 2014, [Accessed 12-05-2024].

[59] me-no dev, "GitHub - me-no-dev/AsyncTCP: Async TCP Library for ESP32 — github.com," https://github.com/me-no-dev/AsyncTCP, 2017, [Accessed 12-05-2024].

[60] ——, "GitHub - me-no-dev/ESPAsyncWebServer: Async Web Server for ESP8266 and ESP32 — github.com," https://github.com/me-no-dev/ESPAsyncWebServer, 2017, [Accessed 12-05-2024].

Appendix A

Individual Appendices

A.1 Scale Design

A.1.1 CAD Rendering

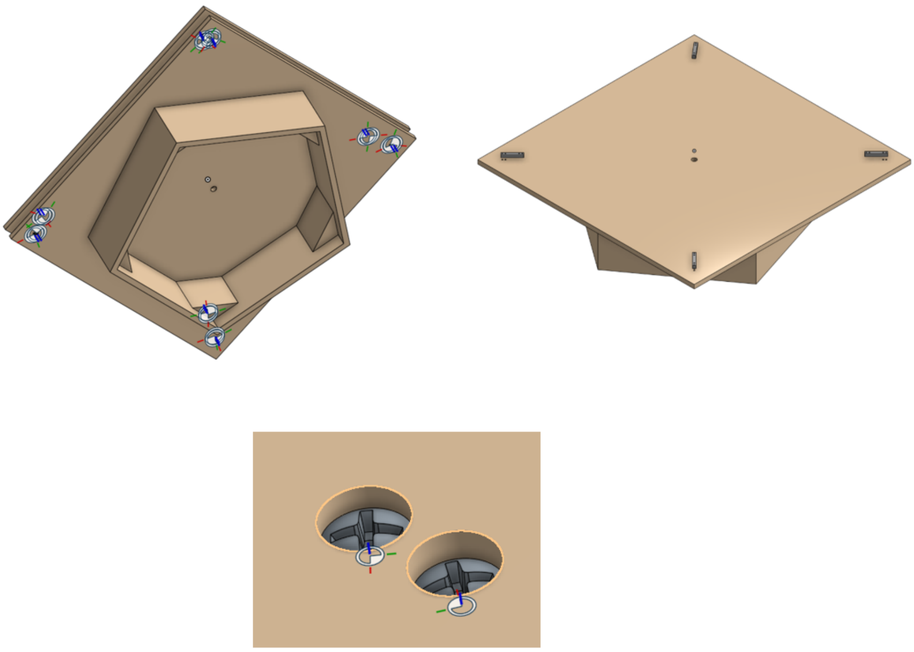


Figure A.1: Full CAD Rendering of design

A.1.2 Drawings

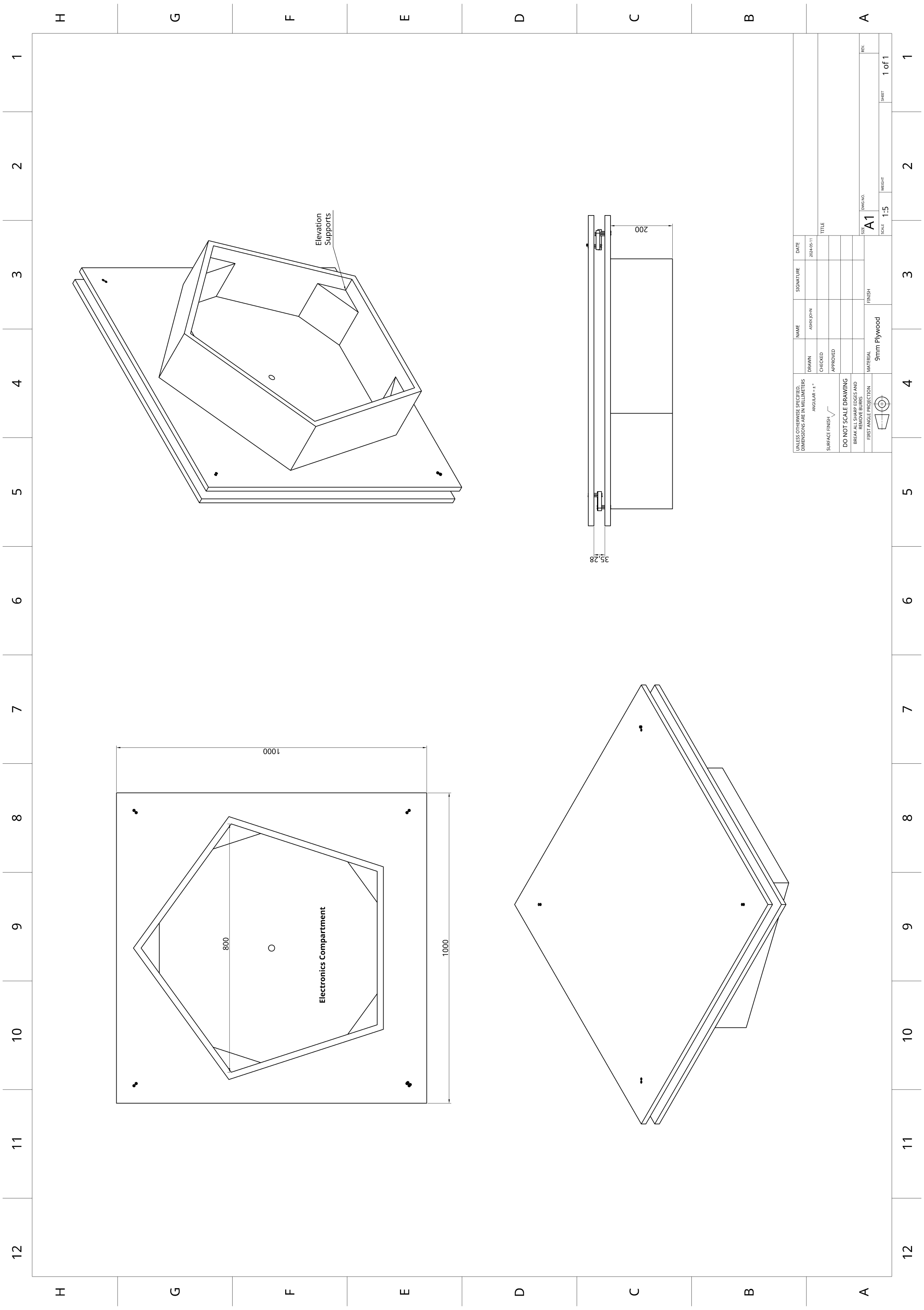


Figure A.2: Drawings with important dimensions

A.1.3 Amplifier

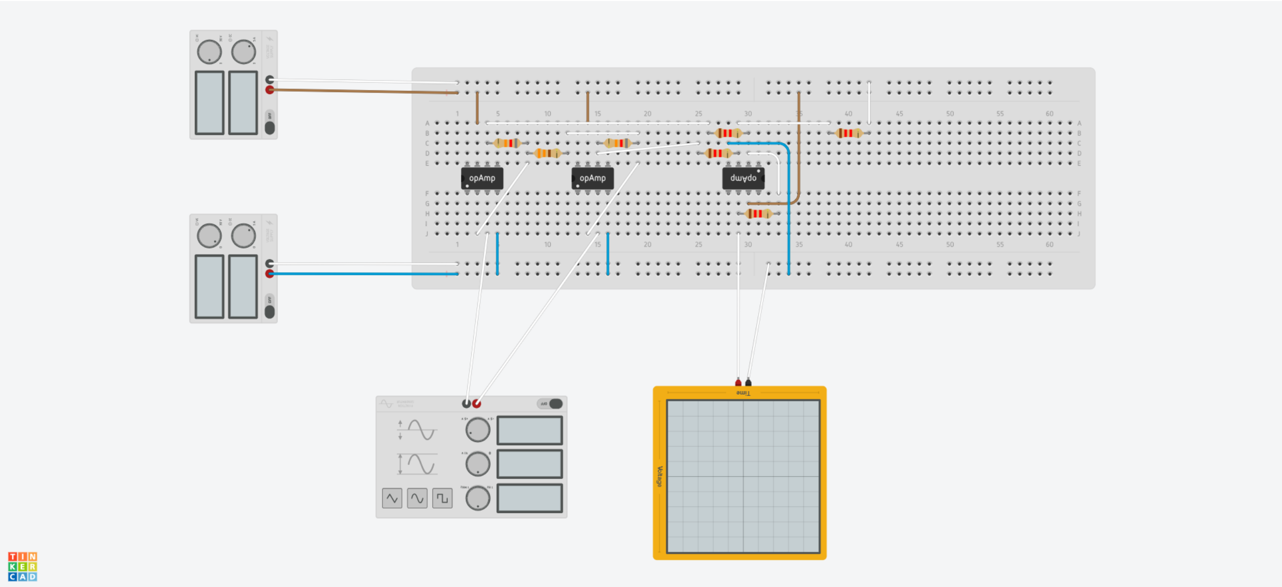


Figure A.3: Testing connection diagram for Instrumentation Amplifier

A.1.4 Prototype

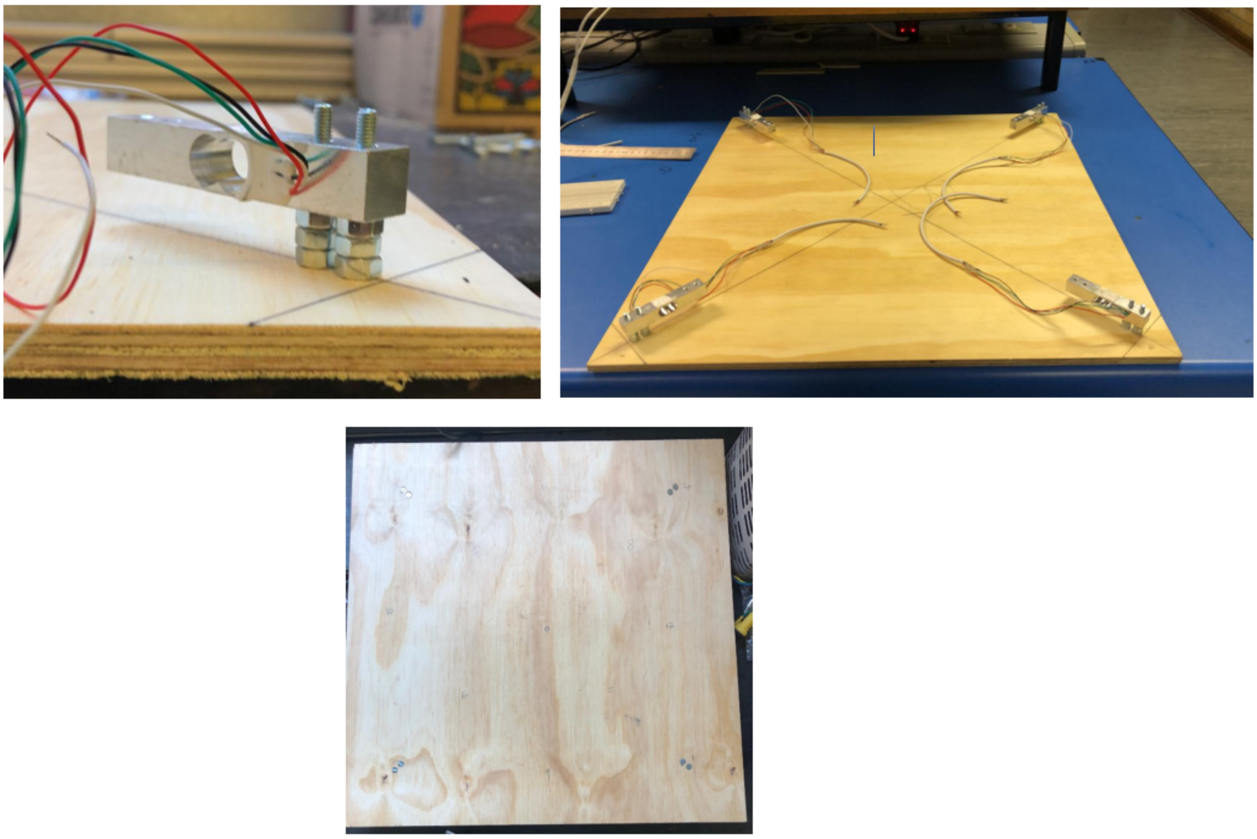


Figure A.4: Prototype building

A.2 Power

A.3 Process and Control

A.3.1 RFID Code

```
void clearSerialBuffer() {
  while (Serial1.available() > 0) {
    char _ = Serial1.read(); // Read and discard each character
  }
}
```

```
bool isAlphanumeric(String str) {
  // Iterate through each character of the string
  for (char c: str) {
    // Check if the character is not a digit or a letter
    if (!isalnum(c) || c == '\0') {
      return false; // Return false if it's not alphanumeric
    }
  }
  return true; // Return true if all characters are alphanumeric
}
```

```
bool readRFID()
{
  clearSerialBuffer();
  delay(300);
  while (Serial1.available() > 0)
  {
    c = Serial1.read();
    ID += c;
    if (ID.length() > 15)
    {
      switch (check())
      {
        case 0:
          Serial.println("Bird Detected - ID: " + ID);
          clearSerialBuffer();
          return true;
        case 1:
          Serial.println("Not a Bird - ID: " + ID);
          clearSerialBuffer();
```

```
        return false;
      }
      clearSerialBuffer();
      return false;
    }
  }
}
```

```
uint8_t check()
{
  ID = ID.substring(1, 13);
  if(isAlphanumeric(ID))
  {
    for(String s: Birds)
    {
      if(ID == s)
      {
        return 0;
      }
    }
    return 1;
  }
  return 2;
}
```

A.3.2 Raw readings

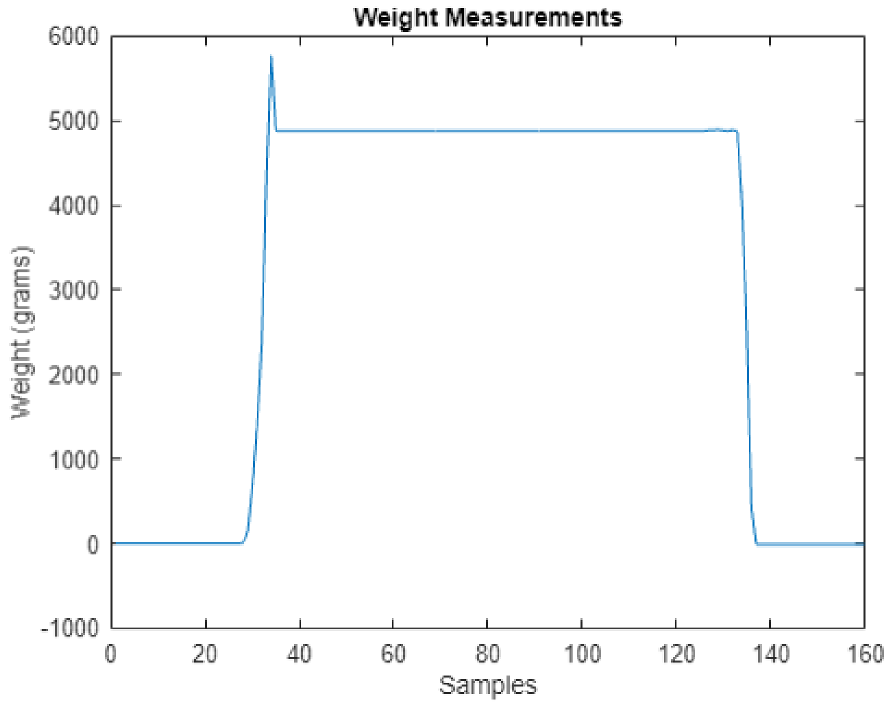


Figure A.5: Raw Clean Data

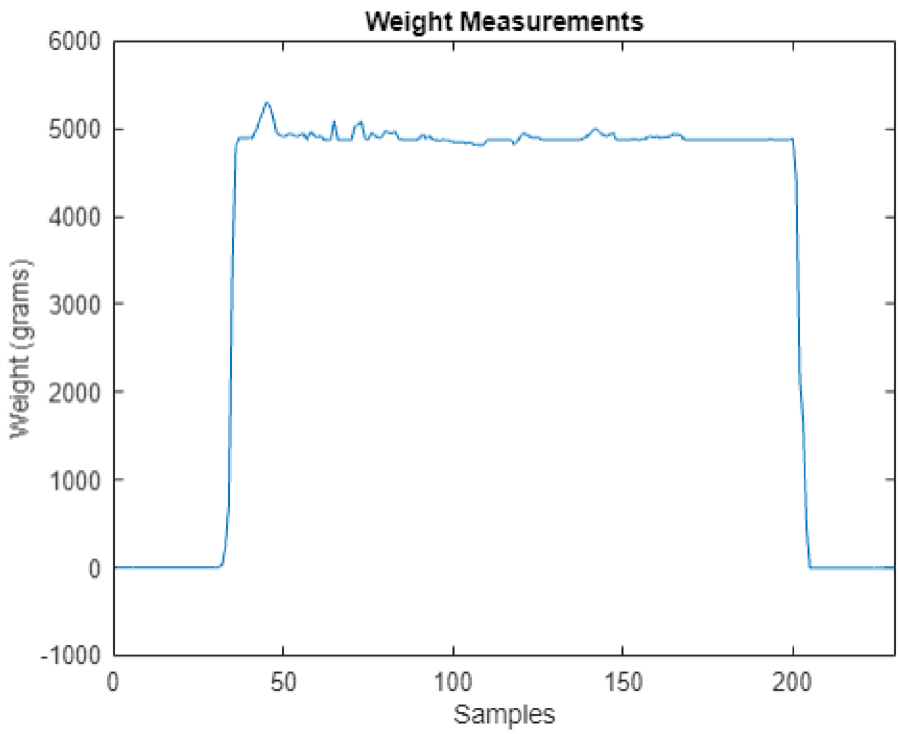


Figure A.6: Raw Noisy Data

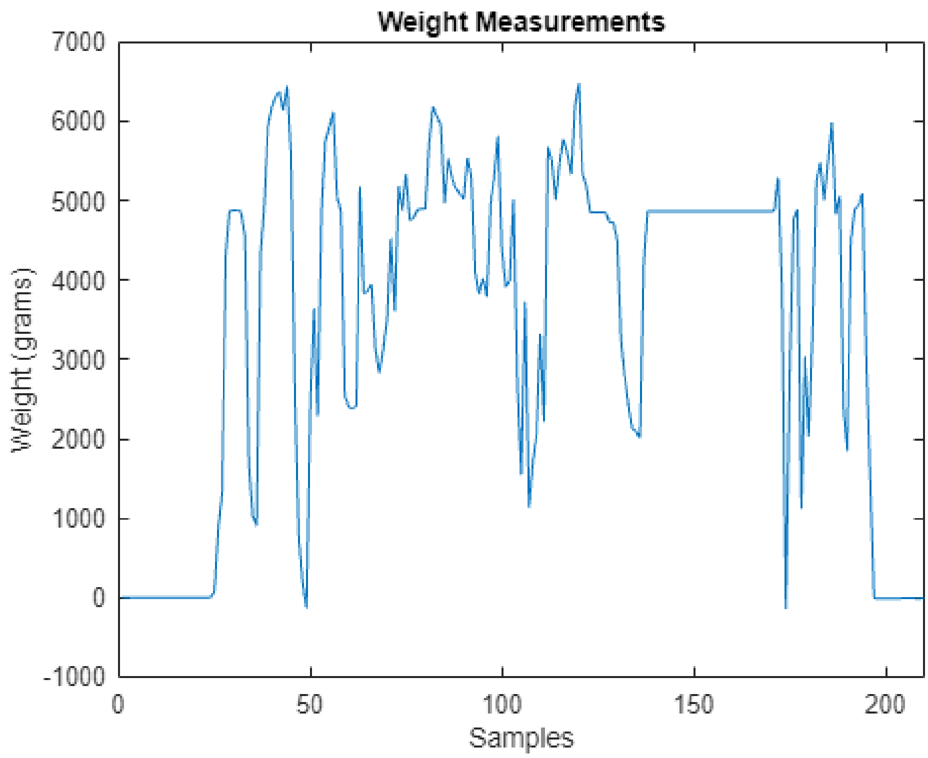


Figure A.7: Raw Bad data

A.3.3 Console output for 1 cycle of control

```
00:50:56.492 -> ESP-ROM:esp32s3-20210327
00:50:56.543 -> Build:Mar 27 2021
00:50:56.543 -> rst:0x5 (DSLEEP),boot:0x2b (SPI_FAST_FLASH_BOOT)
00:50:56.543 -> SPIWP:0xee
00:50:56.543 -> mode:DIO, clock div:1
00:50:56.543 -> load:0x3fce3808,len:0x44c
00:50:56.543 -> load:0x403c9700,len:0xbe4
00:50:56.543 -> load:0x403cc700,len:0x2a68
00:50:56.543 -> entry 0x403c98d4
00:50:56.577 -> true
00:51:07.142 -> false
00:51:17.614 -> false
00:51:18.078 -> Weight detected...
00:51:18.389 -> Not a Bird - ID: 4D0043E50AE1
00:51:28.795 -> true
00:51:39.294 -> true
00:51:49.788 -> true
00:52:00.352 -> false
00:52:00.769 -> Weight detected...
```

```
00:52:01.093 -> Bird Detected - ID: 33000E15674F
00:52:02.855 -> Data added
00:52:12.987 -> true
00:52:23.474 -> true
00:52:34.011 -> true
00:52:44.498 -> true
00:52:55.024 -> false
00:53:05.539 -> false
00:53:16.058 -> false
00:53:16.506 -> Weight detected...
00:53:16.834 -> Bird Detected - ID: 33000E15674F
00:53:18.607 -> Data added
00:53:28.709 -> true
00:53:39.222 -> false
00:53:47.686 -> false
00:53:47.686 -> Remote triggered...
00:53:47.686 -> Starting Access Point
00:53:49.842 -> Access Point Started
00:53:54.841 -> Waiting for connection...
00:53:55.863 -> Waiting for connection...
00:53:56.824 -> Waiting for connection...
00:53:57.868 -> Waiting for connection...
00:53:58.866 -> Waiting for connection...
00:53:59.863 -> Waiting for connection...
00:54:00.824 -> Waiting for connection...
00:54:01.840 -> Waiting for connection...
00:54:02.850 -> Waiting for connection...
00:54:03.860 -> Waiting for connection...
00:54:04.840 -> Waiting for connection...
00:54:05.851 -> Waiting for connection...
00:54:06.860 -> Waiting for connection...
00:54:07.858 -> Waiting for connection...
00:54:08.877 -> Waiting for connection...
00:54:09.824 -> Waiting for connection...
00:54:10.824 -> Waiting for connection...
00:54:11.859 -> Waiting for connection...
00:54:12.855 -> Waiting for connection...
00:54:13.864 -> Waiting for connection...
00:54:14.844 -> Waiting for connection...
00:54:15.870 -> Waiting for connection...
00:54:16.864 -> Waiting for connection...
00:54:17.824 -> Waiting for connection...
00:54:18.853 -> Waiting for connection...
```

```
00:54:19.852 -> Waiting for connection...
00:54:20.841 -> Connection Timeout: Shutting down WiFi
00:54:35.239 -> false
00:54:35.239 -> Remote triggered...
00:54:35.239 -> Starting Access Point
00:54:37.414 -> Access Point Started
00:54:42.406 -> Waiting for connection...
00:54:43.397 -> Waiting for connection...
00:54:44.397 -> Waiting for connection...
00:54:45.419 -> Waiting for connection...
00:54:46.401 -> Waiting for connection...
00:54:47.427 -> Waiting for connection...
00:54:48.424 -> Waiting for connection...
00:54:49.404 -> Waiting for connection...
00:54:50.679 -> Waiting for connection...
00:55:38.423 -> Shutting down WiFi
00:55:48.561 -> false
```

A.3.4 Photos of Hardware

Figure A.8: RF Remote

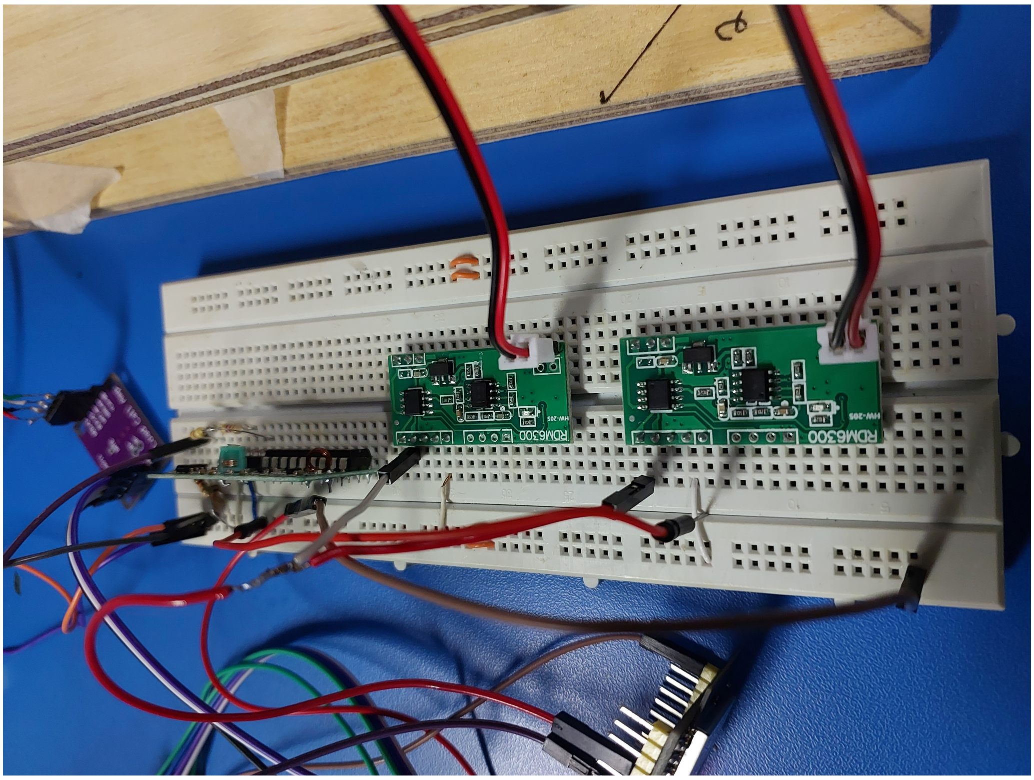


Figure A.9: RFID modules

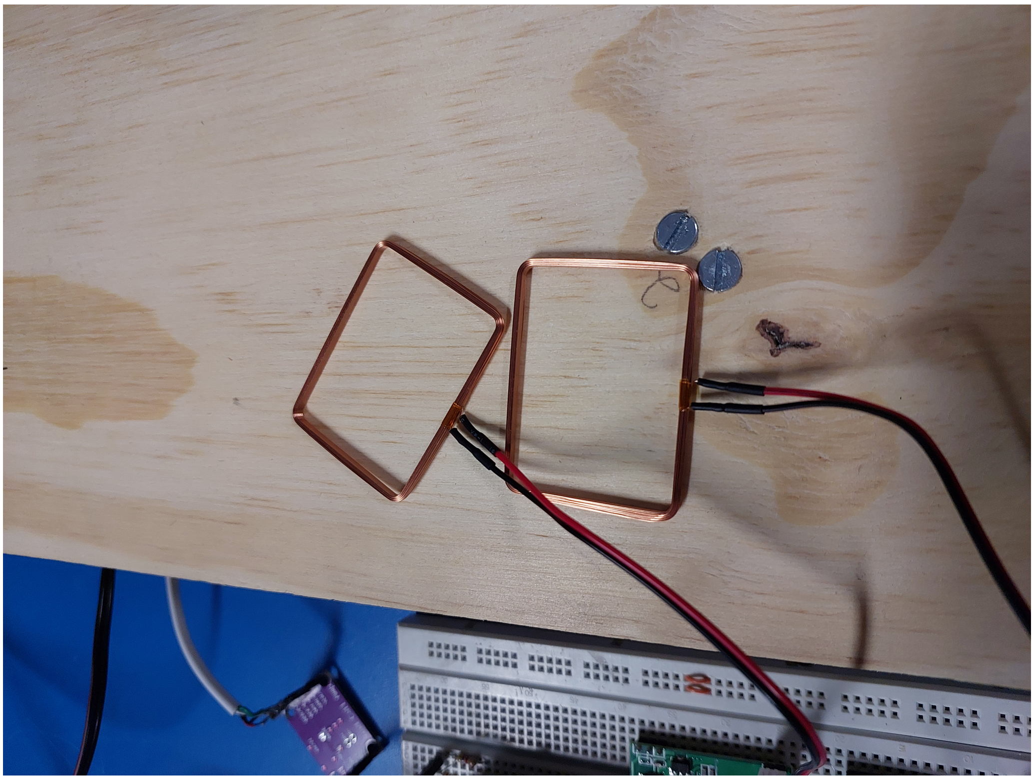


Figure A.10: Antennas

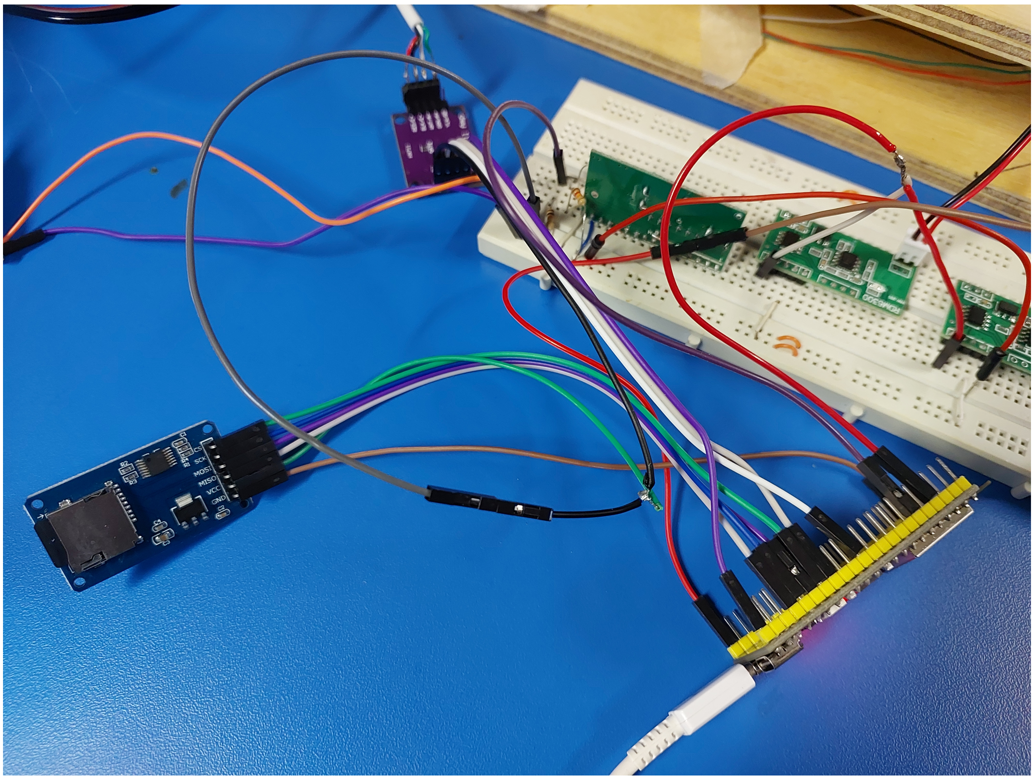


Figure A.11: ESP32, micro SD and HX711

A.4 User Interface

A.4.1 Sample output data

```
4879.44,33000E15674F,89.55
4878.97,33000D51AAC5,89.32
```

Appendix B

BOM and GAs

B.1 Bill of Materials

Item	Quantity	Unit Price (R)	Total (R)
5kg Load Cell	4	45	180
HX711	1	51.75	51.75
9mm Plywood	2 sqm	184.76	369.52
ESP32 S3 Devkit C	1	204,70	204,70
RDM6300 RFID Module	16	84,00	1344.00
433MHz RFID	1	99,95	99,95
Micro SD Card Module	1	56,01	56,01
16GB micro SD Card	1	184.76	369.52
A27 Battery	1	21,79	21,79
Animal Pit Tags	10	385.20	385.20
100x150mm VeroBoard	5	39.10	39.10
Heat Sinks	1	13.80	13.80
9V Battery Holder	2	19,00	38,00
LM317	1	19.95	19.95
100nF Inductor	3	20.00	60.00
Total			3409.69

Table B.1: Bill of Materials for final design

B.2 GAs

User Application, SHWOLI002	Sections GAs met in
GA3	Section 6.3 and Section 6.4. Pages 49 - 56.
GA7	D-School sessions and in deciding the transmission method that would not affect the environment.
GA8	Teams meetings were held regularly and minutes were kept from these meetings. Engagement throughout project duration on Teams channel.
GA10	All submission activities met on time. All communications between our stakeholder and group were professionally written.

Table B.2: GA Tracking for User Application Subsystem, SHWOLI002

Scale Design, JHNASH009	Sections GAs met in
GA3	Section 3.2 and 3.3, Pages 14 - 22
GA7	D-School sessions and use of cost-optimised design with natural materials. Design aims to avoid hazards(3.2.2) and improve wildlife conservation
GA8	Weekly group meetings, with minutes. Regular engagement in the Teams channel, touching on subsystem integration.
GA10	All submission activities met on time. Professional communication between group members and relevant stakeholders.

Table B.3: GA Tracking for Scale design subsystem, JHNASH009

Power Supply, MWNMSI001	Sections GAs met in
GA3	Section 4.1 and 4.3, Pages 27-35
GA7	Attending D School session to understand the environment in which the system will be placed to ensure, to identify the effect of electrical systems on the Southern Ground Hornbills. Using heat management to dissipate heat safely such that the power supply operation does not contribute to heat pollution. Using renewable solar power to charge battery eliminate requirement of non renewable energy.
GA8	Weekly design group meetings where mintues were recorded. Regular collaboration and update messages on subsystem integration on Teams channel.
GA10	All submission activities were submitted on time and regular professional communication with stakeholders was maintained.

Table B.4: GA Tracking for Power subsystem, MWNMSI001

Processing and Control, WXXSIT001	Sections GAs met in
GA3	Section 5.3 and 5.4, Pages 36-42
GA7	D-School sessions and ensuring identification methods adhere to the bird's well being and general ethical practices through stakeholder engagement [57]
GA8	Weekly group meetings, with minutes. Regular engagement in Teams channel, touching on subsystem integration.
GA10	All submission activities met on time and professional communication when engaging with stakeholders

Table B.5: GA Tracking for Processing Control design subsystem, WXXSIT001

B.3 GitHub Repository

GitHub Repository: GitHub Group 10