Contents

List of Figures

Chapter 1

Introduction

This project was one of several presented to the EEE4113F Design class of 2024. The clients were a group of researchers from the Fitzpatrick Institute of African Ornithology, all of whom were engaged in the research of birds in their natural environments across the country. The researchers had approached the class in the hopes that we could make their research easier. This would be done by improving some of the labour intensive methods used for recording and/or retrieving data. This could be done via automation or the introduction of a new technology entirely. Our group (Group 3) decided to work with Dr Sally Hofmeyr, a researcher focused on the Red-winged Starling's breeding habits. Primarily, how a busy environment containing an abundance of food, many people and potential predators affects breeding; as well as why the rate of failure of their nesting attempts is so high.

The problem that Sally brought forward is the difficulty with which they retrieve the weight data of the Red-winged Starling. This information being important as it could lead to insights into potential causes for nesting failure and to see how the weights of the birds fluctuate during the breeding process. Currently the researchers use a standard kitchen scale and place bait of some form (normally raisins) on the scale and wait for the birds to approach and step on the scale. They would then stand near by and observe the value displayed on the scale and manually record it on a laptop spreadsheet or sheet of paper to later be processed. This method has been successful thus far due to the domesticated nature of the Starlings, however it is quite tedious and somewhat cumbersome.

The proposed solution is a portable, chargeable scale that would automatically send stable weight readings to a web server. The client would be able to access this web server from any device with internet connectivity, where they can both view the incoming readings, add valuable information such as the bird's identification and send the data to a back-end Google Sheet. Once all the measurements for the day had been collected, the researchers can access the Google Sheet and download it to their local devices.

The customized scale design aids in making the process more portable. It was designed to be more lightweight than standard scales, while also being less cumbersome to handle due to its smaller size. Additionally, since it was designed with all other features in mid, the entire functionality of the scale is enclosed in a singular closed device.

The appropriate use of filters can be used to collect stable readings from the load cell sensors. It useful to keep the outputs as stable as possible, as the outputs from the scale will be easier for the client to read and associate with the appropriate bird.

Creating a chargeable scale is beneficial due to its simplicity with respect to the client. The researchers don't need to worry about batteries, but can simply ensure the scale is fully charged before they go into the field to weigh the Starlings. The power system has also been designed such that it can last a full working day without needing to be recharged. This provides ample battery life for the researches to complete their work.

The use of wireless communication between the scale and the client's device was decided upon due to the easy access the client will have to the data from the scale without having to be near it. A web server is particularly useful for this application, as it allows for the entire data collection process to be automated - all the data is automatically available on the client's device and they simply need to commit the data to a spreadsheet with the press of a button. This makes the weight-collection process less tedious and labour intensive, and reduces opportunity for human error.

Chapter 2

Problem Analysis

At the Design School (D-School), we discussed and practiced identifying problem spaced and developing problem statements for clients. This includes viewing the problem through a client focused lens, instead of a technical 'engineering' lens. We learnt to first get to know the client as a person, with their own problems and feelings. This was to create a more tailor-made solution that might not have been immediately obvious had we only focused on the technical details of the problem space. We learnt how to develop effective prototypes to communicate the functionality of our product and put this skills into practice. Finally, we were also given the opportunity to communicate with the clients from the Fitzpatrick Institute about their problem spaces.

We decided to tackle the issue of weighing Red-Winged Starlings on UCT Upper Campus. The clients required a method to capture the Starlings' weight without getting too close so as to scare them away. We decided to develop a portable scale that could automatically capture the weight of the birds on a server that the clients could easily access from any internet-connected device. Additionally, the researchers would be able to input necessary information, like the birds' IDs.

We initially considered designing a scale with a long battery life, including solar panels, that could be left for multiple days on end, that would capture photographs of the birds being weighed for identification purposes. After further communication with the clients, however, it was established that this would not be appropriate. The researchers prefer to walk around campus with a portable scale to weigh the Starlings that nest in the different areas on campus. Therefore we opted for a charging mechanism instead, due to its simplicity and ease of use. Since the clients will always be near the scale, it would be very simple to identify the birds themselves. Therefore this idea was neglected in favour of developing a webserver from which the clients could input this data.

The project consists of the following subsystems:

Body and Layout - [redacted] The body and layout subsection focuses on the design of the scales' and ensuring that all the other subsystems fit well inside of it. It was also responsible for ensuring that the weights of the birds could be transferred adequately to the processing sub-module.

Power - [redacted] The Power subsection focuses on the design and implementation of the main source of energy to the rest of the system .The section is responsible for interconnecting all relevant components to provide consistent power over extended periods of time.

Data Collection and Processing - [redacted] The data collection and processing subsystem is aimed at collecting the signals from the weight sensors and converting it into a stable weight reading in grams. This involves manipulating the very small signal from the load cells, feeding it into an analog-to-digital converter (ADC) and converting it into grams, as well as implementing methods of keeping the value stable such that it is simple to read.

User Interface - [redacted] The user interface subsystem is dedicated to creating an intuitive webpage designed to streamline the data capturing process. By simplifying the pipeline of steps involved in labeling and recording data, it enhances efficiency. Additionally, it serves as a front-end platform for users to easily interact with the system in its entirety.

Chapter 3

Literature Review

3.1 Introduction

A bird's body weight is a crucial metric within the field of ornithology, wildlife conservation efforts and commercial breeding. It's a single data point which can help illuminate a bird's health status, energy consumption, breeding behaviour and more. It is because of the wealth of information one can obtain from a bird's weight that there is great demand across avian-related sectors for simple, intuitive weighing scales modified to suit various applications.

Researchers at the Fitzpatrick Institute require a highly portable weighing scale that can automatically weigh Red-Winged Starlings on the University of Cape Town (UCT) campus. Additionally, researchers need to be able to obtain the measurements in real-time without physically approaching the scale. This literature review aims to investigate previously used methods of weighing birds and other wildlife whilst considering various factors that could affect the success of the equipment or disturb the birds. Additionally, it will discuss the technical requirements of such an apparatus, with a focus on it algorithms for data processing, power supply and data transmission, storage and retrieval.

3.2 Significance of Body Weight

A bird's body weight is an important metric within the field of ornithology. G.A. Clark [2] acknowledged the importance of using this metric as a standard unit of comparison between birds. A bird's weight is a reflection of its health, breeding activity and energy consumption [2]. The importance of this measurement is not only limited to research of wild birds; it is vital information for the commercial rearing of broilers [3]. An updating database with the average weight of a population of broilers over time provides farmers with access to crucial health indicators, thereby enabling early detection of a decline in health and quick response [4], as well as the ability to adjust the amount of feed provided to an appropriate volume to adequately control weight gain [3]. Due to the wealth of important information one can obtain simply from a bird's body weight, an accurate, portable scale would clearly have many potential applications within research, conservation efforts and commercial breeding.

3.3 Factors for Consideration when Attracting Starlings to the Scale

Deciding on ways to capture the attention of the Red-winged Starlings long enough to measure them was necessary. The Red-winged Starlings are intelligent birds that inhabit areas from Eastern to Southern Africa [5]. The research on their behaviors and diets may vary according to the specific region the research was done in. The focus in this context was on those that reside in urban areas. However, some relevant points were considered where some traits were shared between some breeds from the same or close families.

3.3.1 Feeding Habits & Diet

Starlings appear to have a wide range of choices when it comes to their diet. They eat everything from agricultural matter to animal matter. From a study done on the European starling, Red-winged Blackbird, and Brown-head Cowbird, varying amounts of corn, insects, animal and plant matter were found in their digestive systems [6]. While the primary source of nutrients does appear to be more flora oriented there is a clear trend of fauna and insect consumption. This is further supported by research done by Sarah Catto on the starlings based on the UCT campus [5]. This indicated a clear correlation between the birds feeding habits and the presence of humans on the campus along a 7 day cycle. There are also direct accounts of the birds consuming and even stealing human food from students [7]. While this does mean that almost any bait would be plausible, it does make it a bit harder to decipher which would be most effective. Sally Hofmeyr, one of the Red-winged Starling researches under the Fitzpatrick Institute stated in a Q&A session on February 23, 2024 that they have been and are keen to continue using squashed raisins as a way to attract the birds while keeping them on the scale for the necessary duration of time.

3.3.2 Appearance of the Weighing Scale

Aside from the correct bait to attract the birds, it is important to consider the physical appearance of the scale, all it's auxiliary parts and the role they play.

One way of attracting the birds to the scale would be to directly design it in such a way that it is inviting to the birds, such as bird feeders. A study into the difference of preferences between urban and rural birds found that there was a strong tendency for urban birds to go for green colored feeders as opposed to other colours [8]. However, it was implied that this has minimal to do with the green resembling nature.

Disguising the scale is an alternative option. This could be anything from covering the scale with leaves and branches to partially burying it/embedding it into the ground. However, this has the potential of causing weighing errors should the birds shift or add foreign objects after it has been calibrated. This may be more harmful than helpful as hiding the scale has a minimal impact on the bird itself. A. Golawski and H. Sytykiewicz [8] somewhat support the interpretation that birds familiar with the urban setting had no direct desire for natural greenery. Additionally, A. Poole and J. Shoukimas directly support it through their research on perch scales: 'This scale takes advantage of the fact that many birds use habitual perches and will often shift to artificial perches if these are placed in their habitual sites' [9]. This implies that our scale appearing as artificial would not deter the Starlings. However, it is important to note that the study was focused on Ospreys and perch mounting birds and this may be different for birds bred in a more urban environment such as the UCT campus.

3.3.3 Potential Disturbances

When considering ways to attract the Starlings to the scale it is also important to consider factors that could deter the birds from interacting with the scale completely. A lack of understanding in these factors could lead to counterproductive design choices.

Electromagnetic Waves (EMW)

A potential solution actively makes use of WiFi transmission of data. Consequently, it is important to consider the impact that the electromagnetic waves transmitting within the MHz radio frequency range (10MHz - 300GHz) [10] will have. Out of all fauna studied, birds are noted to have the highest sensitivity to EMW [10]. As stated by R. Bhattacharya and R. Roy, 'Birds are highly affected due to their thin skull, their high mobility and their feathers as dielectric receptors' [11]. The majority of the negative impact is centered around the nesting characteristics of the birds. Birds tend to create their nests starting at 80m away from cell towers. This has potential adverse impacts on the nest building, egg fertility, hatching and survival of chicks [11]. Taking all of this into consideration, the EMW created by the wireless electronic weighing scale is likely to be insignificant as most of its use will be away from the Starling nests and the EMW already present on the campus (created by the ubiquitous supply of WiFi to the students) will likely overshadow the scale's.

Cables

Birds have a predator/prey relationship with snakes depending on the ecosystem and species of the bird. Due to this, it is sometimes a concern how the birds will react to electric cabling as it can often be misinterpreted for the reptile. One instance of this being the secretary bird attacking and damaging any visible cabling, as snakes are a component of their diet as stated in the Q&A session (Wesley , Secretary bird researcher, Fitzpatrick Institute, February 23, 2024). In the case of the starling, particularly the Red-Winged Starlings on the UCT campus, this may not be a concern due to the nature of the urban environment. Birds in urban environments are less affected by visual deterrents such as artificial snakes, owls, etc; likely due to their high intelligence as well as becoming accustomed to their 'immobile, predictable presence' [12]. This implies that even if any cabling should appear snake-like, it would not be of major concern.

Materials

To prioritise ease of design, cost and construction of the body of the scale, a preferable option would be the use of 3D printing. It has been shown that, generally, birds have a neutral reaction towards 3D printed objects - even imitation eggs placed in nests [13]. It is still necessary to ensure the materials used will not have an adverse impact on the birds themselves. 3D printers are able to use a variety of different filaments based on different plastics and composites, with the objective of having different properties for different uses. Among these is a filament made of polytetrafluoroethelene (PTFE, Teflon) which is also used to line the hot ends of some lower cost printers [14]. This material is commonly used, but it is also highly toxic to mammals and especially birds when the fumes from heating it to ± 202 °C are inhaled - a process which is necessary for the printing of certain materials [15], [16]. While this is a concern, since the scales will be printed separately and indoors, once they are already printed the solid scale will be harmless. The choice can also be made to use friendlier filaments with lower heating points such as Polyactic acid (PLA) which will mitigate both potential sources of concern [14], [17].

3.4 Commonly Used Weighing Scales

An outcome of the importance of a bird's body weight is a multitude of various weighing methods designed and tested for assorted birds and environments. A commonly used method is the capturing and manual weighing of birds [3]. Unfortunately, this method is labour intensive and induces stress in the birds being captured [9], [4]. The use of an automatic scale which does not require the capturing of birds would therefore be beneficial in mitigating these adverse effects.

An early example of a scale used within field research is a spring scale suspended with food provided in a hanging pouch [18]. Advantages of this set up include that it is inexpensive and highly portable [18]. Such a self-centering scale could also have positive effects on its accuracy because exact placement of the load will not greatly affect the measurement, as opposed to strain gauge based scales [19]. The usage of a suspended pouch with food will, however, affect the measurements as the weight of the food will contribute to the total force being measured. Regular calibration of the scale would be required to account for this extra weight which would be changing with time as birds eat. This would likely be a tedious task and negatively affect the accuracy of measurements.

A. Poole and J. Shoukimas [9] designed and tested an electronic scale consisting of a perching platform on top of a plunger. The usage of an automatic and electronic scale was justified as it mitigates the difficulties and wildlife disruption of capture and manual weighing. When loaded, the plunger would push down - aided by a mechanical guide - onto a transducer beam that would output an electrical signal proportional to its deflection [9]. The transducer provided $\pm 1 - 2\%$ error for 'static objects of known weight [that] were fairly well centered on a perch.' The error increased when the perch was loaded on either end [9]. This highlights a critical problem with weight scales: the positioning of a load on the scale can affect the measured weight. This effect of the positioning of the load needs to be mitigated for the purpose of weighing birds in the field, since researchers cannot control where birds will settle.

The position of the load on the aforementioned perch scale impacted the friction between the plunger and the plunger guide due to slight rotation of the device, which in turn affected the force applied to the transducer beam [9]. W.V. Reid [19] addressed these sources of error by placing the weighing platform directly on the transducer beam, as well as placing two sets of strain gauges on the beam to measure the difference in deflection. This overcame the issue of friction, and equalised the measurements for a load placed anywhere along the parallel axis of the beam. It did not, however, remove errors associated with varying position along the transverse axis of the platform.

The use of lever mechanisms in modern scales has developed to increase the independence of measurement accuracy and the exact location of the load [20]. This involves the use of carefully placed levers in the construction of the scale that, based on static force analysis, will result in a constant force applied to the sensor for a given load, regardless of the load's position [20]. Usage of a lever mechanism to improve accuracy is a worthwhile consideration, whether a commercial scale will be used and adapted or if one will be built from scratch.

A potential issue with automatic weighing platforms or perches is ensuring the bird is resting its entire body weight on the weighing scale. Erroneous measurements might be collected if the bird only partially perches on the scale, whilst keeping contact with the floor or another structure [21]. This would have to be considered in the design of the apparatus to maximise accuracy.

Strain gauge load cells are a commonly used sensor device to measure strain within a material, from which the applied force can be obtained [22]. Its common use and reliability for creating weighing platforms is reflected in much research, such as H. Schomburg et al. [4] and D. Zhou et al. [3] who developed strain gauge-based weighing platforms for average weight estimation of broiler chickens.

A strain gauge load cell is likely a suitable sensor to use for the application of weighing red-winged starlings due to its common use, and therefore availability, and its reliability. In combination with lever mechanisms to create load-position independence, as well as physical design choices to ensure the starlings entire weight is measured, the development of a reliable platform scale is feasible.

3.5 Power Supply

3.5.1 Powering Devices for Wildlife Monitoring

The power supply unit plays a vital role in the proposed wildlife monitoring system by effectively overseeing the distribution and utilization of power across different components of the system. There are many ways to power an electronics system in remote areas, more precisely in the wild. A popular solution is using a rechargeable and solar powered battery.

S. S. Sethi et al. [23] discusses the development of a solar-powered autonomous monitoring unit. The author highlighted the importance of designing a robust system to ensure fully continuous monitoring over a long period of time by carefully selecting the battery and electronics equipment to function within different temperature conditions. H. Heldbjerg et al. [24] used batteries to power the GPS devices used to track the movements and foraging behavior of Common Starlings in Denmark, enabling independence from an external power source for up to 32 hours before having to change or recharge the battery.This is desirable to solve Sally issues in the process of weighing starlings

On the other hand, M. Bateson et al. [25] employed a different method for studying European starling behavior, which included the utilization of smart bird feeders equipped with a motorized retractable food hopper and an electronic balance. The station was directly connected to the electricity grid and linked to a computer running control software, eliminating the need for batteries. However this cannot be used for our purposes because the scale needs to be highly portable.

For our project, a solar panel may not be practical due to the portability of the scale, which moves around throughout the day. Additionally the birds need to be weighed at various locations, meaning constant sun exposure cannot be guaranteed.

3.5.2 Battery Management System

S. S. Sethi [23] and M. Bolton et al. [25] mentioned the importance of using a reliable battery management system. M. Bolton experienced battery voltages dropping too low - typically below 6v - during the process of recording images which led to irreversible corruption of the memory cards and the subsequent permanent loss of all the saved images [25]. S.M.Kross et al. [26] highlighted in his paper that battery malfunction happened 10 times, resulting in a loss of 492 hours of filming, which accounted for 14% of the total deployment duration. Additionally, among all camera failures, 52% were attributed to issues with the battery. To ensure the reliable and efficient operation of the system, the power management unit of V. Galvín [27] consists of various essential components, each tailored to perform distinct functions. Such important components should be considered for any power system design.

A reliable power subsystem is crucial for ensuring the seamless collection of data without any corruption in our application of weighing starlings.

3.5.3 Battery Selection and charging system.

V. Galvín [27] went further by selecting lithium-polymer (LiPo) batteries which necessitates an appropriate charging controller for optimal battery performance and longevity. A comprehensive review comparing LiPo and Lithium-ion (Li-ion) batteries highlights their distinct advantages [28], [29]. LiPo batteries offer versatility with various form factors, while Li-ion batteries provide higher energy density for longer runtimes and lighter weight. Additionally, the metal enclosure of Li-ion batteries ensures enhanced safety compared to LiPo counterparts [28].

These insights inform prudent battery selection in diverse applications. Furthermore, C. Alippi [30] utilised a battery with a storage capacity exceeding the daily requirements of the system. Given the battery's capacity exceeds system needs, even during cloudy or rainy days when solar charging is limited, the battery would still retain adequate reserves to sustain system operations. These would be ideal since the starling researchers would like to have batteries that last as long as possible.

In their study, M. Chen et al. [31] emphasized the vital role of a battery charger. This is especially important because Li-ion batteries are sensitive to overcharged voltages, requiring careful consideration in the charger's design. Even minor deviations in undercharged voltages can notably impact the battery's capacity [31]. Thus, meticulous attention to the charger's design and functionality is necessary to guarantee optimal performance and longevity of the battery.

Effective power management is crucial for self-powered bird monitoring systems. Key findings emphasize the importance of selecting appropriate battery technologies, implementing robust battery management systems, and integrating renewable energy sources like solar power. Meticulous attention to design and functionality is vital to mitigate risks and ensure reliable data collection for understanding avian behavior and ecology.

3.6 Algorithms and Neural Networks for Weighing Small Birds

Neural Networks such as Artificial Neural Networks (ANNs), Bayesian Artificial Neural Networks (BANNs), and Back Propagation (BP) neural networks, demonstrated significant utility across diverse fields. A typical Neural Network is structured in three layers. The first layer, known as the input layer, consists of input nodes that are determined by user-defined parameters. The second layer, called the hidden layer, processes the input data through a series of weighted connections. Finally, the third layer, or the output layer, produces the neural network's final output.

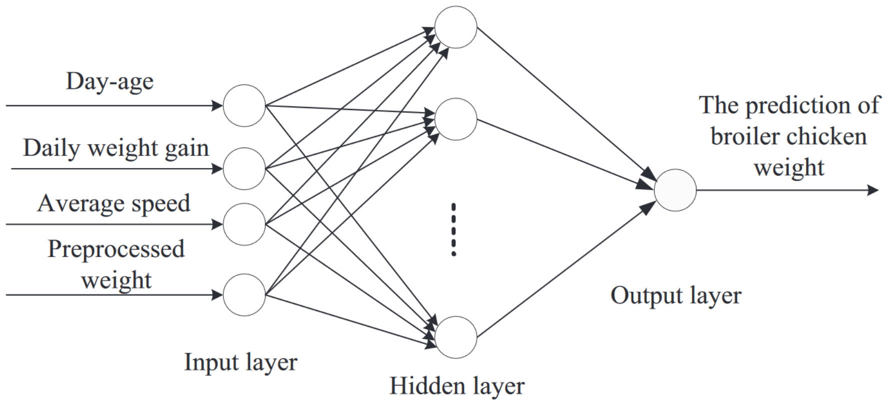


Figure 3.1: Example of a Neural Network implemented by W. Ma et al.[1]

The domain of wildlife monitoring has increasingly utilized neural networks for tasks such as automatic animal weighing [1]. Given the robust modeling capabilities of these networks, it is conceivable that they could be employed for automatically assessing the weight and identifying birds, such as the Red-winged Starlings.

3.6.1 Artificial Neural Networks (ANNs)

Artificial Neural Networks (ANNs) are computational models inspired by the human brain's neural networks, used to recognize patterns in data. They are generally good for tasks where complex patterns need to be identified, such as in identifying bird species based on their characteristics. In a study by D. F. Larios et al. [32], an ANN was used in a weighting system to provide a stress free solution to better predict the weight of birds from unstable readings. Testing was conducted on the Lesser Kestrel and was able to recover 56.21% [32] of the weights without stable measurements. Without the proposed algorithm, all these patterns would have been discarded. For a project involving Red-winged Starlings, ANNs could also be applied to recover weight data from unstable measurements.

3.6.2 Bayesian Artificial Neural Networks (BANNs)

Bayesian Artificial Neural Networks (BANNs) function very similarly to regular Artificial Neural Networks, except the Bayesian approach provides a distribution of possible input weights compared to the static input weights used by ANN [33].They are generally good for tasks where uncertainty needs to be taken into account. For example, a study by Mortensen et al. [33], a BANN was used in a 3D camera-based weighing system for broilers. The BANN predicted individual broiler weights using twelve different input weight descriptors. These were extracted from depth images captured using an Xbox Kinect. The algorithm implemented in their system achieved an average relative mean error of 7.8% between the observed weights and the predicted weights of the broilers [33]. This approach could be applied to estimate the weights of Red-winged Starlings, but the equipment (Xbox Kinect) would not meet the requirements of having a portable solution. Additionally, it would take a significant amount of usable weight data to train the network which can not be realistically obtained within the time-frame of this project.

3.6.3 Back Propagation (BP) Neural Networks

BP neural networks are a mature method for nonlinear mapping which are difficult to solve using conventional computational methods [1]. They are widely used in various fields, including pattern recognition and forecasting. In a study by W. Ma et al. [1], a BP neural network was used in a method for weighing broiler chickens. The network used daily weight gain, day-age, average velocity, and weight data as inputs to predict the weights of chickens. They also investigated whether combining an improved amplitude-limiting filtering algorithm with the BP neural network would lower the error rate. Their investigation found that including amplitude-limiting filtering reduced the error rate from 6% to 3%. Whilst the use of BP neural networks may be beyond the scope of this particular project, the findings of W. Ma et al. [1] regarding amplitude-limiting filtering, could be implemented by setting a threshold on the amplitude of the weight reading of the starling.

3.7 Wireless Data Transfer for Energy-critical Systems

Including a system involving wireless data transfer may be a necessary in order to keep the system as portable as possible. Wireless data transfer technologies including WiFi and Bluetooth Low Energy (BLE) could potentially be well-suited for this application, given their widespread support across various computing devices. However, it is crucial to evaluate factors such as power consumption, data transmission rate and signal range before committing to a particular technology.

In a study conducted by S. Kantis and E. Magnusson [34], experiments were conducted using two testbeds with ESP32-CAM modules to measure energy consumption during data transmission using WiFi and BLE. The variables that they tested included transmission power, distance, obstacles, and the amount of data transmitted. They discovered that WiFi's energy consumption is significantly affected by changes in transmission power, distance and obstacles. By optimising for transmission power, S. Kantis and E. Magnusson achieved energy savings of up to 52% for WiFi [34]. Given these findings, WiFi may be more suitable for connecting to an automatic weighing system as energy consumption is a more critical concern compared to distance, obstacles, and the amount of data transmitted. This could be achieved using the on-campus WiFi network Eduroam.

3.8 Data Storage and Visualisation

A simple method for a person to access transmitted data is through a web server or web application. The data can be stored on a server in a database, from which a web client can access the data and display it on an easily accessible web application [35]. This would enable a person to access and edit real-time mesaurements from any device with internet connectivity.

3.8.1 Database

There are two dominant types of databases to be considered: SQL (Structured Query Language) and NoSQL (Not Only SQL) [36]. NoSQL databases are ideal for non-structured and large amounts of data, and have been shown to have faster runtimes than SQL databases when performing some typical tasks [36]. However, SQL remains an industry standard and therefore has more support available and is often simpler to implement [36]. For an application consisting of modest amounts of structured data, an SQL database would likely be sufficient with respect to runtime and much simpler to use.

3.8.2 Data Visualisation and Retrieval

There are various communication models used to describe the interaction between a web client and a server [37]. One such model is 'push-based data propagation', where data is only transmitted from the server when it is available [37]. This would be suitable for a weighing scale, since real-time data obtained at regular intervals is not of interest; the researcher will only wish to see the scale's measurements when there is a significant reading i.e., a bird is being weighed. The automatic loading of data from the database onto the web application would be necessary to provide an up-to-date stream of data with minimal requirements from the person accessing the web application. This can be achieved through the use of Ajax technology [35]. An Ajax-based web application can request data from the server without interfering with the entire web application's display nor behaviour [35], resulting in a streamlined user experience.

3.9 Conclusion

There is a wealth of information available regarding appropriate weighing techniques that can be adapted to suit our application, and the various factors affecting the success of such equipment. It was clear from the literature that the potential interferences such as electromagnetic radiation and 3D printed materials will not be detrimental to local avian health nor their interest in approaching the scale. Red-winged Starlings reaction to snake-like objects (such as electric cables) requires further research and consideration, as this may differ from other urban birds and relevant research was scarce. Regardless, wireless data transmission will likely be better suited to increase portability. WiFi will be suitable because of the easy access to on-campus networks and its relatively low power consumption. It was clear from the literature that strain gauge load cells are commonly used and reliable sensors for weight-measuring equipment. The addition of methods like lever mechanisms is discussed and tested to further improve the reliability of measurements. There is a much research on the use of neural networks for weighing wildlife, but is currently fairly novel and therefore not as simple and reliable to implement as a simple physical scale. Additionally, neural networks require large amounts of data which we do not have access to. Although many solutions for wildlife monitoring utilise rechargeable and solar powered batteries with great success, solar panels likely won't be practical for our application due to their hindrance on portability. However, A rechargeable, long-life battery with a reliable battery management system will be advantageous. Lastly, displaying and retrieving the captured data through a web server is a simple and well documented solution for easy and reliable access to the data.

Chapter 4

Power Subsystem

4.1 Introduction

The power supply is a critical submodule that provides energy to the rest of the system, without a reliable power source, the system would be unable to accurately weigh birds. The careful design of this module is essential and needs to be reliable. This section discusses the important components of the subsystem such as the battery charging circuit, the battery level monitoring, protection circuits, and voltage regulation. All these components are interconnected to provide consistent power over extended periods of time, improve battery performance, and ensure the system overall functionality.

4.2 User requirements

One of the most important aspects mentioned by Sally is the efficiency of the battery life which needs to last as long as possible. To ensure energy efficiency, several considerations have been addressed. Firstly, the power module should be designed to maximize battery life, because the scale portability needs the conservation of power. This could be achieved using low-power components. Additionally, implementing voltage regulation is crucial to provide a consistent power supply to the rest of the system and avoid any voltage fluctuations resulting from battery discharge.

Choosing an appropriate power source is another critical decision. Options such as rechargeable lithium-ion batteries have been considered, with an estimation of their expected battery life. Furthermore, exploring the feasibility of integrating a small solar panel to recharge the battery during daylight hours has been considered. However, it was not implemented because of lack of sun exposure while measurement is being taken by the researcher. Regarding the power management, the incorporation of a battery monitoring has been considered.

4.3 Requirements Analysis

4.3.1 User Requirements

URe1	**Portable power supply**
Requirement	Sally requires a power supply that is not dependent on the main grid supply because the scale will be moved around and it needs to fit within the scale.
URe2	**Efficient power supply**
Requirement	Sally wants an efficient battery that can last at least for one working day without changing it during the day.
URe3	**Reliability**
Requirement	Sally requires a reliable power supply that can allow them to take continuous readings while weighing birds to get accurate readings, which is crucial for their research.
URe4	**Monitoring the battery level**
Requirement	Sally wants a way to monitor the battery level in order to either charge it or replace it.

Table 4.1: User requirements of the power subsystem.

4.3.2 Functional Requirements

URe1:FR1	**Dimension**
Requirement	The power supply should be compact to fit within the scale.
URe1:FR2	**Portability**
Requirement	The submodule should be lightweight facilitating easy transportation and use in various locations.
URe1:URe2:FR3	**Rechargeable Battery**
Requirement	A rechargeable battery should be used to ensure portability of the scale as well as to guarantee an efficient power supply.
URe2:FR4	**Long Battery Life**
Requirement	The battery should be able to supply power for at least 8 hours per day.
URe2:FR5	**Fast Charging**
Requirement	The battery charger should be able to charge the battery as fast as possible to allow the battery to be ready for the next working day.
URe3:FR6	**Protection Circuit**
Requirement	A protection circuit should be used to protect the hardware from damages.
URe3:FR7	**Voltage Regulation**
Requirement	The power supply should be able to provide stable voltage to the rest of the system.
URe3:FR8	**Interchangeable Part**
Requirement	The power supply should include components that are easily interchangeable and found in the market in case of any failure or breakdown to allow for quick and cheaper repair.
URe4:FR9	**Battery Level Monitoring**
Requirement	The power supply should include a battery level monitoring to display the state of charge.

Table 4.2: Functional requirements of the power subsystem.

4.4 Design Specifications

URe1:FR1:Sp1	**Size of enclosure**
Requirement	the size of the power supply should be less than 6x4.5 cm

URe1:FR2:Sp2	**Weight limit**
Requirement	the power supply should have a total weight less than 1.5kg

4.5 Acceptance Test Procedures

Design Specification	Description
URe1:URe2:FR3:FR4:Sp3	**Battery**
Requirement	The battery should be able to handle the system capacity which is 200mAh. The battery should be able to power the rest of the system with the following voltages: - Microcontroller: 3.3V - Sensors: 8V Finally, the battery must be able to supply at least 1600mAh for a working day.
URe2:FR5:Sp4	**Battery Charger**
Requirement	The charging circuit should charge the battery taking into consideration that: - Input voltage: 5V (from USB) - Charging voltage: 3.7V
URe3:FR6:Sp5	**Reverse Polarity Protection**
Requirement	The circuit should be able to protect in case a reverse polarity of the battery is detected.
URe3:FR6:Sp6	**Over Voltage Protection**
Requirement	Protection circuit should cut off supply of voltage when battery reaches: - Over Voltage: 4.2V ($\pm$ 0.05V).
URe3:FR7:Sp7	**Voltage Regulation**
Requirement	Voltage regulators should meet the following specification: - Output of 3.3V to microcontroller. - Output of 8V to sensors.
URe3:FR8:Sp8	**Interchangeable Part**
Requirement	The power supply should include components that are easily interchangeable and found in the market in case of any failure or breakdown to allow for quick and cheaper repair.
URe4:FR9:Sp9	**Battery Level Monitoring**
Requirement	Any visual display should be included.

Table 4.3: Design Specifications of the power subsystem.

ATP Number	Verified Specifications	Description
ATP1	URe1:FR1:Sp1	Test done by measuring the dimension of the board and should be less than 6x4.5cm
ATP2	URe1:FR2:Sp2	Test done by weighing the board and should be below 1.5kg
ATP3	URe1:URe2:FR3:FR4:Sp3	Verifyng that output voltage meet specifications value of 3.3V and 8 V.
ATP4	URe2:FR5:Sp4	Verify voltage charger outputs meet specified voltage
ATP5	URe3:FR6:Sp5	Test Done by reversing the polarity and verifying circuit protection.
ATP6	URe3:FR6:Sp6	Test done by increasing the voltage value above limit.
ATP7	URe3:FR7:Sp7	Verifying that output of regulators provides specified voltage as per specifications.
ATP8	URe4:FR9:Sp9	Test done by inputing a range of voltages to the monitoring system and monitore the status displayed.

Table 4.4: Acceptance Test Procedures of the power subsystem.

4.6 Design Choices

4.6.1 Block Diagram

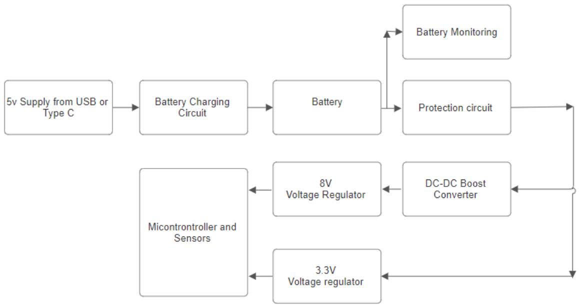


Figure 4.1: Block Diagram

4.6.2 Battery choices

power subsystem will be used to power the entire system.it is important to examine the power requirements, ratings, and consumptions of every device incorporated in the systems. It is worth noting that sensors have a small power consumption compared to microcontrollers. the below table summarise them .

Device	**Rated Input Voltage**	**Average Current Consumption**
Sensor Cells	8V	20mA
ESP32	3.3V	80mA

Table 4.5: Power Consumption Summary

To choose the battery, the total current consumption is required.

Having three load sensors and one microcontroller, the max current is about 140mA, for designed purposes, we will oversize a bit to reach 200mA of max current that the load needs.

Since the researcher needs at least 8h per day:

$$\text{Battery Capacity} = \text{Battery Life} \times \text{Max Current Consumption}$$
$$\text{Battery Capacity for the system} = 8\text{hrs} \times 200\text{mA} = 1600\text{mAh}$$

The minimum capacity of the battery required to achieve the supply for 8hours straight is 1600mAh.It is worth noting that it could last longer since we oversize the current by 60mA.

Two types of batteries were considered:

Battery (rechargeable)	**Rated Voltage**	**Capacity**	**Price**
Lithium Polymer Battery	3.7 V	1850mAh	R196
LC18650 Lithium-ion	3.7V	2200mAh	R202

Table 4.6: Battery choice

From the same vendors, we have made the decision to choose the LC18650 battery for R202, simply because for a difference of 6rand, we get a battery with a much higher capacity than the Lithium Polymer which would be more expensive if we must choose a battery of the same capacity. With 2200mAh, we have about 11 hours of battery which exceeds the 8 hours per day required. Moreover, considering that we over designed, if we take into consideration that we have 140mA of current, the battery will give approximately 15 hours of battery life, adding the standby ability of the microcontroller, the battery could easily go two working days, without needing to be charged.

4.6.3 Battery charger circuit

Battery charger is a very crucial component of the power subsystem as it is the one who will handle the battery charging, which is crucial for ensuring that the scale work at optimum.

The choice of the battery charger has been made based on a simple and reliable design.

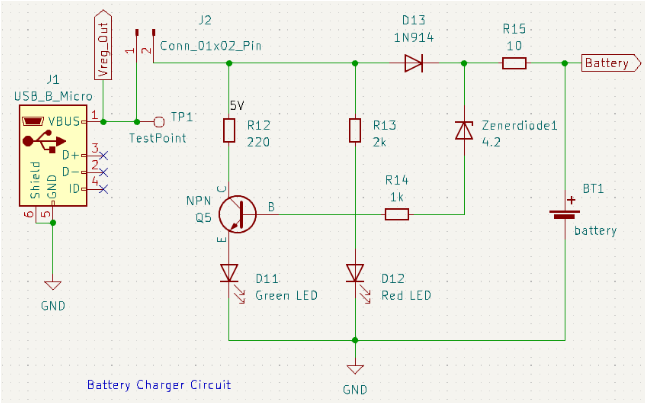


Figure 4.2: Battery Charger Circuit

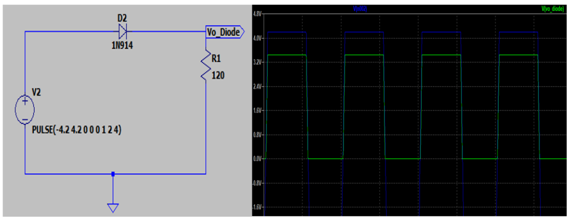


Figure 4.3: Diode Reverse

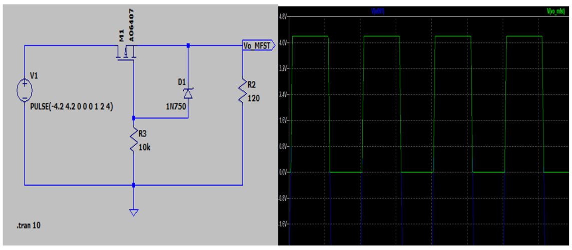


Figure 4.4: reverse polarity protection using Mosfet and simulation

The LT317A regulator input 5v from the USB, we use a voltage regulator to regulate the voltage to about 4.9 to 5v to ensure stable supply.

There is a Led Red which is an indicator to show that there is power being supplied to the battery. Once the battery Fully charge, a Green Led will switch one showing that the battery is charged at full potential this is achieve by the use of Zener diode which is rated at 4.2V the ideal charging voltage for a lithium Ion battery .Once the voltage across the Diode is greater than 4.2 , the diode goes into reverse breakdown to conduct to switch transistor on which light up the green LED.

It is worth noting that once the battery is full, it will stop charging. This happen trough the series Diode which will stop conducting once there is not voltage difference across it, the lack of voltage difference will happen simply because the battery is full and it voltage is equal to the voltage supply This is the Auto cu off option used to avoid overvoltage or over charging which will damage the battery.

4.6.4 Reverse Polarity Protection

Option 1

The simplest way to add DC reverse polarity protection to a circuit is to connect a series diode in front of the protected load or circuit. The circuit diagram below illustrates the proper positioning. When a reverse polarity event occurs, the diode will be driven in reverse bias. However, this circuit comes with a serious drawback which is a heavy loss in power and Voltage drop because the of Diode, this can be seen as per simulation below.

option 2 (chosen one)

The second option, which is the one chosen, is the use of a PmosFet . In the circuit below, the FET is turned on, and the diode is oriented to allow forward-bias operation in positive polarity. When reverse polarity occurs, the FET turns off and the diode is reverse biased, preventing conduction which is illustrated as per simulation above.

It shows that it is more efficient than the diode as we have less losses and voltage drop, which is crucial since we are using a battery that must supply voltage to load and reducing the losses is the most efficient way to send full power to load for a correct operation.

4.6.5 Battery Level Monitoring system

Option 1

one option would be to use an LCD screen connected to the battery trough a circuit in order to read the battery level . However this option would be more costly .

Option 2 (chosen one)

the second option , a simpler one is to use zener diode as well as LED's to switch one depending on the level of the battey ,this can be displayed as per schematic below .

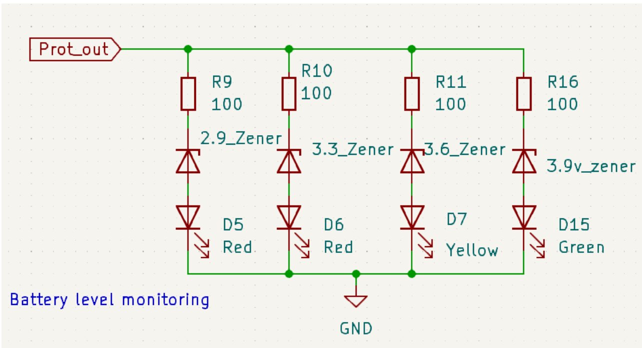


Figure 4.5: Battery Monitoring

4.6.6 Stepping up the voltage

Since one of the equipment for the scaling requires about 8V, we are required to step up the voltage.

option 1

The first idea that came was the implementation of two battery in series to increase the voltage capability however this option would require a charging circuit for each battery which will make the design costly because we will have to use a buck converter to step down the voltage again and use two batteries.

option 2

The option chosen has been the design of a boost converter that can step up the voltage of the battery to the required values. This option is the most cost-effective solution.

Boost Converter Design

The following procedures as been used to determine the values of the boost converter,

Identify the required input and output voltage.

Vo = 8V and Vin = 3.7 V.

Calculating all parameters using the following formula :

1. Calculate Duty Cycle (D):

$$D = 1 - \left(\frac{V_{\text{in}}}{V_o}\right)$$
$$D = 1 - \left(\frac{3.7}{8}\right)$$
$$D = 1 - 0.4625$$
$$D = 0.5375$$

2. Calculate Minimum Inductor Value (L_{min}):

$$L_{\text{min}} = D \cdot (1 - D) \cdot (1 - D) \cdot \frac{R_{\text{load}}}{2 \cdot f_s}$$
$$L_{\text{min}} = 0.5375 \cdot (1 - 0.5375) \cdot (1 - 0.5375) \cdot \frac{33}{2 \cdot 50000}$$
$$L_{\text{min}} \approx 3.794 \times 10^{-5}\,\text{H}$$

3. Calculate Output Capacitor Value (C):

$$C = \frac{D}{R_{\text{load}} \cdot \left(\frac{dV_o}{V_o}\right) \cdot \text{Frequency}}$$
$$C = \frac{0.5375}{33 \cdot \left(\frac{0.5}{8}\right) \cdot 50000}$$
$$C \approx 5.21212 \times 10^{-6}\,\text{F}$$

4. Calculate Inductor Value (L):

$$L = \frac{V_{\text{in}} \cdot D}{dI_L \cdot \text{Frequency}}$$
$$L = \frac{3.7 \cdot 0.5375}{0.06 \cdot 50000}$$
$$L \approx 6.62917 \times 10^{-4}\,\text{H}$$

the above data have been entered in a matlab circuit for simulation . we had to play with duty cycle values as well as inductor values to get close to the expected output .

555 timer PWM

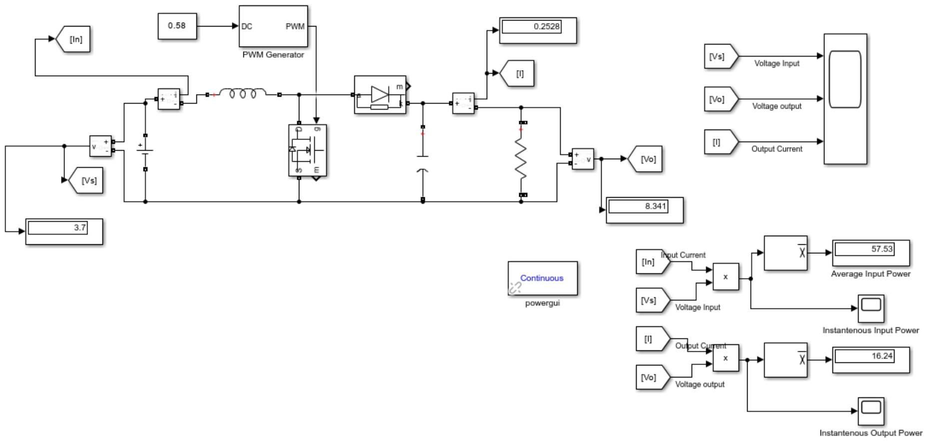


Figure 4.6: Boost Converter Matlab

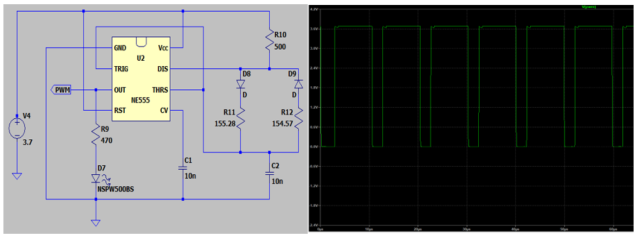


Figure 4.7: 555 PWM .

Another important part of the design is the generation of the PWM . since have to design the power supply as a box , we cannot rely on the microcontroller to send the PWM to the boost converter . the solution to that is to use a 555 to generate the pwm .

Given: - Frequency (f) = 50,000 Hz - Duty Cycle (D) = 0.5375 - Capacitance (C) = 10 nF

1. Calculate T_{on}:

$$T_{\text{on}} = D \times T = 0.5375 \times \left(\frac{1}{50,000}\right) = 10.75\,\mu\text{s}$$

2. Calculate R_2:

$$R_2 = \left(\frac{T_{\text{on}}}{0.693 \times C}\right) - R_1 = \left(\frac{10.75 \times 10^{-6}}{0.693 \times 10^{-7}}\right) - 500 = 155.28\,\Omega$$

3. Calculate R_3:

$$R_3 = \frac{T_{\text{on}}}{0.693 \times C} = \frac{10.75 \times 10^{-6}}{0.693 \times 10^{-7}} = 154.97\,\Omega$$

using the above values , they have been simulated using LT spice.

4.6.7 Voltage Regulator

The voltage regulators are a very important component of the design because they are responsible for delivering steady voltage to the sensors and micro controllers.

The sensors and micro controller need respectively 8v and 3.3v.

Output voltage	R1	R2
3.3V	220 ohms	370 ohms
8V	220 ohms	1.2kohms

The voltage regulator chosen for this application is a LM317 chip chosen for their wide range of output and input voltages.

The voltage being boost to a value of 8v (output of boost converter) some calculations need to be done to determine the correct resistors range to get the correct output from the regulators.

The correct values of resistors can be calculated using the formula:

$$V_{\text{out}} = 1.25\,\text{V} \times \left(1 + \frac{R_2}{R_1}\right)$$

4.6.8 Final Design Schematic

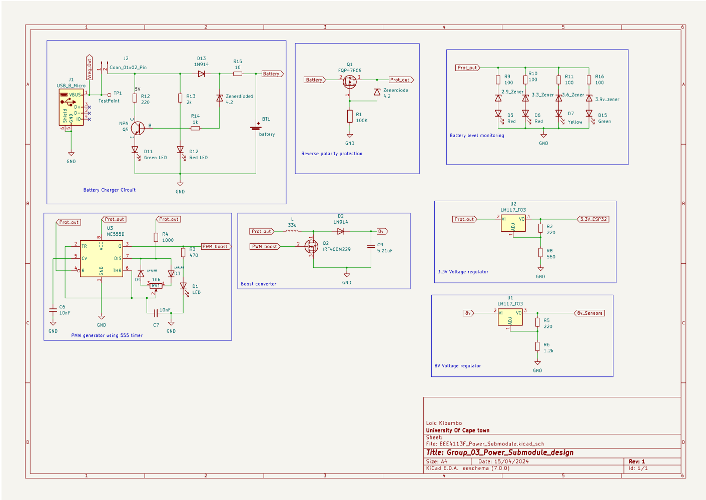


Figure 4.8: Final Design Schematic

4.7 Testing and Validation

4.7.1 Battery Level Indicator

The test was carried by decreasing the voltage to the lowest value and increasing the voltage to it's high to display the state of the battery when it is low and fully charge.

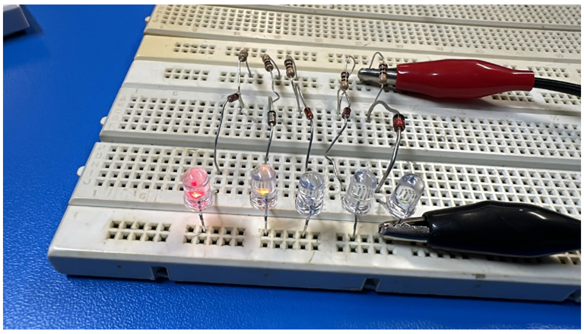


Figure 4.9: Battery Level low

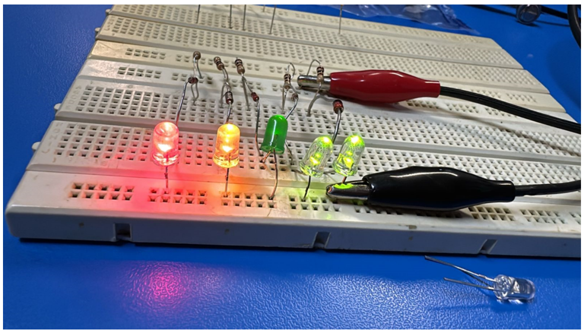


Figure 4.10: Fully Charged

4.7.2 Reverse Polarity Protection

The reserve polarity test has been carried by inversing the polarity of the battery.

4.7.3 PWM and Boost Converter testing

The Testing has been done ,and we could get a output from the pwm that has been inputted to the mosfet of the boost. It could be seen from the picture that we obtained 8.6V ,this is because the voltage of the battery was approximately 3.8 V instead 3.7V . The boost converter does that have any feedback circuit hence why there is a change in output voltage.

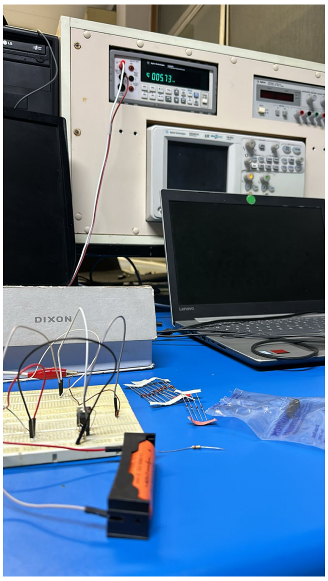


Figure 4.11: Battery Inversed test

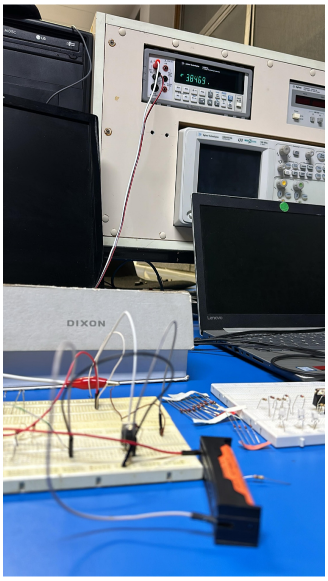


Figure 4.12: Battery Correct Polarity Test

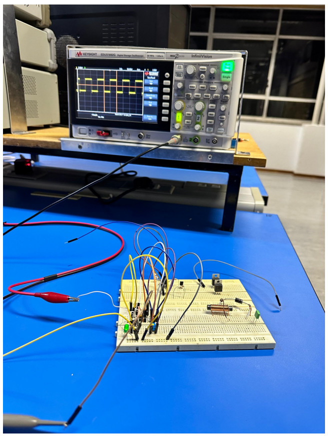


Figure 4.13: PWM test Bread boad

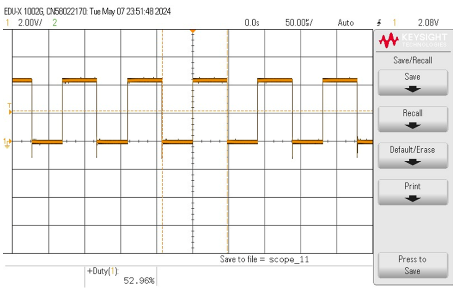


Figure 4.14: PWM scope Screen

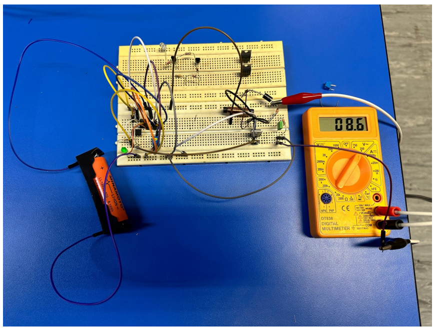


Figure 4.15: Boost Converter Result

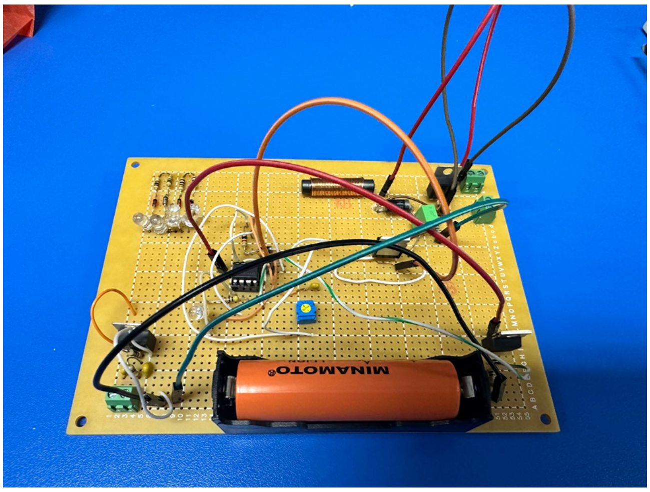


Figure 4.16: Final Circuit

ATP Number	Description	Pass/Fail
ATP1	Test done by measuring the dimension of the board and should be less than 6x4.5cm.	Fail
ATP2	Test done by weighing the board and should be below 1.5kg	Pass
ATP3	Verifyng that output voltage meet specifications value of 3.3V and 8 V.	Pass
ATP4	Verify voltage charger outputs meet specified voltage	Pass
ATP5	Test Done by reversing the polarity and verifying circuit protection.	Pass
ATP6	Test done by increasing the voltage value above limit .	Pass
ATP7	Verifying that output of regulators provides specified voltage as per specifications.	Pass
ATP8	Test done by inputing a range of voltages to the monitoring system and monitore the status displayed.	Pass

Table 4.7: Acceptance Test Procedures Consolidation

4.7.4 Consolidation of ATP's

ATP's not met explanation:

ATP1 : Could not have been made simply because the size of the veroboard used for testing was quite large and bigger in size.

4.8 Recommendations

To be able to meet ATP1 ,a smaller veroboard could have been used to meet the size requirements of the enclosure ,another solution could simply have been the use of a PCB ,which was not used in our case simply because testing needed to be done before ordering pcb's for final product. Another Suggestions Would be the use for the System Integrated Circuit. Those integrated circuit should be used for Battery Charger ,Protection and for the boost Converter as well. the advantage with selecting IC's reside in the fact that during the design phase there is less time spent designing and simulating , more time use for testing and implementation . One more suggestions to improve the design would be to add an under voltage protection as well as a short circuit protection to the circuit and finally a feedback circuit for the boost converter would be great to ensure constant 8v output .

4.9 Conclusion

In conclusion, the design of the Power Subsystem for the bird weighing system was like boxes put together to ensure a smooth and reliable power supply. By focusing on maximizing battery life, choosing the right power sources, and implementing voltage regulation, the design aims to meet the user's needs for a portable and long-lasting power solution.Looking ahead, suggestions for using smaller boards or PCBs and integrating IC would be a great improvement. Overall, working on the design process has been a wonderful experience, with new and interesting challenges.

Chapter 5

Housing and Layout [redacted]

5.1 Introduction

The purpose of this sub-module was the designing of the physical frame of the scale as well as the layout and set up of the load-cells and internal components. These being the power and data processing sub-modules. Given that the body is the main point of interaction when weighing birds this needs to be thoroughly developed. Considerations needed to be given to the overall size of the scale, but also structure and the sizes of the components within.

5.2 User Requirements

When it comes to the housing of the scale there were a few requirements needed by the client regarding the design of the scale. These can be seen in Table 5.1

Table 5.1: Body User Requirements

No.	Specification Description	Acceptance criteria
H-1	The scale should be easy to carry	Scale must have a surface to grip on
H-2	The scale must not be too heavy	Scale total weight should be less than the average laptop
H-3	Bait needs to be able to be placed on the scale	A flat surface is needed to support the bird and bait.
H-4	Scale needs to be easy to set up	Confirm that the average weight of Red-winged Starlings can be applied to the scale.

5.3 Functional Requirements, Analysis and Specifications

To address the specifications H-1 and H-2, the standard size and weight of scales used for human measurement were used as the upper limits. This decision was made due to most personal scales available on the market being designed to be portable. Most being light enough for the average person to carry easily. Among others the Safeway Digital Bathroom classic scale, Nagako commercial scale and the Camry scale were used as references [20]. Based on these scales, a maximum size limit of 34x34x5cm was decided on. An appropriate weight limit of 3kg was set as well. This would also provide adequate space for the platform to fulfil requirement H-3.

In line with requirement H-3, the weighing platform of the scale needs to be a flat, stable surface; such that anything placed on the scale would not move around unnecessarily. This would also prevent the scale shape from deterring the bird from firmly perching on the scale as this could lead to irregularities in the measurement process.

Another requirement for the design would be a fixed product with the only moving part being the scale surface itself. This would prevent making the use of the scale cumbersome, even if they are not familiar with the device prior to use.

When addressing H-5, it is necessary to know the average weight of the Starling birds to get an upper limit for support. The average Red-winged Starling weighs ±200g. Thus, the aim is to be able to support at least 500g.

When factoring all these requirements together, the final product should be an enclosed scale, roughly the size of a dinner plate and with a max weight of 2kg. It will be able to be placed in a location and ready to record the weight of whatever is placed on it immediately and transmit that data to the data processing sub-module located within its case.

The output of this subsystem will be the input to the data subsystem. This will be a $0 - 3V$ varying DC signal which will be representative of the weight currently being placed on the bird. View Figure 5.1 for a visual representation of the sub-module's process.

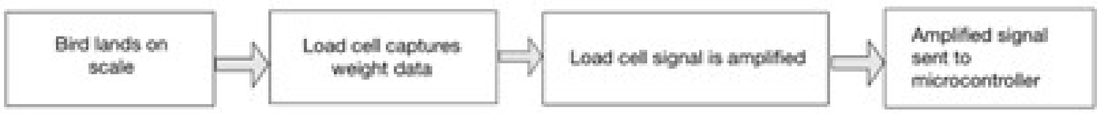


Figure 5.1: Flowchart of sub-module process

5.4 Design Choices

5.4.1 General Concept and Materials

An initial concept design for the scale can be seen below in Figure 5.2. This design incorporates a scale platform as well as a controlled feeder system for the birds and a camera trap system to aid in identification for the birds. The scale would also be able to connect to local Wi-Fi to transmit the recorded weight data to nearby devices. This initial concept was greatly simplified in several ways. The controlled feeder was removed due to the preference of the client to rely on their current method for attracting the starlings; this being placing raisins on the platform and waiting for them to approach it. The camera module was also removed. The housing for the camera system could provide an alternative perch for the birds, which would prevent the data from being recorded while still consuming time and resources. The camera was also unnecessary as the researchers would always be in the vicinity of the scale when recordings are taken and would be able to identify the birds themselves. The wireless transmission of data is however a feature that was maintained and made into a separate sub-module which will be expanded upon further on in the report.

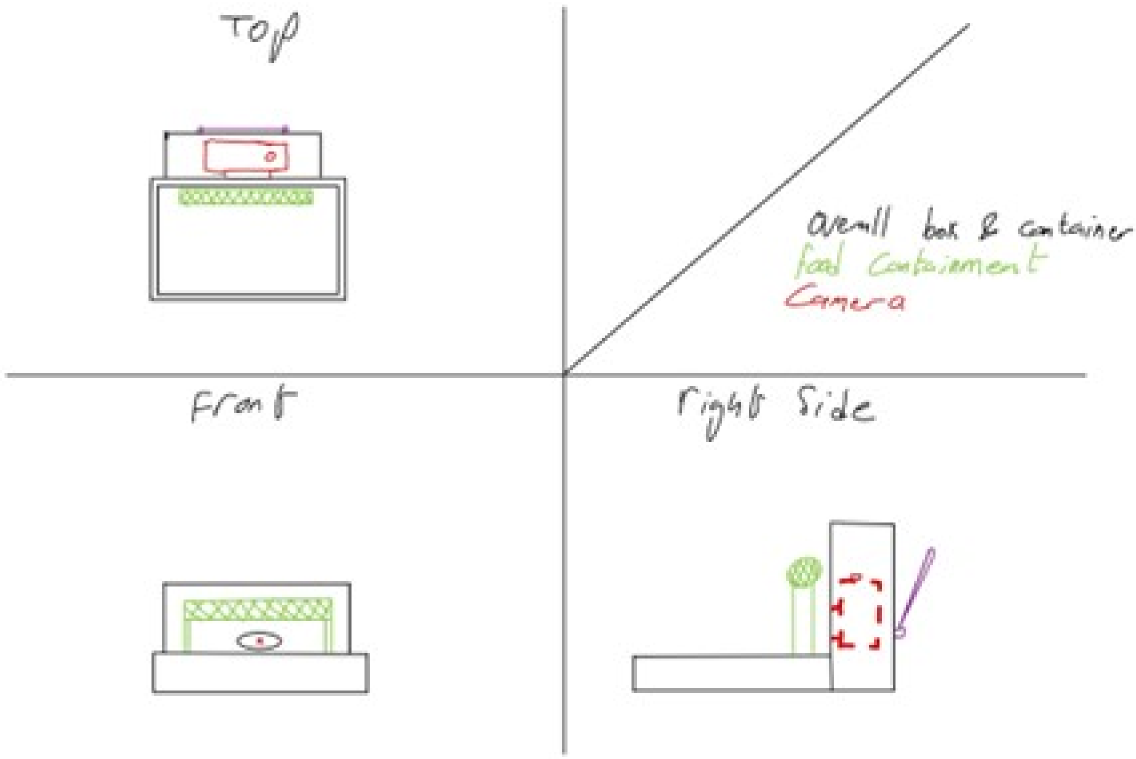


Figure 5.2: Perspective drawing of initial concept

For materials the main objectives were to be lightweight, cost effective and durable. Several materials such as plywood and zinc were considered. However, for the prototype the decision was made to use 3D printing materials. Some factors leading to this decision were the freedom of design, availability of materials and ease of construction. An added benefit being that 3D printed models are inherently lightweight, contributing to the satisfaction of specification H-2. However, for the final product, a more durable material is advised such as solid model plastic like Acrylonitrile Butadiene Styrene (ABS) which is a strong and impact-resistant plastic used in building toys like LEGO blocks.

5.4.2 Load Cell/s

Strain gauges are a common electrical component used for measuring the displacement of a material; with strain gauge load cells being the standard for weight measurement equipment. For this project a few load cells were considered and can be seen in Table 5.2

Table 5.2: Table of load cell choices

	Specification	Source	Price (R)	Precision range	Size(mm)
1	1kg	Communica	45	150g	75x12x12
2	500g	DIY Electronics	200	25g	47x12x6
3	1kg	DIY Electronics	70	50g	-
4	1kg	Takealot	175	150g	-
5	1kg	Botshop	44	-	81x13.5x13.5

Ultimately the decision was made to use option 1 due to the all the necessary specifications being available and the low cost. However, in an ideal situation, the 500g load cell would be the preferred

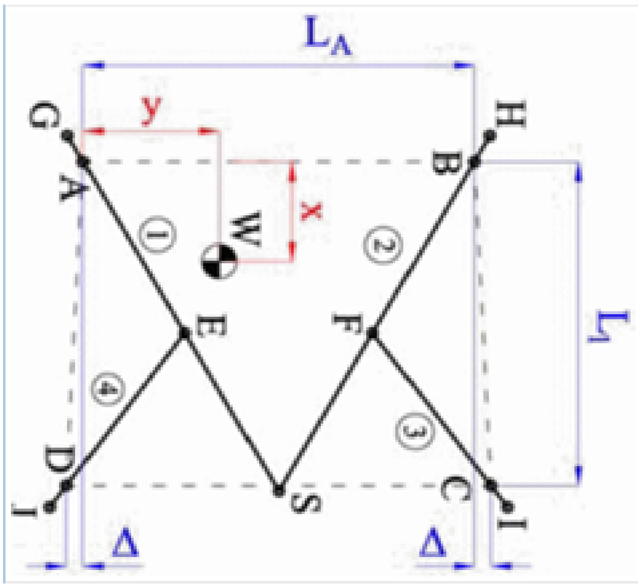


Figure 5.3: Lever mechanism layout

choice. As a lower specification load cell, it has a smaller window of variance; which would be the best option for the bird scale as the average weight of a starling is 200 − 250g and the variance window would be suitable for the H-5 specification.

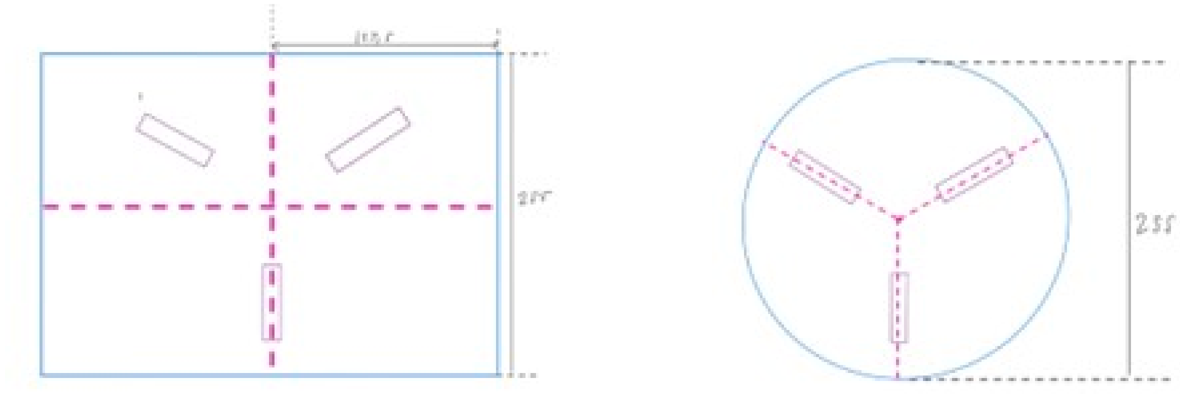
5.4.3 Scale Size, Shape and Load Cell Topology

While a maximum size limit of 340x340x50mm (mm will be used as standard unit of measurement moving forward in this section) was decided on in the requirements analysis, this figure was based on scales meant for weighing humans. With the objective being to weigh birds individually, it is both unnecessary to have such a large scale, and advantageous to have a smaller weighing surface, as this will reduce the chances of multiple birds settling on the scale at once.

The initial layout for the scale and weighing mechanism was a square scale utilizing the lever mechanism mentioned in the literature review[20]. Figure 5.3 depicts the lever layout. This scale was 255x255x50mm and utilized a singular load cell with the various levers necessary to complete the mechanism. However, there were a few problems with this decision. Firstly, there was an oversight in that the lever mechanism only transferred roughly 7% of the actual weight of the object to the load cell. This coupled with the high variance and low output signal of the chosen load cell meant that even once amplified, the detected weight was likely to be quite inaccurate for the purpose of the scale.

To resolve this issue, it was decided that multiple load cells would be used, and a weighted average of their output values used to eliminate discrepancies due to the bird's location on the scale, leading to the concept_v2 design in Figure 5.4a and finally concept_v3 in Figure 5.4b which would be more suitable for the Y-configuration of the load cells. Lastly, the size of the scale would also be too large for the print bed of the available 3D printers (Prusa mini), which could only accommodate prints of 175x175x175mm. The final iteration was shrunk down to accommodate the printing bed size, which would still not be an issue due to the surface still being large enough to accommodate a starling.

Figure 5.4: Early concepts



(a) 2nd concept design

(b) 3rd concept design

5.4.4 Signal Amplification

Typically, it is recommended to buy a load cell amplification integrated circuit (IC) known as the HX711 amplifier, with many stores such as communica directly recommended on the load cell store page. Ideally this is what would be used to get optimal amplification of the output signal, however as this was a prototype, the decision was made to build one from scratch. Given the fact that precise amplification would be desired, an instrumentation amplifier was utilized as the primary driver.

Due to the nuances of the amplified signals usage, the circuit has been designed as part of the data processing sub-module. However, its construction and integration falls under this one and has been expanded upon in the final design.

5.5 Final Sub-module Design

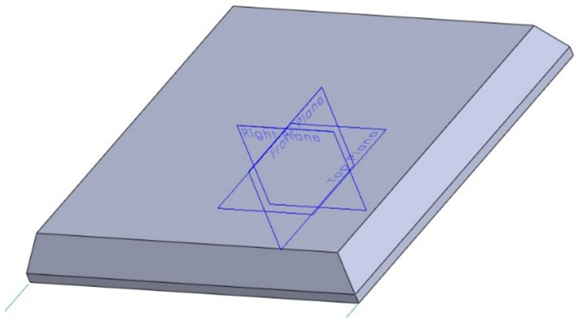
All the above design specifications were taken into consideration when the last implementation of this submodule was carried out.

5.5.1 Case Design

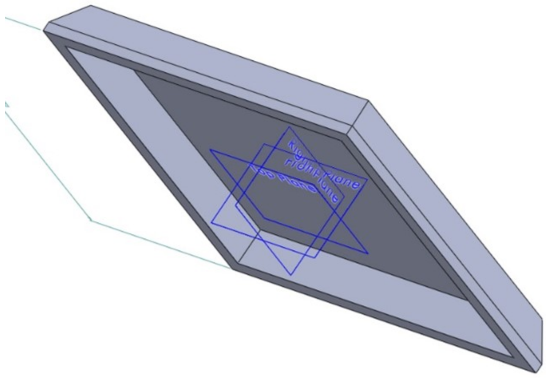
Initially when designing the case, the design process had not been correctly followed. As a result, a full model of the v1 scale design (except for the levers) had been made using the SolidWorks modelling software. Both the lid and base had been fully designed and can be seen in Figure 5.5a - 5.5c. While these have not be used, they did serve as a good basis for how to use the software and improve on the efficiency of the modelling process.

When modelling the v3.1 design, there were a few things to note. One was the reduced size and capacity of the scale. Thus, the first thing to do was create the outer line that the scale would cover. This being set by the size of the printing base, resulting in a diameter of 174mm. Using this as a guideline, an accurate template was sketched on the same plane to observe the amount of space available for wall thickness and space between the cells set up in a Y-configuration in the centre. Figure 5.6 is an example of said calculation. It was estimated that an equilibrium triangle of side length 13mm should be able to fit in the centre of the 3 load cells. Using trigonometry, this meat that each cell needed to

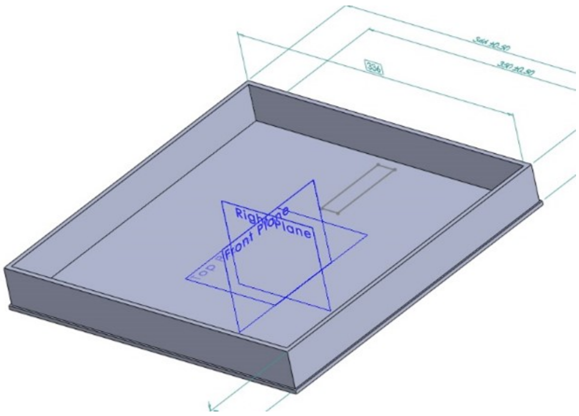
Figure 5.5: Model v1



(a) Lid top side



(b) Lid underside



(c) Base

be at least 4.33mm from the center of the circular scale.

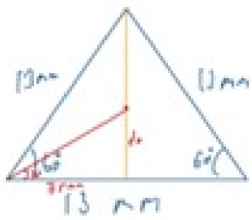


Figure 5.6: Distance calculation for load cells

$$d_0 = 7.5tan(30) \tag{5.1}$$

Upon consulting a web page[38] on the practical applications of strain gauge load cells, it was evident that an elevated platform would be needed to enable the load cells to function properly. Thus, a rough concept for the internal structure of the scale was carried out as seen in Figure 5.7 below.

The final model base designs can be seen in Figure 5.8a & 5.8b below. Holes were made through the elevated platform to accommodate the 4mm screws needed to secure the load cells. At this stage, a

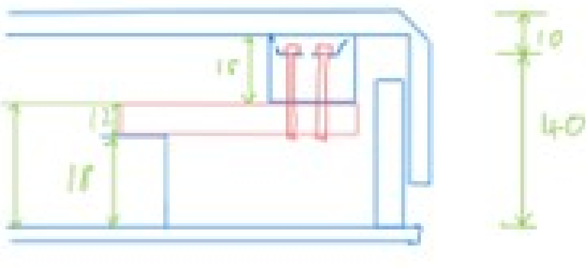
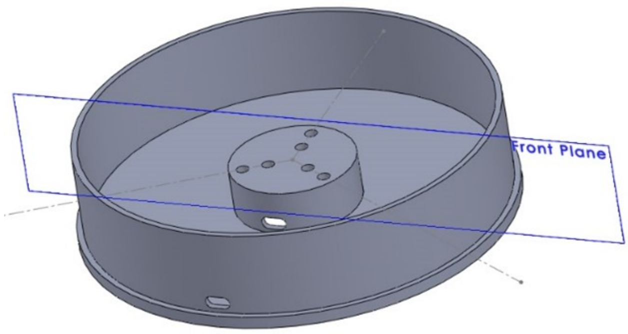


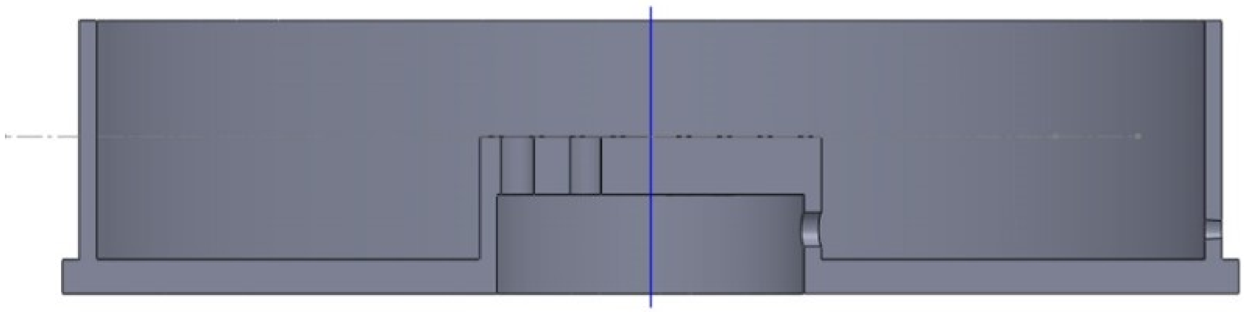
Figure 5.7: Internal scale design

rechargeable power source was being considered for the design, with the intention of using a USB type – C connection. An accommodation for this was made in the inner and outer walls of the base. The

Figure 5.8: Model v2 base



(a) Model Base

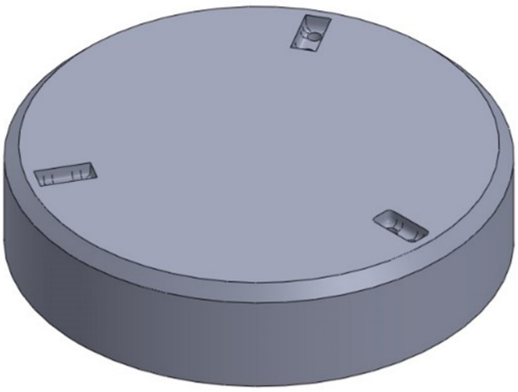


(b) section view

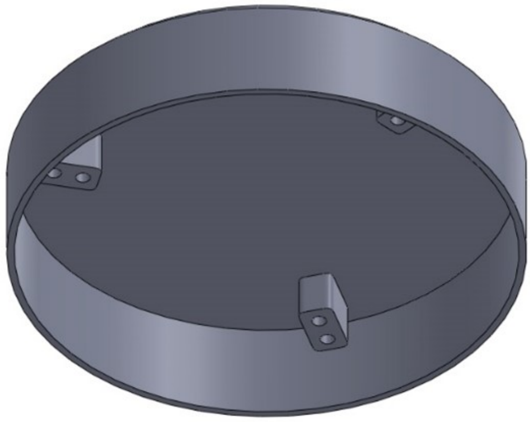
base surface of the scale was made 5mm thick, with the floor of the elevated surface being ±8mm. This was to ensure that it would be able to support the strain as weight is put on the secured cells, especially considering the material being used. The walls were only 3mm. This was partly due to space constraints, but also it was deemed somewhat unnecessary for thick walls as they would not be supporting anything.

When designing the lid, special nodes were designed for securing the load cells. Additionally, these nodes serve to focus the pressure from the lid being pressed down in order to give a more accurate deflection and ultimately more accurate readings. These can be seen in the initial concept above and in the model below (Figure 5.9b). The lid also has accommodations for the screws as well as dips in the outer surface. These dips were meant to aid in concealing the screws for a more clean presentation, while still allowing for easy removal should the internal devices of the scale need to be accessed.

Figure 5.9: Model lid v2



(a) Top view



(b) Underview

(c) Section view

Upon attempting to upload the lid to the printer it was found that the lid would not be able to be printed. It seemed that due to the chamfered edge, the printer would need to place supports there. However, the presence of the supports, although temporary, meant that the overall print was too large for the print bed and thus could not be completed. The chamfer was originally done as a mild deterrent to try prevent birds from perching on the edge and instead being more inclined to settle near the center of the scale. Ultimately it was decided that this feature could be removed and possibly left for future iterations of the scale. The final model is as seen bellow . When printing, a green PLA filament was used in alignment with the research done in the literary review for the optimal 3D print material

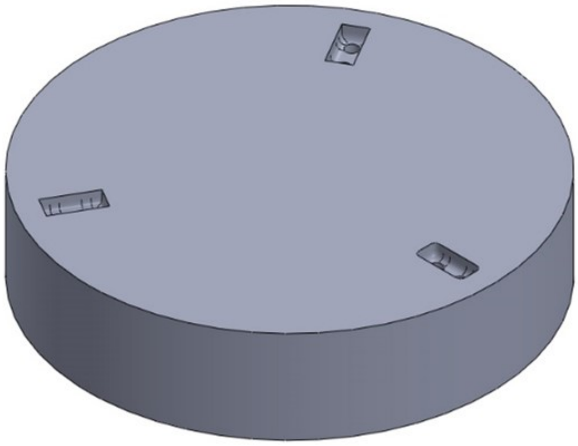


Figure 5.10: Model lid v3

& presentation for the scale. The printed model can be seen below (Figure 5.11a with the load cells already attached to the base. The screws used were M4 x 25 hex socket cap screws with hexagonal M4 nuts.

After printing it was made apparent that miscalculations had bee made, as the screws meant for securing the lid to the base did not protrude from the lid. The height of the nodes had been made too high; however, this did not prevent the lid from being fixed in position. Therefore, the functionality of the scale was not impacted.

5.5.2 Amplification circuit design

While the load cells were elevated, the main objective was to ensure that no components as set under the load cells to prevent any risk of interruption. This meant there were 3 spaces able to accommodate 60x45mm circuit structures. As mentioned above, the circuit was designed under the data processing subsection (Figure 6.2). This circuit was adapted for Veroboard and designed below (Figure 5.12a) . The design was then carried over to the physical board (Figure 5.12b) , with slight adjustments made to accommodate for the physical component sizes.

The wires of the load cells were found to be somewhat flimsy and unreliable when connected to the circuit. As a result, some male-female jumpers were deconstructed and the pins from the male ends incorporated onto the load cell wires (Figure 5.13), while the female ends were soldered to the board (Figure 5.12b). This created a more secure and stable connection.

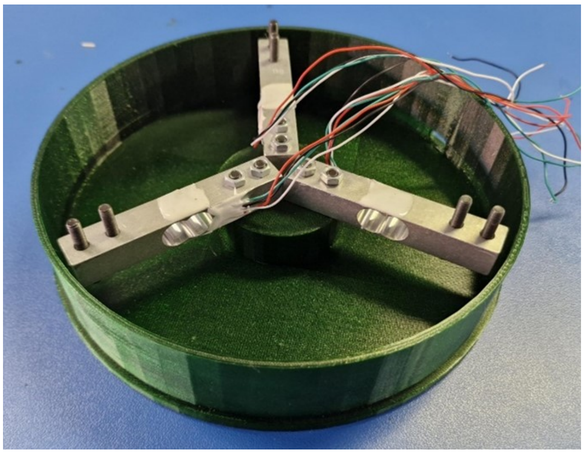
The final assembled setup for the prototype scale (excluding the power subsection) can be seen in Figure 5.14 below.

5.6 Testing and Results

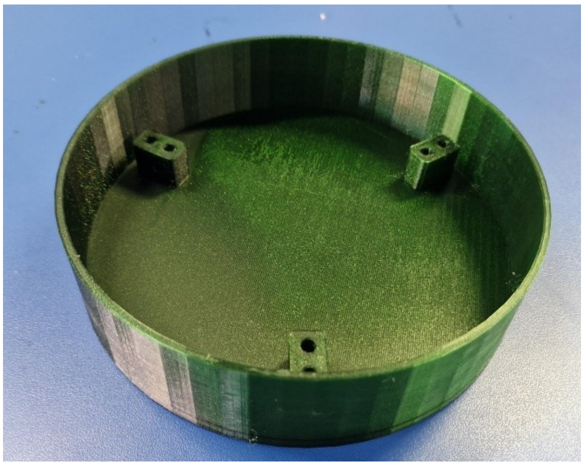
The scale frame and amplification circuit went through various quality assurance tests prior to being checked off to identify any problems, while also ensuring that all necessary functionality is achieved.

The scale was indeed easy to set up as assembly would only require for the lid to be aligned to the

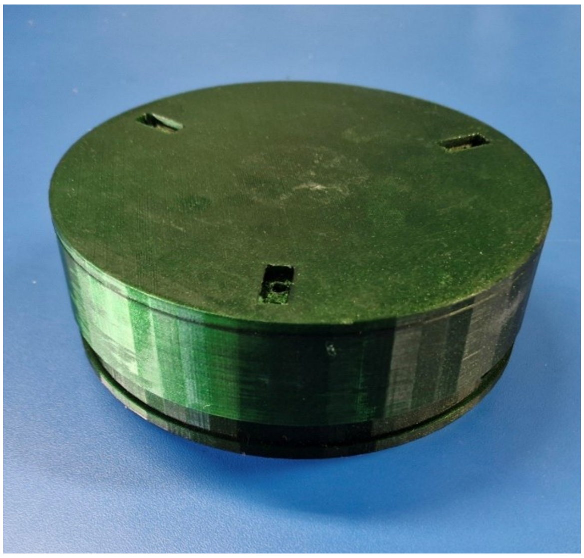
Figure 5.11: Printed scale model



(a) Printed scale base

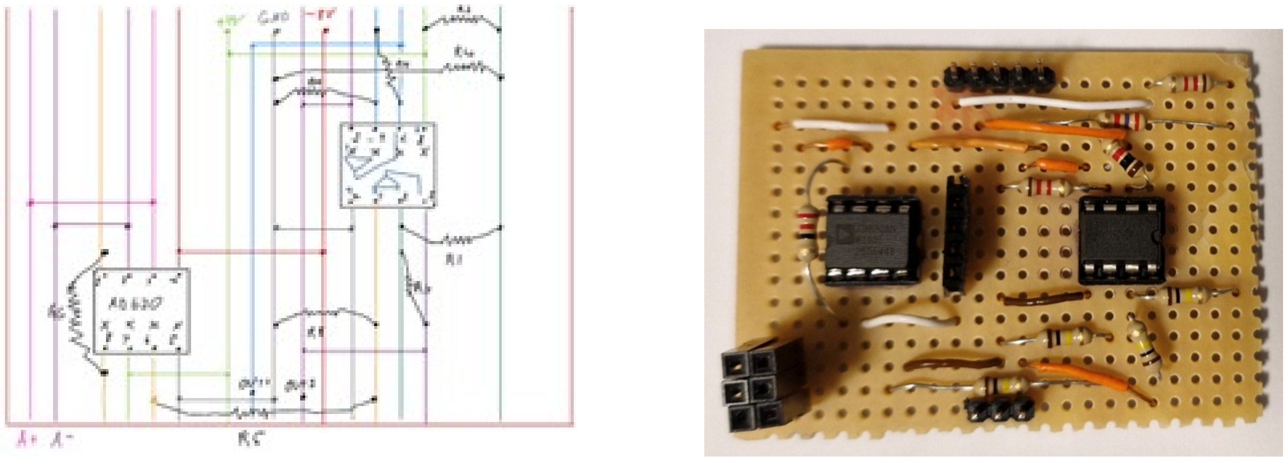


(b) Printed scale lid



(c) Assembled scale shell

Figure 5.12: Veroboard design and implementation



(a) Veroboard layout design

(b) Amplification circuit board

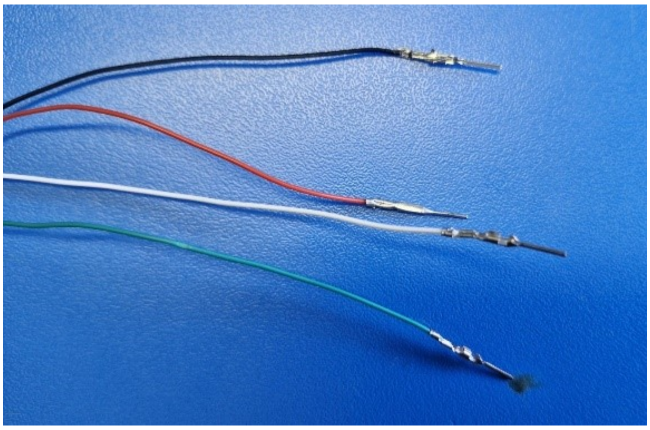


Figure 5.13: Improved load cell connectors

loadcell screws, which is made easier due to the holes in the lid allowing for visual confirmation. However, due to the mismatch in screw length and node height, securing the lid is not possible.

The scale is quite portable and fits well in the average persons hand as confirmed by various independent parties. The scale weighs ±460g fulfilling the need to be lightweight and portable.

When testing the scales' ability to support objects, objects of various weights were placed on the scale. It was confirmed that it would reliably be able to support weights exceeding 1Kg. This would be more than enough to support both birds of various weights, as well as suitable bait such as raisins without any issues such as rolling, or the caving of the surface. However, a concern was made due to the durability of the load cells. Each cell could only safely support a weight of 1.2kg (±3.3kg total considering lid weight) before the strain gauges incurred damage, losing complete functionality. This meant that when moving the scale or setting up bait, care needs to be taken to not put too much force on the surface.

The scale had also been set in the sun to test for adaptability to environment. It was found that the scale did emit a sheen when placed in the sun, but the reflected light was not glaring. This is a success as according to research done in the literary review, birds tend to have an allure to shiny objects which

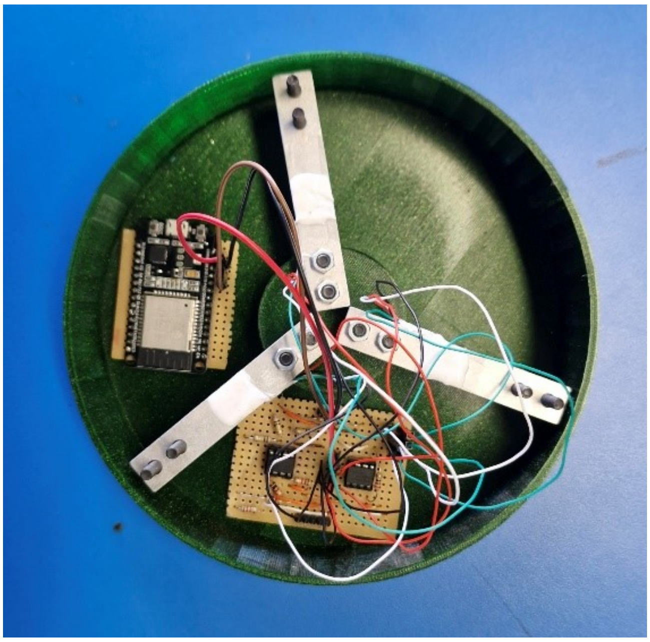


Figure 5.14: semi-assembled scale

don't exert a blinding light.

Lastly the soldered amplification schematic went through testing to ensure that all connections were as intended, with no cross-talk, short or open circuits.

5.7 Conclusion

In conclusion the design achieved its intended functionality, but there is room for various improvements in future models. Namely, the material used as the housing should be changed to one more durable. Should 3D printing be used, a larger printer would be beneficial as this would remove size limits on the design. Alternatively, use of a more durable plastic like ABS, as mentioned in the Design Choices subsection, would be beneficial. The use of longer screws or smaller lid node heights is something that is necessary for future iterations as well. In order to combat the potential damage to the load cells, it is advised for a locking mechanism to be implemented for when the scale is not in use or past a particular weight limit. This would ensure that the scale is likely to have a longer lifespan as well as ensuring accuracy in data readings. Lastly a dip could possibly be incorporated into the centre of the lid as a way of encouraging birds to settle near the centre of the scale.

Chapter 6

Data Collecting and Processing

Author: [redacted]

6.1 Introduction

This chapter discusses the design, implementation and testing of the data collecting and processing subsystem. The aim of this subsystem is to acquire accurate readings from the load cells, convert its data into grams and filter the signal to achieve stability in the output.

6.2 User Requirements

The clients require an accurate scale with which they can weigh Red-winged Starlings on the University of Cape Town campus. The user requirements provided, pertaining to the data collection and processing subsystem, are listed below in Table 6.1.

Table 6.1: User Requirements

No.	Requirement Description
1	The scale must produce a reading in grams.
2	The scale must be accurate to at least 0.1 grams.
3	The scale must be able to accurately weigh starlings between 90 and 160 grams.
4	It must be possible to zero the scale (set the current reading as zero).
5	Readings must be obtained quickly.
6	Readings must be stable and easy to read.
7	Scale must be able to weight the Starlings accurately, despite their movement.

6.3 Acceptance Test Procedures

The Acceptance Test Procedures section summarises the criteria for the data collection and processing subsystem, as well as the tests applied to evaluate whether or not the specifications have been met. The aim of these tests is to ensure the end-product will function as required by the client.

6.4 Design Choices

Since three load cells were being used in an attempt to ensure the measured weight was independent from the position of the weight, the outputs from the three load cells had to be combined into

Table 6.2: Non-Functional Specifications and Acceptance Criteria

No.	Specification Description	Acceptance Criteria
DCP-1	The measured weight must be easy to read without much variation	There must be minimal variation in output once the output has stabilised.
DCP-2	Readings must be obtained quickly.	Settling time for the readings must be kept to a minimum
DCP-3	The ADC input voltage must not exceed its maximum rated voltage.	The maximum possible value out of the load cell circuitry must be approximately 3.3V, with 3.6V as the absolute maximum.
DCP-4	Outputs must be independent of the object's position on the scale.	An object of a constant, known weight must produce the same reading each time it is placed on a different section of the scale.
DCP-5	Readings must have an accuracy of at least 0.1g.	Readings for items of known weights must be accurate to at least 0.1g.

Table 6.3: Functional Specifications and Acceptance Criteria

No.	Specification Description	Acceptance Criteria
DP-6	Load cell must be calibrated to output readings in grams.	Readings for items of known weight must be in grams.
DP-7	The scale must be able to weigh items between 90 and 160 grams.	Readings for items between 90 and 160 grams must be accurate.
DP-8	Must be able to re-calibrate the zero position.	The scale must be able to re-calibrate itself on command such that the current weight is the zero reading, and future readings are accurate according to that zero position.

one. To keep the design simple, the three load cells were placed in parallel to combine their signals. An alternative approach would have been to build interfacing circuitry between the load cells and microcontroller for all three sensors such that each signal was sent to its own analog-to-digital converter (ADC). The readings could then have been combined in code. In the interest of keeping the costs lower, minimising the physical size of the circuitry due to limitations of the housing size and to prioritise simpler debugging for initial design iterations, it was opted to place the sensors in parallel instead.

Load cells output a very small voltage - in the range of a few millivolts - proportional to their deflection. In order to analyse and filter this voltage into stable weight readings, the signal must be appropriately amplified such that the microcontroller's ADC can accurately convert the voltages into digital readings. Typically an instrumentation amplifier is used for this application due to their high input impedance, low noise generation, high gain capacity and easily adjustable gain through the variation of a single external resistor. An AD620 instrumentation amplifier was chosen, due to its suitable power supply range and large gain capacity. Additionally, it is rated to produce very little noise for DC applications, which is important to receive accurate weight readings.

As described above, the instrumentation amplifier's gain can be varied by adjusting the value of an external resistor. The goal was to introduce as much gain as possible without saturating the output of the amplifier at a weight within the range that needs to be measured (90 - 160 grams). The resistor value was determined through trial-and-error, gradually decreasing its value whilst ensuring the output voltage at 160 grams did not reach saturation. The smallest possible value which did not result in saturation was chosen. This has the benefit of the maximum possible gain being utilised, allowing for higher accuracy, and that the amplifier is relatively close to reaching saturation. This means that when excessively heavy loads are placed on the scale, the amplifier will simply saturate. Another amplifier described hereafter adjusts this saturation voltage to 3.3V before feeding it to the microcontroller. This means the system has a built-in maximum output voltage of 3.3V and therefore won't surpass the maximum allowable voltage of the microcontroller's input pin.

Load cell's typically have a DC offset, which is worsened by amplification. To achieve both high amplification and a signal within an ADC typical range of 0 to 3.3V, a large DC offset needs to be removed. This can be achieved with an operational amplifier (op-amp) in a differential amplifier circuit. Additionally, the increasing offset can eventually saturate the instrumentation amplifier's output, thereby limiting the total gain possible. Greater total amplification would increase the millivolt/gram ratio of the system, and thereby increase the accuracy. It was decided to therefore further amplify the signal with another op-amp in a non-inverting amplification circuit. For both these sub-circuits, an LM358 was chosen. It is a widely used op-amp with suitable power specifications for this application.

It was decided to keep the differential and non-inverting amplifier circuits separate, instead of using only a differential amplifier with total gain. Whilst using only one op-amp is beneficial for reducing the total cost and physical space occupied, and means decreases the potential for more noise introduced by components, using two simplifies the debugging process which is very important for the initial design iterations. By having two separate outputs - one from the differential and the other from the non-inverting amplifier - identifying potential issues in the circuit throughout the design process is made easier.

The design of both amplifier circuits required calculation and selection of appropriate resistor values. The offset to be removed was obtained by measuring the output of the instrumentation amplifier from the load cells once they were placed in the scale housing with no other weight on the scale. A voltage divider was designed to output this same DC voltage wihch was fed into the differential amplifier's inverting input. All other resistors used were of the same value such that no additional gain was introduced. The gain of the non-inverting amplifier involved obtaining the output of the differential amplifier when enough weight was placed on the load cells to saturate the instrumentation op-amp. The necessary gain to amplify this voltage to 3.3V was calculated. This ensured that the output from the circuitry - serving as the input the microcontroller's ADC - was never more than 3.3V.

An alternative to all the circuitry explained above is using an integrated circuit such as the HX711 module, which can perform both amplification and offset removal through software. These are widely used modules and widely supported. This module was not used in this design due to the scope of the project - it was advised that we rather design our own system such that all the design requirements for the project are met.

The microcontroller chosen was an ESP-WROOM-32. With respect to data-processing, this was a suitable choice for various reasons. Firstly, it has ample memory capacity at 448KB ROM and 520 KB SRAM, which exceeds that which is required for data conversion and filter implementation. The microcontroller also has an onboard ADC, which allows for a simpler, more compact design than if an external ADC were required.

In order to obtain accurate, stable readings, a low-pass filter is required to remove the high-frequency noise components. This could be done through the implementation of an analog filter made of hardware, a digital filter or a combination of both. It was decided to only implement digital filters, because many design iterations would be required and it is much easier to adjust and test a digital filter by changing the code than it is to rebuild and test analog filters. Additionally, there is a lot of software available for designing and testing such filters, such as Matlab's Filter Designer interface. This enables easy testing and implementation of various types of filters, whether infinite impulse response (IIR) or finite impulse response (FIR). Various filters were designed and compared in Matlab. Their functionality was tested on an array of measurements collected from the unfiltered scale, before they were implemented onto the microcontroller.

Advantages of an IIR filter include that it consists of fewer coefficients and therefore requires less memory space than FIR filters tend to [39]. IIR filters are usually faster, which is very important for this application since the bird's weight needs to be captured quickly before it moves or leaves the scale [39]. They also have analog hardware equivalents, which could be useful for future design iterations if desired in order to limit memory or power requirements. In initial design iterations, it was therefore decided to use an IIR low pass filter. A Chebyshev Type 2 was designed due to its relatively fast transition and flat passband compared to the characteristics of other IIR filters.

It is much easier for an FIR filter to fit design specifications with respect to the critical frequencies and ripple in the pass and stop bands, and therefore could provide useful in designing a better suited filter for this application. This does come at the cost of computational complexity, however, and puts greater strain on memory and power requirements. In later design iterations, a kaiser window filter was designed and tested to establish whether this additional strain was too great for the system, or if the system could withstand it in order to exploit an improved frequency response. A kaiser window filter is adept at achieving greater stopband attenuation, low passband ripple and efficient implementation for real-time scenarios. Through testing, it was determined that the system still functioned well when implementing the filter and the rise time and stability of the weight output were greatly improved, as shown in Figure 6.1. Therefore, a Kaiser Window FIR filter was used instead of the Chebyshev Type 2 IIR filter.

6.5 Final Design

6.5.1 Interface Circuitry

The circuitry serving as the interface between the load cells and the microcontroller was designed as shown in Figure 6.2. The circuitry, consisting of an AD620 instrumentation amplifier and two LM358 op-amps as differential and non-inverting gain amplifiers, served to amplify the signal from the load cells, remove the DC offset and amplify again to normalise the readings between approximately 0-3.3V. The output was fed directly into the ESP-32's ADC.

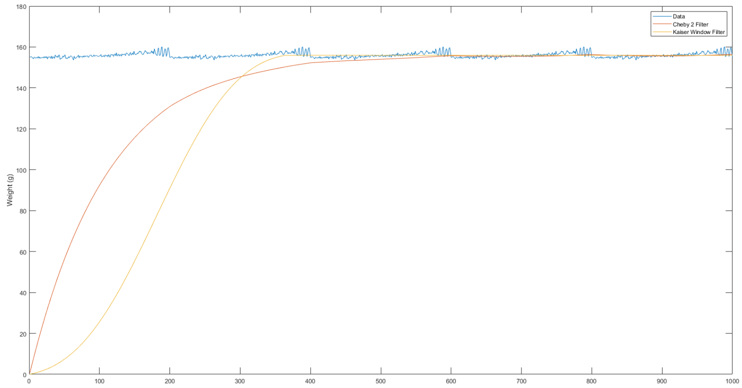


Figure 6.1: Comparison of the step responses of different filters, with the raw, unfiltered data as a reference.

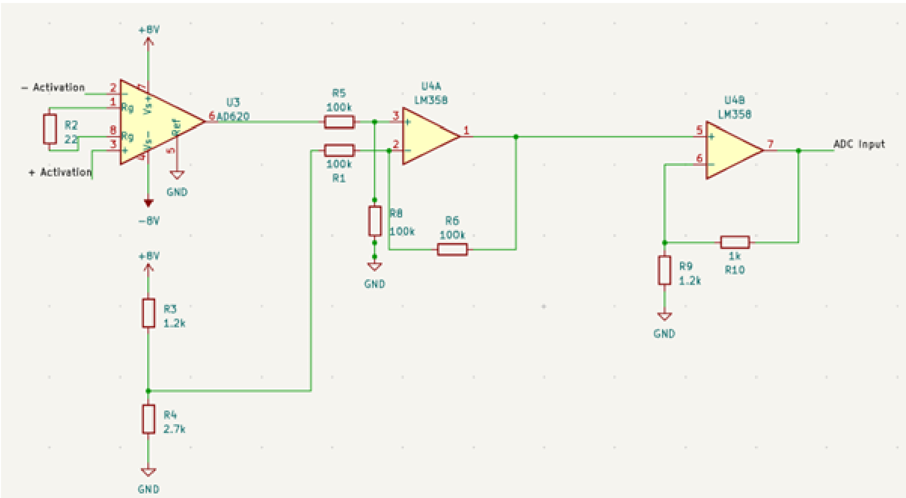


Figure 6.2: Interface circuit diagram connecting load cell to the microcontroller's ADC.

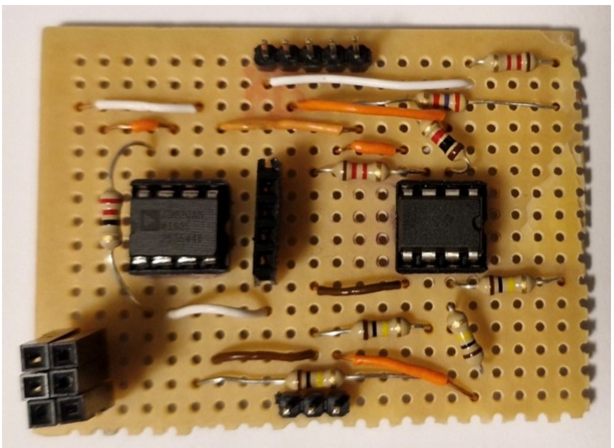


Figure 6.3: Soldered interfacing circuitry.

6.5.2 Data Conversion

The voltage at the output of the interface circuitry is directly proportional to the deflection of the load cells. The ESP-32's ADC normalises input voltages in the range 0 - 3.3V to a value from 0 -

4095. The linear relationship between the weight placed on the load cells and the output ADC value therefore had to be obtained in order to accurately read the weight. This was done by measuring the ADC input voltage for a series of known weights, from which the gram-voltage ratio could be found. The voltage-to-ADC value ratio is known to be $\frac{3.3}{4095}$, meaning the gram-to-ADC value ratio could be calculated as the product of the two ratios. The slight offset present was accounted for by calculating the ADC value for the ADC input voltage when no load was applied. This conversion was applied in code, as shown in Figure 6.4.

```
rawWeight = 0.07405*average - 45.7; //linearising equation to convert ADC value to grams
```

Figure 6.4: Code to convert the ADC value to grams.

6.5.3 Filtering

A Kaiser Window filter was implemented to remove the rapid fluctuations in weight readings. Matlab's Filter Designer interface was used to design the filter according to desired specifications - namely a very low passband frequency, a fast transition and great stopband attenuation - and obtain the filters' coefficients.

Pass band frequency (Hz)	Stop band frequency (Hz)	Pass band gain (dB)	Stop band attenuation (dB)
1	50	1	50

Table 6.4: Specifications of the minimum order Kaiser Window low pass filter.

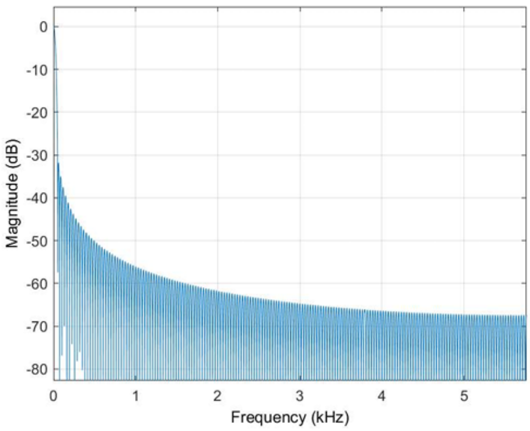


Figure 6.5: Magnitude of the Kaiser Window filter's frequency response.

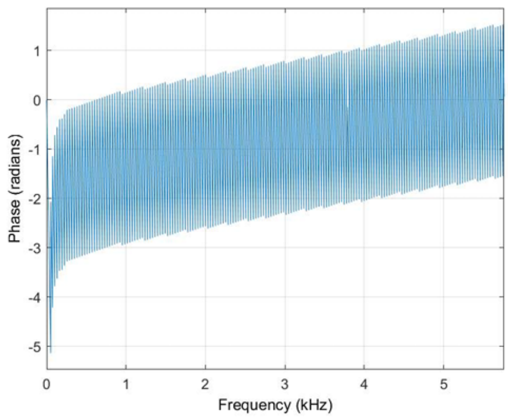


Figure 6.6: Phase of the Kaiser Window filter's frequency response.

The function in Figure 6.7 implements the filter, where its coefficients are stored in the array 'coefficients'. The filter is implemented through convolution with the incoming signal stored in 'inputBuffer'. Note, the impulse response of the filter (the coefficients), does not need to be reversed to perform convolution, because the array is symmetrical, as is typical of FIR filters. The values in 'inputBuffer' are constantly updating as new readings are collected. When the input array is full, the index value circles back to zero to avoid overflow errors.

```
// Function to apply the Kaiser Window Filter
float kaiser_filter(float input) {
  // Add new input data to the buffer
  inputBuffer[inputIndex] = input;

  // Compute filtered output
  float output = 0;
  for (int i = 0; i < NUM_COEFFICIENTS; i++) {
    int index = (inputIndex + i) % NUM_COEFFICIENTS;
    output += coefficients[i] * inputBuffer[index];
  }

  // Update input buffer index
  inputIndex = (inputIndex + 1) % NUM_COEFFICIENTS;

  return output;
}
```

Figure 6.7: Function to implement the Kaiser Window low pass filter on the incoming data.

In addition to the low pass filter, a moving average filter is applied. This is implemented in conjunction with the code used to evaluate whether the input signal has stabilised, as shown in Figure 6.10. An array of input values ('buffer'), with a circulating index, is constantly updated with new input values. Each time the array is filled, the average is calculated and outputted as the final reading.

6.5.4 Offset Re-calibration

The researchers communicated that food will be placed on the scale to attract the birds. Therefore, the scale needs to be able to re-calibrate the weight at which it reads zero in order to account for the weight of the food. The code in Figure 6.9 shows how this zero-functionality is implemented. If the string 'zero' is sent as an input, an offset of the same value as the 'raw weight' is added to the final weight reading.

```
rawWeight = 0.07405*average - 45.7; //linearising equation to convert ADC value to grams
weight = rawWeight - offset; //apply offset introduced from zeroing
```

Figure 6.8: Code to convert the ADC value to grams, in addition to an offset added to re-calibrate the zero position.

6.5.5 Final Output

It is necessary that the reading sent to the server does not fluctuate much such that the value is quick and easy to read. The first algorithm introduced to address this issue is the function 'checkStability', shown in Figure 6.10, to evaluate whether the input values have stabilised. When the buffer array is full of new input values, the array is passed to the function. The array is iterated through to calculate whether each reading falls within the 'stabilityThreshold' (within 3% of the previous reading). If these conditions are met, the average of the array is calculated. Secondly, a new stabilised value is only sent as an output if it differs significantly from the previous value. This is shown in Figure 6.11, the weight needs to differ from the previous valid reading by at least 0.1 grams.

6.6 Testing and Results

Table 6.5: Non-Functional Specifications Assessment

No.	Specification Description	Acceptance Criteria	Test Result
DCP-1	The measured weight must be easy to read without much variation	There must be minimal variation in output once the output has stabilised.	Passed. Once the reading has stabilised, a new output will only be sent if there's significant variation (>0.1 grams). Typically the reading will remain constant for multiple seconds, and at worst vary with ± 0.4 grams. This is still fairly easy to read.
DCP-2	Readings must be obtained quickly.	Settling time for the readings must be kept to a minimum.	Passed. The time for a stable reading to be outputted is consistently within 0.5 seconds, which is fast enough for this application.
DCP-3	The ADC input voltage must not exceed its maximum rated voltage.	The maximum possible value out of the load cell circuitry must be approximately 3.3V, with 3.6V as the absolute maximum.	Passed. The largest voltage reached, when the instrumentation op-amp saturates, is 3.4V.
DCP-4	Outputs must be independent of the object's position on the scale.	An object of a constant, known weight must produce the same reading each time it is placed on a different section of the scale.	Failed. Placing the same object at different positions on the platform resulted in approximately 5% variation in output.
DCP-5	Readings must have an accuracy of at least 0.1g.	Readings for items of known weights must be accurate to at least 0.1g.	Failed. The scale's accuracy is approximately ±0.4 grams.

```
//read zero command
static char inputBuffer[10]; // Buffer to store incoming characters
static int index = 0; // Index for the buffer

// Check if there's data available to read from the serial monitor
if (Serial.available() > 0) {
  // Read the incoming byte
  char input = Serial.read();

  // Check if the input is not a newline character
  if (input != '\n') {
    // Store the character in the buffer
    inputBuffer[index++] = input;

    // Check if the buffer is full
    if (index >= sizeof(inputBuffer)) {
      // Clear the buffer and reset the index
      memset(inputBuffer, 0, sizeof(inputBuffer));
      index = 0;
      Serial.println("Buffer overflow. Please enter 'zero' again.");
    }
  } else {
    // Null-terminate the buffer
    inputBuffer[index] = '\0';

    // Check if the input is 'zero'
    if (strcmp(inputBuffer, "zero") == 0) {
      Serial.println("Zeroing scale...");
      offset = rawWeight;
    } else {
      Serial.println("Invalid input. Please enter 'zero'.");
    }

    // Clear the buffer and reset the index
    memset(inputBuffer, 0, sizeof(inputBuffer));
    index = 0;
  }
```

Figure 6.9: Code to re-calibrate the weight at which zero is read.

```
//function to determine whether inputs have stabilised and apply moving average filter
bool checkStability() {
    for (int i = 1; i < bufferSize; i++) {
        average = average + buffer[i]; //calculate total sum of inputs
        if (fabs(buffer[i] - buffer[i - 1]) >= stabilityThreshold * buffer[i - 1]) {
            average = 0;
            return false; // Not stable
        }
    }
    average = average/bufferSize; //calculate average of all inputs
    return true; // Stable
}
```

Figure 6.10: Function to evaluate whether the input values have stabilised, and to apply a moving average filter.

```
//print variable (or send to server) if it differs from the previous reading
if (fabs(weight - prevWeight) >= 0.1){
  Serial.println(weight, 1);
  prevWeight = weight;
}
```

Figure 6.11: Code to only send a new output value if a significant change occurs.

To test the variation in output reading, a single weight was placed on the scale and 100 stabilised readings were collected and copied into an Excel spreadsheet where the maximum variation could be calculated. All readings were processed according to the procedures outlined in the Final Design section, namely the kaiser window low pass filter, the moving average calculation and the evaluation of stability. The condition to only output a value if at least a 0.1 gram variance occurred was removed, as repeating readings are necessary to calculate the total variance over set sample size. This was repeated with all the filtering systems removed to provide a benchmark value. The filtered-system resulted in $\pm$ 0.4 grams variation, whereas the non-filtered system resulted in $\pm$4.9 grams variation.

It had to be evaluated how quickly the output would stabilise once a new weight is placed on the scale, to determine whether this system would be applicable for a real-life scenario wherein starlings will be

Table 6.6: Functional Specifications Assessment

No.	Specification Description	Acceptance Criteria	Test Result
DP-6	Load cell must be calibrated to output readings in grams.	Readings for items of known weight must be in grams.	Passed. Readings of known weights are provided in grams.
DP-7	The scale must be able to weigh items between 90 and 160 grams.	Readings for items between 90 and 160 grams must be accurate.	Passed. The scale can provide readings until the instrumentation amplifier saturates at approximately 200 grams, as well as accurate 0 gram readings.
DP-8	Must be able to re-calibrate the zero position.	The scale must be able to re-calibrate itself on command such that the current weight is the zero reading, and future readings are accurate according to that zero position.	Passed. A 'zero' command successfully re-calibrates the scale's zero position and remains there indefinitely.

jumping on and off the scale rather quickly. The application of filters increases the system's rise-time and therefore the time it takes to get a stable, accurate reading. To determine this stabilisation time, the time from when a weight was placed on the scale and the stable reading was outputted was measured. For varying weights, this consistently occurred within 0.5 seconds, which is fast enough for this application.

Testing whether the output measurement is independent from the position of the load on the scale was as simple as collecting multiple measurements for the same weight placed at various positions. Readings were found to very by as much as 7.4 grams.

The maximum variance in the outputs provides insight into the scale's accuracy. Seeing as a variance of ± 0.4 grams can occur, the accuracy of the scale of a centered weight is only about ± 0.4 grams. Seeing as the output is not independent from position though, the inaccuracy of the scale is further compounded by varying placement of weights.

A stable 0 gram reading clearly indicated that the scale's minimum possible reading is far less than 90 grams. The design of the interfacing circuitry dictated that the maximum weight the scale could accurately read would be the weight at which the instrumentation amplifier saturated. Please see the Design Choices section for an in-depth explanation of this feature. Through measurement of the instrumentation amplifier's output voltage with a gradually increasing weight placed on the scale, it was determined that the instrumentation amplifier saturates at approximately 200 grams. The scale's maximum accurate reading is far greater than the required 160 grams. Additionally, 1kg load cells were used which can withstand a weight of 1.5kg before deformation occurs. Therefore, the scale can easily provide measurements for weights between 90 and 160 grams.

The output voltage of the interfacing circuitry - and therefore the ADC input voltage - was measured once the maximum weight was placed on the scale as described above. This voltage was found to be 3.4V, which is less than the ESP-32's absolute maximum ADC input voltage of 3.6 volts.

The ability of the scale to re-calibrate its zero position was tested by performing the re-calibration function at various weights and ensuring that the following readings were accurate. Figure 6.13 exhibits this functionality where a weight of 82.8 grams was placed on the scale, set to be the new zero point, and then removed from the scale.

```
13:29:12.683 -> Zeroing scale...
13:29:12.922 -> 0.0
13:29:15.680 -> 36.1
13:29:15.918 -> 122.2
13:29:16.156 -> 121.8
13:29:16.395 -> 121.6
13:29:17.348 -> 121.5
13:29:17.586 -> 121.3
13:29:17.822 -> 121.8
13:29:18.011 -> 121.6
13:29:22.009 -> 117.4
13:29:22.200 -> 6.8
13:29:22.439 -> -0.1
13:29:24.775 -> -0.0
13:29:25.725 -> 11.1
13:29:25.962 -> 84.7
13:29:26.194 -> 82.6
13:29:29.926 -> 82.4
13:29:31.073 -> 61.3
13:29:31.312 -> -0.1
```

Figure 6.12: Depiction of typical output for basic functionality, including re-calibration of the scale and measuring two weights: 122 grams and 83 grams.

```
13:30:42.451 -> Zeroing scale...
13:30:42.547 -> 0.0
13:30:46.255 -> 15.3
13:30:46.495 -> 72.7
13:30:46.733 -> 82.8
13:30:49.878 -> Zeroing scale...
13:30:49.973 -> 0.1
13:30:50.453 -> -0.1
13:30:52.778 -> 0.3
13:30:53.014 -> -35.5
13:30:53.252 -> -82.8
```

Figure 6.13: Outputs portraying the effective offset re-calibration.

6.7 Conclusion

The data collection and processing subsystem consisted of interfacing circuitry between the load cells and microcontroller, aimed at adjusting the signals from the load cells to an appropriate range of voltages for the ADC, as well as software to convert and filter the data into stable weight readings in grams.

The circuitry functioned as expected, although might have introduced too much noise which contributed to the non-ideal accuracy of the final system. Using only one op-amp instead of two for the removal of the offset and further gain could improve the amount of noise in the system. The accuracy will also improve if the system functions across a smaller range of weights. This could be achieved by setting the zero voltage at a higher weight, such that the millivolts/grams ratio is greater. Alternatively, an IC such as the described HX711 module can be used as they result in very accurate readings.

Some adjustments would also need to be made in order to ensure the readings for a given weight are independent of the position of the weight. The use of 'trimming' would likely be appropriate, which is to use potentiometers to weight the signals from the various load cells before combining them. This is to account for differences in the load cell's outputs for the same weight and therefore to ensure they produce the same signal under the same load. Alternatively, the load cells could each have their own interfacing circuitry which feeds into separate ADCs. This enables the signals to be combined in code where a weighing function could also be implemented.

The software successfully converted the data to grams, and performed very well at stabilising the final readings. This could likely be further improved, however, in order to obtain a higher accuracy. More research would have to be done into more sophisticated filtering techniques that might behave more favourably for this application.

Chapter 7

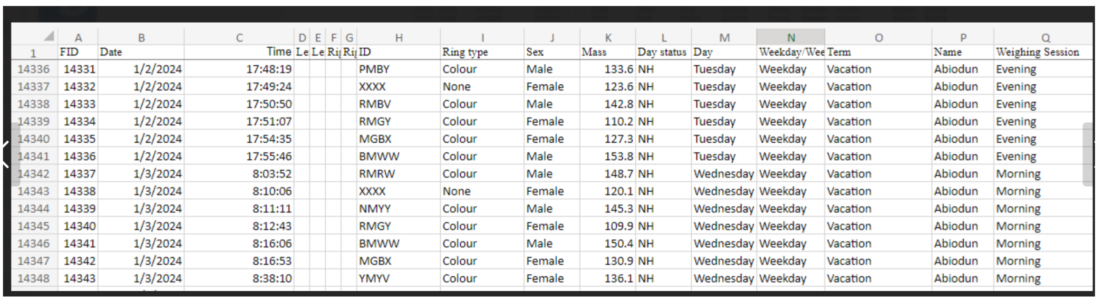
User Interface

7.1 Introduction

The user interface (UI) plays an important role in bridging the gap between technology and the end user. In the context of our project, designing an effective user interface involves understanding the specific requirements and workflows of the ornithologists involved in the bird weighing process. This chapter delves into the details of designing a user-centered interface that seamlessly integrates into the existing workflow of the researchers. It then proceeds to describes the functionality of the design. Lastly it delves into the testing phase before laying out the results of the performance tests that were conducted.

7.2 User Requirements Outline

When we interviewed the researches at the department of ornithology, they described their current method for weighing the starlings. The current implementation involves weighting the bird on kitchen scale, reading the value off the scale, noting it down on a smartphone and entering the data in a spreadsheet when returning to the office. This is a very manual process with room for automation. However, automating this task requires us to consider a solution that can be a ‘drop in’ replacement for the current workflow of the researches. Designing the user interface around this concept is crucial, considering that it serves as the primary point of interaction for researchers with the system. We asked them for a copy of the spreadsheet get a better understanding of what information they were recording and we were provided with the following:



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	FID	Date	Time	Le	Le	Ri	Ri	ID	Ring type	Sex	Mass	Day status	Day	Weekday/Wee	Term	Name	Weighing Session
14336	14331	1/2/2024	17:48:19					PMBY	Colour	Male	133.6	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14337	14332	1/2/2024	17:49:24					XXXX	None	Female	123.6	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14338	14333	1/2/2024	17:50:50					RMBV	Colour	Male	142.8	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14339	14334	1/2/2024	17:51:07					RMGY	Colour	Female	110.2	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14340	14335	1/2/2024	17:54:35					MGBX	Colour	Female	127.3	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14341	14336	1/2/2024	17:55:46					BMWW	Colour	Male	153.8	NH	Tuesday	Weekday	Vacation	Abiodun	Evening
14342	14337	1/3/2024	8:03:52					RMRW	Colour	Male	148.7	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14343	14338	1/3/2024	8:10:06					XXXX	None	Female	120.1	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14344	14339	1/3/2024	8:11:11					NMYY	Colour	Male	145.3	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14345	14340	1/3/2024	8:12:43					RMGY	Colour	Female	109.9	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14346	14341	1/3/2024	8:16:06					BMWW	Colour	Male	150.4	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14347	14342	1/3/2024	8:16:53					MGBX	Colour	Female	130.9	NH	Wednesday	Weekday	Vacation	Abiodun	Morning
14348	14343	1/3/2024	8:38:10					YMYV	Colour	Female	136.1	NH	Wednesday	Weekday	Vacation	Abiodun	Morning

Figure 7.1: Sample of Ornithology Research Spreadsheet

Armed with this information, we can identify additional information beyond just the bird’s weight that users will need to log. These encompass ring color codes for identification, the bird’s sex, the date and time of recording, and the researcher’s name. Utilizing these primary entries, other cells in the spreadsheet can be automatically populated. From this information we can extrapolate the user requirements shown in Table 7.1

Table 7.1: User Requirements for User Interface

No.	User Requirement
UI-R-1	Record the weight of the bird
UI-R-2	Label the reading by including the ring colour codes and sex of the bird
UI-R-3	Timestamp the reading
UI-R-4	Record the name of the researcher taking the reading
UI-R-5	Must be compatible with smartphones, laptops & tablets
UI-R-6	'Fit in' with their existing workflow

7.3 Acceptance Test Procedures

7.3.1 Non-Functional Specifications

Table 7.2: Non-Functional Specifications and Acceptance Criteria

No.	Specification Description	Acceptance Criteria
UI-1	Performance	When the user requests for the webpage, it should respond within 5 seconds under normal load conditions
UI-2	Button Press Delay	Live weight values should resume 5 seconds after Append Button is pressed
UI-3	Reliability	The webpage should maintain an uninterrupted connection to the user for 30 minutes without crashing or requiring the ESP32 to restart
UI-4	Multiple User Handling	The ESP32 should handle a minimum of 4 simultaneous connections without a significant decrease in performance under normal load conditions

7.3.2 Functional Specifications

Table 7.3: Functional Specifications and Acceptance Criteria

No.	Specification Description	Acceptance Criteria
UI-5	Live Weight Monitoring	Live weight values on the interface should update at least once every 1 second
UI-6	Ability to Label and Record Data	Users should be able to correctly label each new entry with corresponding tag colors, sex, time and name
UI-7	Compatibility	The webpage should be accessible and functional on commonly used devices such as smartphones, tablets, and laptops

7.4 User Interface Design Choices

The core of design choices revolves around using a Wi-Fi enabled microcontroller capable of polling a series of weight sensors, such as load cells, and instantly making the readings accessible to users through a webserver hosted on the microcontroller. Initially, the selection process entailed choosing the appropriate microcontroller to support the development of this webserver. Several options were evaluated, drawing from a range of locally available Wi-Fi enabled microcontrollers. These options included the Raspberry Pi Pico W, ESP32 Dev Board, NodeMCU (ESP8266), and the Arduino Nano 33 IoT. Their specifications and price are compared in Table 7.4

Table 7.4: Microcontroller Board Specifications

No.	ESP32 Dev Board	NodeMCU (ESP8266)	Raspberry Pi Pico W	Arduino Nano 33 IoT
Clock Speed	240 MHz	160 MHz	133 MHz	48 MHz
SRAM	520 KB	160 KB	264 KB	32KB
ROM	448 KB	384 KB	2 MB	256KB
Price	R159	R150	R134	R538

Based on the specifications and prices of the above boards, we can easily cut out the Arduino Nano 33 IoT as an option for clearly having the worst price-to-performance ratio. The ESP32 has highest clock speed, most SRAM and second highest capacity of Read Only Memory (ROM) compared to the NodeMCU (ESP8266) and Raspberry Pi Pico W. Despite its superior specifications, is is only marginally more expensive at R159 compared to NodeMCU's R150 and Pi Pico W's R134. The ESP32 Dev Board also has other benefits such as including an onboard USB to UART chip for easier programming and also has Bluetooth Low Energy(BLE) support that could be used as a backup alternative to using wifi. It also has a well establish set of libraries specifically catered towards wifi related features which could aid the development process.

Another design consideration would be to have live readings available on the webpage. This could be done by showing the live values for each individual load cell and also for the live weight reading. The benefits of this is that it gives the user a high degree of visibility. It also serves as a substitute to the digital display of the scale that the researches are currently using. Lastly it also provides a quick and easy way to spot an error. For example, if one of the load cells is not functioning correctly the user will be able to see that live. but if this was not the case and only the weight value was being displayed, the user would have no immediate way of knowing.

An additional design consideration involves aiming for a widely compatible web interface. We were informed by the researches that smartphones are the primary device used to record the weight and labeling information. Therefor a more mobile centric web interface may be more suitable. But this should not come at the cost of a less usable PC interface. Fortunately, modern web development tools make it easy to facilitate compatibility between devices.

Another key design point to consider would be how exactly to record and label the readings. Some initial options revolved around saving the data to an SD card or including a button on the website that allows the user to download the data that they have recorded in that session. However, this doesn't help to improve the existing workflow of the researches as it just introduces more steps that they have to take for the data to end up in the Spreadsheet. A far better solution would be to integrate the website directly with the spreadsheet itself. This could be done by having button configured to directly send data to specific cells in the spreadsheet. This would reduce the workflow down to the single press of a button.

After taking into account these design decisions, libraries and examples of hosting a webserver on an ESP32 were explored. The layout of the webpage was designed using HyperText Markup Language (HTML), the style is defined using Cascading Style Sheets (CSS) whilst the webpage behavior is programmed by JavaScript. The ESP32 was programmed in C++ and used either Extensible Markup Language (XML) or JavaScript Object Notation (JSON) to send data back and forth between the ESP32 and the webpage. In Terms of online resources avaliable, a tutorial was found to set up live data readings for a webpage on an ESP32 by Kris Kasprzak [40] which used XML to parse data to and from the ESP32. There is also an Arduino library by K. Suwatchai [41] for manipulating data in Google Sheets from an ESP32 which was also used.

7.5 Final User Interface Design

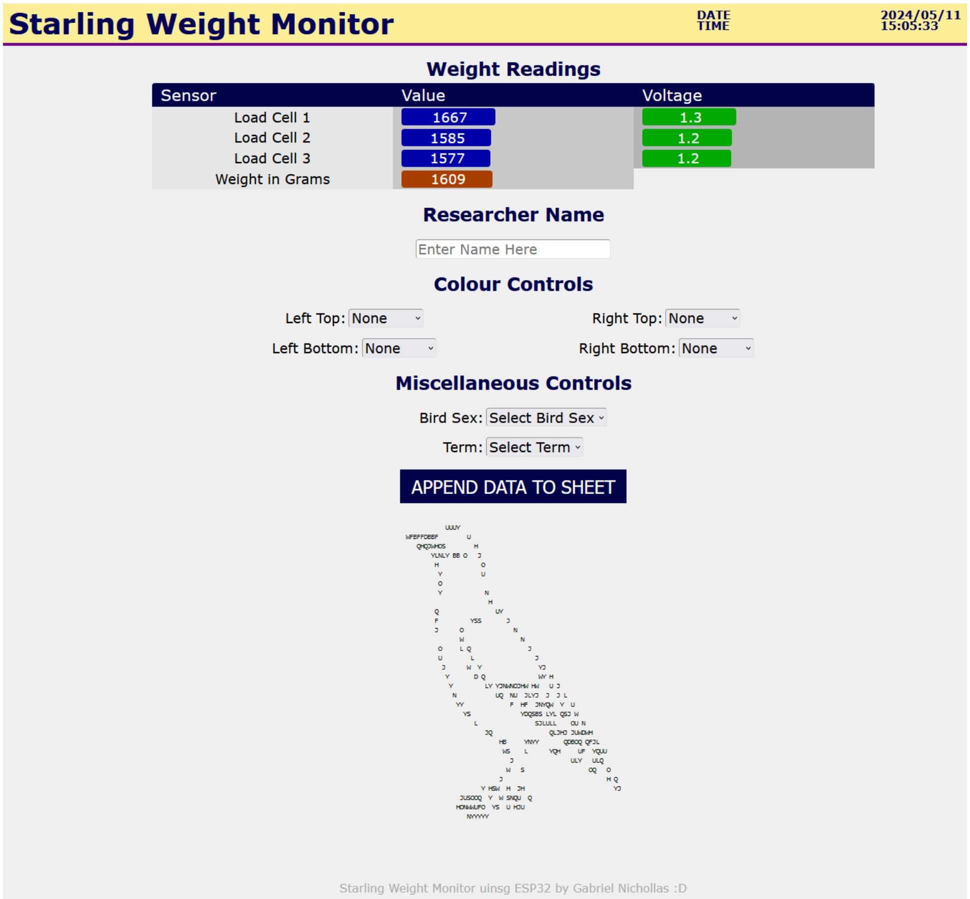
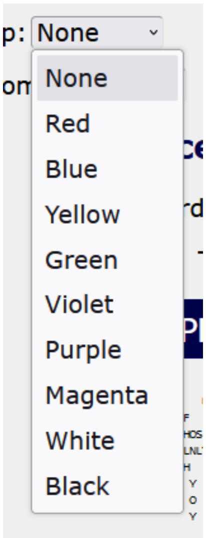


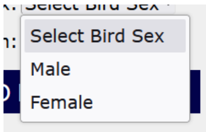
Figure 7.2: Final Webpage Interface Design

Figure 7.2 shows the Final Design of the Webpage Interface. The webpage has title, and a date and time counter in the header section for the user. The next section is the Weight readings table that displays the weight and the sensor values. The table has entries for the readings and voltage of each individual load cell as well for displaying the weight value. Since implementing the weight and filtering algorithm is out of the scope of this subsystem, the current implementation just polls the ADCs of the ESP32 and calculates the average of the three values for the weight entry. The voltage entries just display the voltage reading of the respective ADC pins. The Value and Voltage columns have also been designed with a progress bar. The bar fills up a horizontal percentage of the cell depending on the ratio between the reading and the max value of the cell. for example the Values columns would be 100% full when the value of the ADC is at its max of 4095 (12 bits). The same is true for the voltage column which is at its max for 3.3 Volts. The horizontal bars update at the same frequency as the reading which can be used as a helpful indicator of the stability of the scale. High fluctuations in readings will result in the bars fluctuating drastically which could be used as an indication that the weight platform is not yet stable.

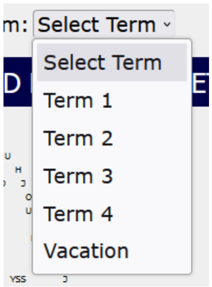
The next section of the webpage revolves around handling the user inputs for labeling the reading. Underneath the table is a text box for the researcher to enter their name. Following that is the Colour Controls section, featuring four drop-down menus for users to select the colors of the rings. Each dropdown is positioned on the webpage corresponding to the respective ring's location on the bird's leg. The list of colours has been derived from the colours listed in Research Spreadsheet 7.1. There are also drop-down menus for selecting the sex of the bird as well as which term the data was captured in. These drop-down menus are shown in Figure 7.3



(a) Colour Selector Drop-Down Menu



(b) Bird's Sex Drop-Down Menu



(c) Term Drop-Down Menu

(d) Miscellaneous Drop-Down Menus

Figure 7.3: Drop Down Menus for Labeling Weight Reading

Once the User has entered in all the necessary information, They need to press the 'Append Data to Sheet' button that will collect the weight reading and all the entered information and append it to the corresponding columns into a Google Sheet as shown in Figure 7.4

FID	Date	Time	Left Top	Left Botto	RIght Top	Right B	ID	Ring Type	Sex	Mass	Day Statu	Day	Weekday/We	Term	Name	Weighing Session
14343	2024/05/12	12:39:28	Red	Purple	Yellow	Yellow	RPYY	Colour	Male	21	NH	Sunday	Weekend	Term 1	1U Test 1	Afternoon
14344	2024/05/12	12:40:10	Yellow	Purple	Black	White	YPNW	Colour	Female	32	NH	Sunday	Weekend	Term 2	1U Test 2	Afternoon
14345	2024/05/12	12:40:45	White	Red	Purple	Magent	WRPM	Colour	Male	9	NH	Sunday	Weekend	Term 3	1U Test 3	Afternoon
14346	2024/05/12	12:41:12	Red	Yellow	Violet	Green	RYVG	Colour	Female	15	NH	Sunday	Weekend	Term 4	1U Test 4	Afternoon
14347	2024/05/12	12:42:08	Red	Yellow	White	Black	RYWN	Colour	Female	15	NH	Sunday	Weekend	Vacation	1U Test 5	Afternoon
14348	2024/05/12	12:43:52	Purple	Magenta	Green	Blue	PMGB	Colour	Male	33	NH	Sunday	Weekend	Term 1	1U Test 6	Afternoon
14349	2024/05/12	12:44:37	Red	Red	Red	Red	RRRR	Colour	Female	39	NH	Sunday	Weekend	Term 2	1U Test 7	Afternoon
14350	2024/05/12	12:44:56	Blue	Yellow	Green	Green	BYGG	Colour	Male	4	NH	Sunday	Weekend	Term 3	1U Test 8	Afternoon
14351	2024/05/12	12:45:23	Red		Red		RXRX	Colour	Female	67	NH	Sunday	Weekend	Term 4	1U Test 9	Afternoon
14352	2024/05/12	12:53:06					XXXX	None	Male	81	NH	Sunday	Weekend	Vacation	1U Test 10	Afternoon
14353	2024/05/12	12:58:19	Magenta	Red	Violet	Yellow	MRVY	Colour	Male	23	NH	Sunday	Weekend	Term 1	4U Test 1	Afternoon
14354	2024/05/12	12:58:27	Magenta	Red	Violet	Yellow	MRVY	Colour	Male	43	NH	Sunday	Weekend	Term 2	4U Test 2	Afternoon
14355	2024/05/12	12:58:46	Green	Magenta	Violet	Red	GMVR	Colour	Female	57	NH	Sunday	Weekend	Term 3	4U Test 3	Afternoon
14356	2024/05/12	13:08:11	Red	Blue	Yellow	Yellow	RBYY	Colour	Male	61	NH	Sunday	Weekend	Term 4	4U Test 4	Afternoon
14357	2024/05/12	13:08:23	Green	Magenta	Red	Blue	GMRB	Colour	Female	40	NH	Sunday	Weekend	Vacation	4U Test 5	Afternoon
14358	2024/05/12	13:08:39	Yellow	Yellow	Green	Red	YYGR	Colour	Male	78	NH	Sunday	Weekend	Term 1	4U Test 6	Afternoon
14359	2024/05/12	13:08:52	Magenta	Purple	Magenta	Black	MPMN	Colour	Female	9	NH	Sunday	Weekend	Term 2	4U Test 7	Afternoon
14360	2024/05/12	13:09:11	Purple	Purple	Blue	Blue	PPBB	Colour	Male	80	NH	Sunday	Weekend	Term 3	4U Test 8	Afternoon
14361	2024/05/12	13:09:53	Red	Red			WRXX	Colour	Female	19	NH	Sunday	Weekend	Term 4	4U Test 9	Afternoon
14362	2024/05/12	13:10:09					XXXX	None	Male	4	NH	Sunday	Weekend	Vacation	4U Test 10	Afternoon

Figure 7.4: Spreadsheet of Data Readings Captured from Webpage

7.6 User Interface Code Design and Breakdown

This section deals with the explanation of the code that runs the entire webpage interface subsystem. For the sake of avoiding having code snippets of the entire program, code that deals with parsing data between the user, webpage and google sheets will be focused on. Other parts of the code, such as the HTML and CSS code will be touched on lightly. However, all the code used for this subsystem will be included on **GitHub**.

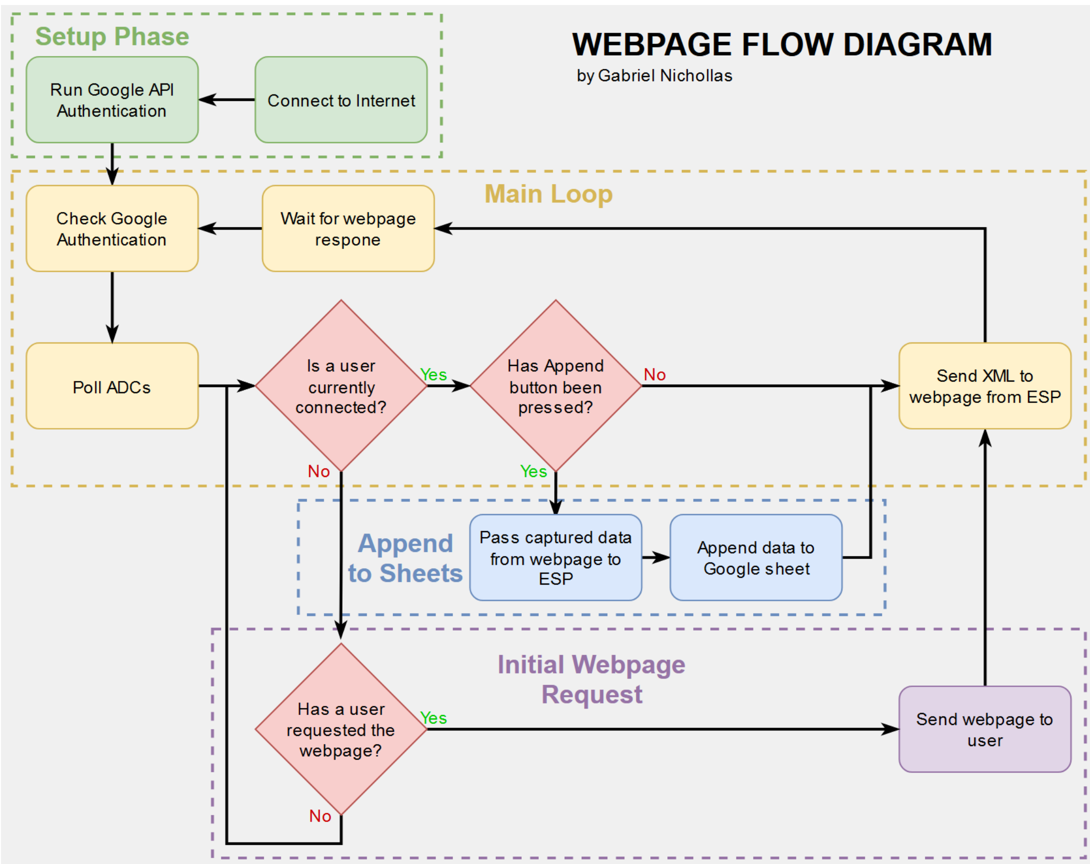


Figure 7.5: ESP32 Webpage Code Flow Diagram

7.6.1 Setup Phase

The first phase is the Setup Phase which runs as the ESP32 is powered on or rebooted. It connects to a WiFi network and sets up Google API authentication. It also defines several callback functions (shown in Listing 7.1) for handling HTTP requests from the webpage. Finally it starts the HTTP server.

```
// upon ESP getting "/" (root path) string, the web page will be sent
server.on("/", SendWebsite);
// upon esp getting /XML string, ESP will build and send the XML
server.on("/xml", SendXML);
// upon ESP getting /UPDATE_SUBMIT string, ESP will append data to Google Sheets
server.on("/UPDATE_SUBMIT", UpdateSubmit);
```

Listing 7.1: Webserver Callback Functions

7.6.2 Main Loop Phase

The Main Loop Phase refers to the loop of operations that keep the webpage live with the latest weight readings to the user. Firstly it check on the status of the Google Sheet connection to seen if the authentication token is still valid. It then reads the ADC values (after every 50ms), converts them to voltage values, and handles incoming HTTP client requests. The ESP32 must constantly handle incoming requests otherwise the webpage will not get instructions to do something and freeze.

The ESP32 will then listen for one of the callback functions to decide what to do next. If a user is currently connected to the ESP32 then it receives a callback for the SendXML() function which will send an HTTP response containing an XML string with the readings and voltages of the ADCs to the webpage. The webpage will then populate the values in the table and update the horizontal bar based on the XML payload. Once the values have been updated, the webpage will make an HTTP request for the SendXML() function. Once the ESP32 has check the authentication and polled the ADCs, it will listen a again for a callback function and execute the SendXML() function again. This process continues until either the Append Button has been pressed or another user request the webpage.

7.6.3 Append to Sheets Phase

The Append to Sheets Phase occurs outside the main loop. If the user presses the Append to Sheets button then the webpage will executed the sendSubmit() JavaScript function. It gets values of the weight, date, time, colour drop-down, name, term and bird sex HTML elements on the page using document.getElementById(). It then performs some formatting and creates an XMLHttpRequest object containing the values of all the elements and sends it to the ESP32.

This process invokes the UpdateSubmit() function which retrieves the values of various parameters sent with the HTTP request. It then prepares a JSON object to be sent to Google Sheets. It fills this object with the values received from the request parameters. Then it calls the GSheet.append() method to append the data to the Google Sheets. The spreadsheet ID, destination range and JSON object are passed to the function which appends the values to the corresponding spreadsheet. An example of this entire process can be seen in Listing 7.2

```
// JavaSript function for sending example values to ESP32
function sendSubmit() {
    var parameter_value1 = document.getElementById("element_id1").value;
    var parameter_value2 = document.getElementById("element_id2").value;
    var xhttp = new XMLHttpRequest();
    xhttp.open("PUT", "UPDATE_SUBMIT?PARAMETER1=" + parameter_value1 +
                                    "&PARAMETER2=" + parameter_value2, true);
    xhttp.send();
}

// C++ Function for appending example values to Google Sheets
void UpdateSubmit() {
  String parameter1 = server.arg("PARAMETER1");
  String parameter2 = server.arg("PARAMETER2");

  FirebaseJson response;
  FirebaseJson valueRange;

  valueRange.add("majorDimension", "COLUMNS");
  valueRange.set("values/[0]/[0]", parameter1);
  valueRange.set("values/[1]/[0]", parameter2);

  bool success = GSheet.values.append(&response /* returned response */,
                                      spreadsheetId /* spreadsheet Id to append */,
                                      "Sheet1!B3" /* range to append */,
                                      &valueRange /* data range to append */);

  server.send(200, "text/plain", ""); //Send web page
}
```

Listing 7.2: Funtions for the Append to Sheets Phase

7.6.4 Webpage Request Phase

This Phase is initiated whenever a new user connects to the ESP32. Upon entering the URL into a browser, the ESP32 receives a request for the root path ('/'). It responds by calling the SendWebsite() function. This function sends the main web page (PAGE_MAIN) to the user. The PAGE_MAIN variable is defined in a separate header file (myWebPage.h) and contains a large HTML string. This HTML string defines the structure and content of the main web page. It includes all the HTML, CSS, and JavaScript code.

7.7 User Interface Testing and Results

7.7.1 Testing Overview

Most of the testing involved was conducted on a PC through the network tab in the browser's integrated developer tools. The first test had a single user connected and measured the webpage load times, update period for displayed readings, the delay of pressing the Append Button and connection duration. The webpage was reloaded 10 times after every 1 minute to collect load time and update period times. At the end of the test, the Append Button was pressed to append data to Google Sheets, each time with a different set of labels. After the 10 page reloads, the page was then left live for 60 minutes to test the connection duration. These tests were then re-run with 4 users connected on a variety of devices. Where a single user was performing the tests while the other 3 devices were left connected. Tests were also conducted to check the correctness of the data being appended to Google Sheets.

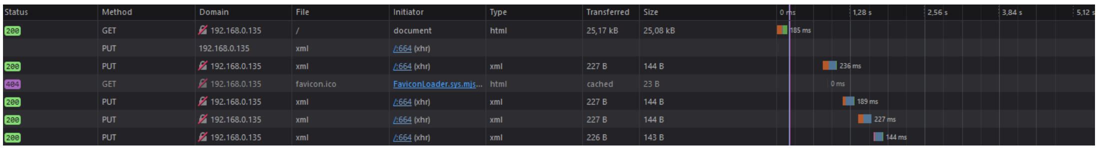


Figure 7.6: Screenshot of Network Tab of Browsers Development Tools

7.7.2 Testing Results

Table 7.5: User Interface Testing Results - 1 User Connected

Test	Minimum	Average	Maximum
Page load time	101 ms	364.5 ms	897 ms
Time to update reading	135 ms	242.7 ms	544 ms
Button delay duration	1278 ms	1876.3 ms	2756 ms

Table 7.6: User Interface Testing Results - 4 Users Connected

Test	Minimum	Average	Maximum
Page load time	326 ms	511.3 ms	1145 ms
Time to update reading	282 ms	340.1 ms	773 ms
Button delay duration	1944 ms	4129.4 ms	10646 ms

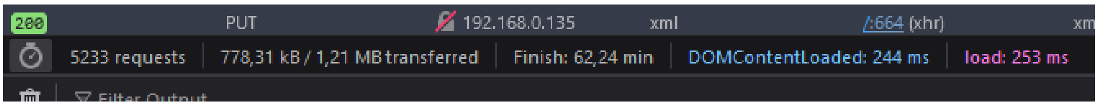


Figure 7.7: Screenshot of Network Tab Timing Connection

Overall the test results show a lot of promise for the system. Table 7.5 Show that with a single user connected, all the tests passed the ATPs even for the worst case. The endurance test in Figure 7.7 show the connection duration is able to go over an hour without interruptions. However, there is some notable performance degradation when 4 users are simultaneously connected. Table 7.6 shows higher values in all cases compared to a single user. In the case of the Button delay duration, the maximum value well exceeded the minimum of 5 seconds. There was also no issue with data not being appended to Google Sheets Figure 7.4 shows that all entries were correctly captured.

7.7.3 Functional and Non-Functional Specification Assessment

Table 7.7: Non-Functional Specifications Assessment

No.	Specification Description	Acceptance Criteria	Test Result
UI-1	Performance	When the user requests for the webpage, it should respond within 5 seconds under normal load conditions	**Passed**. The webpage took an average time of 364.5 ms to load for the user
UI-2	Button Press Delay	Live weight values should resume 5 seconds after Append Button is pressed	**Passed**. The webpage took an average of 1.8763 s to resume sending live weight values
UI-3	Reliability	The webpage should maintain an uninterrupted connection to the user for 30 minutes without crashing or requiring the ESP32 to restart	**Passed**. The webpage was able to maintain a live connection for 60 minute without issue
UI-4	Multiple User Handling	The ESP32 should handle a minimum of 4 simultaneous connections without a significant decrease in performance under normal load conditions	**Failed**. With 4 simultaneous connections the ESP32 was unable to resume 5 seconds after Append Button was pressed with the worst case taking 10.646 s

Table 7.8: Functional Specifications Assessment

No.	Specification Description	Acceptance Criteria	Test Result
UI-5	Live Weight Monitoring	Live weight values on the interface should update at least once every 1 second	**Passed**. Live weight reading take an average of 242.7 ms to display on the webpage
UI-6	Ability to Label and Record Data	Users should be able to correctly label each new entry with corresponding tag colors, sex, time and name	**Passed**. Data is correctly appended and labeled to Google Sheets with all required fields
UI-7	Compatibility	The webpage should be accessible and functional on commonly used devices such as smartphones, tablets, and laptops	**Passed**. The webpage is accessible and functional on mobile and PC devices

7.8 Conclusion

In conclusion, the development of a user interface for an automatic scale in ornithological research, proved to be a multifaceted problem. Developing A solution that would be ideal for the end user required a thorough understanding of the user's need before any development could begin. Once these needs were well understood, design decisions were made to best meet the needs of the end user and facilitate development. The final design was demonstrated and explained along with outlines of the tests that were conducted to measure the suitability of the proposed system. It was found that the system meets all the performance targets but does run into challenges with multi-user handling.

Ongoing refinement and adaptation of the user interface will be essential to maintain optimal functionality and user satisfaction. A future suggestion would be to optimize the code to enable better performance when multiple users are connected to the ESP32. By prioritizing user feedback and addressing the minor shortfalls, the interface can continue to evolve as a vital tool in advancing ornithological research endeavors.

Chapter 8

Conclusions

The purpose of this project was to create a standalone scale capable of automatically weighing the Red-winged Starling and transmitting the weight readings to a web server to make that data available the researchers. The report begins with a look into the groups journey in the D-School course and the insights gained from engaging with the researchers. The problem analysis continues to give a breakdown of the groups design options and the choices leading up to the proposed solution. This goes into information such as initial concepts and features as well as perspectives given by the clients from the Fitzpatrick institute of African Ornithology. This is followed by the literature review, where the group gained insights on existing technologies and methodologies around our solution. The literature review's purpose was to gain a deeper understanding of how to approach the project in an efficient and effective manner.

The next few chapters contain the majority of the design process, as it details all the work done for the four subsystems: Power, Housing & Layout, Data Processing and User Interface. Firstly, the relevant requirements and specifications for the subsystems are listed. Each subsystem then details the design process undertaken to complete the section to the extent that the applicable requirements and specifications were met. The tests conducted to ensure appropriate performance of the subsections are detailed, as well as the outcomes of these tests. These tests were done thoroughly so that a quality product could be delivered to the client. In addition, the sections expand upon the insight gained into the design of the subsystems and methods to improve upon them.

In the end, not all tests were sufficiently passed. Unfortunately the scale was not as accurate as the clients required, which would need to be addressed in future design iterations. This can be done through the use of alternative interfacing circuitry between the load cells and the microcontroller, or more sophisticated digital filters. The physical size of the power circuitry was too large and would need to be reduced. This can be done by using a printed circuit board as well as building a larger housing structure. Before deployment into the field, the housing will also need to be developed with alternative materials such as ABS. The web server performed sub-optimally when multiple clients connected. This can be addressed by optimising the method used by the ESP-32 to handle web requests.

In summary, the project was successful at achieving the majority of the required functionality despite the improvements that would need to be made in future iterations. This was also achieved within the proposed budget for the project.

Chapter 9

Bill of Materials

Component	Individual Price	Number Used	Total Price
ESP-WROOM-32 DevKit	R159.00	1	R159.00
1KG Strain Gauge Load Cell	R45.00	3	R135.00
M4 Nut	R0.49	12	R5.88
M4 x 25mm Hex key cap screw	R0.90	12	R10.80
LM358P	R2.50	1	R2.50
22Ω resistor	R0.63	1	R0.63
100kΩ resistor	R0.63	4	R2.52
1.2kΩ resistor	R1.04	2	R0.28
2.7kΩ resistor	R0.14	1	R0.14
1kΩ resistor	R0.69	1	R0.69
AD620	R34.00	1	R34.00
LM317T	R9.95	6	R59.70
Rectifier Diode	R0.44	5	R2.20
Zener diode	R1.32	5	R6.60
Green LED	R1.09	5	R5.45
Multicolour Led	R50.00	1	R50.00
1/4W 220 ohm	R0.16	5	R0.80
1/4W 2k ohm	R0.07	5	R0.35
5W 10 ohm	R2.59	5	R12.95
Wire Wound KNP Resistor	R3.39	5	R16.95
10k pot	R10.81	5	R54.05
Zener diode	R0.87	2	R1.73
Zener diode	R0.72	2	R1.44
Zener diode	R2.09	2	R4.18
Zener diode	R1.72	2	R3.44
Resistor	R0.40	2	R0.80
Resistor	R0.40	2	R0.80
Resistor	R0.40	2	R0.80
Resistor	R0.40	2	R0.80
Resistor	R0.25	2	R0.50
Zener diode	R1.36	2	R2.72

P-Mosfet	R20.61	2	R41.22
voltage regulator	R26.45	1	R26.45
Schotkky diode	R4.26	2	R8.52
Inductor	R3.32	4	R13.28
Inductor	R3.32	5	R16.60
Capacitor	R2.88	1	R2.88
Capacitor	R0.52	1	R0.52
DRIVER FET DIP DUAL ICL7667CPA	R66.35	2	R132.70
OPTO Coupler	R16.85	2	R33.70
			R1055.57

Table 9.1: Bill of materials for final product.

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