Automated Bird Scale

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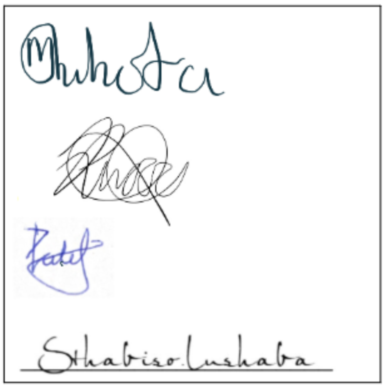

October 3, 2023

Name Surname

Date

Acknowledgements

> No man is an island entire of itself; every man is a piece of the continent, a part of the main.
>
> —*John Donne*

Our thanks goes to Riyaad Jacobs for helping us build the mechanical structure and Dr Schonken for his insightful supervisory role through out the design and development process

Abstract

This paper presents a detailed description of a system aimed at automating the weight-capturing of raptors and eagles in the Kalahari desert. Bird-watching, whether it be a recreational pastime, a lifelong passion, or professional pursuit for ornithologists helps monitor bird populations, track migrations and assess the health of ecosystems which all contribute to awareness about environmental issues that impact birds and their habitats. The traditional methods typically used for capturing the weights of the birds have proven to be strenuous and laborious as they often rely on outdated technology (i.e. binoculars) and human presence to monitor and record the weights. The proposed solution aims to leverage the up-to-date technological resources available to improve the weight-capturing process, this includes; Communication protocols, Scale sensors, renewable power systems, etc. The system offers a landing platform for the birds(raptors and eagles) to interact with the system, employs a sensor to translate the force exerted by the bird to readable weights, and uses a camera to capture the bird species corresponding to the weight reading and communicates that information with birdwatchers devices(laptops, smartphones, etc.) through communication protocols. This effectively improves the weight-capturing process as everything is automated, and requires no human interference, therefore, the weight can be recorded under different environmental conditions, and more readings are attainable within a relatively short period of time. In addition, the electronic sensors employed by the system offer more accuracy in comparison to the traditional methods which are relatively more manual and are subject to human error whether it be when interacting with the system or manually recording the weights. This paper details the system design, system requirements, and specifications to meet the requirements. Moreover, justifies the design choices and provides measurements to ensure system requirements have been met.

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Chapter 1

Introduction

> Philosophers have hitherto only interpreted the world in various ways; the point is to change it.
>
> —*Karl Marx*

This report provides a comprehensive account of the design and development process of an automated bird scale. The primary objective of this project was to address the weight acquisition challenges faced by an American researcher named Chris. Currently, Chris encounters arduous and physically demanding endeavors to obtain accurate weight measurements of birds.

1.1 Background

Bird weight measurement is an essential parameter in avian research, providing valuable insights into various aspects of avian biology [3], behavior, and ecology. Researchers often rely on accurate weight data to study growth patterns, assess health status, monitor migration patterns, and investigate the impact of environmental factors on bird populations. However, traditional methods of acquiring bird weight measurements have proven to be labor-intensive, time-consuming, and physically demanding especially according to Chris.

To address these challenges and improve the efficiency and welfare of both researchers and birds, the development of automated bird scales can serve as a good solution. An automated bird scale offers a non-intrusive and less labor-intensive approach to obtain accurate weight measurements while minimizing stress on the birds. By creating a platform where birds can perch naturally, weight data can be collected without the need for physical manipulation or restraint.

1.2 Objectives

The following specific objectives guide the implementation of this project:

- A robust perch structure
- Accurate and precise bird weight measurements
- Some form of bird identification in terms of which weight belongs to which bird
- Organised data storage and easy access

1.3 System Requirements

To achieve the objectives, the following system requirements were to be considered:

- The customer must be able to read the weight of raptors and eagles digitally
- The measurements must be able to be used by other sub-modules
- The weight sensor needs to provide accurate measurements
- The weight sensor must not fail and be robust to support various forces and moments
- Load Cell or Weight Sensor: The automated bird scale should incorporate a high-precision load cell or weight sensor capable of accurately measuring the weight of birds. The sensor should have a suitable weight range to accommodate different bird sizes and be sensitive enough to provide precise measurements.
- Bird Identification System: To associate the weight measurements with specific birds the weight and its time stamp should be associated with the bird's picture

1.4 Scope & Limitations

The scope of this project focused on the design and development of an automated bird scale to alleviate the physical strain associated with bird weight acquisition for researchers. The project aimed to provide accurate and reliable bird weight measurements while incorporating a bird identification system. The scale was designed to be portable, user-friendly, and capable of processing and storing weight data for analysis. The project primarily targeted American researcher Chris's weight acquisition problems, but the developed scale can be adapted for use by researchers in similar contexts.

Despite the successful development of the automated bird scale, there are certain limitations that need to be acknowledged:

- Bird Size and Weight Range: The scale's design and load cell capacity (5 kg) were optimized for a specific range of bird sizes and weights. Extreme variations in bird sizes or weights may fall outside the scale's optimal measurement capabilities, potentially affecting the accuracy and precision of weight readings.
- Environmental Factors: The scale's accuracy may be influenced by environmental conditions such as the wide desert temperature range and humidity.
- Bird Cooperation: The successful operation of the automated bird scale relies on the voluntary participation of birds to perch on the scale. However, certain bird species may exhibit reluctance or resistance to land on the artificial perch, which could impact data collection and the overall usability of the system.

1.5 Report Outline

This report presents a comprehensive overview of the development and implementation of an automated bird scale, designed to alleviate the challenges associated with bird weight acquisition in research settings. The report is structured as follows:

- Introduction:
  - Background: Provides an overview of the difficulties faced by researchers in obtaining accurate bird weight measurements and highlights the need for an automated solution.
  - Objectives: Clearly defines the objectives of the project and outlines the desired outcomes.
  - Scope and Limitations: Identifies the scope of the automated bird scale and acknowledges any limitations or constraints that may impact its implementation.
- Literature Review: Presents a review of traditional bird weighing methods and technologies currently employed in avian research. Furthermore it discusses the drawbacks and challenges associated with manual weighing techniques along with the potential benefits of automation
- Design and Development: This encompasses chapters that detail the design and development process of 4 subsystems of the project.
- Conclusion and Recommendations: These sections conclude the report and motivate any improvements that can be made to the project in future.

Chapter 2

Literature Review

> If you wish to make an apple pie from scratch, you must first invent the universe.
>
> —*Carl Sagan*

The monitoring of bird weight in remote areas such as deserts is a critical component of avian research. However, automated weight data processing specifically targeting birds such as eagles and raptors in the desert is currently lacking. To fill this gap, a comprehensive weight data processing and transmission approach that draws on existing technologies is proposed. Furthermore, various methods of attracting the birds to the scales for weight measurement are discussed along with different methods of measuring weight. Moreover, significant attention is paid to how power could be delivered to the weight-capturing equipment and how the equipment can be protected from the harsh desert environment it operates in.

2.0.1 Weight Data Processing

The processing of the weight data collected from the measurement is a key component of the overall monitoring process. This is so because detailed analyses can only be drawn from well processed data. Therefore, it is fundamental for the appropriate data processing methods to be selected. Now scales, as with most other instruments that measure physical quantities, interface with the raw data in its analog format. This data then has to be converted to a digital format before logging it so as to minimize data loss during wire transmission [4]. This analog to digital conversion is typically done using ADCs (Analogue-to-Digital Converters) which use the I2C communication protocol. The ADCs can have their resolution configured to a number of bits with the most common being 12-bit resolution. For the purposes of unique bird weight measurement, the weight data would have to be captured with an associated time stamp. Thus, each weight measurement then becomes a data packet which consists of the weight of a bird and the time the weight was taken. Now, The requirement of time stamps along with each weight measurement could result in the need for a higher storage capacity. However, this could be offset by the fact that the targeted birds exist as a small population which would correspond to a manageable quantity of weight data for storage. These digital packets can typically be logged onto a portable data terminal as an interim storage medium. For example, one research paper suggests the use of the Texas Instruments Model 765 as a suitable data terminal for poultry weight data [5]. The terminal can then be connected to a computer which can then further process and store the data it would have gathered. The Model 765 would be a suitable on-site data terminal for desert research because of its low-cost maintainability and capability to do some standalone data processing. For research being conducted in remote areas, wireless transmission of data becomes necessary. A good contender for such capability is GSM/GPRS (Global System for Mobile-communication/General Packet Radio Service). It is more convenient than the internet as it allows broader wireless communication coverage [6] making it suited to remote areas like the desert were internet connectivity is likely to be very poor. Furthermore, GSM/GPRS modules are relatively a cost-effective solution for remote data transmission.

In retrospect, there does not seem to be an existing method of automated weight data processing that specifically targets birds in the desert such as eagles and raptors. This presents a gap in the solutions space for bird monitoring in remote areas such as deserts. To fill in this gap, a comprehensive weight data processing approach will be used which draws on the fore-mentioned existing technologies to create a solution specific to the problem statement. The proposed solution will seek to automatically capture weight readings of raptors and eagles along with their associated time stamps as digital data. Unlike current weight data acquisition methods that mostly focus on the animals collectively, the implementation of a time stamp can potentially uniquely identify each bird. The digital data would then be stored on an on-site data terminal before being sent over wireless transmission to an offsite computer for further processing and interpretation.

2.0.2 Methods of Measuring Weight and Integration of Weight-Measuring Devices

There are many methods of measure weight, regardless of the animal being measured. Competitive methods in the market, especially birds, are Computer Vision Systems, Stress-Strain sensors and Spring scales. There are currently many examples of the integration of these measuring systems in the agricultural sector and wildlife preservation sphere.

Computer Vision Systems

There has been great progress in agricultural sector in determining the weigh of an animal. A computer vision system is set up as an input to produce an entirely algorithm based output. A camera is set up to view an object and background and will provide an input to an AI or Machine Learning (ML) process. These AI or ML processes are then used to produce information on the video or picture from the camera.

An integration example, currently being applied to broiler houses, uses a 3D Computer Vision system for weight prediction. The camera had been placed with a top down view in which an algorithm was used to determined the height of a various points in the picture. This height information was used to calculate the volume of chickens with generally correlates to their mass. [7]. This process is unique due to its non-invasive nature, resulting in great benefits of reducing stress to the broilers and being able to get weight measurements of immobile broilers. However, there are drawbacks including the 11% error rate of the predicted versus actual weight of the broiler. This is due to the movement of these birds, resulting in the neck and tails being removed in the volume calculations [7]. Overall, this led to poor weight prediction which needs to be shown consideration in further applications to the bird industry.

Stress-Strain Sensors

Most domestic weight scales contain strain gauges that measure small deflections on a piece of metal. Therefore, a load on an elongated piece of metal would produce a deflection of a certain length, with a force and, thus, weight can be calculated. These are applied to the bird industry by concealing a contraption on a perch, such that a strain gauge produces a weight measurement on the perch.

An integrated example, currently being applied to ground-based nesting birds, uses a weight balance that measures the stress on a nylon string via a potentiometer. The potentiometer outputs a voltage proportional to the weight [8]. The implementation the scale means the it is placed under the birds nest. If this was to be implemented for raptors, it is important to consider where there nests are located and what would currently be in the nest when the weight is calculated. This provides the main concern for this method of implementation and measuring just the nest yields a difficult activity.

Another integrated example, currently being applied to wildlife birds, uses an artificial ground-based perch. This perch serves as the load location or element that deflects a piece of metal with strain gauges at the other end of it. This acts as a transducer that produces a voltage proportional to the weight of bird on the perch [9]. There are important factors to consider since this system is electric which constrains the need for a power supply. An important factor is that raptors are open to new perches around their habitat and highlights the ease of implementation of the system.

Spring Scales

Spring scales uses the spring constant and the distance the spring moves to calculate the force on the scale. The force is proportional to the weight of the object being measured. The use of the scales can be applied to the wildlife bird industry by concealing it as a bird perch.

An integrated example, currently being applied from domestic households to wildlife birds, uses a feeder system to conceal the spring scale. When a bird lands on the perch, the spring stretches and the weight can be read from the analog scale, while the bird feeds [10] [11]. What is important to consider is the food that a raptor eats and the fact that such a scale is not digital and transmissible.

2.0.3 Methods of attracting raptors

Having looked into some methods of measuring the weights of the raptors, attracting the raptors to the weight-capturing infrastructure becomes one of the biggest challenges as this is dependent on numerous factors including but not limited to the environmental conditions surrounding the infrastructure. As with raptors, classic methods like baited traps, cannon nets, etc tend not to be as effective because raptors are a class of predatory birds that often prey upon their food [12].
Attracting raptors has been a common practice among farmers for many decades as a means of pest control. Specifically, rodent control, because it does not involve the use of poison baits, trapping, or destroying tunnels which could potentially harm other species or in some cases may not be allowed by the local authorities with the rise in environmental awareness [13]. One of the most effective methods to attract raptors is to ensure that the weight-capturing infrastructure is placed in a raptor-friendly environment and this can be achieved by meeting the raptor's needs which include food, water, shelter, and nesting sites [14]. Most raptors are carnivores and prey upon small mammals, reptiles, and large insects [15]. In order to attract the raptors, these animals as a source of food for the raptors should be present, where they congregate the raptors will most likely be found. To attract the raptors a small monitored ecosystem consisting of these animals could be implemented, these prey could be attracted

by supplying the area with each species' appropriate source of food.

Most raptors get enough hydration from the blood of their prey, however, they need water to cool off and wash off. The researcher's specified location is a desert-like area, ensuring a water source in such a limited water access area will definitely attract raptors [14]. Raptors gravitate towards areas with stable perches to spot prey and roost after catching prey. Ensuring that the environment in which the weight-measuring infrastructure will be has strong perches or branches would help attract raptors. This can be done by planting trees in the area for the raptors to land on, roost, and in some cases may hide from other birds. Rarely, the raptors may even end up nesting in the vicinity. Farmers have also used methods to attract raptors for centuries for pest control by placing large and stable nests and perches in pesticide-infested parts of the farm to provide infrastructure for the raptors to land on while they hunt for prey.

In this digital era unfortunately research has mainly focused on raptor-avoidance technologies with the rise in environmental awareness, an example being radar technology being used to design raptor-proof wind farms focusing on mitigating the impact between wind turbines and the raptors [16]. This leaves modification of the environment to be raptor-friendly to be the most effective solution as in the case of pest control, it doesn't endanger other species and is in line with environmental awareness.

2.0.4 Power Supply in Remote Areas

The study and research conducted on these birds is done in remote, arid areas and as a result needs a power supply to power the electronics and other devices. This power supply needs to be stable in that it must ensure that there is continuous power to the devices, avoiding human interaction as much as possible. The primary ways in which this is done is through the use of power storage devices such as batteries and renewable energy sources.

Power Storage

Power storage comes primarily in the form of batteries and are used to store power when a continuous supply is unavailable, since research sites are situated in remote areas, batteries are utilised to power research devices such as scales and cameras. The size is dependent on two factors: what needs to be powered, and the lifespan to which it needs to be powered. Current battery use for similar research projects use deep-cycle batteries to power the electronics, however these are bulky, heavy and aren't as efficient as other batteries in the market such as Lithium-ion [17] [18]. Current research station modules power each component separately leading to multiple trips to the research site to ensure a continuous research operation with minimal disturbances. Renewable energy can be used to avoid unnecessary time and data collecting cost to power the devices and charge the batteries to ensure a continuous power supply.

Solar Power

Solar panels are used to harness the sun's light and convert it into electrical energy so that devices can be powered directly through connection or indirectly through a battery. One needed to supply a typical research station such as this would require a 50W solar panel with approximate dimensions and weight of 53 x 67cm and 4kg respectively [19]. Solar panels are bulky and placement is essential in ensuring direct contact with sunlight and can also be a deterrent to birds, hindering the ability to do thorough research [20].

Wind Power

Wind turbines are used to harness the wind and convert mechanical energy into electrical energy such that devices can be powered directly through connection or indirectly through a battery. A 50W wind turbine would be sufficient to power a research station of this size with approximate dimensions and weight being 63x30 cm and 5kg respectively [21]. Wind turbines are only operational with wind and can be bulky in that they can only be placed on the ground. They can as well be a deterrent to birds hindering the ability to do thorough research.

2.0.5 Weatherproofing Electronics for Extreme Environments

Research stations placed in harsh, deserted locations need to ensure the integrity of the equipment in order to record accurate data and such that the equipment is suited to operate in such extreme environments. These components need to ensure operation between extreme temperatures, heavy rainfall in short periods of time as well as sandstorms. This is achieved through weather proofing the components, specifically providing heat resistance as well as water and dust proofing.

Dust Proofing

Excessive dust build up can result in device failure and make the device become unreliable. When come into contact with electronics, the dust functions as a layer of insulation, prohibiting the essential process of device cooling resulting in overheating and shorting of circuits [22]. It will also greatly affect mechanical parts to the extent they become jammed. Air filters can be used to protect electronic components from dust exposure. [23] Electronic components should be kept in a closed container, however, where ventilation or an opening is needed an air filter can be used to meet the desired ingress protection (IP) rating [23]. The IP rating is the extent to which the device is protected from a contaminant, in this case, dust [23].

Water Proofing

When come into contact with electronics, water can result in a short circuit resulting in the device becoming dysfunctional, in an environment where heavy rain may occur in short periods, it is essential that every electronic component is waterproofed [24]. Ensuring the electronic components are secured in an enclosure will protect the components from water such as rain, more intricate protection needs to be secured in order for small droplets and moisture to be prevented from entering. Epoxy or silicone can be used as a potting material, where the printed circuit board (PCB) is covered in the material, epoxy provides greater strength than silicone and so is preferred [24].

Heat Proofing

Due to the environment of which these electronic components will be situated, heat management is essential in order to preserve the life of the electronics. The electronics ultimately need to have good air flow and not be placed in direct sunlight [25]. Installing fans in the enclosure of the electronics allows for hot air inside the enclosure that has been sitting in the sun to be displaced by cooler air from the outside. [25] Using a non-absorbing enclosure such that it doesn't get excessively hot will contribute to the heat-alleviating effect [25]. Potentially covering the enclosure with roofing can provide shade and further reduce the heat created, ensuring that other critical components aren't hindered is essential.

To sum up, various methods of weight measurement and weight data processing have been detailed with a focus on bird monitoring in the desert. The goal being to come up with a less labour intensive solution to bird weight capturing in line with the problem statement. Although the present technologies are not directly applied to ornithology in the desert, they can be amalgamated into a specialised solution that addresses Chris' bird weight capturing challenge.

Chapter 3

Physical Implementation of Weight Sensor and Design of Base and Housing Module (PTLAMA004)

3.1 Physical implementation of Weight Sensor

3.1.1 Introduction

This module makes up the apparatus that determine the weight on the scale. This sensor must be able to provide values for varying types of raptors and eagles. While, the sensor measures the weight, it must not be affected by other forces than the force of gravity of the bird. These external forces include any other mass on the scale and, additionally, the landing forces of the birds. Lastly, the weight sensor must be able to communicate with other sub-modules so as to integrate with the rest of the system.

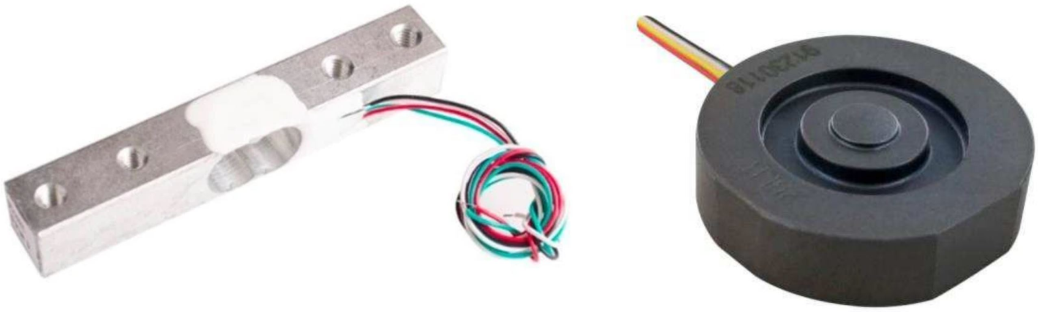
3.1.2 Requirements

When designing the weight sensing sub-module, the following requirements need to met

- Requirement 1: The customer must be able to read the weight of raptors and eagles digitally
- Requirement 2: The measurements must be able to be used by other sub-modules
- Requirement 3: The weight sensor needs to provide accurate measurements
- Requirement 4: The weight sensor must not fail and be robust to support various forces and moments

3.1.3 Design Choices

The weight sensor design was inspired on how normal kitchen scales work. Most kitchen scale use a load cell with a custom PCB to output the weight of items on the scale. Therefore, various load cells were considered for weighing of raptors and eagles. Throughout this subsection there will be comparisons between the HKD Load Cell and the Compression Load Cell. Additionally, each type of load cell has many model variants with different properties. This means that the a model will be chosen for each type of load cell and then a final comparison for each type of load cell will serve as the design choice.



(a) HKD Load Cell

(b) Compression Load Cell

Figure 3.1: Weight Sensor Considerations

Firstly, The **HKD Load Cell** relies on three stress strain gauges to produce a weight in the form of a varying voltage. In Figure 3.1a, the bar like structure acts like a transducer that measures the bending moments from one end to the other. Therefore, if one end is fixed and the weight of the bird acts on the other end, then this would act as suitable weight sensor for birds. However, this means that the structure must be designed in a way to prevent any other forces acting on the weight sensor so as to prevent inaccuracy.

There are many models of this load cell product available at Communica. The load cell has a rated output of 1mV/V and therefore need an amplifier chip to get voltage ranged that are easy to sample using an ADC. The only difference between the load cell models are the maximum amount of weight that they can measure. There are 2kg, 5kg, 10kg, 20kg, and 50kg load cell variants. Therefore, in order to choose the variant, it is important to know that weight of raptors and eagles. It was determined that the 5kg HKD Load Cell variant would be sufficient enough for this purpose. This satisfies Requirement 3 and 4

In order to satisfy Requirement 1 and 2, the output of the load cell needs to manipulated from analog to digital and to connect to a micro-controller. By using an amplifier chip, the weight sensor system will be able to convert its analog signals to the digital as well as transmit the weight through a serial connection to a micro-controller.

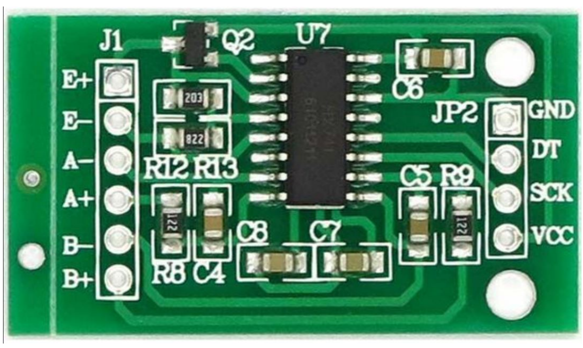


Figure 3.2: HX711 Amplifier IC

In Figure 3.3, the various pin connections can be seen, where the stress strain wires form the input and the amplifier outputs the serial data on the 'DT' pin. Therefore, by using the amplifier chip and the load cell together, the weight measurement will be able to be used by other sub-modules as well as allow for digital interfacing with a micro-controller.

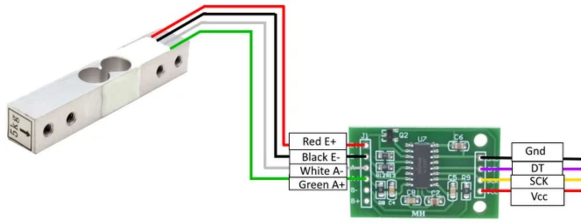


Figure 3.3: Diagram of Pin Connections between the Load Cell and HX711 Amplifer

The **compression load cell** offers properties that are different to the load cell discussed in Figure 3.1a. The structure seen in Figure 3.1b shows an inner circular area where the cell measures the force acting on it. This structure is advantageous to measuring birds, because measuring weight will exert a compression force on the cell. This means that only the weight of the bird will be measured whereas all other forces such as torques are not measured an will not influence the results. There are many models available at RS Components with many different properties. Below, in Table 3.1, is the comparison between different properties from various models.

Compression Load Cell				
Properties	1) FX292X-100A-0010L	2) FX293X-100A-0010L	3) FX29J1-100A-0010L	4) FX29K0-100A-0010L
Output	20mV/V	0.5-4.5V	I2C (no sleep)	I2C (sleep)
Output Types	Analog	Analog	0x36	0x28
Cable Length (mm)	100	100	100	100
Connector	Without	Without	With	With
Maximum Force (lbf - N - kg)	10 - 50 - 5	10 - 50 - 5	100 - 500 - 50	25 - 125 - 12.5

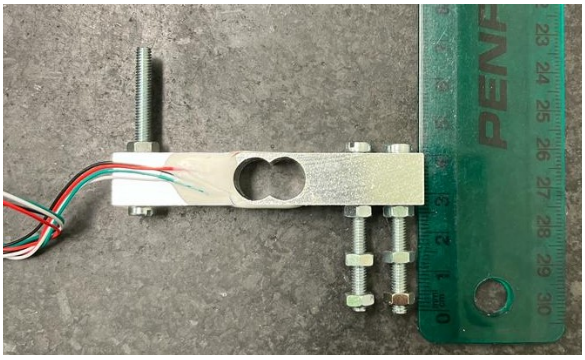
Table 3.1: Table of Various Compression Load Cells

Analysis of choosing the Compression Load Cell: In Table 3.1 , 1) FX292X-100A-0010L and 2) FX293X-100A-0010L have analog properties while 3) FX29J1-100A-0010L and 4) FX29K0-100A-0010L have I2C capabilities. This means that 1) and 2) need the have some sort of step to convert the analog data to digital to satisfy requirement 1 and 2 while 3) and 4) already have the capability. This means that 3) and 4) are favourable, however, the maximum force that the load cell can handle is too much 50kg in 3) and 12.5kg in 4) thus sacrificing accuracy. This means that only 1) and 2) will be considered since its has the correct maximum force of 5kg it can handle. In order to meet requirements of having a digital output the both 1) and 2) there needs be an ADC (Analog to Digital Converter). For 1) the same HX711 Amplifier, in Figure 3.7, can be used, however, 2) needs to be connected to a micro-controller with custom code to configure the weight measurement. Therefore, out of all the compression load cells the 1) FX292X-100A-0010L can be used.

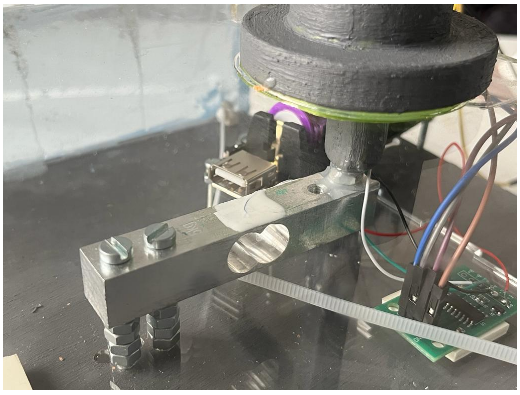
3.1.4 Final Decision

Ultimately, the HKD Load Cell was chosen over the FX292X-100A-0010L Compression Load Cell. Both models met all the requirements when complemented with the HX711 amplifier chip. The reason that the HKD Load Cell was chosen was due to the tapped M4 drill holes as it provided easy integration in mounting and positioning, with the compression load cell would need to how a custom designed housing for mounting.

In Figure 3.4a, the HKD Load Cell is shown with the M4 screws secured into it. This allows for mounting the load cell securely with the two M4 screws in the right side of the picture, while allowing for the perch to be attached with a screw on the left side of the picture for direct force transmission.



(a) Load Cell Decision



(b) Load Cell Implementation

Figure 3.4: Weight Sensor Implementation

3.1.5 Subsystem prototyping

When the Load Cell and HX711 Amplifier chip was connected to the mechanical enclosure, perch and base, it yielded the following system connection Figure 3.4b. The Load Cell was bridged with M4 screws and bolts to connect it the the bottom panel of the mechanical enclosure and the metal base plate. The perch was also connected to the load cell by screwing onto the upward facing bolt and was secured by using glue so the perch does not rotate.

3.1.6 Testing and Results

The physical implementation of the load cell was tested by ensuring that the HX711 chip was able to serially output the analog values of the load cell.

The test for continuity was used to ensure that the connections the HX711 chip was soldered properly.

3.1.7 Conclusion

3.2 Mechanical Enclosure Design

3.2.1 Introduction

This module makes up the apparatus the house all sensitive and electrical equipment. The enclosure houses the ESP32, HX711 Amplifier, BMS (Battery Management System) and the HKD Load Cell. The mechanical housing provides structural integrity to the system with 3mm Perspex while preventing weathering effects from the environment. The housing also connects the bird perch, perch guide, load cell and the base plate together with M4 screws and bolts. Lastly, the enclosure has a hinged side panel to allow access to the electrical components.

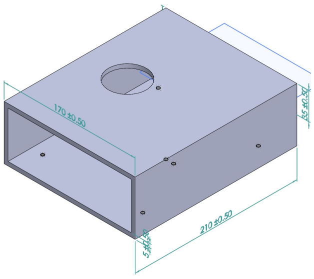
3.2.2 Requirements

When designing the mechanical enclosure, the following requirements need to met

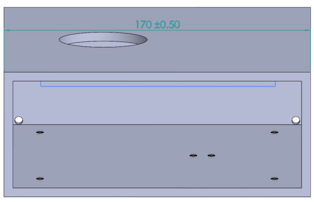
- Requirement 1: The enclosure must have structural integrity
- Requirement 2: The enclosure must be waterproof
- Requirement 3: The enclosure must house all sensitive components
- Requirement 4: The enclosure must have some type of easy access to the electrical components

3.2.3 Subsystem prototyping

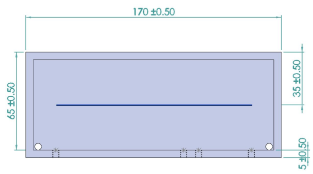
In order to get a rough idea of how to make the mechanical enclosure, a rough sketch was drawn in Solidworks.



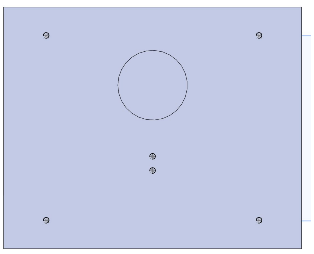
(a) Corner View



(b) Top Corner View



(c) Side View



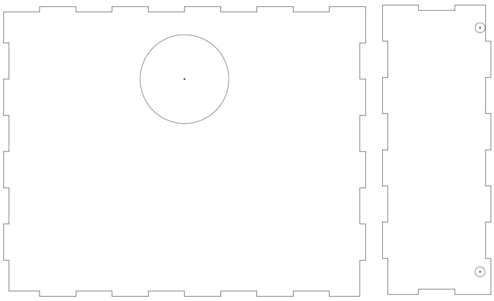
(d) Top View

Figure 3.5: Rough Solidworks Drawing of the Mechanical Enclosure

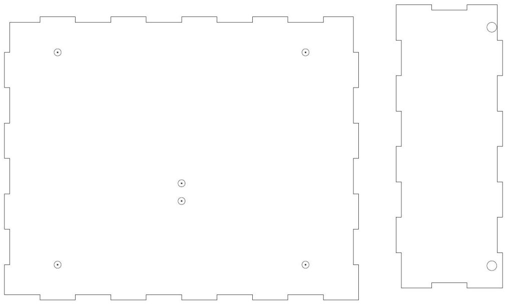
3.2.4 Design Choices

The mechanical enclosure had perspex and hardboard as its material type. The perspex material would comprise of a 3mm thickness while the hardboard was 2mm thickness. Both provides strong structural integrity.

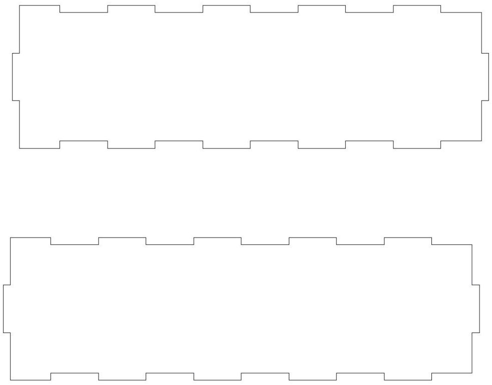
3.2.5 Final Decision



(a) Top and Side Pieces



(b) Bottom and Side Pieces



(c) Side Pieces

Figure 3.6: Laser Cutting Diagrams for the 3mm Perspex Box

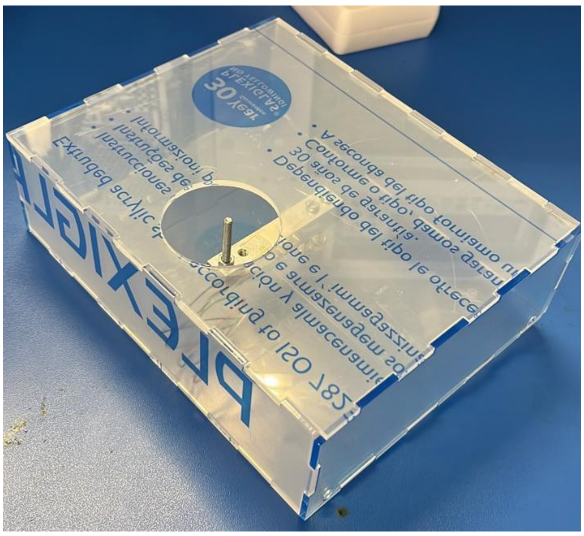
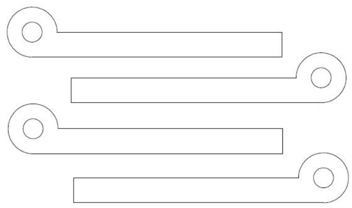
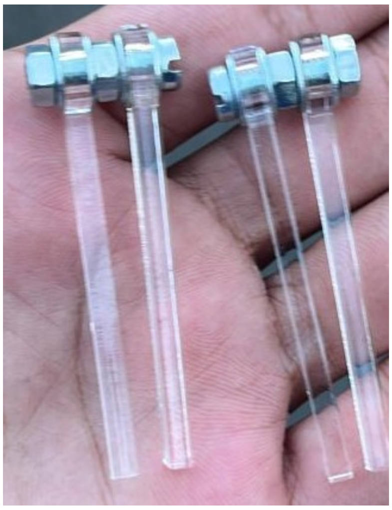


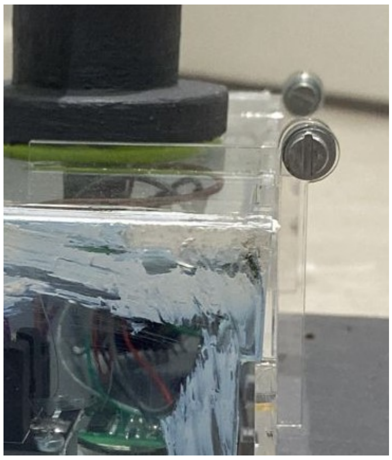
Figure 3.7: Laser Cutting Pieces Assembled



(a) Laser Cutting Diagram of the Hinge Mechanism



(b) Side Profile of Hinges



(c) Hinge Implementation on the Side Panel

Figure 3.8: Hinge Decision

3.2.6 Testing and Results

The mechanical enclosure was tested by spraying water, running water and then submerging the whole system. The first test, was to simulate rain by spraying the water all over the automated raptor scale. This resulted in the mechanical enclosure having no water inside. The second test of running water also yielded the same. However, by submerging it in water, the enclosure leaked water into it due to the pressure exerted.

The structural integrity was also tested, by means of the testing impact forces on the perspex cage. This survived all crash tests.

3.2.7 Conclusion

The mechanical enclosure met all requirements by it being made of 3mm perspex and having drill holes for connecting other sub-systems on it. It further housed the electrical components while maintaining waterproofing.

3.3 Mounting Plate

3.3.1 Introduction

This module makes up the apparatus to secure the whole system to a tree. The base plate must support the mechanical enclosure, the perch and the bird that lands on it while on the tree. The location to place the whole system is on the tree branch that is nearly horizontal in nature. Furthermore, the base plate has small drill holes in it to additionally connect with UV resistant zip ties to fasten the whole system on to the branch.

3.3.2 Requirements

When designing the mechanical enclosure, the following requirements need to met

- Requirement 1: The base plate must have structural integrity
- Requirement 2: The base plate must be waterproof
- Requirement 3: The base plate must connect with the mechanical enclosure
- Requirement 4: The base plate must be fasten to a tree branch

3.3.3 Subsystem prototyping

In order to get a rough idea of how to make the base plate, a rough sketch was drawn in Solidworks.

(a) Corner View

(b) Top View

(c) Side View

Figure 3.9: Rough Solidworks Drawing of the Base Plate

3.3.4 Design Choices and Final Decision

The base plate consists of a half-hexagonal side profile to aid in maximising the contact area and ,therefore, the base plate cannot be just a rectangular piece of material. Furthermore, UV resistant zip ties are the element that secure the rigid metal base to the tree branch. This accounts for the rough surface and size of the branch. Additionally, there are drill holes at various locations longitudinally such that the zip ties can go through the base to meet the diameter requirements of the tree branch.

Firstly, the material choice was between wood and metal. Both materials are strong and rigid enough to to maintain structural integrity. However, the base plate must be waterproof, meaning that if the wood is not treated with varnish then the wood can bloat from rain. A metal base plate will not have this problem. Both materials are easy to make drill holes for connecting the mechanical enclosure to itself. However, since it is difficult to construct the half-hexagonal shape of the base plate with wood, metal was chosen as the material.

Secondly, the measurements should be chosen where it will support the mechanical enclosure while contacting the tree branch. Therefore, the measurements of 30cm (width) by 25cm (length) with 5cm of each side of the width being bent by 45 degrees.

Thirdly, the base plate must be securely fastened to the branch. The idea was to either have zip ties or a fastening belt attached to the base plate to crimp into the branch. Both ideas would work, however due to budgetary reasons zip ties were chosen. Furthermore, zip tie holes were made into the base plate to fasten the zip ties into, as can be seen in Figure 3.10.

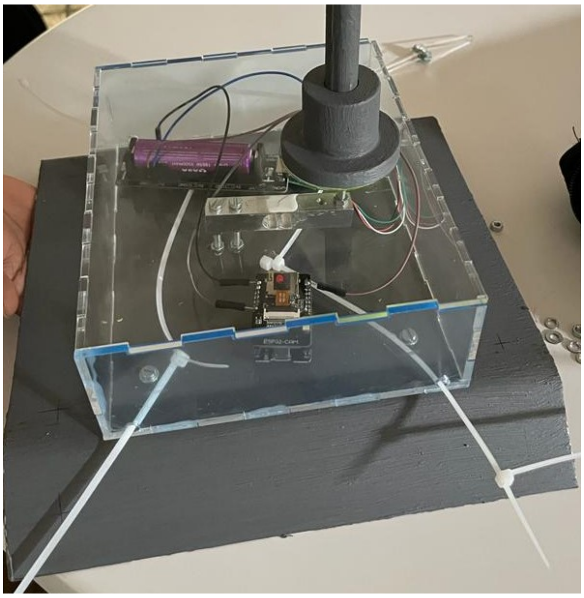


Figure 3.10: Base Plate Decision

3.3.5 Testing and Results

The base was fastened to many types of tree around the campus of UCT meaning the it was able to handle its location flexibility.

3.3.6 Conclusion

The base plate met all the requirements by it being made of 2mm metal. It was angled to have maximum contact area while being fastened to varying tree branches.

Chapter 4

Weight Capturing and Processing (CHHBLE001)

The present is theirs. The future for which I have really worked, is mine

—*Nikola Tesla*

4.1 Objectives

The objectives of the weight data processing component mainly encompassed accuracy and reliability. In particular, weight range flexibility, weight precision and enhanced measurement accuracy along with bird identification. Firstly, our aim was to develop a weight capturing functionality that could accommodate a wide weight range, estimated to be from around 200g to just under 5kg. The stakeholders could not confirm an exact weight range in time hence the estimate which was deemed to be a fair one based on some web research.

Secondly, we sought to achieve a weight precision of approximately ±5g. This agreed-upon precision level was deemed sufficient to enable researchers to detect any significant changes in weight for individual birds accurately. By ensuring a high level of precision, our intention was to provide valuable data for monitoring the weight of the birds.

Furthermore, we recognized the importance of reinforcing the reliability of weight measurements. To achieve this, our objective was to improve the accuracy of each weight measurement by averaging multiple weight readings for each bird. This approach aimed to mitigate potential fluctuations caused by external factors, such as bird movement or scale sensitivity, thereby enhancing the overall accuracy and reliability of the recorded weights.

In addition, we aimed to establish a reliable bird identification method. This involved implementing a camera that allowed researchers to associate specific weight measurements with the corresponding birds. By incorporating the camera, we hoped to reduce ambiguity in the weight data.

By addressing these objectives, our goal was to provide researchers with a comprehensive weight data processing component that offered more accurate and reliable measurements compared to their existing methods of weight processing.

4.2 Design Choices

4.2.1 ESP32-CAM Micro-controllers

The decision to utilize TWO ESP32-CAM micro-controllers was driven by their networking capabilities and built-in camera functionalities. ESP-A was designated for data acquisition from the load cell, while ESP-B was assigned the task of bird identification through photography. This choice allowed for a modular design which would facilitate the programming process as well as make debugging easier.

4.2.2 Library Functions

The microcontroller coding process was streamlined by utilizing functions from pre-existing libraries, namely HX711.h and esp_now.h. This decision was driven by the recognition that these libraries are well-established and frequently maintained, ensuring optimized and efficient functionality. By leveraging these libraries, we could benefit from their optimized codebase, resulting in overall improved performance and efficiency in the programs running on the two microcontrollers. This approach allowed us to focus on implementing the specific features and functionalities of the automated bird scale system while relying on the robust and reliable foundation provided by the pre-existing libraries.

4.2.3 Arduino IDE

The arduino ide was decided upon as the programming environment. The Arduino IDE provides a simple and intuitive interface. Its user-friendly design allows for easy navigation and quick setup. In addition, the Arduino IDE has a vast library ecosystem, offering a wide range of pre-written code modules and libraries that can be readily integrated into the project. These libraries provide ready-to-use functions and features, saving significant development time and effort.

Another advantage of the Arduino IDE is its cross-platform compatibility. It works seamlessly on multiple operating systems, including Windows, macOS, and Linux. This compatibility would allow for the flexibility to work on different PCs.

Lastly, the Arduino IDE's serial output functionality greatly enhances the program testing process by providing a human-readable format for monitoring and debugging. This feature enables the observation of the program's behavior in real-time, troubleshoot errors efficiently, and ensure the proper functionality of the code.

4.3 Design

The data acquisition was accomplished by two networked ESP32-CAM micro-controllers named ESP-A and ESP-B for easy referencing. ESP-A was set up to interface with the load cell via the HX711 amplifier while ESP-B was programmed to handle the bird identification through photography. Fig 4.1 illustrates the process flow.

ESP-A was programmed to establish a connection with the load cell by 'listening' to pins GPIO4 and GPIO16 of ESP-A, to which the load cell was physically wired. Once the connection was established, some initial functions (described in table 5.1) were invoked to read the raw data received on these pins.

The subsequent step involved calibrating the scale functionality. For calibration, an iPhone 11 weighing 194g was selected as a test weight due to its verified weight. The test weight was placed on the load cell, and its corresponding raw reading was recorded. The calibration factor was then computed as the ratio of the raw reading to the test weight, resulting in a value of 0.2417525773 (raw reading: 46.9, test weight: 194). This calibration factor served as input to a function responsible for calibrating the scale based on the calculated factor. Following calibration, the scale initialization process was completed by applying a tare function to reset the scale.

Moreover, a weight threshold of 100g was defined. This was so that anything much lighter than the targeted weight range would not get its weight unnecessarily captured. Whenever a measurement from the load cell exceeded this threshold, 5 readings of this measurement were averaged to limit the influence of bird movement on the accuracy of the bird's weight. A function was then triggered to signal ESP-B to capture a picture. Alongside the signal, ESP-A transmitted the measurement value and its corresponding timestamp to ESP-B. In the program of ESP-B, the captured picture was named using the format '<date><time><weight>.jpg' before being stored. All the functions used are described in detail in table 5.1. The program was developed in C++ on the arduino ide.

Function Name	Argument(s)	Description	Source
scale.begin()	Two positive integers	'Listens' to the connected pins for any weight readings	HX711.h library
scale.read()	None	Returns a raw reading from the load cell	HX711.h library
scale.set_scale()	Calibration factor	Calibrates the scale according to the input calibration factor	HX711.h library
scale.tare()	None	Tares the scale by resetting it to 0	HX711.h library
scale.get_value()	A single integer number x	Returns the average of x readings after taring	HX711.h library
esp_now_send()	index of ESP-B data to be sent data size	Sends weight and timestamp to ESP-B	esp_now.h library

Table 4.1: Important functions used for data acquisition

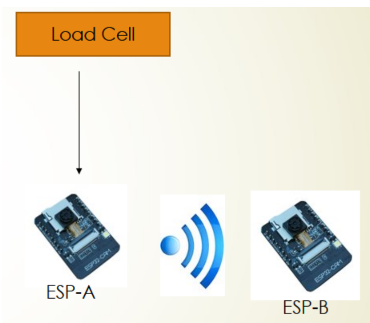


Figure 4.1: Image showing the weight data processing block diagram

4.4 Testing Methodology

To ensure the effectiveness and reliability of the developed automated bird scale using ESP32-CAM microcontrollers (ESP-A and ESP-B), a comprehensive testing methodology was employed. The testing process was broken down as follows:

4.4.1 Load Cell Interface Testing

This involved checking the functionality of the pins (GPIO4 and GPIO16) on ESP-A, which were responsible for receiving the raw data from the load cell. The load cell was subjected to various weight loads by simply pressing down on the load cell with different intensities. The corresponding readings on ESP-A were observed using the arduino ide's serial output monitor to ensure that there was some data acquisition.

4.4.2 Calibration Verification

The calibration factor was calculated based on the assumption that the relationship between the raw reading and actual weight due to a load is linear. This linearity was tested by plotting an actual weight vs raw reading graph based on 5 ordinary household items each with a verified weight. The plot is presented in fig 4.3.

4.4.3 Threshold Testing

The defined weight threshold of 100g was tested to ensure that only weight measurements above this threshold triggered further actions, such as capturing a picture. Test weights below the threshold were applied to ascertain that no unnecessary picture taking or data transmission occurred.

4.4.4 Averaging for Accuracy

To ensure accurate weight measurements and minimize the impact of bird movement during landing, the 'get_value()' function (described in Table 5.1) was employed. This function was utilized for each weight reading obtained from ESP-A. To assess the accuracy of the averaging process, the average value calculated by this function was tested against the verified weights of four household items previously used in the calibration verification process (as described in Section 4.4.2). This testing served the purpose of evaluating whether the averaging mechanism successfully mitigated the effects of bird movement, resulting in precise and reliable weight measurements.

4.4.5 ESP-B Integration Testing

The integration between ESP-A and ESP-B was tested to verify the successful transmission of measurement data and timestamps from ESP-A to ESP-B. This involved simulating a weight measurement above the threshold and confirming that ESP-B received the corresponding data along with the signal to capture a picture. The captured pictures were examined to ensure they were named correctly based on the provided format.

4.5 Test Results and Analysis

4.5.1 Load Cell Interface Testing

Figure 4.2 illustrates the results of the load cell interface test conducted to assess the functionality and correct interfacing of the load cell with ESP-A. The load cell was subjected to different intensities of pressure, providing valuable insights into its performance. Initially, a firm press on the load cell yielded a reading of approximately 1.3kg, demonstrating its capability to accurately measure higher weights. A subsequent gentle press resulted in a lower measurement of approximately 219g, confirming the load cell's sensitivity to lighter pressures. Furthermore, a moderate press on the load cell produced a higher reading of approximately 482g, further validating its dynamic range. These results effectively verified the load cell's functionality and its successful integration with ESP-A, laying a solid foundation for subsequent testing and evaluation of the weight processing component of the system.

```
Readings:
Weight: 1334.98g
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:      Delivery Success
Weight: 219.38g
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:      Delivery Success
Weight: 482.07g
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:      Delivery Success
```

Figure 4.2: Screenshot of the serial output showing the results of the load cell interface test

4.5.2 Calibration Verification

Table 4.2 presents the weight data of five household items used for calibration purposes. To assess the effectiveness of the calibration process, a graph depicting the relationship between converted weight and raw reading was plotted (see Figure 4.3). The graph exhibits a high degree of linearity, affirming the validity of the assumption made during the calculation of the calibration factor. Moreover, the inverse of the gradient of the graph approximates 0.246, which closely aligns with the previously calculated calibration factor. This successful linearity test instilled confidence in the accuracy and reliability of the scale's calibration, further validating its suitability for weight measurements in the target range.

Object	Raw reading	Converted weight
5 Rand coin	2.3	9.8g
iPhone 11	46.9	197.4g
250ml container of water	60.5	250.3g
bag of salt	475.6	1989.3g
5l container of milk	1255.7	5022.8g

Table 4.2: Table showing raw readings against their corresponding converted weight readings

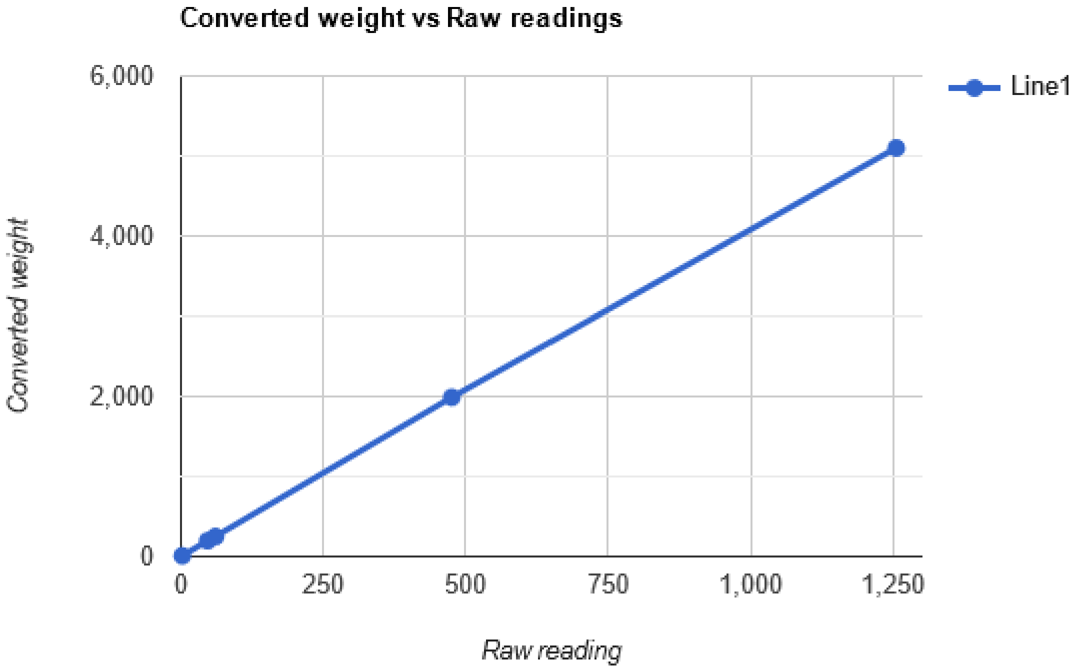
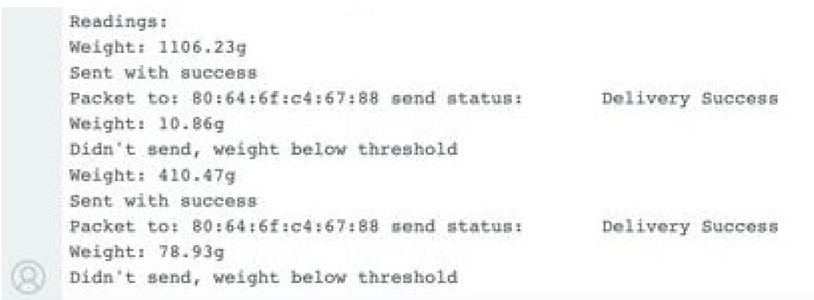


Figure 4.3: Plot showing Converted weights vs Raw readings

4.5.3 Threshold Testing

The results depicted in Figure 4.4 provide a comprehensive analysis of the weight threshold testing conducted on ESP-A. It is evident that ESP-A effectively filters and transmits weights only when they surpass the predefined threshold of 100g. This threshold was strategically chosen to ensure that only substantial weight measurements, indicative of a bird landing on the perch, trigger further actions. By implementing this threshold, the system mitigates unnecessary data transmission and processing for negligible weight changes that may be attributed to factors other than bird presence. The successful application of the weight threshold demonstrates ESP-A's ability to discern significant weight variations, thus optimizing the overall efficiency and accuracy of the automated bird scale system.



```
Readings:
Weight: 1106.23g
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:      Delivery Success
Weight: 10.86g
Didn't send, weight below threshold
Weight: 410.47g
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:      Delivery Success
Weight: 78.93g
Didn't send, weight below threshold
```

Figure 4.4: Screenshot of the serial output showing the results of the threshold test

4.5.4 Averaging for Accuracy

The test results presented in Table 4.3 provide valuable insights into the accuracy achieved by the averaging process implemented in ESP-A. Within the weight range of 200g to 5000g, the readings demonstrate a high level of accuracy, as the deviations from the true values are relatively small. However, it is noteworthy that at the highest weight of 5000g, the deviation exceeds 20g, indicating a slight decrease in accuracy. It can be concluded that the averaging process significantly enhances the accuracy of weight measurements falling well within the specified weight range.

While it is evident that averaging more than five readings could potentially further improve accuracy, it is crucial to consider the trade-offs associated with such an approach. Additional readings would result in delayed weight data transmission and increased computation, leading to higher power consumption. Thus, a balance was sought, and it was determined that averaging five readings strikes a reasonable compromise between accuracy and practical considerations. This choice allows for efficient real-time weight data processing while maintaining an acceptable level of accuracy.

Object	Converted weight	Verified weight
iPhone 11	197.4g	194g
250ml container of water	250.3g	250g
bag of salt	1989.3g	2000g
5l container of milk	5022.8g	5000g

Table 4.3: Table showing weights measured by the scale against their verified weights

4.5.5 ESP-B Integration Testing

In order to evaluate the effectiveness of the communication between ESP-B and ESP-A, a test was conducted by placing a carton of milk on the scale. The serial output of ESP-B was carefully examined to assess the seamless interaction with ESP-A. Figure 4.5 displays the serial output of ESP-B, alongside the corresponding weight of the carton as measured by ESP-A. The successful transmission of weight data from ESP-A to ESP-B is evident, indicating the robust networking and communication capabilities of the microcontrollers.

Moreover, ESP-B accurately adheres to the desired naming convention for the captured pictures, as outlined in section 4.3. This adherence to the specified naming format further demonstrates the effective coordination and integration between ESP-B and ESP-A.

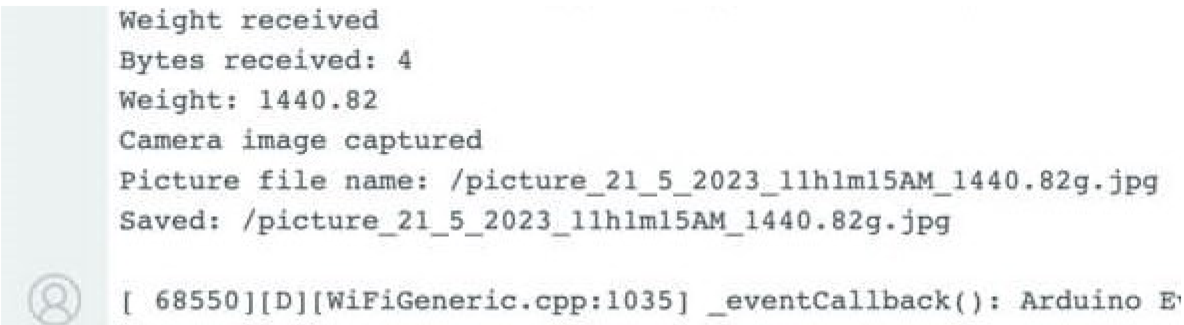


Figure 4.5: Screenshot of the serial output showing the results of the ESP-B integration

In conclusion, the weight data processing component of the automated bird scale project was successful in achieving its objectives and delivering a functional and reliable solution. Through the utilization of two networked ESP32-CAM microcontrollers, ESP-A and ESP-B, the data processing was effectively implemented. ESP-A interfaced with the load cell through the HX711 amplifier, while ESP-B was responsible for bird identification through photography.

The design choices made during the project were carefully considered and justified. The Arduino IDE was selected as the programming environment due to its user-friendly interface and cross-platform compatibility. This choice facilitated the development process and ensured optimized and efficient programs running on the microcontrollers.

Several tests were conducted to verify the functionality and performance of the system. The calibration process, supported by a verified test weight, ensured accurate weight measurements within the targeted range. The implementation of a weight threshold and averaging of multiple readings effectively reduced the influence of bird movement, enhancing the accuracy of the weight measurements.

Integration between ESP-A and ESP-B was successfully achieved, as demonstrated by the examination of the serial output and the accurate naming of the captured pictures. This confirmed that the microcontrollers were well-networked, enabling effective weight data processing and bird identification.

Throughout the project, considerations were given to reliability and accuracy. The project's success can be attributed to the careful selection of components, the utilization of optimized libraries, and the systematic approach to testing and validation.

In summary, the feasibility of using ESP32-CAM microcontrollers for data acquisition was affirmed as the scale was able to produce accurate and reliable weight measurements, along with efficient bird identification through photography.

Chapter 5

Data Transmission & Storage (WDXKEN001)

5.1 Introduction

The automated bird scale comprises a data transmission and storage subsystem which is interfaced with a user-friendly graphical user interface (GUI). This subsystem utilises two ESP32-CAM microcontrollers to facilitate the seamless process of weighing raptors, capturing images, storing data and interfacing with the scale. The weight-measuring ESP, ESP-A, records the weight above a set threshold to ensure it is a bird and transmits the data wirelessly to the webserver ESP, ESP-B. Upon receiving the weight data, ESP-B captures a picture of the bird from an appropriate viewpoint and saves it along with a timestamp and the corresponding weight recording. The GUI, accessible via Wi-Fi, allows users to conveniently access the stored images and weight recordings. Through the GUI, users can view a list of available images along with their timestamps and weight information and do other relevant functions. This subsystem provides an integrated solution for bird weight monitoring, combining data transmission, storage, and a user-friendly interface.

5.2 Design Choices

5.2.1 ESP32-CAM

The ESP32-CAM microcontroller is a compact and powerful development board that combines the ESP32 chip with a camera module. It is ideal for data collection and transmission in IoT and surveillance applications. With its low power consumption and integrated Wi-Fi capabilities, it can efficiently connect to wireless networks and transmit data to remote servers or store it locally [26]. The ESP32-CAM supports multiple communication protocols, making it compatible with existing network infrastructure and IoT platforms [27]. Its GPIO pins allow easy integration with external sensors, enabling versatile data collection. Overall, the ESP32-CAM is a versatile and efficient microcontroller for capturing and transmitting data.

5.2.2 Data Transmission

Data transmission between two ESP32-CAM boards can be achieved using various communication methods. One option is to utilise Wi-Fi capabilities where both boards connect to the same Wi-Fi network or one board acts as an access point (AP) to create a network [27]. By using the WiFi library provided by the ESP32 Arduino core, the Wi-Fi connectivity can be configured to employ methods such as HTTP requests or socket connections to transmit data between the boards. Another option is to use ESP-NOW, a low-power and low-latency protocol designed for direct communication between ESP32 devices [27]. By initialising ESP-NOW, a direct communication link can be established between the ESP32-CAM boards without the need for a Wi-Fi network. ESP-NOW offers fast and reliable data transmission, making it suitable for real-time applications requiring efficient communication between devices in close proximity [27].

5.2.3 OV2640 Camera Module

The ESP32-CAM module utilises the OV2640 camera sensor which has a resolution of 2 megapixels (1600 x 1200 pixels) [28]. The module features a fixed focus lens with a wide field of view, typically around 60 degrees, allowing for capturing a substantial amount of the scene within the frame, suitable in the context for the automated bird scale [28].

5.2.4 Data Storage

The ESP32-CAM offers different options for data storage. It provides dedicated pins for connecting an SD card module or adapter, enabling convenient and expandable storage [29]. With the appropriate library, such as the ''SD_MMC.h'', reading from and writing to an SD card can be done easily, which comes in various capacities to accommodate larger amounts of data [29]. Secondly, the ESP32-CAM supports SPIFFS, a file system that stores files in the internal flash memory [30]. Similar to storing files on an SD card or hard drive, SPIFFS provides a user-friendly interface for file operations and directory management [30]. The storage capacity of SPIFFS is however limited by the size of the internal flash memory and so would be best suited for small data storage such as the weight recording.

5.2.5 WiFi Access Point and GUI

The system creates a soft access point using ESP-B to enable access to the stored images. ESP-B is programmed to start a soft access point with a defined SSID and password from which users can connect their devices, forming a local network [30]. By entering the IP address of ESP-B in a web browser, users can access the graphical user interface to view and interact with the stored images. The GUI allows users to browse through the directory and perform actions like downloading or deleting. The soft access point configuration process involves initialising the soft AP mode, defining SSID and password, and assigning IP addresses to connected devices [30].

5.3 Final Design

5.3.1 Data Transmission

The data transmission processes consists of two different communication channels. The first being an inter-ESP connection through the ESP-NOW communication protocol and the second being between the user and ESP-B using WiFi as a soft access point.

Data Transmission Process on ESP-A

ESP-NOW is a wireless communication protocol that operates at the data-link layer, effectively condensing the five layers of the OSI model into a single layer. Consequently, data transmission bypasses the network layer, transport layer, session layer, presentation layer, and application layer. Additionally, the protocol eliminates the necessity for packet headers and unpackers at each layer, resulting in swift responses and minimizing delays attributed to packet loss in congested networks [31]. ESP-NOW coexists with Wi-Fi and offers a fast and user-friendly pairing method, while enabling control over them. Furthermore, the protocol incorporates a window synchronization mechanism that significantly reduces power consumption which is suited for the context of the automated bird scale [31].

Protocol needs to be initialised in order for data to be transmitted by including the library.

```
#include <esp_now.h>
```

ESP-B's MAC Address is needed such that ESP-A can send the data.

```
uint8_t broadcastAddress1[] = {0x80, 0x64, 0x6F, 0xC4, 0x67, 0x88};
```

A typedef struct function is created whereby the variable is stored.

```
typedef struct test_struct {
  float weight;
} test_struct;

test_struct test;
```

In the setup() function, WiFi needs to be setup as a WiFi Station.

```
WiFi.mode(WIFI_STA);
```

When the scale reads a value above 100g, the following function sends that value to ESP-B.

```
esp_err_t result = esp_now_send(0, (uint8_t *) &test, sizeof(test_struct));
```

Data Transmission Process on Receiver ESP (ESP-B)

The same typedef struct as defined in ESP-A needs to be defined and also set up as a WiFi station. The following function is declared in setup() to receive data.

```
esp_now_register_recv_cb(OnDataRecv);
```

The following function will be called when data is received where the weight is stored in the defined variable *weight*.

```
void OnDataRecv(const uint8_t * mac, const uint8_t *incomingData, int len) {
  memcpy(&myData, incomingData, sizeof(myData));
}
```

5.3.2 Data Storage

In order to capture images for future use, data storage becomes essential. This section includes camera initialisation, including the file-naming system to store the images in the microSD card. The data storage and image capturing is achieved through ESP-B, where a microSD card inserts into the provided port. The microSD card is formatted to FAT32 due to compatibility and practical reasons. FAT32 is compatible with various operating systems and is universal in that sense whereby reading and writing can occur, the ESP also only supports microSD cards that are FAT32 formatted such that libraries can read and write files to and from them [32].

The following library is used to create functionality with the SD card and the camera module.

```
#include "SD_MMC.h"
#include "esp_camera.h"
```

The two modules are initialised in the setup() function with the following code:

```
configInitCamera();
initMicroSDCard();
```

The OnDataRecv() function is modified to call the takeSavePhoto() function when a weight measurement is received. The takeSavePhoto() contains a function which includes the time and weight measurement to save the image as.

```
void OnDataRecv(const uint8_t * mac, const uint8_t *incomingData, int len) {
  memcpy(&myData, incomingData, sizeof(myData));
  takeSavePhoto();
  Serial.println();
}
```

5.3.3 GUI and System Functionality

The GUI serves as a user-friendly interface for interacting with the automated bird scale system, providing access and monitoring of its functionalities. Through it, users can initiate actions, configure settings, and retrieve data as it enables the convenient wireless download of recorded data. Users can also configure various system parameters, including time settings for accurate image capturing and data recording. Additionally, the GUI, coupled with Wi-Fi connectivity, allows for easy remote access to recorded data and images. Users can connect to the automated bird scale system via their browser-enabled devices over the ESP's soft access point, accessing and downloading data conveniently through the GUI's file management system.

The GUI offers 5 different functionality capabilities:

- Download:
  The download functionality facilitates the retrieval of recorded data or images from the automated bird scale system. Through the GUI, users can initiate the download process, enabling them to save the data locally on their device for further analysis or archiving. This functionality offers a convenient means to access and utilise the captured information.

- Storage:
  The storage functionality provides information about the amount of storage space utilised by the recorded images on the microSD card of the automated bird scale system. Through the GUI, the user can monitor the storage usage and ensure that sufficient space is available to continue capturing data without interruptions. It helps the user keep track of storage limitations and manage the system's capacity effectively.

- Delete:
  The delete functionality allows the user to remove unwanted images or those that have already been downloaded from the automated bird scale system. By utilising the GUI, the user can select specific files to delete. This feature helps maintain an organized and clutter-free storage space, ensuring that only relevant data is retained.

- Directory:
  The directory functionality provides a means to navigate through the file system of the recorded data and images. Through the GUI, the user can browse different directories or folders to locate specific files or access different sets of data. This feature aids in finding and managing data efficiently, especially when dealing with a large number of recordings.

- Time:
  The set time functionality enables the user to configure the system's internal clock or time settings through the GUI. By providing the option to set the time, the user can ensure accurate timestamp association with the captured image.

5.4 Testing & Validation

Four different testing methodologies were deployed so as to ensure its performance, functionality and reliability are accounted for, these consists of: unit testing, integration testing, performance testing and error and exception handling testing.

Functionality	Calls Function	Description	Source
Downlaod	File_Download()	Takes input from user, calls SD_file_download() to download the file.	SD_MMC.h
Storage	SeeStorage()	Gets bytes from SD_MMC and displays it to the GUI.	SD_MMC.h
Delete	File_Delete()	Takes input from user, calls SD_file_delete to delete the file.	SD_MMC.h
Directory	SD_dir()	Sets up the directory table and calls printDirectory() to populate it.	SD_MMC.h
Time	SetTime()	Takes input from the user and uses rts.setTime() function to set ESP clock.	ESP32Time.h

Table 5.1: GUI Functionality Buttons and Their Respective Function

5.4.1 Unit Testing

Unit testing comprises the testing of the individual modules of the system in isolation. The sending and receiving of data was tested in the serial port to ensure ESP-NOW is functioning correctly, with the camera module tested and the file naming format to ensure the correct data is transmitted and received. Finally, the WiFi access point on ESP B is connected to ensuring the GUI is functioning and displaying as intended.

ESP A Transmit Data

```
ESP-NOW initialised:
Peer added
Initializing the scale
Before setting up the scale:
read:           -361361.00
read average:           -361345.34
get value:              -361346.00
get units:              -361347.8
After setting up the scale:
read:           -361375.00
read average:           -361364.91
get value:              -3.81
get units:              -0.1
Readings:
Weight Sent:
1646.41
Sent with success
Packet to: 80:64:6f:c4:67:88 send status:       Delivery Success
```

Figure 5.1: Initialisation of ESP-NOW on ESP-A

The screenshot above shows the successful initialisation of ESP-NOW and the transmission of the weight data to ESP B. The first two lines indicate it was initialised and the peer (ESP B) was added. The last 4 lines show the weight sent, the status “sent with success” and the MAC address of ESP A to which it was sent.

```
ESP-NOW initialised
Initializing SD card...Card initialised... file access enabled...
Initializing the camera module...Ok!
Initializing the MicroSD card module... Starting SD Card
AP IP address: 192.168.4.1
HTTP server started
[ 33837][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 12 - AP_STACONNECTED
[ 33994][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
[ 36442][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 12 - AP_STACONNECTED
[ 36659][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
[ 37155][D][WiFiClient.cpp:546] connected(): Disconnected: RES: 0, ERR: 128
[ 37787][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
[ 40888][D][WiFiClient.cpp:546] connected(): Disconnected: RES: 0, ERR: 128
[ 42724][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 13 - AP_STADISCONNECTED
[ 47233][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 12 - AP_STACONNECTED
[ 47459][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
[ 49849][D][WiFiClient.cpp:546] connected(): Disconnected: RES: 0, ERR: 128
[ 51695][D][WiFiClient.cpp:546] connected(): Disconnected: RES: 0, ERR: 128
[ 53585][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 13 - AP_STADISCONNECTED
[ 56323][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 12 - AP_STACONNECTED
[ 56492][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
[ 59488][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 13 - AP_STADISCONNECTED
[ 62824][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 12 - AP_STACONNECTED
[ 63215][D][WiFiGeneric.cpp:1035] _eventCallback(): Arduino Event: 14 - AP_STAIPASSIGNED
Weight received
Bytes received: 4
Weight: 1440.82
Camera image captured
Picture file name: /picture_21_5_2023_11h1m15AM_1440.82g.jpg
Saved: /picture_21_5_2023_11h1m15AM_1440.82g.jpg
```

Figure 5.2: Initialisation of ESP-NOW on ESP-B, Image Capture and File Naming

ESP B Receive Data, Image Capture, File Naming

The figure above above tests 3 different modules namely: ESP B receiving data, image capturing and file naming. The first line shows ESP-NOW has been successfully initialised, along with the camera module in line 3. The sixth-last line indicates that the weight was received and so the ESP-NOW data transmission protocol is functioning correctly in which it is able to send data from ESP-A and receive it in ESP-B. The third-last line indicates that the image was capture, indicating the file name and the fact that it was saved with the filename beneath that.

Graphical User Interface

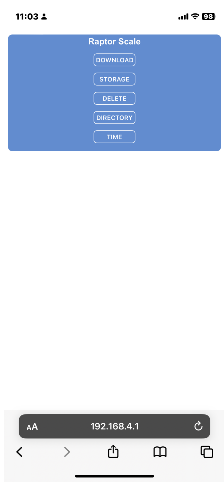


Figure 5.3: Graphical User Interface Homepage

The figure above shows that the HTTP server had been started in the sixth line from the top with the IP address given above that. This indicates that the GUI is operating and so connecting to the WiFi called "Raptor Scale" and entering the password "raptorsarecool" enables for the connection of ESP-B, but ultimately the automated bird scale. As can be seen in figure x+2 above, the GUI is displaying as intended with the correct functionality.

5.4.2 Integration Testing

Integration testing tests the integration of the subsystem components to ensure they are functioning together correctly. In this context, each functionality, essentially represented by a button each, is tested to ensure both ESPs, the camera module, the storage mechanism (microSD card) and the user are all seamlessly interacting with one another.

Figure 5.4: Image Downloaded Using GUI

The figure above demonstrates that an image can successfully downloaded wirelessly from the microSD card. This image was taken during testing and so the download functionality functions correctly.

Figure 5.5: Available Storage

Figure y+1 shows the total storage and the total storage used, indicating that only 2MB out of

30417MB is used which rounds off to 0% used of total storage used.

Figure 5.6: Deleted File

The figure above shows that a specific file had been deleted from the microSD card. This translates practically to when images take when deployed are downloaded for analysis, they can then be deleted to ensure enough space is available for further research.

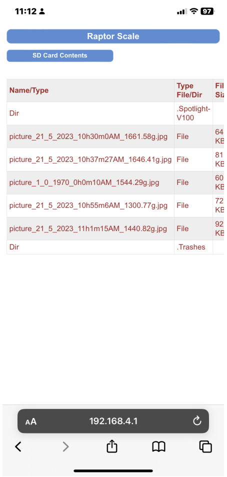


Figure 5.7: Directory

The above figure shows the directory of the microSD card and lists all files (images) with their corresponding filenames of “picture<date><time><weight>.jpg” and their corresponding file sizes. This provides ease of use when looking for a specific image and to ensure data is being recorded correctly.

The above figure shows the time-setting functionality to ensure the clock of the ESP-B is set correctly. This is essential in order for accurate research to take place and proper analysis of the data as no network connectivity is accessible in remote locations.

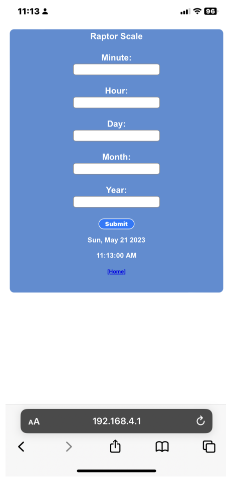


Figure 5.8: Set Time

5.4.3 Performance Testing

ESP-NOW Distance Transmission

Since the ESP-NOW is the communication protocol between ESP-A and ESP-B, and considering the fact that the scale needs to be in the field of view of ESP-A's camera, it's not going to be further than a couple of metres when deployed. The transmission distance was however tested to 10 metres at which signal strength is still good and data is transmitted. In an open field, the ESP-NOW protocol is able to transmit data up to a distance of 220m, and so distance between the two ESP's shouldn't be of concern [33].

WiFi Distance Transmission

WiFi transmission distance was measured to be 25m, i.e. the user's device and the ESP could still communicate up to 25m away. However, the ESP-B was only discoverable without being connect 7m away, and so this distance needs to be taken into consideration. Since the automated bird scale is likely to be in a tree, it can, in theory, only be about 7m high from the ground in order for wireless data transmission and communication to occur.

5.4.4 Error and exception handling tests

Error and exception handling testing tests the subsystem's ability to handle errors and exceptions in a user-friendly manner in the GUI. Two were integrated into the GUI, that being 'No SD Card present' and 'File does not exist'.

The errors were tested by removing the microSD card and inserting an incorrect file name respectively. The simulations both resulted in the expected error handling scenarios to be triggered. This ultimately makes it easy for the user such that debugging isn't necessary in determining why the GUI isn't functioning as intended.

Figure 5.9: SD Card Error Handling

Figure 5.10: File Doesn't Exist Error Handling

5.4.5 Conclusion

Overall, the designed system successfully achieves the functionality objectives of this subsystem. ESP-A effectively transmits data to ESP-B, allowing for image capture and storage on the SD card. The graphical user interface facilitates seamless interaction with the automated bird scale, primarily for the purpose of image downloading. Although the transmission distance could potentially be improved, it can be easily addressed by adding an antenna to the ESP. In conclusion, this design is well-suited for its intended context, enabling easier retrieval of recorded data and potentially advancing research and development in the field of raptors.

Chapter 6

Power Supply and Artificial Perch System Design(LSHSTH002)

6.1 Power Module

6.1.1 Introduction

The power module is responsible for powering the entire system. It does so by ensuring that all the components from separate subsystems receive the required power supply to function as expected. The module utilizes one input voltage from an external source(i.e. battery) and manipulates the voltage using regulators to output different voltages desired by the different subsystems. The following details user requirements as well as limitations and constraints for the requirements.

6.1.2 User Requirements

In tabular form, the user requirements for the power supply are defined and assigned an identification number, see table 6.1.

Table 6.1: Power module user requirements.

Requirement ID	Requirement Description
RID1	Implement an eco-friendly power source
RID2	Power module as a whole must be durable and stable.
RID3	A single power source must be used.

6.1.3 Requirements Analysis and Specifications

6.1.4 Acceptance and Test Procedures (ATPs)

Having derived the subsystem specification, table 6.1 below lists ATPs to provide a clear and standardized approach to validate the performance and functionality of the power subsystem.

Table 6.2: Power module specification derived from the user requirements 6.1

Specification ID	Specification description	Derived from
SID1	The chosen source of power must be rechargeable and harmless to the environment(i.e. Lithium batteries).	RID1
SID2	The power module device must be strong enough to withstand harsh environmental conditions, more specifically the Kalahari desert...	RID2
SID3	The power module must step down/up the voltage from a single power source to match the required power by the other subsystems	RID3

Figure 6.1: Power module ATPs

ATP Number	Specification	ATP
1	SID1	This is a hardware choice and will not be tested as the batteries from the manufacturer are listed as rechargeable , however, a comparison between the available rechargeable battery regarding environmental effects will be investigated.
2	SID2	To verify this, multiple tests such as simulating the bird-system interaction and noting the effect on the power module device, deploying the system in different settings and noting its effects (i.e., Placing the prototype in a tree) will be sufficient for verification
3	SID3	The system will be designed to output the required voltages and this will be verified using a multimeter/Oscilloscope

6.1.5 Design Choices

This section discusses the different possible options that can deliver on the power system specification 6.2 derived from the user requirements 6.1. The focus is shifted mainly to getting power from a rechargeable battery and regulating the voltage from the power source to meet the voltage required by the other components in the other respective subsystems. But firstly a brief contrast between disposable batteries and rechargeable batteries is done to assess whether the cons of choosing a rechargeable battery outweigh the disposable.

6.1.6 Batteries

Using rechargeable batteries is beneficial to consumers and is in alignment with the user requirements as one can use them without having to buy more batteries within a short period of time(less costly) and are environmentally friendly as one does not have to dispose of them ever so frequently[1]. In addition, when compared to disposable batteries, rechargeable batteries can operate at higher temperatures, this is shown in figure 6.2, with the lithium rechargeable operating at a higher temperature(60 degrees Celsius) which is higher than the rest of the other batteries, this makes it a suitable option given

BATTERY CHEMISTRY	SHELF LIFE	CYCLE LIFE	RECHARGE TIME	ENERGY DENSITY	Operating Temperature
Nickel Metal Hydride (NiMH)	3 to 5 years	700 to 1000	12-36 hours (Slow) 1 hour (Fast)	55 (Gravimetric density) 180 (Volumetric density)	-4F° to 122° F (-20° to 50° C)
Lithium Rechargeable	2 to 4 years	600 to 1000	Varies (Slow) 1 hour (Fast)	90 (Gravimetric density) 210 (Volumetric density)	40° to 140°F (-40° to 60°C)
Nickel Cadmium	1.5 to 3 years	1,000+	4-10 hours (Slow) 0.25 – 1 hour (Fast)	50 (Gravimetric density) 140 (Volumetric density)	22° to 140°F (-30° to 60°C)
Lead Acid	6 months	Varies	24 hours (Slow) 3-5 hours (Fast)	30-50 (Gravimetric density) 30-90 (Volumetric density)	77F° to 92° F (25°C to 33° C)

Figure 6.2: Disposable vs. rechargeable battery comparisons. Adapted from [1]

Figure 6.3: With TIP 2 X 18650 3.7V 3500MAH LI-ION CEL

the higher temperatures in the Kalahari desert. The 18650 3.7V 3500MAH LI-ION CELL battery is chosen as the power source for the subsystem, it is chosen based on the fact that its rechargeable and can offer power for relatively long hours, considering the current drawn by ESP32(more than 200mA with WiFi turned on) and the other components in the system. Figure 6.3 below shows the batteries, followed by table **??** detailing the battery specifications.

Table 6.3: With TIP 2 X 18650 3.7V 3500MAH LI-ION CEL Specs

Brand	LASA
Battery Size	8650 - Lithium - 3.7V
Battery Type	Lithium-ion
Battery Capacity	3400 mAh
Rechargeable	Yes

6.1.7 Voltage regulation

Voltage regulators manipulate input voltage to a fixed output voltage regardless of the changes in the input or load. There are two types of regulators; Linear and switching regulators, which both offer fixed regulation of input voltage, however, switch regulators offer relatively more efficiency [2] As can be seen in figure6.4, Switching regulators offer more efficiency (typically 95) and offers more

	Linear regulator	Switching regulator
Efficiency	Low (typically 60% to 70%)	High (typically 95%)
Control method	Passive or active an op amp	PWM signal
Polarity	Same as input voltage	Reversible
Scaling	Step-down	Step-up or step-down
Max. voltage output	Low	Moderate to high
PSRR	Broadband, up to ~70 dB depending on frequency	~50 to 100 dB, depending on frequency
Noise	Low frequency noise that matches input ripple	- 10-1,000 kHz noise due to the PWM signal and switching. - Ripple on the output.

Figure 6.4: Linear Vs. Switching regulators. Adapted from [2]

advanced features such as reversible polarity. In addition, has the ability to step up or step down the voltage. This makes it a suitable choice for the module as the 18650 battery used as a power source has a maximum voltage output of 3.7v but components used in other subsystems need voltages higher and lower than 3.7v; 3V for the HX711 amplifier 5V for the ESP32-CAM. The DC-DC Boost module shown in figure 6.5 is chosen as a regulator to regulate the 3.7 volts from the 18650 lithium-battery to 5V so it can power the ESP32, by adding the appropriate resistors the 3.7 volts from the battery can be stepped down to 3v to meet the Hx711 amplifier voltage requirements.

Figure 6.5: DC-DC BOOST MODULE USB 5V 0.6A - DFROBOT

6.1.8 Constraints and limitations

The feasibility of this module is limited by the possible limitations and constraints, this section briefly examines these limitations to mitigate issues that may impact the physical implementation of the subsystem. This subsystem as a whole is expected to have a protection circuitry element, which protects against overcharging, reverse polarity, etc. In addition, it should be safe to use and in alignment with the safety standards, see [34]. This puts limitations on the components to be chosen and the overall implementation of the system and adds on to the motivation for choosing rechargeable batteries as this avoids the risks that come with exposure to chemicals inside disposable batteries when changing them. Choosing switching regulators adds to the safety of the system as they account for reverse polarity. Unforeseen events which may arise(i.e. issues with ordering components to build the system) have a massive impact on the final design decision. Moreover, the size of the entire solution infrastructure also limits the size of the power system device and with all these factors considered a final decision is taken and discussed in the following section.

6.1.9 Final Decision

A final decision on the power module architecture is made with prioritization of the specifications [6.2] derived from the user requirements but more importantly, given the complexity, debugging that may arise from implementing the system from 1st principles and the time it may take for shipping of components and the cost of shipping from various places a cheaper battery management system(BMS) is chosen for the module. The CMU 1X18650 USB BATT HOLDER/CHRG shown in figure 6.6 is chosen, following are the specifications of the BMS.

Table 6.4 details the product specifications of the CMU 1X18650 USB BATT HOLDER/CHRG BMS and it is evident that the BMS(Using the 18650 battery) is the perfect option for the power module as it produces all the necessary voltage outputs, has a charging feature to charge the 18650 lithium battery via a micro USB port. In addition, it has battery protection against overcharge or over-discharge. Through the voltage output channels, the power module interfaces with the other components from

Figure 6.6: CMU 1X18650 USB BATT HOLDER/CHRG

Table 6.4: CMU 1X18650 USB BATT HOLDER/CHRG product specifications

Specifactions
Battery protection(Overcharge or Over discharge)
Micro USB port Input
Type-A USB Output
0.5A current charging
1 switch control USB output
5 8V Input Voltage
3V 1A Output and 5V 2A Output
LED indicates (Green means full, Red means charging)
3V output port x3 and 5V output port x3

[overlay,remember picture] [coordinate] (start) at (pic cs:start) ; [coordinate] (end) at (pic cs:end) ; [<-, line width=1pt, red] (-7.5,5) – (-11,7); [anchor=east] at (-11,7) The Power Module;

Figure 6.7: CMU 1X18650 USB BATT HOLDER/CHRG BMS Integration to the system

Port	Multimeter reading
3V, 1A Output	3.13v, 1,01A
5V, 2A Output	5.12v, 2,11A

Table 6.5: Validation test results for the voltage output ports

the other subsystems as shown in figure 6.7 below.

6.1.10 Validation Tests

Using a digital multimeter(Fluke Fluke 115 Compact Multimeter), to verify the specifications voltage readings were measured and recorded in table 6.5 below. It should be noted that the readings in table 6.5 are averages taken at full charge battery. While it might be useful to verify the BMS specs, only the specs of the ports or features used for the system are tested. As can be seen in figure 6.7, the module fits in perfectly in the system and is attached to the base via screws that connect to the base using double-sided tape, the enclosure prevents any interruption of the power module that may negatively impact its stability. Figure 6.8 below, shows the BMS charging, and as indicated in table 6.4 the red LED is lit on indicating that the BMS is charging the 18650 lithium battery. In conclusion, the above-mentioned validation tests have delivered on the specifications derived from the user requirements therefore the subsystem is valid.

Figure 6.8: Caption

6.2 Artificial Perch

6.2.1 Introduction

Some sort of platform for the raptors and eagles to interact with the system is required, and this is where the idea of an artificial perch comes into play. The perch acts as a landing platform for the raptors and eagles to land and it is connected to the load cell. The load cell then measures the stress/strain resulting from the bird on the perch to the weight of the bird and this is translated to the weight of the bird.

6.2.2 Requirements

1. The perch should be strong enough for eagles and raptures
2. The perch must be Eco-friendly

6.2.3 Prototyping

The perch is designed to mimic a typical tree branch or perches that birds of prey are likely to be attracted to. It is chosen to be a T-shaped perch that accesses the load cell through a hole at the top of the enclosure. In addition, for stability, a perch guide is designed to ensure that the infrastructure doesn't tilt in response to the landing or taking-off forces exerted by the birds on the perch.

6.2.4 Constraints and Limitations

The artificial perch, together with the guide is 3rd printed using poly lactic acid plastic which is environmentally friendly, this is alignment with the perch requirements. And due to the limitations of the 3rd printer as far as dimension, the perch is limited to 180x180mm in size.

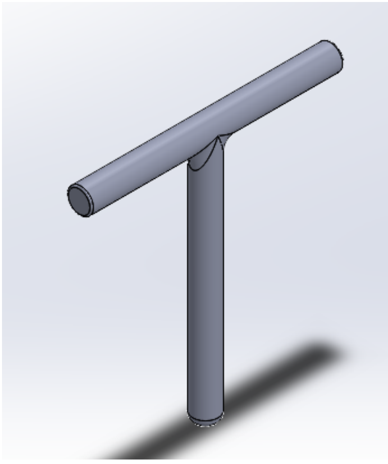


Figure 6.9: T-shaped perch design

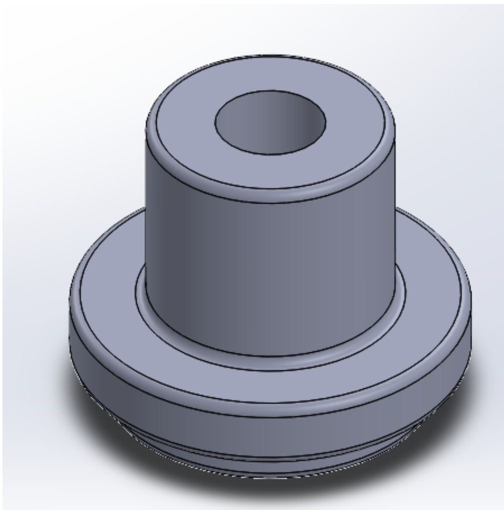


Figure 6.10: The perch guide

Chapter 7

Conclusions

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

The purpose of this project was to develop an automated bird scale to alleviate the physical strain associated with the laborious bird weight acquisition that the researcher goes through. In addition, the project sought to provide researchers with accurate and reliable data. Throughout this report, the progress and outcomes of this endeavor are presented.

This report commenced with an informative introduction that shed light on the formidable challenges researchers encounter when acquiring bird weight measurements and motivated the need for an automated solution. In addition, a well-defined set of objectives was identified for the project, accompanied by a depiction of the system requirements that align with these objectives. The introduction also emphasized the importance of precise weight data in avian research, while candidly addressing the scope and limitations inherent in the automated scale. Collectively, these introductory sections served as a solid foundation, setting the stage for the following chapters.

The literature review, covered in Chapter 2, provided a comprehensive overview of existing methods and technologies used for bird weighing. It revealed the limitations and drawbacks of traditional approaches and highlighted the potential benefits of an automated bird scale. The review served as a foundation for the design and development of the scale.

The bulk of the work for this project followed in Chapters 3 and 4 , where the artificial perch design was explained, along with the incorporation of a load cell as the weight sensor. This involved building a mechanically sound structure which could also house the crucial electrical components.

In Chapter 5, we discussed the selection and integration of two networked ESP32-CAM microcontrollers to process the weight readings into useful data for the researcher. Furthermore, we presented the results of the experimental validation and performance evaluation of the automated bird scale. The accuracy, precision, and reliability of the weight measurements were assessed through a comprehensive testing methodology. The results demonstrated that the scale achieved the desired goals and provided consistent and accurate weight readings.

Finally, chapter 6 attempted to illustrate the data transmission across the microcontrollers and data access from storage. This was accomplished through different communication protocols along with a comprehensive Graphical User Interface for the data access.

In summary, this project successfully achieved the goals that were set out. By designing and demonstrating an automated bird scale, we addressed the challenges faced by the researchers in bird weight acquisition. The scale's artificial perch design, load cell, and networked ESP32-CAM microcontrollers collectively contributed to accurate and reliable weight measurements. The project not only alleviates the physical strain on researchers but also enhances data management capabilities in this field of research.

Chapter 8

Recommendations

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

Based on the successful development and outcomes of the automated bird scale project, some recommendations can be made to further enhance its functionality and application in avian research. For example, we could explore the possibility of expanding the scale's compatibility with various bird species. This can be done by conducting additional research and testing to ensure accurate weight measurements across a wider range of bird sizes and types.

Furthermore, we can investigate the feasibility of implementing long-term monitoring capabilities. This by enhancing the scale's power management system through solar power.

Lastly, the implementation of a GPS module could be explored to ensure that the time stamps are always accurate thus limiting the human intervention required. By considering these recommendations, the automated bird scale can continue to evolve as a valuable tool for avian research.

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