Group 24 Literature Review

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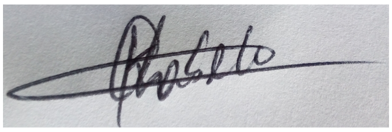

May 3, 2024

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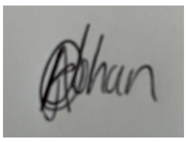

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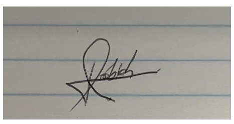

May 3, 2024

Revashan Soobiah

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Contents

Chapter 1

Introduction

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1.1 Background

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1.6 Introduction

The development of electronic devices that can effectively operate in the wild is an important consideration when dealing with the problem at hand which is that Ben Murphy who is a PHD Student that does research in the Kalahari needs a way to record weight data, with ID of Fork-Tailed Drongos to understand the species better. To achieve such a task, electronic devices will be deployed into the Kruger to gather data on the Fork-tailed Drongos. The systems that Ben uses need to operate accurately regardless of the environmental conditions. This literature review aims to examine existing technologies that have been used in the field of wildlife conservation, specifically focusing on their application in wildlife monitoring, with a particular emphasis on recording weight data and identifying Fork-tailed Drongos.

1.7 Sensor technologies for wildlife monitoring

The following section addresses existing wildlife monitoring sensor technologies that have been/ are currently being used in the field.

1.7.1 Camera Traps

The utilization of electronic devices in challenging environmental conditions, particularly in the domain of wildlife monitoring, is an area of growing importance as the need for efficient, and effective conservation techniques increases with the decline in environmental welfare, due to global warming. This is exemplified in a study conducted on Barro Colorado Island in Panama that employs motion-sensitive camera traps to monitor the movement and distribution of terrestrial bird and mammal populations [1]. The study underscores the significance of employing sensor technologies in addressing environmental challenges such as invasive species, infectious diseases, and climate change. Camera traps offer a 'non-invasive' and efficient means of recording animal activity by, 'capturing photographs with invisible infrared flashes' [1] to minimize disturbance to wildlife. The article highlights the advantages of camera traps, including their ease of deployment, robust data collection capabilities, and the potential to record not only species presence but also behavior. Moreover, the study emphasizes the importance of randomizing camera deployment locations and avoiding the use of baits to reduce bias and ensure accurate data collection. By integrating sensor networks with wildlife monitoring efforts, researchers can gain valuable insights into species diversity, abundance, and ecological interactions, ultimately contributing to informed conservation decisions and management strategies. This study [1] serves as a compelling example of the potential of electronic devices and sensor technologies to advance our understanding of wildlife dynamics in harsh environments.

1.7.2 Passive Intergrated Transponders (PIT)

A method for identifying an individual bird when gathering data on them (i.e to determine if the bird named Bonga, or Rev is on the scale at a particular point in time) was found to be via the use of passive integrated transponders (PIT) tags. The tags are 'either implanted or attached to a leg ring. Birds then can be identified automatically each time they approach an antenna at a feeder, a balance, or a nest box' [2]. They do not require a power source, they are small and very light [3]. This shows that PIT tags are an effective method of identification for relatively close proximity uses. The tags work off RFID technology that transmits a 10-character code when near a scanner [3]. This opens up the potential for 'automated recognition of birds' [2].

1.7.3 Other Tracking Methods

The utilization of sensor technologies for wildlife monitoring, particularly focusing on birds, has significantly advanced our understanding of avian behavior and migration patterns. Researchers have been able to attach lightweight tracking devices to birds, allowing for the study of their movement in unprecedented detail [2]. Biotelemetry techniques enable the tracking of individual birds during migration flights [2], providing insights into flight duration, route selection, and energy expenditure. Satellite tracking has further expanded the scope of monitoring, allowing for the tracking of birds over vast distances, revealing remarkable long-distance migrations such as the record-breaking flight of an Eastern Bar-tailed Godwit across the Pacific Ocean [2]. Geolocator loggers have also contributed to tracking migrating songbirds by recording data on dawn and dusk times to calculate geographical coordinates. These technologies, while facing limitations such as device size and retrieval challenges, continue to evolve, promising even greater insights into avian ecology and migration behavior[2].

1.7.4 Complete System Of Weight and Identification

Boisvert and Sherry [3] present a comprehensive system for the automated recording of feeding behavior and body weight in avian species, focusing particularly on black-capped chickadees. Utilizing passive integrated transponder (PIT) tags, the authors describe a method that uniquely identifies individual birds and continuously records their visits to a food source along with their body weight [3]. This system, comprising a PIT tag scanner, electronic balance, and perch with an infrared photobeam, and a food source enclosed in a waterproof housing, operates autonomously, providing detailed data on feeding behavior and body weight dynamics. Notably, the accuracy of body weight measurements is highlighted, with birds remaining on the perch while taking seeds, ensuring precise weight recordings. By overcoming the limitations of traditional repeated capture techniques, this innovative approach offers a non-invasive and continuous monitoring solution for studying avian feeding behavior and body weight regulation [3]. The system is shown in Figure 1

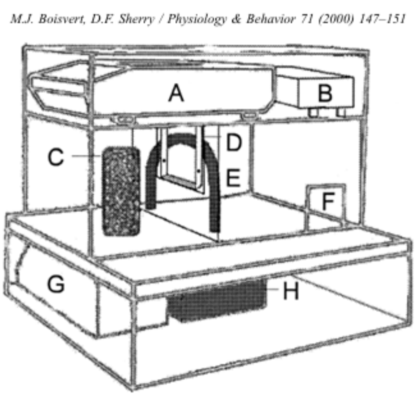


Figure 1.1: Boisvert and Sherry's Avian Monitoring System [3]
A-Balance, B-Interface, C-Food Source, D-Photobeam, E-Scanner Loop,F-Entrance G-Reader, H-Scanner

1.8 Traditional Techniques for Bird Detection and Recognition

The ability of birds to change spatial location at a rapid rate poses challenges that make it difficult to detect, image, and associate biometric data with a specific bird. Additionally, body size and plumage can affect a viewer's ability to recognize a bird from a distance, or in low-light conditions. The following section assimilates the traditional methods for detecting, imaging and acquiring avian biometric data. Furthermore, the following discusses adaptations of traditional methods in developing avian biometric collection, and identification, as well as locating wild birds as they fly around their natural habitat. Specifically, techniques that rely on the naked-eye and naked-ear, including the use of colour to mark birds, binoculars, as well as standard sound, and image-capturing devices, were considered to be traditional methods. Advancements in these methods that are discussed include radar imaging, which uses reflected radiowaves to construct an image of a large region, as well as thermal imaging, which uses infrared to produce surface temperature mappings of objects in the surroundings. Typically, systems offer singular modalities of bird detection and bird data collection that do not offer the advantages of other modalities. For example, devices that measure weight data typically do not offer imaging capabilities. This chapter reviews methods that combine modalities of detection, imaging, as well as bird recognition.

1.8.1 Using Dye to Mark, Detect and Identify Birds

Bird detection and recognition allow ornothological researchers to associate biometrics, such as weight data, with a specific bird. This is significantly difficult to achieve when the bird has a small body size and dark plumage. Patterson elaborates that the fact that colour plays a significant roll in the how birds interact with one another and the environment, it is not always suitable to use coloured dye markers to identify the birds [4]. Careful consideration has to be taken in selecting dye as the wrong chemical composition can deter birds from interacting with a marked bird [4]. Crucially, dyes for marking birds only last until the molt, i.e. when a bird typically loses plumage feathers. The chemical composition of the dye also has an effect on the health of the bird's plumage and possibly, the overall health of the bird. A suitable dye that was implemented by Ellis and Ellis [5], uses *picric* acid, which is a pale yellow substance typically found in low-cost human hair dyes [4]. In their experiment, molted Golden Eagle feathers were dotted with mixtures of commercial human hair dyes to produce dark and light colours [5]. The durability of the dye was measured by leaving the marked feathers unprotected from the weather and sunlight for two months[5]. The best durability was achieved for dark colors, which were prominent at the end of the two month weathering period [5].

After conducting a durability test, white Golden Eagle nestlings were spotted with a black aniline dye [5]. Remarkably, the dye was still noticeable and the bird was identifiable after of 21 months from fledging, showing that the dye was an effective method for bird recognition after 1 annual molt [5]. Therefore, one of the advantages of this traditional method used in detecting and recognizing birds using the naked-eye is that the dye can last for a sufficient amount of time to analyse changes in the weight of a bird. Another advantage, is that dye is easy to apply and remove, where Ellis and Ellis state that excess dyeing solution was removed using a sharp tool to scratch it off and water to rinse the feathers [5]. Finally, the dye-marking technique offered the advantage of causing minimal to no disturbance in the behaviour of the birds [5], which is critical for ensuring their survival.

1.8.2 Augmenting Capabilities of the Naked-eye for Bird Detection and Recognition

Although the dye technique offers low cost, durability, easy application, as well as being non-disruptive to bird behaviour, a critical shortcoming becomes apparent when the bird is not in range of visibility, i.e. when the bird is too far from the human to distinguish the markings on its feathers. Typically, ornothological researchers and wildlife conversationists work in sparse natural habitats. This increases the chances of having to retrieve information from a long distance from the target. A traditional method for augmenting the capabilities of the human naked-eye employs binoculars to bring birds that are out of the range of visibility into a closer and more discernible field of view. Glowinski [6] posits that the affordability of binoculars has made *birdwatching* (or *birding*) - which is defined as 'the active observation, identification, and/or photography of birds for recreational purposes' - more accessible to the general public [6]. However, due to the need for human cross-validation, binoculars are typically used by researchers for visual surveys. For instance, Duberstein et al. [7] performed a study of automated image processing for detection and classification of bird species that inhabit nearshore marine environments in which the primary data acquisition method was video capture [7]. Although the primary method was video capture, an observer was required to perform concurrent visualizing using image-stabilized binoculars. This is indicative of the importance of binoculars in the conservation of birds in that they remain a fundamental device in ensuring that the correct data is retrieved from a bird-sighting. However, traditional binoculars do not offer good visibility in low-light conditions and the ones that do are typically expensive and apply non-traditional techniques for augmenting human vision.

1.8.3 Traditional Methods for Detecting and Identifying Birds in Low-light Conditions

To overcome the challenge of detecting and identifying birds in low-light conditions, a different form of energy transfer may be required, other than the transfer of electromagnetic energy in the form of visible light that occurs when a bird is observed using dye and binoculars. Ornithologists, and indeed the lay observer, typically use the musical call of a bird, called a `song`, to detect the birds using the naked-ear or a sound capturing device. In this case, the mechanical energy is transferred as the sound from the bird propagates as longitudinal waves through the air, with frequencies that are unique to that species of bird. Since this uses the propagation of sound through air, the brightness of the surroundings as well as the colour of the plumage do not have an effect on the detection and identification of a bird.

Although sound detection offers a solution for detecting birds in low-light conditions, errors due to noise in the environment can lead to false detections of birds. Another significant shortcoming of using sound detection is that birds, such as the fork-tailed Drongo, mimic the calls of other bird species [8]. A study by Samira et al. (2014) on quantifying vocal mimicry in the greater racket-tailed drongo suggests that human cross-validation is still neccesary despite advancements in technology [9]. Furthermore, Samira et al. suggests that automated and human cross-validation techniques for vocal mimicry analysis have similar accuracy. This indicates that sound detection is not a suitable for implementation as the only technique for detecting and recognizing birds.

1.8.4 Application of Cameras in Traditional Bird Detection and Identification Techniques

A traditional method for overcoming many of the shortcomings of sound detection and relying on the naked-eye, involves employing cameras to detect and identify birds, as introduced in in section 1.7.1. This can be extended to annotated camera videography, as well as other uses of permanent cameras. For example, Vertraeten et al. (2010) suggest that webcams are low-cost and can be easily enhanced to withstand extreme weather conditions. The experiment investigated the performance limits of a webcam's detection and tracking capabilities in relation to a bird's velocity, contrast and size using a pendulum to model a flying object [10]. Stereo image recording was used, which requires the set up of two webcams that are positioned on a level plane and point in the same direction as shown in figure 1.2. Using this apparatus, the pendulum experiment by Vertraetren et al. resulted in larger objects, of about 1.6 cm, being more visible at higher speeds than objects that were smaller, about 0.6 cm in size [10]. The study also found that objects with a darker contrast (black) displayed longer visibility than objects with a lighter contrast (white)[10]. The study highlights the importance of selecting the

Figure 1.2: Showing a stereo image recording setup with two webcams mounted on a level plane and pointing in the same direction. [10]

correct algorithm for processing camera recordings. These algorithms are required to compensate for the issues that arise from high speed motion detection and the fact that webcams have low cost plastic lenses which can give an obscured representation of reality. Using motion detection by background subtraction, stereo vision and lens distortion, Vertraeten et al. (2010) demonstrated that webcams can sufficiently indicate a moving object's minimum size, velocity and required contrast - provided that a suitable modular processing scheme is selected. The following section investigates adaptations of traditional methods that use different frequencies of electromagnetic waves and rely on computational interpretations, only using human naked-eyes and ears to validate computational results.

1.9 Advanced Techniques for Avian Detection and Recognition

In recent years, radar and infrared sensing has seen a rise in popularity due to the ability to overcome the shortcomings of the traditional methods. For example, infrared detection works well in low-light conditions and is therefore useful in ornithological analyses of nocturnal birds. The following subsections investigate the implementation of advanced techniques that have been implemented in bird detection and imaging.

1.9.1 Radar and Thermal Detection and Imaging

Methods for detecting and identifying birds for biometrics extraction such as stereo imaging can lead to errors if multiple birds moving at the same velocity, altitude and also have the same size in the visibility field of the camera. Sidney et al. proposed a more accurate technique to overcome this potential difficulty where an upward pointing static radar beam, together with an upward pointing thermal imaging camera were used to accurately tally birds moving passed a stationary circular sampling region and to accurately measure the altitude of the bird [11]. This technique was applied in the study of migratory birds by analyzing video footage recorded between the year 2000 and 2003. In a more recent study by Horton et al. [12], a combination of weather surveillance radar, thermal infrared cameras and an acoustic recorder were implemented to quantify the patterns of nocturnal traffic estimates of birds and bats between 2011 and 2012. Horton et al. [12] suggests that deploying 'weather surveillance radar in ornithological research provides unique means of monitoring avian movements' because radar is suitable for flying animals located in a sparse environment [12]. Sidney et al. suggest that an application of these three modalities, i.e. radar and thermal imaging, as well as acoustic detection, is sufficient for providing satisfactory estimates of bird biometrics such as density, mass and size [13]. In their study, Horton et al. collected data during morning and evening twilight, and downloaded square kilometer resolution reflectivity data from the National Mosaic [12]. The downloaded data was used to determine the average reflectivity of radiowaves across all the radar scans, so as to measure the relative density of an animal through the night [12]. Together with thermal imaging and acoustic detectors, the experiment was able to detect 16573 animals during spring [12].

1.10 Measuring Weight of Birds

As previously highlighted by Ben, the assessment of weight for fork-tailed Drongos has emerged as a pivotal factor in understanding why this avian species is not affected by extinction factors such as global warming. Weight serves as a key indicator for researchers to evaluate a bird's physiological condition, with fluctuations in weight often reflecting variations in energy expenditure associated with activities such as foraging [14]. Notably, the impact of global warming has been observed to correlate with a decline in body weight among passerine birds[15], a weight category encompassing the Fork-tailed Drongo.

1.10.1 Techniques Used to Weigh Small Animals

Various methodologies have been employed to ascertain the weights of small animals, each tailored to suit specific research requirements and environmental constraints.

Traditional approaches to weighing small animals, commonly entail the use of scales. Specially designed scales, compact and portable, offer convenience and usability in challenging environmental settings. These scales utilize gravity and the object's mass to determine its weight [16].

Zoologists have devised strategies to weigh small birds without inducing stress, thereby enhancing measurement accuracy. As noted by the Smithsonian National Zoo, enticing birds onto scales using a baited log, typically with live worms, proves effective, as birds naturally investigate the bait, affording researchers sufficient time for measurements [17]. However, it's important to note that this method is applicable primarily within controlled zoo environments and not wildlife habitat.

Alan Poole and Jon Shoukima observed challenges associated with obtaining repeated weight measurements of wild adult birds due to factors such as birds' transient behavior and environmental variability [14]. Their innovative approach, depicted in Figure 1.3, involved utilizing perch-like poles to simulate natural perching spots, minimizing disturbance to birds while enabling weight measurements.

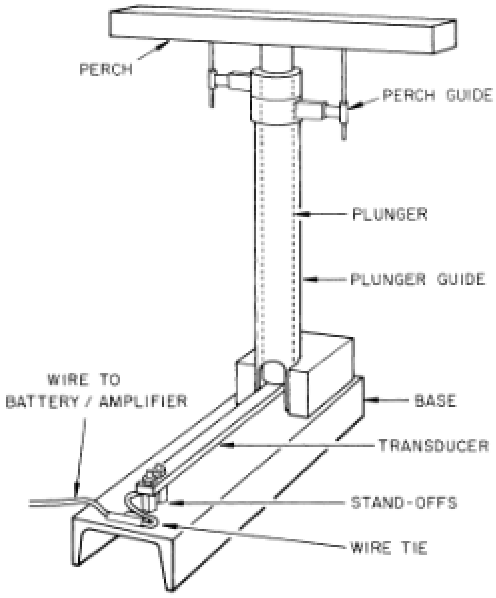


Figure 1.3: Showing a bird scale used in wildlife research taken from source[14]

1.10.2 Effect of Unpredictable Bird Movement on Accuracy Readings

The unpredictable movements of birds pose significant challenges when attempting to weigh them, particularly in field research settings. Birds' agility and erratic behavior make securing them for precise measurements challenging.

The operation of scales involves transducer beams detecting changes in electrical resistance upon object placement, with readings relayed to controllers via analog-to-digital converters [18]. The prolonged measurement process of scales can be influenced by birds' unpredictable movements. Nevertheless, innovative methodologies have been devised to accommodate and mitigate such challenges, as discussed in the previous subsection.

1.10.3 Challenges and Limitations

Power Limitations

In the realm of wildlife research, employing technology for data collection and storage presents notable challenges, particularly concerning power constraints in harsh environments [19]. Electrical components exhibit temperature thresholds and susceptibility to damage under excessive force. The temperature thresholds has been accounted for by using heat sinks,etc[20].

However, the primary challenge arises from the need for prolonged device operation, often spanning hours or days, in remote locations devoid of electricity. While batteries offer temporary solutions, harsh environmental conditions, including sunlight exposure, can compromise their efficacy. As a remedy, scales must prioritize reduced power consumption, often necessitating alternative power sources like solar panels [21].

1.11 Conclusion

In conclusion, this literature review highlights the critical role of advanced sensor technologies, traditional methods, and machine learning approaches in wildlife monitoring and conservation. Camera traps and passive integrated transponders (PIT) tags offer non-invasive monitoring and automated recognition, while tracking technologies provide valuable insights into avian behavior and migration patterns. Traditional techniques like dye markers and binoculars are augmented with modern technologies to overcome limitations. Challenges in measuring bird weight and data storage/transmission are addressed through innovative approaches such as cloud storage, wireless transmission, and data compression. Machine learning algorithms play a crucial role in managing and interpreting vast amounts of data efficiently. By integrating these tools and techniques, researchers can gather accurate data, gain insights, and inform evidence-based conservation decisions effectively, contributing to the protection of biodiversity and ecological integrity.

1.12 Data Storage and Transmission

Technological progress boosts ecological research but faces data storage challenges [22, 23]. This section examines solutions to this critical issue.

1.12.1 Cloud Storage

Significant improvements in wireless access networks or the internet at large is the motivation behind development of internet-based storage and computing. Cloud storage basically refers to infrastructure that allows users to access data on the internet at anytime, anywhere in the world [24]. The word 'cloud' here refers to a cluster of high-performance computers and servers that remotely store and do computations on data [25]. Over the years, this storage paradigm has been deployed by a number of enterprises because of its countless advantages. With cloud storage, one has cost effective [25], convenient, safe and flexible storage [24]. Furthermore, cloud storage has unlimited storage space as opposed to a traditional personal desktops [24].

Within the field of wildlife conservation and monitoring, cloud storage can be used as a central storage for large amounts of data acquired by sensor networks to be used for research. This has an advantage of allowing researchers to collaborate on a single storage platform. Internet storage has recently been deployed by a number of wildlife conservation organisations. For instance, eBird is an internet-based program that was developed by Cornell Lab of Ornithology and National Society to keep bird data at a central location [23]. It engages individuals from all over the world, often called 'citizen-scientists' to make observations on birds [22] [23].

In a nutshell, internet-based data storage is a convenient storage approach that could speed-up analysis and access to data acquired by sensor networks used in wildlife monitoring systems. This storage guarantees high data integrity, confidentiality, and accessibility.

1.12.2 Wireless Data Transmission

Wild animals are often not friendly with electronics around their habitats. Thus, wireless data transmission is an inherently important option to consider when designing a wireless sensor monitoring system for wildlife. There are a number of wireless technologies that have been proposed in literature, and some have been deployed in wildlife monitoring systems. However, the choice of a wireless technology is significantly influenced by its power consumption [26].

Bluetooth is a wireless technology that has been around for about 20 years. It was one of the first wireless technologies to be implemented [26], and has gained increasing relevance recently. Although it would provide a cheap alternative for ecologists to interface with wireless sensors, it is inherently disadvantaged by its power consumption rates, and the high complexities of its protocol stack [26]. Long range wireless technologies could be used to mitigate these problems. However, the wild habitats where the wireless sensor systems will be used are normally out of cellular coverage [27]. Fortunately, developments and active research in wireless technologies have resulted in more power efficient technologies that could be deployed in resource constrained wildlife monitoring systems. For instance, the development of Bluetooth Low Energy [26] or BLE-Mesh [27] promises to resolve the disadvantages of classical Bluetooth. Furthermore, Ayele et al argue that the emergence of recent low power wide area (LPWA) wireless technologies such as LoRa and Sigfox also promise to provide large coverage and lower power consumption [27].

1.12.3 Data Compression

In resource-constrained wildlife monitoring systems, the implementation of data compression techniques is crucial for reducing both storage requirements and transmission bandwidths for data collected by sensor nodes. Data compression, the process of encoding information to use fewer storage and network resources [28] [29], is categorized into *lossy* and *lossless* types. *Lossy* compression techniques allow for data reduction at the cost of losing some information [29], whereas *lossless* compression ensures data is preserved without loss during decompression [28]. Various compression algorithms have been explored in the literature, with some already being implemented in wireless sensor networks for wildlife monitoring. The selection of a suitable compression algorithm largely depends on its efficiency in terms of computational resources, speed, and power consumption, with preference given to those that are cost-effective yet high in computational resource efficiency, catering specifically to the constraints of wireless sensor networks in wildlife monitoring environments.

1.13 Data Processing

Wildlife research struggles with data processing and analysis, despite technological potential [30]. This section reviews traditional methods, identifies challenges, and explores machine learning's capacity to expedite data processing.

1.13.1 Traditional Data Processing

Traditionally, wildlife data gathered by monitoring systems is analysed and processed by researchers manually. For instance, the eBird program that has been mentioned before [23] consists of citizen-scientists manually counting birds and observing their behaviour. This approach to data gathering and analysis has proven to be time-consuming, labour intensive and expensive [30]. Advancement in sensor technologies has significantly improved data acquisition techniques [30], with the challenge of large volumes of data gathered in small amount of time. For instance, Snapshot Serengeti gathered 3.2 million images [22], and processing these images manually could be time-consuming. The demand for autonomous data processing arises from these challenges.

1.13.2 Machine Learning Approaches

The advent of sensor technologies in wildlife research has led to an unprecedented surge in data collection, notably through camera traps, posing challenges in data processing due to the sheer volume of information [30] [22]. Machine learning, a subset of computer science focused on pattern recognition and predictive analysis, emerges as a promising solution to manage and interpret these data effectively [30]. It encompasses both supervised algorithms, which learn from labeled data to predict outcomes for new inputs, and unsupervised algorithms, which infer patterns from unlabeled data [30]. These technologies have been applied in various wildlife monitoring efforts, notably integrating machine learning with unmanned aerial vehicles for the classification of high-resolution thermal imagery. Among the machine learning algorithms deployed, support vector machine (SVM) classifiers and convolutional neural networks (CNN) have shown significant promise in enhancing the efficiency and effectiveness of wildlife conservation efforts [31] [22].

Chapter 2

Scale and Housing Design

This section was completed by Ankush Chohan [CHHANK001]

2.1 Introduction

This sub-module details the process used to design the perch, scale housing, and weighing mechanism to obtain the raw weight data of the Fork-Tailed Drongos. The perch design was based off the current design that Ben Murphy employs, as it successfully allows the Drongos to land on the scale. The weighing system was designed to attain accurate weight readings, in terms of a voltage which is then processed by the micro-controller sub-system. The entire scale unit is designed to be placed on the floor, with the perch sticking up, allowing the Drongos to land, and feed from a 'food bowl' while their weight data is recorded. This sub-section is divided into two parts, namely, the load cell circuitry, and external housing. The process for the design and implementation of this sub-module is detailed in the following sections.

2.2 Requirements

2.2.1 User Requirements

After an interview with Ben Murphy, the following user requirements relevant to this section were identified.

- The scale must accurately weigh Fork-tailed Drongos with an accuracy of 0.1g
- The system must identify the bird which is being weighed
- The system must be deployed in the Kalahari Reserve

2.2.2 Requirements Analysis

- **Accurate Weighing of Fork-Tailed Drongos:** This requirement specifies that the scale must accurately weigh the birds with an accuracy of 0.1g. This implies that the system must be capable of precise measurements tailored to the weight of the birds.
- **Identification of Birds:** This suggests the need for a bird identification mechanism embedded in the solution.

- **Deployment in the Kalahari Reserve:** This implies environmental considerations such as ruggedness, and weather resistance.

2.2.3 Design Specifications

- **Accurate Weighing of Fork-Tailed Drongos:** A load cell and corresponding circuitry must be employed to detect weight changes with a sensitivity of 0.1g.
- **Identification of Birds:** The hardware must be designed such that an RFID scanner can be placed at the correct distance to a bird on the perch.
- **Deployment in the Kalahari Reserve:** The solution must be waterproof and dustproof (IP54) [1], as well as protect the internal components from outside temperatures of up to 50°C.

2.3 Design Choices

2.3.1 Load Cell

For weight measurement, the use of an electronic load cell was found to be the most commonly used mechanism and was employed for this sub-module. Full bridge load cells consist of four strain gauges placed on a metal bar in a wheat-stone bridge configuration. When a mass is placed on the load cell, the metal bar bends slightly, thus changing the resistance of the strain gauges, which then output a voltage depending on the degree of deflection on the metal bar, which in turn is proportional to the weight of the mass applied.

Load cells offer several benefits, they provide higher accuracy compared to other types of load cells due to the redundancy and balancing of multiple strain gauges within the bridge configuration. The bridge configuration enhances sensitivity to small changes in force or weight, making them suitable for applications where precise measurements, such as the 0.1g accuracy specification, are necessary. One of the main reasons why a load cell was chosen, was due to the thermal compensation of the full bridge configuration. The operation of the load cell depends on very small changes in the resistance of the strain guages. Changes in their resistance are caused by either deflection of the bar, or changes in temperature, where resistance decreases with temperature. However, since the temperature of all the strain guages will increase/decrease by the same amount, and the output voltage is gained via a voltage divider principle, temperature changes have a negligible effect on the output readings. This is an important principle due to the location that the scale is designed to be deployed in, where daytime temperatures reach up to 50°C.

For this application, an HKD Electronic load cell of 1Kg capacity was bought from Communica. While the Drongos weigh between 42 and 62g, the load cell has to withstand the weight of the perch, as well as the force of the birds landing and taking off, thus leading to the selection of a capacity of 1Kg.

An entire unit was purchased for this application, to ensure the highest possible accuracy. The alternative was to purchase 4 strain gauges and mount them onto a flexible bar, however, due to the

[1] IP54 means protection from limited dust ingress and protected from water spray in any direction. Find more information here: https://www.iec.ch/ip-ratings

difficulty of the mounting process, as well as procurement of bar that would bend consistently led to the choice of purchasing an entire unit at the cost of a higher expense.

2.3.2 Load Cell Circuitry

Amplification, protection, and filtering circuitry is required to convert the output signal of the load cell to a level which a microcontroller can handle, and read accurately. Load cells output very small voltage readings, typically in the millivolt range, this is too small a range to be accurately sampled by the 12 bit ADC on the ESP32 which is the micro controller that was selected for this design. To explain further, a 12 bit ADC has 4096 levels. The maximum input voltage of the ADC is 3.3V, that means that each level corresponds to 0.8mV, therefore, lots of information will be lost in the reading. The voltage from the load cell will therefore be propagated through the following systems:

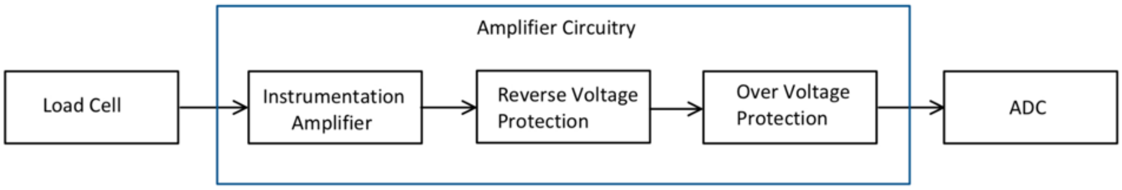


Figure 2.1: Amplifier Circuitry

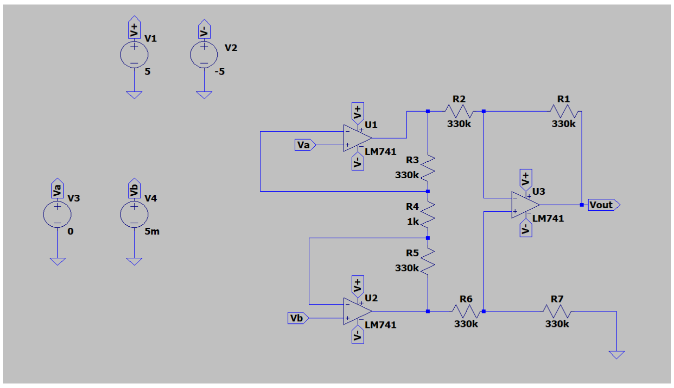
Amplifier

An instrumentation amplifier configuration was selected for this design. Instrumentation amplifiers are used to provide large amounts of gain for very low level signals [32]. This is a useful property for the function of amplifying the small voltage outputted by the load cell to a value that the ADC can use. Instrumentation amplifiers are in fact often used to to directly amplify signals from passive sensors such as strain guages [32]. Additionally, instrumentation amplifiers have a high common-mode rejection ratio (CMRR), therefore, the amplifier will be less affected by electro-magnetic interference and noise that could arise from the other modules of the entire system, especially the RFID scanner. Instrumentation amplifiers are designed to maintain stability over a wide temperature range [2] which is desirable since the scale will be placed out in the open in the field.

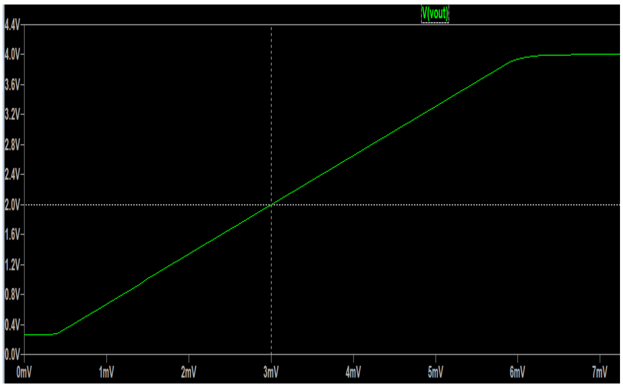
The design of the instrumentation amplifier began with the following circuit shown in simulation:

A gain of approximately 660 was chosen to amplify signals from the mV range to the V range, i.e. 5mV is amplified to the maximum ADC input voltage of 3.3V. Fig 1.2(b) shows that the response is linear, but saturates at 4V, which turns out to be an ideal characteristic as voltages above 4V will have to be rejected anyway due to the ADC's capacity. The circuit was built on a breadboard, however, it did not function as expected. After some research it was found that an instrumentation amplifier with the precision required for this design cannot be made from basic lab components, as it requires precision resistors to achieve accurate and stable performance. Therefore, a complete unit AD620 instrumentation amplifier was purchased from micro-robotics.

[2]The temperature range for specified performance of the AD620A is -40 to +85°C



(a) Amplifier Circuit



(b) Amplifier Response

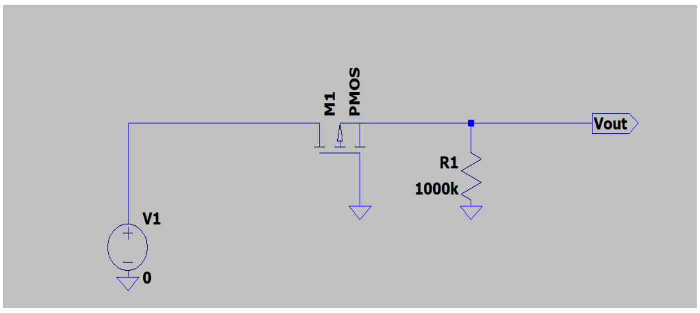
Figure 2.2: Amplifier Simulation

The AD620 was chosen for the following qualities:

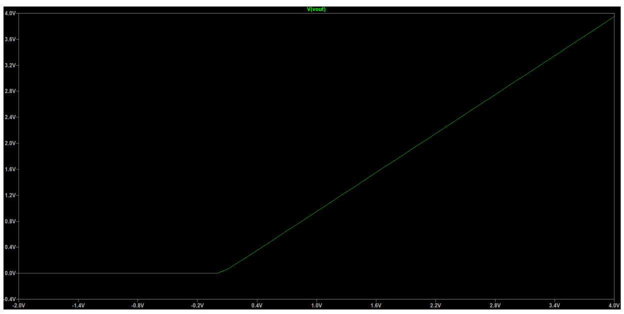
- It is a low cost, high accuracy amplifier
- It requires only one external resistor to set the gain between 1 and 10 000.
- It offers low power consumption making it a good fit for this battery powered application.
- It can be supplied with ±5V which is within the power sub-system capability.

Reverse Voltage Protection

If the load cell bends downwards i.e. in the expected direction, then a positive potential difference is present at the output. If however, it is to bend upwards, which could happen during the takeoff or landing of a bird on the scale, a negative voltage will be present at the output. This negative voltage could damage subsequent components which are configured to only positive voltages. Thus, a reverse voltage protection circuit is implemented at the output of the amplifier. The chosen circuit is shown as follows in simulation:



(a) Reverse Voltage Protection Circuit



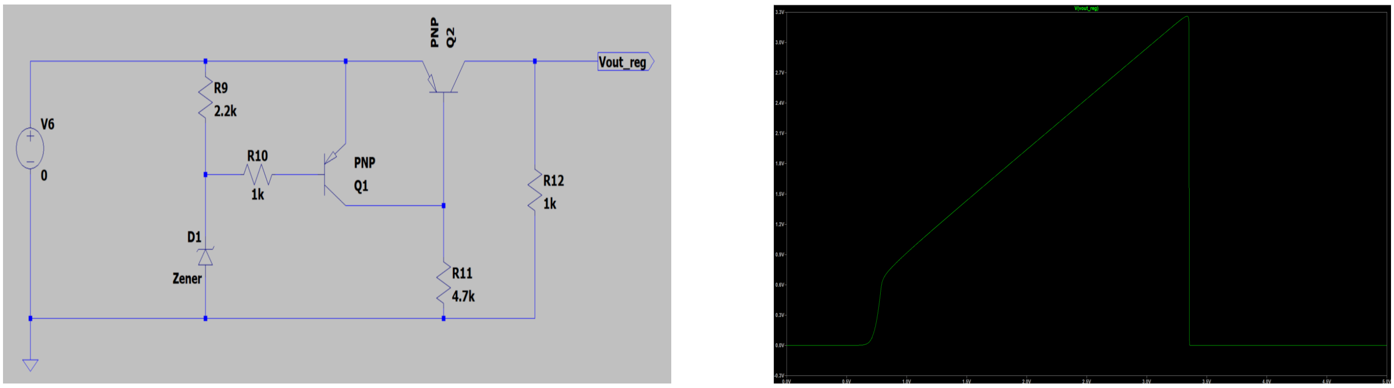
(b) Reverse Voltage Protection Circuit Response

Figure 2.3: Reverse Voltage Protection Simulation

As can be seen from Fig 2.3, the circuit rejects negative input voltages, but allows positive voltages through. For this application an, IRF9540N P-Channel MOSFET was selected, and purchased from Micro Robotics. The main considerations when choosing this particular MOSFET were the relatively low on-state resistance $R_{DS(on)}$ of 0.2 Ω which will result in minimal losses, allowing the battery consumption to be optimised. Additionally, the IRF9540N has an operating temperature of 175°C and is equipped with a heat-sink, allowing for optimal performance in the field.

Over Voltage Protection

The maximum voltage that the ADC pin of the ESP32 micro-controller can handle is 3.3V. Depending on the mass placed on the scale, the output of the amplifier circuit can reach voltages above 3.3V. Therefore, to avoid damage, an over voltage protection circuit needs to be implemented. The following circuit shown in simulation implements the required over-voltage protection functionality:



(a) Over Voltage Protection Circuit

(b) Over Voltage Protection Response

Figure 2.4: Over Voltage Protection Simulation

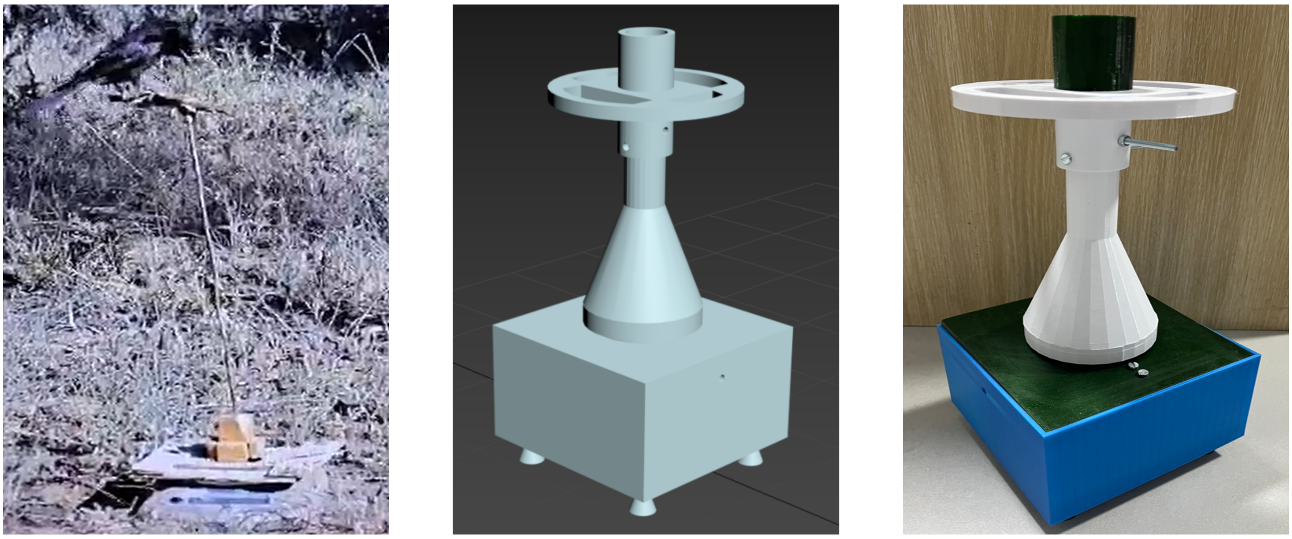
A zener diode with a breakdown voltage of 3.3V is used to allow the output to cut off at values larger then 3.3V. A PN2907A transistor was used to build the circuit. This transistor was selected due to it on hand availability, low leakage current [3] which helps in minimizing power consumption which is essential for this battery operated device, and low saturation voltage [4] which means that it can switch on an off rapidly with minimal power loss.

2.3.3 Design Choices for Housing

The design of the housing of the scale is based on the current set up that Ben uses in the field.

The scale components were modeled using 3ds Max, and subsequently printed using a Prusa Mini 3D printer. The system was designed in 10 pieces, and then put together using glue for some parts, and M4 nuts and bolts for others.

[3] 50nA at 25°C
[4] 0.3V to 0.5V depending on collector and base current

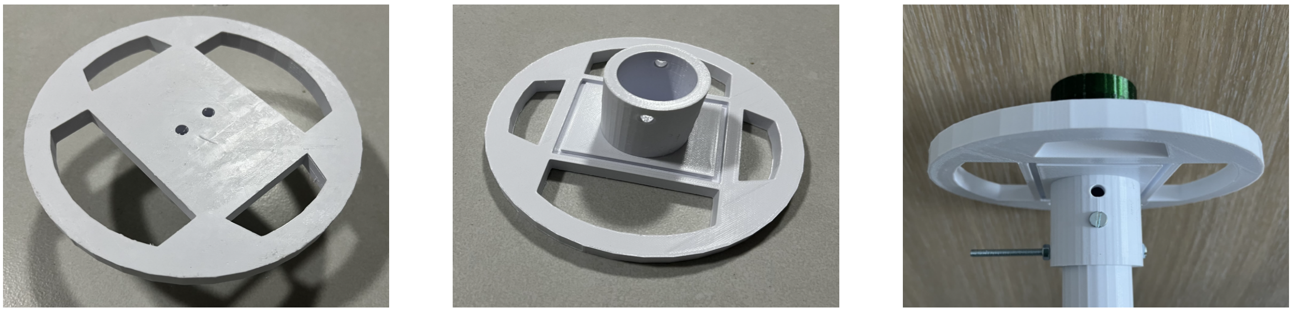


(a) Ben's Setup (b) CAD Model of Scale (c) 3D Printed Scale

Figure 2.5: Complete Setups

Perch and Pole

The bowl placed at the very top of the scale is designed to hold the food that will attract the Drongos to land on the perch which is the circular section with gaps. The width of the circular part of the perch is 1cm to allow the Drongo's to hold onto it with their small feet.

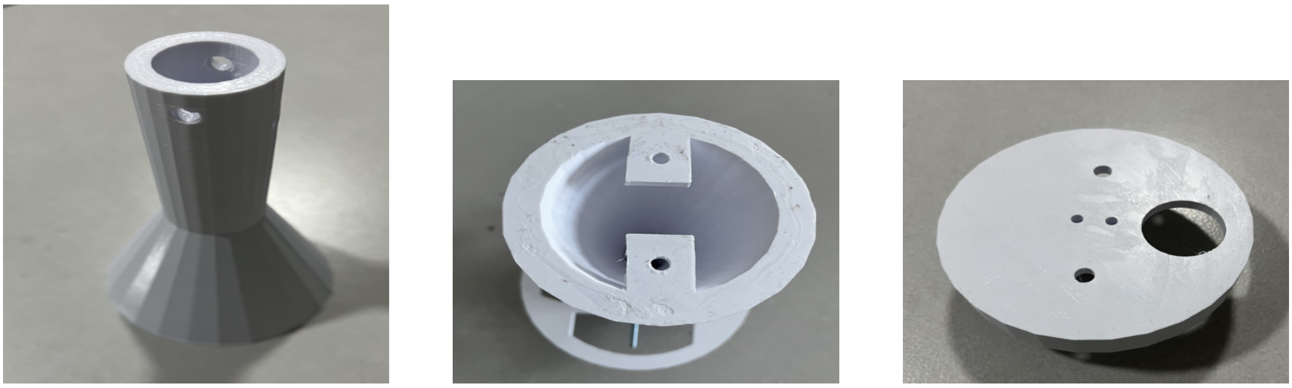


(a) Top Of The Perch (b) Underneath Of Perch (c) Image Showing Cable Hole

Figure 2.6: Perch

Fig 2.6a shows the M4 holes to connect the food bowl to the middle of the perch. The food bowl has corresponding holes on its base. Fig 2.6b shows the underneath of the perch where the RFID scanner will be placed. The rectangular groove has dimensions of 50x62x3mm to house the RFID antenna, protecting it as much as possible. The image also shows the holes used to fix the perch to the pole. Fig 2.6c shows the perch connected to the pole, as well as a hole to feed the cable of the RFID antenna through and into the base of the scale. The circular section was designed to have a maximum distance of 4cm from the coil as per specification supplied by the micro-controller subsection.

As shown in Fig 2.7a, the pole has M4 holes at the top to fix onto the perch. the base has a conical design to avoid the buildup of debris on the scale which would affect the weight measurements. Fig 2.7b shows the underneath of the pole, which has been hollowed out to allow the cable from the RFID antenna through, as well as allowing the part to be printed faster, and with less material. The fixtures

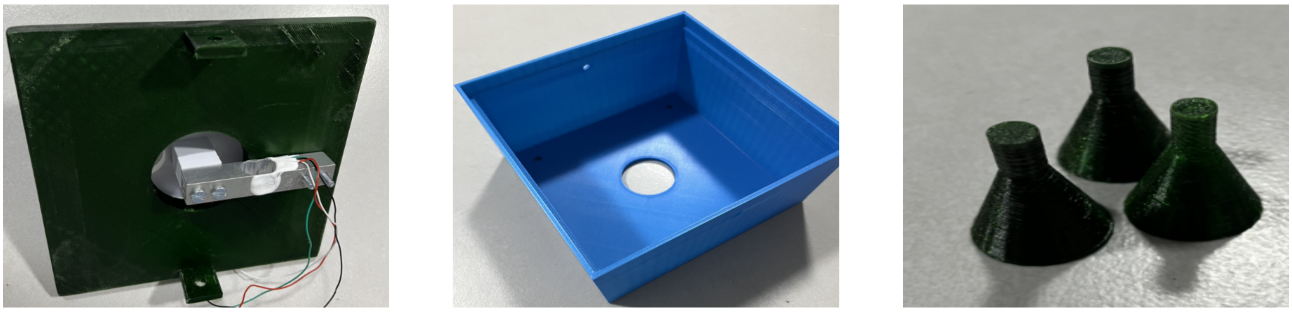


(a) Pole (b) Underneath Of Pole (c) Top of Plate

Figure 2.7: Pole and Plate

that are be bolted to the plate can also be seen in the image. The plate shown in Fig 2.7c connects to the pole on its top section. The large hole is to allows the cable from the RFID scanner through to the base of the scale.

Load Cell Fixture and Base



(a) Load Cell Fixture (b) Scale Base (c) Legs

Figure 2.8: Load Cell Fixture, Base and Legs

As seen in Fig 2.8a, the load cell is bolted to the underneath of the green cover on one end, and bolted to the underneath of the plate on the other end. This keeps the load cell perfectly horizontal, and fixes the perch, pole and plate firmly to the base of the scale. The green cover was designed to be 1cm thick rather than 0.5cm like many of the other components. The added thickness is to ensure that the cover does not bend when a mass is placed on the perch, as one end of the load cell has to be securely fixed to a stiff support (i.e the cover) to gain accurate readings. The cover has two fixtures with M4 hols to bolt to the box. Fig 2.8b shows the base of the scale where all the electronic components of the design are to be stored. It has and inset around the top perimeter to allow the cover to slot in. This provides the cover with maximal support as well as seals the box. There are four small holes in the base of the box to secure the legs. The large hole in the base was included to allow for easy access to components during the testing process and will not be present in further iterations of the design. The legs have a conical shape to prevent them from sinking into the ground when the scale is placed in the field. The weight of the scale will be distributed on the large flat surface of the legs, providing stability to the structure, as well as raising the scale base off the ground to protect it from moisture, and heat from the ground.

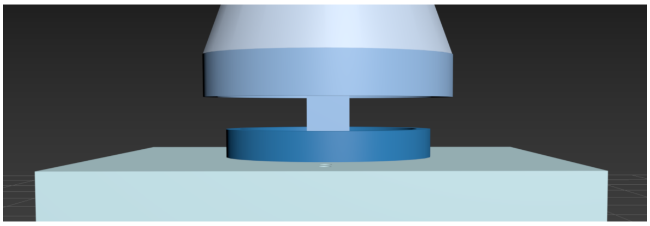


Figure 2.9: Overlap

As can be seen from the above image, there is a lip on the top of the cover that fit into, and overlaps with a corresponding lip on the plate. The figure is taken from the CAD model as it is difficult to see on the 3D printed model. This overlap is designed to protect the components in the box from water and dust.

2.4 Preliminary Testing

Load Cell

The load cell was connected to a power supply of ±5V, and the voltage between the two output leads was recorded after adding a masses of known weight to the perch which the load cell was mounted on.

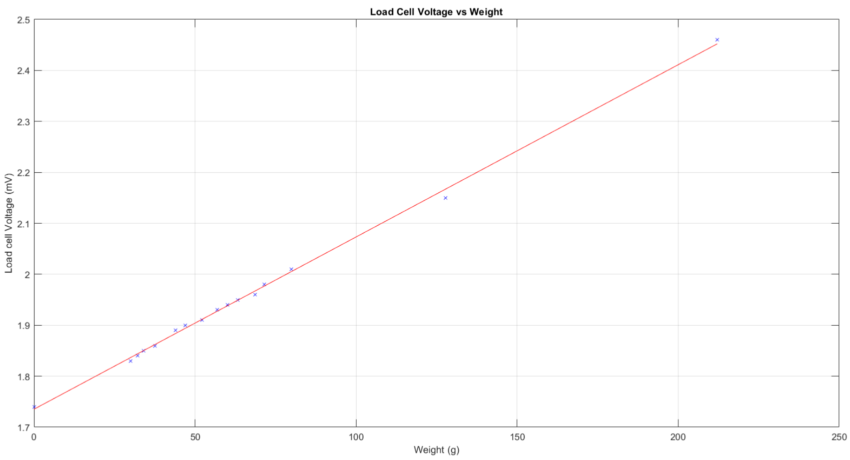


Figure 2.10: Load Cell Response

As can be seen from the line of best fit plotted on the graph, the relationship between mass and output voltage is linear. Ideally with no weight on the perch, the load cell would output 0V, since the bridge configuration is supplied with ±5V, however, due to the weight of the perch itself, the load cell outputs 1.74mV with no added weight on the scale. A description of how this is accounted for is detailed later in the report.

Reverse Voltage Protection

The reverse voltage protection circuit was built on veroboard and tested with a range of input voltages. The results are shown in the following plot:

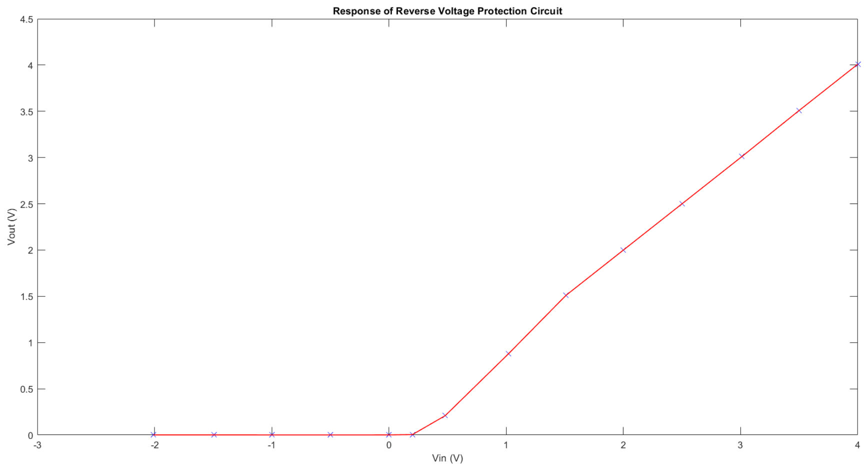


Figure 2.11: Reverse Voltage Protection Response

As can be seen from the graph, the circuit effectively rejects negative voltages, and allows positive voltages through, with minimal losses. At low voltages there is non-linear behaviour, therefore, the overall system is designed to operate at voltages above 0.5V thus nullifying the initial non-linear behaviour.

Over Voltage Protection

The over voltage protection circuit was built on veroboard and tested with a range of input voltages. The results are shown in the following plot:

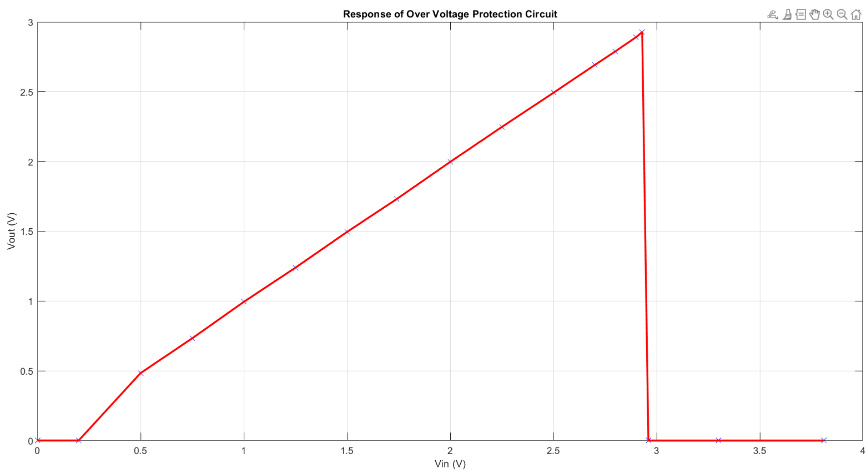


Figure 2.12: Over Voltage Protection Response

As can be seen from the graph, the circuit effectively cuts off the output when the input goes over 2.93V. The circuit was designed to cut off at 3.3V, however, due to the non-ideal behaviour of practical components, it cuts off at a slightly lower voltage. For the required application of protecting the micro controller, the circuit still performs effectively. At low voltages, the circuit has non-linear behaviour. This was seen in simulation as well as in practice. As was the case with the reverse voltage protection circuit, the overall system is designed to operate at voltages above 0.5V thus nullifying the initial non-linear behaviour.

2.5 Subsequent Design Choices

To account for the 1.74mV output of the load cell when no weight was placed on the perch, a differential amplifier configuration was employed. This effectively 'zeros' the scale to account for the weight of the perch itself, allowing the full voltage range (0.5V-2.9V) to be used for weighting the birds.

The updated circuitry of the system is shown in the following block diagram:

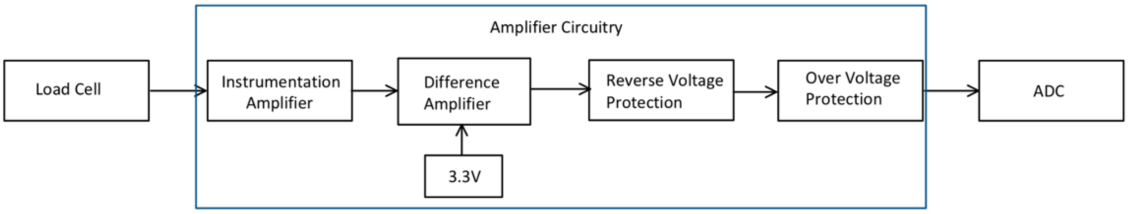


Figure 2.13: Amplifier Circuitry Updated

The voltage from the load can not go to the differential amplifier directly, since the differential amplifier can not accurately process such small voltages, therefore, the output of the instrumentation amplifier is fed into the difference amplifier. The theoretical gain of the instrumentation amplifier was set to X2745, as this gain resulted in the output being slightly less than 3.3V when there was no load on the scale. The scale was then calibrated by adding small weights until the output was 3.3V. The output from the instrumentation amplifier, as well as 3.3V from the micro controller are inputted into the terminals of the difference amplifier to zero the scale.

Differential Amplifier

The Differential Amplifier circuit is as follows:

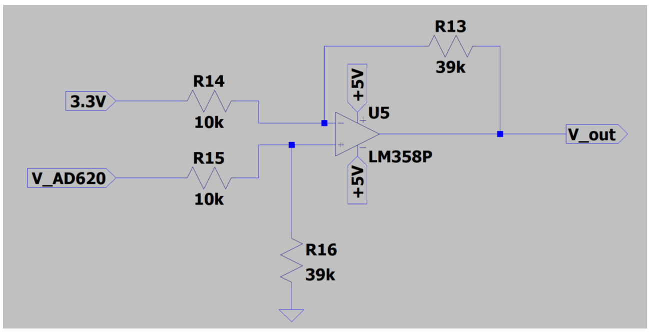


Figure 2.14: Differential Amplifier

The LM358P was chosen due to on hand availability, as well as the fact that it can be powered off the same ±5V supply as the rest of the circuitry. The gain of the differential amplifier is set to a value of X4 to further amplify the signal.

2.6 Final results

Housing Testing

A paper towel was placed in the box, and water was splashed on the entire structure. The paper towel was then inspected and showed no signs of moisture.

Circuitry Testing

The entire system for this subsection was connected up, and tested with various values of known weight. The following plot shows the results:

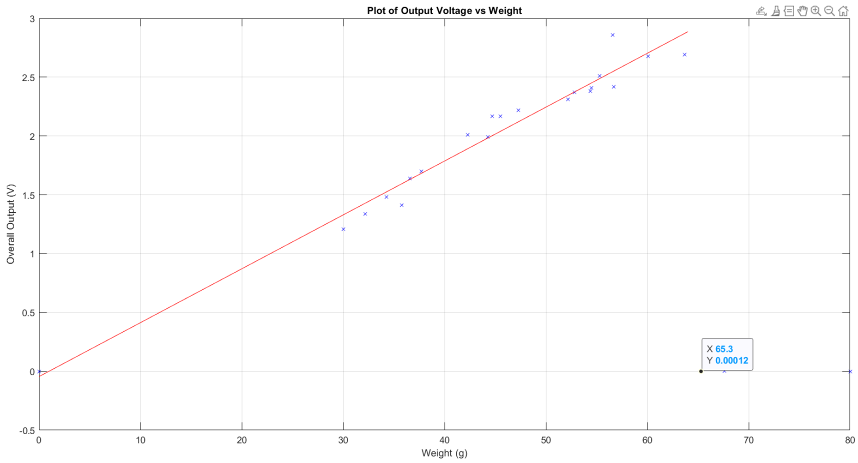


Figure 2.15: Overall Scale Results

Weights around the average mass (44g) of a Fork-Tailed Drongo were used to test the system. As can be seen from the graph, the system outputs voltages in the range of 0V-2.9V corresponding to masses of 0g-64g. If a weight larger than 64g is placed on the scale, the voltage from the difference amplifier exceeds 2.9V, and the over voltage protection circuit kicks in, and cuts off the signal. This is shown by the data points at 65g and 67g. All of the sepected weights output voltage readings above 0.5V, thus validating the fact that the design operates in the linear region of the over voltage and reverse voltage protection circuits.
Since the 12 bit ADC has 4096 levels, and takes in voltages up to 3.3V, each level corresponds to 0.8mV. Since the output range of the scale is 0V-2.9V, the output voltage can be represented by 3625 levels [5]. those levels correspond to 0g-64g. therefore, each level corresponds to 0.017g [6]. Therefore, the scale has an accuracy of 0.018g. It is important to note, however, that this calculation is largely theoretical, and the actual accuracy will have to be determined when the data is processed through the subsequent systems.

2.6.1 Acceptance Test Procedures

The following acceptance test procedures were considered for this sub-section:

[5] 2.9/0.8mV
[6] 64/3625

User Acceptance Testing (UAT)

- **Accuracy of 0.1g:** This is tested by investigating the resolution of the final signal that is outputted. The expected result is that one ADC level corresponds to 0.1g
- **The system is weatherproof:** This is tested by subjecting the system to weather conditions or simulations thereof. The expected result is that no water or dust enters the system.

Unit Tests

- **Reverse voltage protection:** This is tested by subjecting the reverse voltage protection circuitry to reverse voltages and observing the output. The expected result is that the circuit rejects reverse voltages and allows forward voltages through.
- **Over voltage protection:** This is tested by subjecting the over voltage protection circuitry to voltages above 3.3V, and observing the output. The expected result is that voltages below 3.3V are allowed to pass, while voltages above 3.3V are cut off.
- **Water proof to IP54 standard:**[7] This is tested by splashing water on the housing and observing if any moisture enters it. The expected result is that there will be no trace of water in the housing.
- **Dust proof to IP54 standard:** This is tested by deploying the system in the field and observing if any dust enters the housing. The expected result is that no dust will enter the housing.
- **Protection from temperatures up to 50°C** This is tested by subjecting the system to high temperatures in the field. The expected result is that the system will continue to operate optimally.
- **Scale subsystem interacts with microcontroller subsystem:** This is tested by connecting the output of the load cell circuitry to the ADC pin of the microcontroller. The expected result is that the microcontroller reads in the voltages.

2.7 Results of Acceptance test Procedures

ATP	Result	Comment
Accuracy of 0.1g	Pass	System has an accuray of 0.018g
Reverse voltage protection	Pass	
Over voltage protecton	Pass	
Water proof to IP54 standard	Pass	Partially satisfies UAT 2
Dust proof	N/A	Needs to be tested in the field
Protection from temperatures up to 50°C	N/A	Needs to be tested in the field
Interaction with microcontroller	Pass	Further details are in the UC subsection.

[7]IP54 means protection from limited dust ingress and protected from water spray in any direction. Find more information here: https://www.iec.ch/ip-ratings

Chapter 3

Data System Design

This section was completed by Kananelo Chabeli [CHBKAN001]

3.1 Introduction

This chapter details the design process of data acquisition and retrieval subsystem. This subsystem is responsible for detecting drongos birds when on the scale and estimate its weight saving the results to file in memory for later retrieval. To address the problem effectively, the system was further divided into two sub-subsystems: **data acquisition**, and **data storage and retrieval**. the former detects the bird when it lands on the scale and samples noisy analog signal from scale system. This signal is then filtered to get a better approximation of the bird's weight. Data storage and retrieval, is tasked with storing data into the system memory and retrieving it when needed. This subsystem also integrates hardware wireless communication interface that communicates with the mobile application. The chapter begins with detailed analysis of requirements, design choices made to meet these requirements and system design procedures followed to implement these choices. Moreover, tests results made on the system and acceptance test procedures are presented and conclusions are drawn based on these results.

3.2 Requirements

The user requirements of the system were gathered and refined through continuous engagement with the end-user (Ben). The requirement are analysed in section 3.3, when considering different design options available to meet each user requirement. From these analysis, the user requirements were effectively translated into function requirements and design specifications. Table 3.1 below summarises the outcome of the process.

Table 3.1: Summary of system requirements and design specifications

Requirement ID	**User Requirements**	**Functional Requirements**	**Design Specifications**
UR01	System must be power efficient	Must be driven to deep sleep mode when IDLE	Must draw maximum of 15uA when in sleep mode
		Must operate using external interrupts	
UR02	The system must be cost effective	Must be designed to minimize operational and maintenance costs	Total cost must not exceed R500.00
UR03	System must transmit data wireless	System must support Bluetooth Low Energy	Should have maximum latency of 2 seconds
		System must set up WiFi Access Point and HTTP Web Server	Must maintain minimum data transmission success rate of 99%
UR04	Must estimation weight within 0.1g uncertainty	Must deploy optimization digital filter	Will deploy Kalman filtering algorithm
		Should use high resolution ADC	Should have ADC with minimum of 10-bit resolution
		Must calibrate non-ideal Effects of ADC	Calibrate gain and offset error using 2-point calibration
UR05	System should operate in Kalahari conditions	Should be small enough to fit within the scale	Must be soldered on
		Should be resistance to high temperature	Must operate in temperature above 45deg C
		Must have no ports exposed to the outside environment	

3.3 Design Choices

3.3.1 Development Boards and Microprocessor Selection

Three micro-controllers were evaluated for the project based on their ability to meet specified user requirements: the Xtensa LX6 on the ESP32 DevKitC board, the ATMEGA328P on the Arduino Uno R3 board, and the Xtensa LX7 on the ESP32-S2 DevKit development board. These controllers were selected primarily for their wireless communication capabilities (UR03). The key user requirements influencing the choice were UR01-04. Requirement UR01 specifies low power usage, which is achievable through a processor with a high clock speed, an Ultra-Low Power (ULP) co-processor, and minimal current consumption in sleep mode.

Additionally, the system must be cost-effective and capable of shutting down power to ancillary subsystems like the scale system when not actively acquiring data or transmitting it. To satisfy UR04, the system requires a high-resolution analog-to-digital converter (ADC) for accurate sampling from the scale and dynamic digital filtering, suggesting a need for more RAM and higher processor speeds. The microprocessor selected also needs to support SPI, and have ample SRAM and ROM. A comparison of these micro-controllers is provided in Table 3.2.

Table 3.2: Microprocessor comparison

Features	ESP32 Dev(Xtensa LX6)	ESP32-S2 Dev(Xtensa LX7)	Uno R3(ATMEGA328P)
cost	R205	R199.94	R120
CPU Speed	240MHz	240MHz	16MHz
ADC Res	12-bit	12-bit	10-bit
ROM	448KB	128KB	512B
RAM	520KB SRAM	320KB SRAM	2KB SRAM
Cores	Dual Core	Single Core	Single Core

The table reveals that the ATMEGA328P microprocessor fails to satisfy most of the requirements except for cost-effectiveness. However, the modest cost difference is not justified by its limited capabilities, leading to its exclusion in the initial selection phase. In contrast, both the Xtensa LX6 and Xtensa LX7 microprocessors advanced to the next round of evaluation due to their shared features, such as 240MHz clock speeds and 12-bit ADCs, fulfilling the requirements for high-speed processing and high-resolution ADC. Additionally, both processors are reasonably priced.

Among these, the Xtensa LX6 (ESP32) stands out with more memory and a dual-core architecture, enhancing its ability to handle multiple tasks simultaneously through multi-threading with reduced time-slicing compared to single-core processors. This capability ensures smoother system operations. Moreover, the Xtensa LX7's higher current consumption in sleep mode makes it less appealing for fulfilling the low power requirement (UR01). Stakeholder feedback emphasized the importance of power efficiency, measurement accuracy, and ease of data retrieval. Consequently, the Xtensa LX6 on the ESP32 DevKitC development board was chosen as the most suitable processor for this system.

add sleep current of processors in the table!

3.3.2 Bird Identification

For the system to be power efficient, effectively meeting requirement *UR01*, it was necessary that major power consuming components(such as scale) of the overall system remain powered down when there is no acquisition processes undergoing. Thus, a mechanism to automatically detect when the bird is on the scale and start taking samples was needed. Two possible options were considered after active engagement with the stakeholder. These are **Image Bird Detection** and **RFID Tag Detection**. The former translated to implementing object detection algorithm which obviously needed tons of data to achieve higher generalisation. Furthermore, it meant keeping the camera on almost always and continuously monitoring objects in the field of view of the camera to detect presence of drongos. However, **image bird detection** was found to be much cheaper, thus is would meet requirement *UR02*.

Contrary to that, using RFID reader to detect birds turned out to be extremely power efficient. For instance, the reader and controller could both be driven to sleep mode when no acquisition process is under-going, and reader interrupts the controller when bird's RFID tag is detected in range of the reader. The drawback of this approach was that the RFID Reader module are costly. Thus, a trade-off needed to be made between cost and power efficiency of the system. Accessing cost and power from all other systems, and considering the user weights (preferences) to costs and power effectiveness, the method of detecting birds was chosen to be through the use of **RFID Reader module**.

3.3.3 Data Storage, Retrieval and Transmission

Data Storage and Retrieval For data storage, external non-volatile memory options such as EEPROM or SDCard were initially considered. However, these options increased the overall system costs and the complexity of the circuitry. Therefore, internal memory was chosen for file storage. The ESP32 utilizes the LittleFS file system, which is efficient and user-friendly. It allows for file operations similar to those in a standard operating system, enabling data to be stored in a readable and useful manner.

Data Transmission Becauset the system is required to work in harsh Kalahari Desert conditions, traditional data retrieval methods such as plugging device via USB port present significant challenges. First, desert dust could fill-in the USB port and damage its internal circuitry. Secondly, continued tempering which the scale system result is malfunctioning of the system, needed repeated reboots. Lastly, it would not be feasible to wait under hot Kalahari sun and load data manually into a device.

Alternative approach is to use wireless data transmission techniques. The ESP32 board supports Bluetooth Classic, Bluetooth Low Energy (BLE) and Wifi. Classic Bluetooth consumes more power per each byte transmitted compared to BLE. Also, Wifi is also power consuming technology. To achieve power effectiveness, BLE is the best option to consider. However, for data integrity and security, BLE has flaws as it is less secure than WiFi. Furthermore, setting up ESP32 as both Server and WiFi Access Point(AP) turns out to be the most convenient to manage data transmission. As such, wireless communication approach taken in this system is WiFi with ESP32 as the server and WiFi AP, while the mobile will be acting as the client, and a WiFi station. In this way, the user can set custom WiFi password and SSID.

3.4 System Design

3.4.1 Hardware Interfaces

This section details description of how this system interacts with other subsystems, as well as explanation of inter-subsystem interfaces.The first interface is **HW-I01**. This interface comprises of two power lines: 5V and GND power lines to power the ESP32, RTC module and RDM6300 RFID reader module.

The second hardware interface is **HW-I02**. This interface comprises of a single line from the scale, and carries analog voltage from the output of the scale. This voltage is sampled and filtered during data acquisition mode, to obtain the estimate to the bird's mass. Thirdly, a hardware interface **HW-I03** comprises of connection lines between the ESP32 and RFID Reader mode. This interface consists of two lines: First line is UART Transmit line(Tx), and second line is Interrupt line. The Tx line, is used for reading identification number of the tag on the birds and the Interrupt line is used to interrupt the ESP32 sleep mode when the RFID tag is within the antenna's reading range.
The interface **HW-I04** connects the ESP32 with the Real-Time-Clock (RTC) module for obtaining accurate timestamps. This interface comprises of two signal lines: serial data line, and serial clock line. The last hardware interface is **HW-I05**. This interface is a push-button that the user presses to interrupt the sleep mode of ESP32 when they want to download data file or configure the system. These interfaces are summarised in the table below, and are shown in figure 3.1.

Table 3.3: Hardware Interfaces

Interface Number	Description	Pin Description	
HW-I01	Power Interface	ESP32 PIN	Description
		GND	Common Ground
		ESP32 V_{in}	5V from Power
HW-I02	Voltage from Scale System	Connects to ESP32 GPIO35	
HW-I03	RFRD Reader Interface	ESP32 PIN	RDM6300 PIN
		ESP32 GPIO5	RDM6300 Tx
		ESP32 GPIO21	RDM6300 Interrupt pin
HW-I04	RTC D3132 Interface	ESP32 PIN	D3132 PIN
		ESP32 GPI22	D3132 CLK
		ESP32 GPIO21	D3132 SDA
HW-I05	User Button	ESP32 GPIO34	

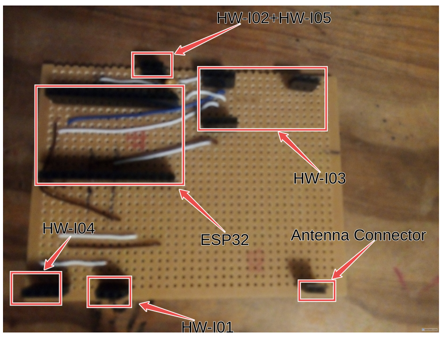


Figure 3.1: Hardware interfaces

3.4.2 Software Interface

The software interface was designed for interacting with the mobile phone. This consists of application programming interface that the mobile app interfaces with to retrieve data from the ESP32 Web Server to the Mobile app. Data entry in a file is encapsulated by the structure:

```
typedef struct data_entry_t{
    String tag_id;
    String time;
    String data;
    float weight;
};
```

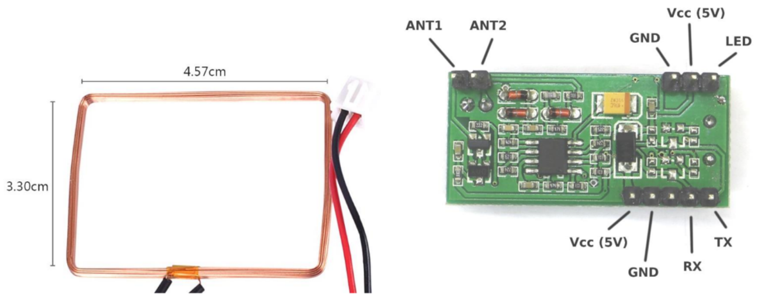
During data retrieval, the function $int\ get\_data(File * \ root, data\_entry_t * \ data)$; is invoked. For each invocation, this function retries a data entry from the data file system, and encapsulates into structure mentioned above. This is then translated JSON file for transmission to the Mobile. Additionally, the API $float\ get\_battery(void)$; return the estimated percentage of the battery, and can be called to communicate battery life to the user.

3.4.3 Data Acquisition

As mentioned before, the Data System is divided into Data Acquisition and Data Retrieval sub-modules. This section presents description for the former module.

Data acquisition process detecting when bird is on the scale, sampling analog voltage from scale and approximating weight of the bird.

RFID Detection From active engagement with the user (Ben), he argued that Drongos bird he's researching on have RFID tags, and this is being used in this system to detect when the system is on the scale, and each measurement entry in the file storage is uniquely identified by the bird's Tag ID. The initial design was to use 134.2kHz RFID reader module, which is detects the frequency that the actual birds use. However, the component was out of stock at time of ordering, as such a 125kHz reader was considered as an alternative for testing purposes. This module together with reading antenna are shown in fig.3.2, and figure 3.3 shows picture of unit testing to RFID Reader module.



(a) 125kHz Antenna

(b) RDM6300 125kHz RFID Reader module

Figure 3.2: RFID Reader and Reading Antenna

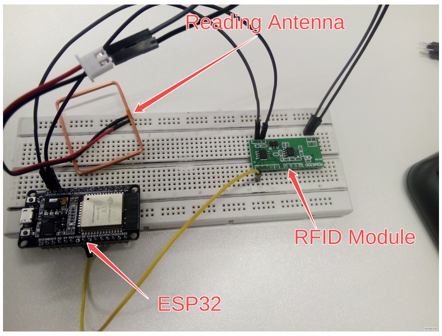


Figure 3.3: Interfacing RDM6300 with ESP32

To use as minimal power as possible, the system is driven in deep sleep mode when there is no acquisition process undergoing. Pin labelled LED in fig.3.2b is used to interrupt the system when a tag is within the reading range of the antenna. Moreover, pins ATN1 and ATN2 are antenna connections (polarity does not matter), and Tx is the UART pin that is used for reading the ID of the tag(see table 3.3). The power pins (VCC 5V and GND) are connected directly to the power interface, **HW-I01**. The rest of the other pins are not used.

Analog-to-Digital Converter When the bird land on the scale, the scale will output analog signal that needs to be sampled. ESP32's 12-bit ADC is used in this project to obtain digital codes of the input signal. The ADC input voltage range is 0V- 3.3V, and is supported by 16 channels on ESP32.Unfortunately, this ADC suffers extremely from DC non-ideal effects such as gain error, offset error, and differential non-linearity. To achieve specified precision of weight measure, these effects needed to be calibrated out. The method used to calibrate ADC's gain and offset error is two-point calibration method.

This method involves taking two input to the ADC to ($V_{in,A}$) 10% and ($V_{in,B}$) 90% of full scale and record the corresponding ADC codes. The slope of non-ideal transfer function is thus given by

$$Slope_{non-ideal} = \frac{ADC\ Code_B - ADC\ Code_A}{V_{in,B} - V_{in,A}} \tag{3.1}$$

Using arbitrarily point ($V_{in,A}, ADC\ Code_A$), the non-ideal transfer function is given by

$$ADC\ Code = Slope_{non-ideal}(V_{in} - V_{in,A}) + Code_A \tag{3.2}$$

Substituting $V_{in} = 0$ in equation 3.2, gives the ADC offset error. The linear model of an ideal 12-bit ADC transfer function is given by

$$ADC\ CODE_{ideal} = 2^{12}\left(\frac{V_{in}}{V_{ref}}\right) \tag{3.3}$$

Thus one can easily use equation 3.3 to find the ideal ADC code for the calibration input voltages $V_{in,A}$ and $V_{in,B}$, and the slope of ideal transfer function can be defined by

$$Slope_{ideal} = \frac{Code_{B,ideal} - Code_{A,ideal}}{V_{in,B} - V_{in,A}} \tag{3.4}$$

and ADC gain error is given by:

$$Gain\ Error = \frac{Slope_{non-ideal} - Slope_{ideal}}{Slope_{ideal}} \tag{3.5}$$

With this offset and gain error, the calibrated ADC code is given by:

$$Code_{calibrated} = (Code_{raw} - offset) * \frac{Slope_{ideal}}{Slope_{non\_ideal}} \tag{3.6}$$

This calibration approach was designed and tested during initial phases of the project and was deemed unreliable because of unstable ESP32's reference voltage. The comparison between this calibration and ADC calibration provided by express-if API was made and results are presented later.

Kalman Filtering With ADC calibrated, we needed to design a filter to mitigate the noisy analog signal from the scale as result of dynamic bird on the scale. The filtering used is One-dimensional Kalman filter. This filter analyses the system variable over time, and attempt to provide optimal estimate of the system variable. It is performed in the following steps:

- **Step 1 Initialization**: Provide initial estimate of the system state $X_{0,0}$ and variance $\rho_{0,0}$.
- **Step 2: Measurement**: This step is performed at every iteration in the filter. In provides current state measurement Z_n and its variance r_n.
- **Step 3: System Update** In this step, the filter uses current measurement, and previous state estimate to obtain current state estimate. This is done if the following steps:
  1. Compute Kalman gain by $K_n = \frac{\rho_{n,n-1}}{r_n + \rho_{n,n-1}}$, where $\rho_{n,n-1}$ is state variance estimated in the previous iteration, and r_n is measurement variance.
  2. Update state using state update equation

     $$X_{n,n} = X_{n,n-1} + K_n(Z_n - X_{n,n-1}) \tag{3.7}$$

     where $X_{n,n-1}$ is state estimate obtained in the previous state.
  3. Compute current state variance $\rho_{n,n} = (1 - K_n)$
  4. Extrapolate the state variance and state estimate using dynamic model of the system: $X_{n+1,n} = X_{n,n}$, and $\rho_{n+1,n} = \rho_{n,n} + q_n$, where q_n is the process noise variance.

The block diagram of kalman filter is shown in figure 3.4.

Figure 3.5 shows the flow diagram of data acquisition process.

3.4.4 Data Storage and Retrieval

The second sub-module of the Data System handled data storage ad retrieval from the ESP32 file system. The details of this module is presented in this section. For each data acquisition event, a data entry if the form: **<Tag ID> <Time> <Weight>**, is written to the data file. The file is stored

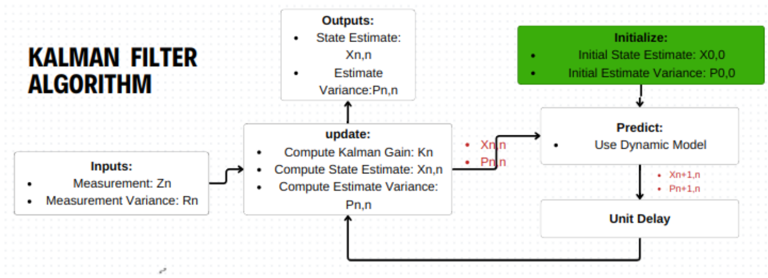


Figure 3.4: Kalman Filter Block Diagram

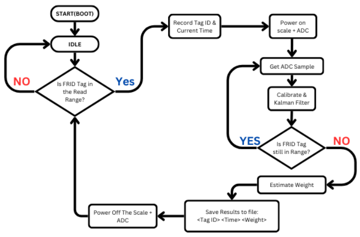


Figure 3.5: Flow chart of data acquisition process

in ESP32's light weight file system called **LittleFS**. *Tag ID* is bird's tag ID and is used to uniquely identify each data in JSON format, the **Time** is tie when that particular measurement was obtained These values are obtained from extremely accurate Real-Time-Clock module D3132. Furthermore, time is stored in format *HH:MM:SS*. The flow chat that shows how data is stored and retrieved from the system is depicted in figure 3.6. Also the system can receive configuration instructions from the mobile app, such as instruction to zero the scale,and so on.

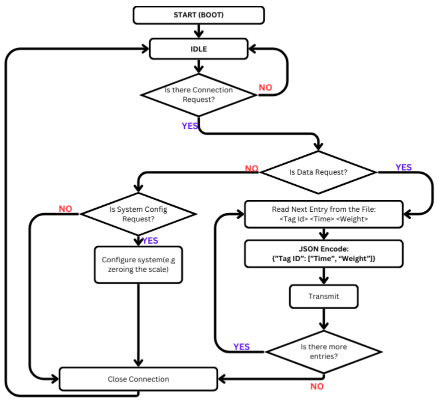


Figure 3.6: Data Storage and Retrieval Flow chart

3.4.5 Overall System Integration

The overall system state machine is shown in figure 3.7. As can be seen from the figure, the system has three states: IDLE, DATA ACQUISITION, and DATA TRANSMISSION. The IDLE is entered on boot and basically describes when ESP32 is in sleep mode. It is interrupt from the sleep mode in two ways; first by bird landing on the scale, interrupt is generated by the RDM6300 RFID reader module. Secondly, by the user button that is pressed when the user wants to configure the system or to retrieve data.

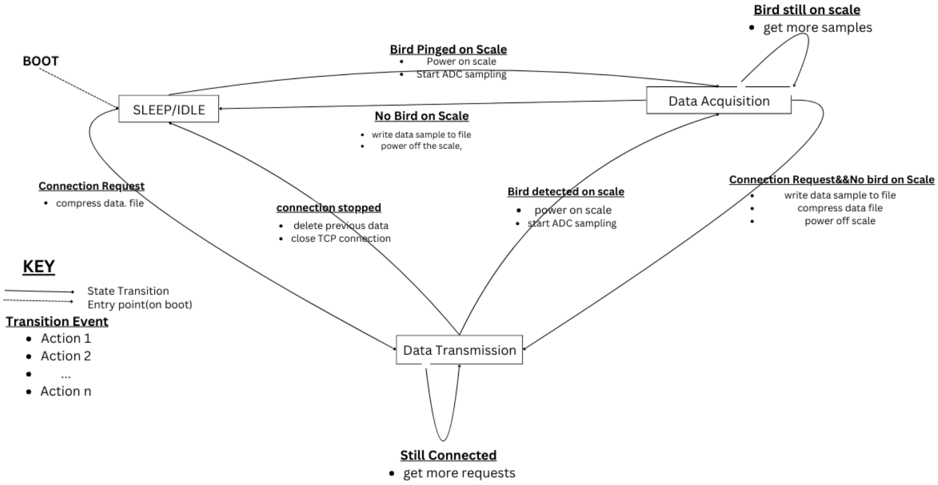


Figure 3.7: Data System State Machine

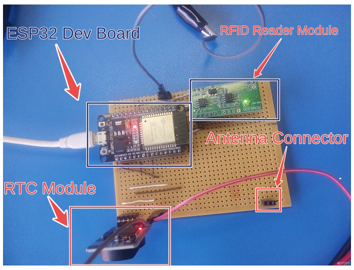


Figure 3.8: Final System Integration

3.5 Testing and Results

3.5.1 Acceptance Tests

3.5.2 Acceptance Test Procedures

This section details procedures followed to access if the system meets specifications and requirements.

ATP01- Calibrate Gain and Offset Errors of ADC This acceptance test procedure aims at obtaining accessing if the ADC output code correctly match to the input voltage. The pass of this contributes towards meeting user requirement **UR05**. Connect ESP32 Board to power via USB cable, a red power LED should immediately be on. Upload the sketch $ADC_Calibrate$, connect GPIO36 to the power supply. Firstly, set the input voltage to 0.33V (10% of 3.3V), and record ADC codes displayed on the Serial Monitor. Repeat this with input voltage set to 2.97V. Use equations 3.2 to 3.6 to obtain gain and offset error. Now set the input arbitrarily to 2.0V and use equation 3.6 to obtained the calibrated ADC code. The calibrated ADC code should map to input voltage with at-least 0.05V deviation from 2.0V.

ATP03 - Filter Converges to Optimal Input Voltage in Varying Input Voltage This acceptance test procedure was performed with the Scale. connect the output of the scale to GPIO36 of ESP32, and upload $kalma_test$ sketch, place a known mass of 33.0g on the scale and dynamically move it to mimic bird movement on the scale. The output of the filter should converge to an optimal input voltage that maps to weight of the object on the scale. When used with the voltage-to-weight transfer function, it should give approximation of mass within 0.1g uncertainty, effectively meeting user requirement $UR05$

ATP03- Write files to ESP32 LittleFS memory and read them back Connect ESP32 to the PC with USB as in ATP01, and upload the sketch, $LittleFS$, observe the texts being written to the file, and retrieved back to the file on the Serial Monitor.

ATP04-Minimal Power Consumption This ATP aims to access the amount of power that the system draws when in sleep mode, as compared to power consumed in active mode. The results from this ATP would validate if the system meets user requirement **UR01**, and system specification $SS02$. Connect all components of the system as shown in figure .3.8. Connect ammeter in series with the power supply, and upload sketch *test_sleep.ino* to the ESP32. Press the 'en' button to run code. The code will run and after approximately 5 seconds, will enter into sleep mode. After waiting that 5 seconds, record the current value displayed on the ammeter. This will be the sleep current of the system. Now bring 125kHz RFID tag to within 5cm from the antenna and wait for 2 seconds, this will interrupt system sleep mode, and drive it to active mode. After two seconds have elapsed, record the current value displayed on the ammeter. This will give current drawn when in active. This test will be passed if the sleep current is at-least 10 times smaller than the active current.

ATP05-Detect 125kHz RFID tag when within 5cm from reading antenna Connect GPIO5 and GPIO4 of ESP32 to Tx and Rx pins of RDM6300(see fig.3.2), and VCC and GND pins to V_{in}, and GND pins of ESP32 respectively(See fig.3.9). The green LED of RDM6300 board should be on. Upload the sketch $RFID$ to the ESP32 and press 'en' button to start. Bring the 125kHz RFID card to tag to within 5cm of the Reading Antenna. The Tag ID should be displayed on the Serial Monitor.

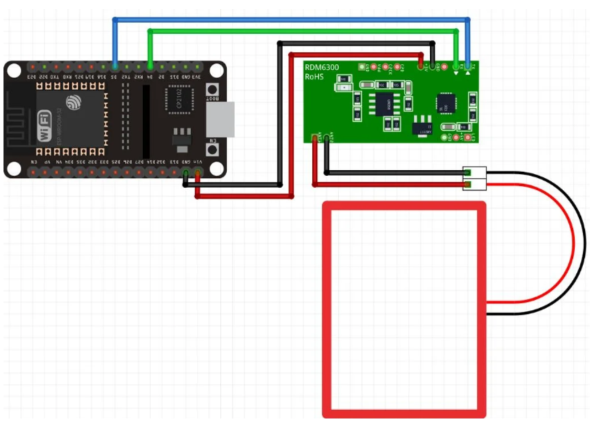


Figure 3.9: Circuit connection for testing RFID Tag Detection

ATP06-Timestamp data This acceptance test procedure validates with correct data timestamps of **HH:MM:SS** can be obtained from the D3231 RTC Module. Connect GPIO22 to SDA pin to D3132 and GPIO21 to CLK. the power pins, VCC and GND, should be connected to ESP32's 3.3V and GND, respectively and shown in 3.10. The read power LED on D3132 board should be powered on. Upload the sketch *Timestamp* into the ESP32 and start it by pressing 'en' button. The current time should accurately be displaying on the serial monitor in the format HH:MM:SS.

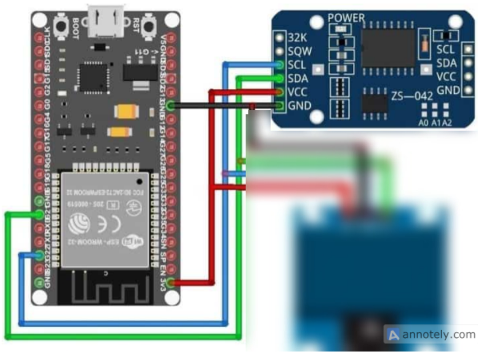


Figure 3.10: Circuit connection for reading data and time information form the D3132 RTC module

3.5.3 Results and Analysis

ADC Calibration

The following are data collected for calibrating the ADC:

- $V_{ref} = 3.3V$
- $V_{in,A} = 0.1 * V_{vref} = 0.33V$
- $V_{in,B} = 0.9 * V_{vref} = 2,97$

The ADC codes that were obtained as explained by**ATP01** are $Code_A = 278$ and $Code_B = 3870$. With these measurements, equation 3.1, were used to calculate the slope on non-ideal transfer function as was found to be $Slope_{non-ideal} = 1327$. Furthermore, ideal transfer function given in equation 3.3 was used to find the ideal ADC outputs, which were found to be $Code_{A,ideal} = 409$ and $Code_{B,ideal} = 3686$. This gave ideal slope of $Slope_ideal = 1241$.

From these measurements, the ADC offset error was found to be $Offset - Error = -159$. The ideal and non-ideal slopes were then used in equation 3.6, to obtain ADC codes, with gain and offset errors calibrated. Additionally, the input to the ADC was then set to 2.0V, and code recorded was 2384. Using the calibration above, this estimates the input to the ADC as 1.916V which amounts to $2.0 - 1.916 = 0.084$ uncertainty, thus failing ATP01.

The plot of ideal and non-ideal transfer functions of the ADC are shown in figure .**??**

3.5.4 Regression

To be able to obtain a relationship between scale output voltage and weight, several objects of known weight were placed on the scale and output voltages were recorded. A simple linear regression was

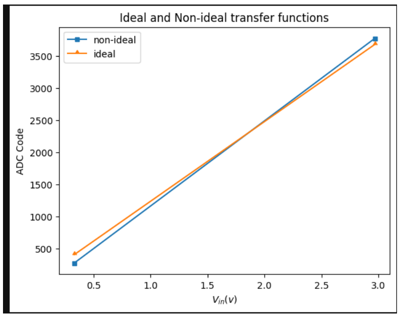


Figure 3.11: Ideal and non-Ideal transfer function of ESP32’ ADC1

then fitted into this dataset to try to obtain voltage-to-weight relationship. The plot of the model is shown in figure 3.12.

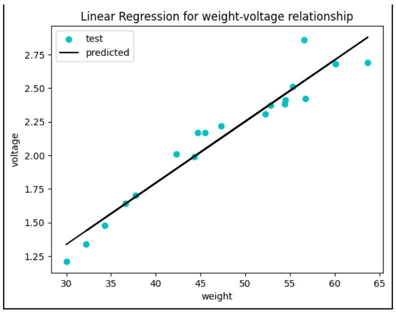


Figure 3.12: Linear Regression model used to obtain voltage-to-weight relationship

Kalman Filter Simulation Results

To validate the working of Kalman filter deployed in this system, it was first simulated in software using Jupyter notebook. The filter simulation data was gathered as explained in **ATP02**. The goal of the simulation was to verify that the filter converges to an optimal value of voltage input at the ADC pin. Furthermore, data was collected with calibrated ADC, from results found in the previous section.

The filter was expected to converge over at least 100 samples (100 iteration), and as shown in figure .3.13 this works as expected, effectively passing Acceptance Test 02.

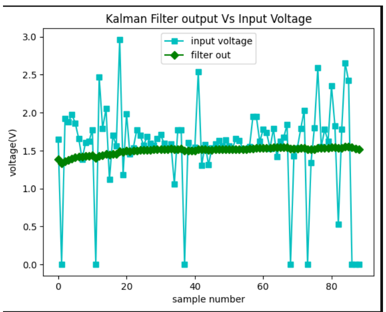


Figure 3.13: Kalman Filter Simulation Results

3.6 Conclusion

Chapter 4

Power Design

This section was completed by Revashan Soobiah - SBHREV001

4.1 Introduction

The power sub-system plays a crucial role in the design process, as it is the backbone of modern civilisation.Ben Murphy uses a scale to collect data on the weights of the fork-tailed Drongo birds, this data helps to identify the effect that the climate has on birds, therefore the continuous operation of the device requires a reliable power subsystem that is able to withstand harsh conditions.

This chapter details the design process of the power module. It is responsible for supplying power to the scale sub-system and the data acquisition and retrieval sub-system. The current system runs on batteries that are manually replaced. The new design mitigates this with a combination of batteries, solar panels and power management systems.

4.2 Requirements

4.2.1 User Requirements:

An interview with Ben Murphy was held towards the beginning of March. From that interview, the following requirements were provided:

Label	User Requirement
UR01	It must be cost effective
UR02	The power system must have a long lifespan
UR03	It must be able to show battery percentage
UR04	it must be able to withstand the harsh conditions

Table 4.1: User Requirements

4.2.2 System Functional Requirements

From the user requirements, further requirements can be made in terms of the physical power subsystem.

Label	System Functional Requirement
SFR01	In order to meet UR01 cheap components must be selected within reasonable ranges
SFR02	In order to meet UR02 solar panels and rechargeable batteries must be implemented
SFR03	In order to meet UR04, SFR01 must be taken into consideration when choosing components for harsh environments

Table 4.2: Functional System Requirements

4.3 Specifications

From the above User Requirements and System Functional Requirements, specifications are able to be drawn.

Label	Specifications
SP01	Must supply a regulated 5V to the ESP32
SP02	Must supply a +-5V to Instrumentation amplifier.
SP03	Batteries must use solar energy to recharge and store energy.
SP04	UVLO circuit regulates input to 5V, if voltage goes below threshold, it cuts off
SP05	Voltage range of 6V - 16V solar power regulated down to 5V
Sp06	Over-voltage protection circuit cuts off when voltage after the linear voltage regulator goes higher than 5.2V

Table 4.3: Specifications

4.4 Design Process

Talk about what other peoples sub-system need, what I need to do for it. Include power requirements of each sub-system, as well as perhaps solar energy - come later maybe final iteration - Voltage and current requirements Various factors are taken into consideration when analysing the specific power requirements needed for the scale.

4.4.1 Power Source

Since Ben works in the Kalahari desert, solar power with rechargeable batteries will be the optimal choice in renewable energy, such that Ben does not need to replace batteries often. Talk More on here

4.4.2 ESP32 Micro-Controller

The ESP32 Micro-Controller has 3 different options in order to power on:

Scale Sub-module

The scale sub-module uses an instrumentation amplifier to amplify small voltages in the presence of high noise levels. This is what will be used to determine different weights at different voltages. As such, it needs +5V and -5V in order to operate.

Options:	Reasoning:
3.3V	Initially, the 3.3V pin was chosen, however since the RFID reader uses 5V, it was deemed inefficient to use this 3.3V pin. Hence why it was not chosen.
Micro-USB	This option was not viable due to the power module being placed within the scale, it would be hard to reach the point of insertion. Hence why it was not chosen.
5V	Since the RFID reader uses 5V, it was deemed efficient to use this pin as there would not be added components to step-up the voltage. Hence this pin was chosen.

Table 4.4: Options to power on the ESP32

Since voltage is determine by a point and ground, a secondary ground is created. 10V will be supplied, using a Dc to Dc Boost converter. A voltage divider circuit will be used to create +5V and ground, the +5V will now be the new 'ground' and ground now becomes -5V.

4.4.3 System Overview

Insert the picture here. Do it somewhere online

4.5 Design Choice

Talk about designing - Go backwards, Include how I got design, LVR, OV , UVLO , Boost COnverter - 555timer etc. and Power Source

4.5.1 Linear Voltage Regulator

4.5.2 Boost Converter-555timer

4.5.3 Over Voltage Protection

4.5.4 Under Voltage Lock Out Protection

4.5.5 Charging and Discharging Circuit

4.6 Acceptance Test Procedures

4.6.1 Unit Testing

Test Everything Individually

Battery and Solar Panel

Charging and Discharging Circuit

Linear Voltage Regulator

Boost Converter

Protection Circuitry

4.6.2 Integrated Testing

Test everything together

4.7 First Iteration

Include Actual Boost-converter -'actual' on veroboard

4.7.1 Power Losses

4.8 Final Design

Include veroboard - If I have time Include if anything went wrong -Why I chose this and why I change to PCB, etc. Include boost IC

4.9 Next Iteration

PCB iteration

Chapter 5

User Interface

5.1 Introduction

An appraisal of the problem analysis indicates that a significant amount of time was spent by the user in reviewing data acquired in the field. Previously, the user would read mass values from the scale using binoculars from a distance so that the subject could land on the device. This method of recording and viewing mass was inefficient: requiring a significant amount of time to setup data capture and to analyse the data.

This chapter details the design of the user interface and wireless communication which addressed the shortcomings of the method described above. The chapter begins with a recount of the user requirements in the context of viewing the weight data. An analysis of the requirements follows, which is then used to support the formulation of design choices in the next section. The subsystem design section describes the mobile application and wireless communication it establishes with the micro-controller. The chapter ends with a description of tests of the mobile application and the wireless network. A conclusion is drawn on the results from the acceptance tests of the subsystem.

5.2 Sub-system Requirements

5.2.1 User Requirements

The user interface was required to be a mobile application to interact with the scale. The following user requirements were given in the initial stages of the design process:

- The user interface must run on a mobile device
- View the mass of the bird weighed by the scale
- Associate a mass with a bird identity

5.2.2 Functional Requirements

The following functional requirements are expanded from the above user requirements:

- The mobile application should be compatible with commonly used mobile devices, e.g. smartphones, tablets, laptops, and commonly used operating systems, eg. Android, Linux, Windows.
- The interface must be able to send and receive packets of data from the micro-controller subsystem.

- The interface must display weight measurements in real-time from downloaded data, allowing users to monitor ongoing data capturing events promptly.
- The application must provide features for associating measured mass values with specific bird identities, either through manual input or automated identification.
- The subsystem must be able to interact with the scale device by sending operational commands such as resetting the scale between weighing subjects.
- The application should be able to store collected data for future access and viewing while maintaining the state of the data.

5.2.3 Non-functional Requirements

The following requirements serve as a basis that can be used to benchmark the operation of the system:

- The user interface should be intuitive and easy to navigate and require no training for users to operate effectively.
- The application must ensure consistent performance and present data accurately under different conditions.
- Contents of data views must be streamlined and allow for searching and data manipulation processes to minimize the time and effort required for data analysis.
- The mobile application should be built at a low cost.

5.2.4 Requirements Analysis

One of the main requirements of the user interface subsystem is that it must operate on a mobile device. A mobile application would provide users the flexibility to access the interface in remote areas where avian targets are located. In the case where the weighed subject is located in a remote area such as in the desert, the mobile application would require means to send and receive data from the scale device. Therefore, this subsystem must also consider the design of a wireless communication protocol to facilitate data transmission between the host device of the mobile application and the scale device. The integration with the wireless communication protocol should be seamless, allowing for transmission of different types of data associated with weight and the operation of the scale.

The value of the mass captured in the micro-controller subsystem needs to be transferred to the user interface for viewing through the wireless communication protocol that connects the mobile device to the scale's micro-controller. This addresses the core functionality of the user interface subsystem, facilitating data interpretation and analysis. A review of the problem analysis also indicates that this requirement must be considered with respect to how the data being viewed is sorted because users spend a lot of time sorting field data. Overall, the view of the data must be easy to read and interpret, and must not inundate the user with unnecessary information. It must clearly show the mass of the weighed subject and clearly label other information related to the user's objectives. These objectives form a guideline about other data that is required to make information about the mass of the target to be more robust. This may include information about where the data was collected and a timestamp to indicate the time and date of capture.

Each data capturing event is associated with a specific subject. The user needs to be able to reliably identify the subject that provided the mass reading being viewed. This will allow the user to be able to efficiently identify patterns in the mass of the birds, and allow for grouping and sorting the data for further analysis of an individual bird. This implies that the user interface subsystem needs to transmit an ID value along with any information capture with a data capture event.

The direct link between the mobile application and the scale device is such that each component cannot operate fully without the presence its counterpart. This implies that a user also needs to view information about the status of the scale device. This could include information about the wireless connection facilitating the communication between the mobile device and scale, as well as information about memory and power usage.

Users also need the user interface for access to the hardware features on the device. Since the scale will be designed to be used for birds, a typical scenario for data capture would require the user to be located away from the scale. Allowing the user to be able to perform operations such as resetting the scale reading before a subsequent weighing event. This implies that the subsystem must provide means to transfer instructions from the mobile application to the scale to avoid disturbing the subject during a data capturing event.

5.2.5 Design Choices

The following section discusses considerations for meeting the requirements, compares available options and elaborates on the selected solution. The focus of the considerations includes figures of merit related to cost, implementation, ease of testing, reliability and maintenance costs in the design process.

Mobile Application Prototyping Tools:

The design cycle of the user interface includes a prototyping stage. The aim of a prototype is to allow for the visualization of the app interface, user interactions, and user flows. Prototypes can be low fidelity, high fidelity, manual, and interactive. Mobile application prototyping tools are a type of software that allow designers to create high-fidelity prototypes efficiently.

When considering mobile app prototyping tools, Figma stands out as a comprehensive solution offering numerous benefits over other options. Here, we compare Figma with two honorable mentions—InVision and Adobe XD—highlighting Figma's advantages in various aspects:

Figma vs. InVision:

Figma offers a seamless and intuitive interface, allowing designers to create high-fidelity prototypes efficiently. Unlike InVision, Figma provides robust collaboration features that enable real-time editing and feedback, eliminating the need for cumbersome approval processes. Moreover, Figma's compatibility with multiple operating systems and devices makes it a versatile choice for design teams working across different platforms. While InVision excels in user-friendliness and offers a wide range of templates, Figma surpasses it with its advanced prototyping capabilities and extensive plugin ecosystem.

Figma vs. Adobe XD:
Figma outshines Adobe XD with its cloud-based platform, enabling seamless collaboration and version control among team members. Unlike Adobe XD, Figma offers a more flexible pricing structure, making it accessible to freelancers and small design teams. Additionally, Figma's robust prototyping features, including advanced interactions and animations, give designers more creative freedom in crafting interactive prototypes. While Adobe XD boasts tight integration with other Adobe Creative Cloud apps and a familiar interface for Adobe users, Figma's collaborative workflow and extensive feature set position it as a top choice for mobile app prototyping.

Comparison Table:

Features	Figma	InVision
User Interface wide range of templates	Intuitive and seamless	User-friendly with a
Collaboration	Real-time editing and feedback	Collaboration features with version control
Compatibility	Multi-platform support	Limited compatibility with certain devices
Pricing	Flexible pricing structure	Pricing upon request
Prototyping Features	Advanced interactions and animations	Standard prototyping capabilities

From the comparison above, it's evident that Figma offers a superior combination of features, collaboration capabilities, and flexibility compared to its competitors, making it the preferred choice for mobile app prototyping.

Mobile Application Platform Selection:
Flutter vs React. Web vs App
Wireless Communication Protocol Design:
HTTP vs Bluetooth vs USB vs Cloud
Real-time Data Display Optimization:

User Interface Data Sorting and Labeling: Sorting algorithms

Subject Identification Mechanism:

Scale Device Status Monitoring:

Hardware Control and Interaction:

5.3 Submodule Design

5.3.1 Design Specifications

5.3.2 Testing and Validation

Unit Testing

Test individual components

User Acceptance Test

Performance tests

Operational Acceptance Testing

Integration Testing

Test integrated component

5.3.3 Alpha Testing

System Testing

Test the entire system

Acceptance Testing

Test the final system

Chapter 6

Bill of Materials

Scale Subsystem	
Item	**Price**
AD620	R39.10
Load cell 1kg	R45.00
LM358	R2.88
IRF5904N	R6.9
Through hole resistors*8	R1.12
Zener diode	R1.04
3D printing filament	R90
PN2907A*2	R2.02
Total	188.06
Power Subsystem	
Item	**Price**
Item 1	Price 1
Item 2	Price 2
Item 3	Price 3
Item 4	Price 4
Item 5	Price 5
Item 6	Price 6
Item 7	Price 7
Item 8	Price 8
Item 9	Price 9
Item 10	Price 10
Microcontroller Subsystem	
Item	**Price**
ESP32	R205
D3132 RTC Module	R52,17
RDM6300 RFID Reader	R73,04
Total	R330.21
GUI Subsystem	
Item	**Price**
Item 1	Price 1
Item 2	Price 2
Item 3	Price 3
Item 4	Price 4
Item 5	Price 5

Table 6.1: Table with 2 columns and 10 rows

Chapter 7

Conclusions

> The same rule holds for us now, of course: we choose our next world through what we learn in this one. Learn nothing, and the next world is the same as this one.
>
> —*Richard Bach, Jonathan Livingston Seagull*

The purpose of this project was to...

This report began with...

The literature review was followed in Chapter...

The bulk of the work for this project followed next, in Chapter...

In Chapter...

Finally, Chapter... attempted to...

In summary, the project achieved the goals that were set out, by designing and demonstrating...

Chapter 8

Recommendations

It is for us the living, rather, to be dedicated here to the unfinished work which they who fought here have thus far so nobly advanced.

—*Abraham Lincoln*

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