ESP32 Camera Trap System

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May 21, 2023

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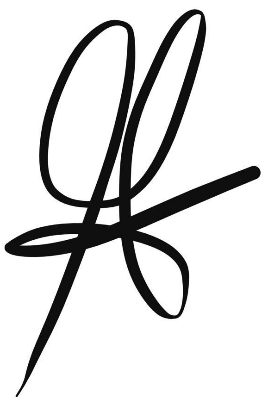

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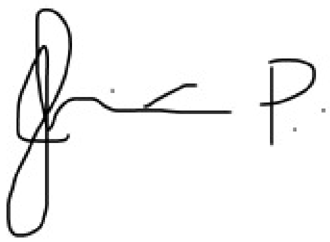

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May 21, 2023

Leseli Matsoso

Date

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Chapter 1

Introduction

1.1 Background

Camera trap systems are widely used for tracking and photographing wildlife. They are wide-lensed, high quality devices that take pictures when motion is detected. In fact, some high quality camera traps only take pictures when motion is detected and change in ambient temperature is detected. The reason for this is to limit the amount of false triggers, if the camera trap was purely governed by a motion sensor, then a mere leaf floating passed the camera would cause it to take a picture, this would fill the onboard SD card with undesired images very quickly. Unfortunately, many camera traps make use of onboard SD cards as the form of storage, which means that for data to be retrieved, the site of interest has to be visited. This means that the environment in which the species of interest resides gets disturbed every time the researcher has to retrieve the SD card. disturbing the environment is undesirable, as the point of tracking wildlife in their natural habitat is to study their behaviour where there is no human intervention. High quality camera traps are quite expensive and hence the design of a low-cost camera trap system is desirable. This report will discuss a possible design for the creation of a low-cost camera trap system with some additional functionalities to solve some of the problems face by the client.

Dr. Chris Vennum is a predetorial bird researcher, whose research is based in the Kalahari. He currently has a setup with a camera trap placed 0.5 - 2 meters from the nest, powered by a battery which is being charged by a solar panel. Dr Vennum has recently been experiencing difficulties with his setup. The walk to the site alone is roughly 2km long, combining that with the weight of the gear he has to carry makes this journey very uncomfortable. Once on the site, Dr. Vennum has to climb the tree to retrieve the SD card from the camera trap, and readjust its position. This is not only dangerous, but it also disturbs the wildlife's environment. The purpose of this project is to design a system that mitigates the problems faced by Dr.Vennum.

1.2 Problem Statement

'We met Dr Chris Vennum, a Bird Researcher, who needs a way to manage remotely, set-up and position camera traps in a safe and efficient manner because interestingly in their world they go on site too often which may disrupt the species and the equipment used is not always adequately configured.'

1.3 Scope & Limitations

The scope of this project is to design a functioning camera trap system that solves the problems faced by Dr. Vennum. To achieve this, this project was split into 4 subsections: - Sensor and Servo Motor control -ESP32 camera initialisation and user interface -power -power 2 These 4 subsections are to be integrated with each other to create a system that functions as a camera trap but also has additional features like: Wireless data transfer, Wireless camera positioning, Battery monitoring, Temperature and Humidity data and a protective power module.

The limitations of this project include a R2000 budget and hard deadline for the finished product (21 May 2023).

1.4 Report Breakdown

This report can be broken down into an introduction, 4 subsections and a conclusion. The four subsections are: -Sensor and Servo Motor control -ESP32 camera initialisation and user interface -Protection subsection -Battery subsection The Sensor and Servo Motor control subsection involves the design of a system with the following capabilities: When motion is detected in the nest, a picture is captured and the temperature and humidity readings are recorded. A system that facilitates the use of a user controlled angular position system to adjust the direction in which the camera is facing. This subsection specifically tests all the components, initialises them, designs a circuit which allows for their effective control and integrating with a webserver to ensure that the sensors and Servo Motor can be controlled wirelessly.

ESP32 camera initialisation and user interface - This subsection included the initialisation of the ESP32-CAM module, and the creation of a HTML webserver, from which the user can: control the angular position of the camera, view/edit/download the contents of the onboard SD card, capture an image and view the latest temperature and humidity reading.

Protection subsection- This subsection facilitated the design of a circuit which provided: Overvoltage protection, Reverse polarity protection, Voltage regulation, Undervoltage protection, Overcurrent protection and thermal protection.

Battery subsection - This subsection revolved around the charging of the battery via a solar panel, and a battery monitoring system.

Chapter 2

Literature Review

This Literature review was prepared in the interests of research around the photography and studying of birds. Wildlife photographers often use camera traps to gather high quality photos, which they can use to study their animal of interest. Camera traps are designed to require minimal human intervention, this is achieved through the use of motion and temperature sensor to trigger the camera to take a picture. This way the photographer does not have to be on site constantly (which would disturb the wildlife site) to manage the camera traps. The research revolves around the camera traps which includes camera protection, remote control, camera positioning, data transfer and the powering of the camera traps. This Literature review will be used to propagate possible solutions for the design and creation of a low-cost, power efficient camera trap system that requires minimal hands-on maintenance.

2.1 Early Work in Camera traps

The effectiveness of camera traps in the past:

The field of camera traps has evolved drastically over the past few years. With an increase in endangered wildlife, the researches around certain species are needed. Camera traps is one of the most popular tools used to analyse and identify the behavior of certain species of bird, as described by Chris Vennun in an interview . According to various researches, the effectiveness of these camera traps mostly come from the fact they allow for the monitoring and the analysis of wildlife patterns and behaviors for an extended period of time [1]. Franck Trolliet et al demonstrated the effectiveness of these camera traps by conducting various tests and experiments on the wildlife. These researches also highlighted the fact that these camera traps allowed for the collection of data of rare species in a very non-disruptive manner.

System limitations:

It is clear that the biggest challenge with regards to the use of camera traps in the wildlife is the possible malfunctioning of the system. It was discussed in a research conducted by Franck Trolliet et al that issues such as the battery life or the placement of the traps can be quite critical. These camera traps operate over a motion sensor which would take pictures after detection movements. However, it was discovered that most of the footage was useless data which had been triggered from a branch or a leaf moving [1]. In an interview, Chris Vennum, highlighted the critical aspect of camera positioning and how accurate it needs to be. The camera positioning must be close enough to the nest of the species being monitored so that it is able to get adequate footage. However, the camera must not disrupt the wildlife and cause disturbances in the behavior of the animals. Furthermore, Chris Vennum, discusses the possible safety issues that were associated with the setting up of such camera traps in an interview. The camera traps must often be positioned in trees which are several meters high. This means that the tree must be climbed for the camera trap to be set-up adequately. This can be dangerous as a potential fall would cause serious injuries.

2.2 Batteries and different ways of powering devices

Lithium-Ion Batteries:

Several researches were conducted with regards to Lithium-Ion batteries, their effectiveness as well as their possible challenges. Juan Pablo Rivera-Barrera, Nicolás Muñoz-Galeano and Henry Omar Sarmiento-Maldonado conducted a research in 2017 regarding these aspects. According to their review, lithium-ion batteries are the main source of power generation in modern day technologies. These batteries have several possible sizes and can output different voltages. This makes Lithium-Ion batteries very versatile which can gives it an edge on other types of batteries [2]. Being so popular, Lithium-Ion batteries also have quite an affordable price in comparison to more technical types of batteries. There is a wide variety of applications for Lithium Ion batteries. They can be used to power small electronics such as cameras, smartphones or laptops but they can also be used to power vehicles and larger-scale electronics. It was further discussed in the review that lithium-ion batteries also have a key factor associated to them being the fact that they are very easily rechargeable [2]. This allows for these batteries to be used on the long term. Solar panels can be used as a tool to recharge these batteries in an effective manner. However, Juan Pablo Rivera-Barrera et al, also highlighted the fact that there are several factors that can be considered as challenges or disadvantages with regards to Lithium-Ion batteries. Some of the key materials for the manufacturing of Lithium-Ion batteries can be quite scarce. There are also safety concerns associated to these batteries. In the past, there has be a few incidents where Lithium-Ion batteries have exploded which can cause damage to the product around them or to the users [2].

Impact of batteries in the environment:

Placing lithium-ion batteries in an environment requires a few procedures in order for it to be safe. These batteries can be placed underground and connected with wires to power several electronic objects. This is the case in the mining industry but is also seen wildlife technologies [3]. The main concern with Lithium-Ion batteries is the possibility of an explosion. This would be disastrous in an environment surrounded by nature. Researches have proven that the materials used Lithium-Ion batteries can be toxic to the wildlife [4]. This means that in the case of an explosion, the toxic components used could be a hazard that can affect the nature around it. Furthermore, in a dry environment, the explosion of a Lithium-Ion battery would be the cause of a possible fire according to an investigation by Shuai Ma et al.

The impact of the environment on the battery:

The environmental conditions can also have an impact on the equipment that is used. Batteries, such as Lithium-Ion batteries, can be affected by the temperature of the environment around them. At high temperature, the performance of the battery is affected. The chemical reaction that occurs within the battery is affected by the temperature of the environment around it [4]. A research from Shuai Ma et al found that this leads to the battery self-discharging rate to be increased. This also affects the capacity of the battery. Additionally, high temperatures have a serious impact on the safety of Lithium-Ion batteries. At high temperatures, the batteries could experience thermal runaway which could lead in the batteries exploding. Furthermore, the lifespan of the battery can be severely reduced from the batteries being exposed to high temperature regularly. It is essential that the battery is kept at a constant temperature for efficient and safe functioning [4].

Solar Panel technologies:

Researches in the field of solar panels has increased over the last few decades due to several factors. This is mainly due to the fact that this source of energy is clean and renewable. Researches have found that batteries, such as lithium-ion batteries, are rechargeable in a solar photovoltaic method. These researches found a way to use crystalline and amorphous silicon photovoltaic modules in order to recharge the strings of the lithium-ion batteries [5] According to a research conducted by Thomas L. Gibson, Nelson A. Kelly, iron phosphate type Lithium-Ion batteries would charge at a rate of 1.5C which results in the batteries being fully charged after 40 minutes [5]. These research also concluded that the best optimization for the photovoltaic system and the batteries was to match the maximum power point voltage output of both systems [5]. Further testing by Thomas L. Gibson, Nelson A. Kelly proved that solar Lithium-Ion battery also featured a self-regulating system due to the fast drop in power of the photovoltaic system. As a result of this, the over-heating and possible damage of the battery were then prevented. The potential safety challenges of Lithium-Ion batteries were therefore reduced by using photovoltaic systems to recharge them, as it was further highlighted in Thomas L. Gibson, Nelson A. Kelly research [5].

2.3 Camera angling and positioning

Positioning techniques of the camera traps:

The position and placement of the camera is very important when photographing wildlife. If the camera is in the incorrect place, it may disrupt the environment in which the desired wildlife resides, or it may not get images of sufficient quality. This is why many wildlife photographers/researchers tend to use stationery, wide lens cameras. The majority of cameras used for wildlife capturing have lens angles varying from 40 degrees to 110 degrees, depending on the study, the wide angle lens camera may be more effective, as said by Anke Seidlitz et al [6]. This is quite useful as it means that the cameras can be placed fairly close to a nest (say 0.5-5m) and still have a reasonable scope of vision. This will result in high-quality close-up images without sacrificing the scope of the image. Since this project involves the photography of birds, and the camera needs to be kept safe, stable, and out of the way of the birds, it should be positioned on a large sturdy branch higher up in the tree than the nest or area of interest (this will also allow the camera to be tilted slightly down for better quality images). This will protect the camera from wind (and taking blurry pictures due to wind), anything the birds drop from their nests, while still getting high quality images of the birds of interest. The camera should be small, camouflaged and have capabilities to take pictures during the day and at night (this is done with an infrared flash, rather than a white light flash which would disturb the wildlife), as described by Naturespy [7].

Camera Remote control capabilities:

The remote-control capability of the camera is also important to discuss. Most wildlife trail cameras have the capability to take pictures based of motion and temperature sensing. The way this works is that when motion and an ambient temperature change is detected the camera will take a picture[7], as described by Naturespy, this is done to reduce the amount of pictures taken due to a leaf floating past the camera for example, however, some cameras are sensitive enough that a windblown tree will cause the camera to take a picture, as pointed out by George Cairns[8]. This may however be problematic for the environment in which this camera is going to be used. This camera is going to be placed in a tree in the Kalahari which is a very warm environment, which means that when the wind moves the branches and leaves of the tree, the amount of dappled light (sun rays) that penetrate the tree will change, causing an ambient temperature change and motion detection as the branches will be moving, this was gathered from an article written by Naturespy [7]. This will cause many undesired pictures to be taken. The idea to use a camera that does not autonomously take pictures, but rather, is being monitored by a person and the pictures are taken at the discretion of the user, is therefore raised. This solution of a remote-controlled trigger wouldn't cost a lot extra either, all that would be needed is two transmitters, as said by Mac Stone[9]. Will Nicholls gives examples of manufactured remote-controlled triggers in his article [10]. The topic of having a camera that can rotate to move the area of observation still needs to be discussed. First of all, this would definitely increase the cost, power consumption and size of the photography system. However, it would allow for one camera to cover a wider area of space. Combined with a wide lens, a rotatable camera may prove an efficient way to take high quality pictures while having very good coverage. While being very effective, It may disturb the birds if the camera keeps moving. Despite the idea of a rotatable camera potentially being effective, it should be noted that most wildlife photographer's camera traps are stationary, as per Avni Gupta's definition of camera traps [11].

2.4 Data Transfer and gathering

Data transfer has been done in various ways in the past, depending on the available technology and the nature of the data being transferred. There are several ways to transfer data, including wired and wireless connections. From the 2000s, USB drives became increasingly popular for data transfer. These small, portable devices can store large amounts of data and are easily transportable. In recent years, wireless networks have become the norm for data transfer. Wi-Fi and cellular networks allow users to access the internet and transfer data without the need for cables or physical connections.[12]

Data can be communicated through hardware or software methods. In the electronics industry, there are micro-controllers, and numerous protocols such as Universal Asynchronous Receiver/Transmitter (UART), I2C, SPI and RS485 for data transmission. The main function of UART is to convert the parallel incoming data from the Central Processing Unit (CPU) to serial data. The transfer of data process from transmission pin to receiving pin in the UART device [13]. UART uses only two wires for its transmitting and receiving ends. The I2C protocol involves using two lines to send and receive data, a serial clock pin (SCL) that the Arduino Controller board pulses at a regular interval, and a serial data pin (SDA) over which data is sent between the two devices. These methods have been used to retrieve data in wildlife photographer[13].

Data transfer refers to the process of moving information from one device or location to another. Storing data is all about saving information in a secure and organized manner for later retrieval and use. There are many different methods and technologies used to store data, including hard disk drives (HDDs), solid-state drives (SSDs), cloud storage, and tape backup systems. Furthermore, gathering data remotely refers to the process of collecting information or data without physically being present at the location, where the data is being generated [12].

Physical data gathering can be a useful method for collecting information, but it is important to consider the potential disadvantages and limitations associated with this approach. It can be a time-consuming and costly, it may take a considerable amount of time to travel to different locations and collect data from different sources. Moreover, collecting data physically may also present safety concerns, particularly if the data collector is working in a dangerous or remote location may also have a negative impact on the environment, particularly if it involves transportation [14].

The problem can be solved by switching to remote data transfer/collection. This is suitable as it offers a significant benefits in terms of accessibility. This allow users to access their data from any location, as long as they have an internet connection [14]. However, remote data collection also poses some challenges, such as possible inconsistent data quality and lack of physical control. Gathering, transferring, and storing data remotely requires a reliable and stable internet connection. Any disruptions or downtime can interrupt the data transfer process, which can lead to data loss or corruption. To overcome these challenges, it's important to carefully design and execute the data collection process, and use the appropriate tools and techniques to verify and validate the data [14].

By allowing organizations to choose their method of data transfer that are most relevant to their needs, they have greater flexibility and control over their data, which will allow for organisations to create low-cost, effective data transfer methods specific to their needs.

2.5 Physical and Electrical protection of the camera:

To preserve the longevity and functionality of cameras used in bird studies, physical and electrical protection is required. The protective techniques that are accessible include; camera enclosures, camouflage skins, surge protectors, and voltage regulators to name a few. Researchers can keep their cameras functioning and get high-quality data by employing these precautionary measures.

Physical protection:

Shielding the camera from physical harm brought on by animals, the environmental conditions, or human activity, including deliberate acts of vandalism and theft, is known as physical protection [15]. Using camera enclosures or housings, which are designed and modified to shield cameras from moisture, dust, and impact, is one popular technique. For instance, the Outex Pro Kit is a camera housing that is shockproof and waterproof that can be used to safeguard cameras in sandy or wet settings [16]. According to Hance, use of automated and disguised camera traps triggered by infrared sensors have revolutionised wildlife research by providing a safe means of capturing otherwise shy animals intimidated by human being and standard camera shapes as foreign objects in their habitats leading to major discoveries in wildlife conservation whilst protecting the camera equipment from possible attacks by the animals themselves even as an act of curiosity [17]. One camera trap of particular interest, is that designed by Close Air Solution, that houses three cameras at a time, with each camera having mobility control allowing 360 degree view of the surroundings, from a 120 degree view limitation. This design also comes with seals that render it waterproof, dust-proof and pressure-proof [18]. Some camera enclosures employ a fan heater system as a mean of thermal-regulation to allow cameras a gradual change in temperature without overheating or drastic cooling that could otherwise damage the electronics [19]. However, camera traps depending on the available additional features have proved to be costly, particularly in developing countries such as most African countries which have a vast majority of untouched wildlife.

The use of camouflage covers or skins to conceal the camera and lessen the possibility of it being discovered by people or animals is another technique of physical protection. For a range of camera models, camouflage skins are available and are simple to apply and remove, providing a cheap and lightweight alternative to camera housing or traps in an application where concealment and size or weight of the camera is a major objective. Meek et al argue in their survey, that camouflaging proved to be 73% effective in providing camera safety by deterring human beings and animals, leading to collection of high quality data without compromising quality. The possibility of compromised quality is more prevalent in other camera traps as they usually have an additional piece of glass obstructing the cameras lens in a bid to provide maximum protection [15].

Electrical protection:

Electrical protection is crucial for camera's electronic components, to prevent damage from power surges, lightning strikes, and other electrical disturbances. Devices called surge protectors are made to withstand electrical surges, guard against damage to electronic equipment and have found a good application in wildlife research especially for cameras. They function by rerouting extra electrical energy away from the camera and into the earth [19]. One effective tool that can be used to shield cameras from power surges brought on by lightning strikes is the HDE Camera Surge Protector. Surge protectors were employed in a study by Jia et al., to safeguard cameras in a remote sensing network. The scientists discovered that the surge protectors successfully shielded the cameras from electrical surges and lightning strikes. However, they pointed out, that for the surge protectors to work properly, installation had to be done properly.

Voltage regulators are devices that are designed to ensure that electronic devices receive a steady and safe supply of power, and work in a similar manner for cameras, by stabilizing the voltage, preventing fluctuations that can damage the cameras electronics [19]. Power inverters are used to ensure constant supply of power to camera's equipment in cases whereby charging is required on site. According to Jia et al., failure of voltage regulators used in wildlife research was largely attributed to poor installation.

2.6 Summary of the literature review

Lithium-ion batteries effectiveness, reaction to changing temperatures, effect on the environment and rechargeability were explored. Research on solar panels was conducted to see the viability of them as a renewable source of energy to charge Lithium-ion batteries. Camera trap positioning and the possibility of a rotatable camera trap was explored in the interests of reducing human interaction with the camera trap, while retaining high quality data. A brief history of data transfer was provided followed by research into different data transfer methods (UART, I2C etc.) and data storage methods (USB, the cloud etc.). The final topic in the literature review covered physical and electrical protection of the camera traps. This was an important section that covered methods of protecting the camera from weather conditions, possible power surges and perhaps even attacks from wildlife. Its also important that the camera doesn't malfunction and hurt any wildlife in any way.

Chapter 3

Sensor and Servo Motor Control

This chapter within the report has been authored by Jahar Persad (PRSJAH002), representing exclusive contribution to this subsection of the design.

3.1 Introduction

This subsection forms part of a system used to track and photograph predatorial birds. The proposed system will be setup within 3 meters of the bird's nest, with a camera facing the nest and have the following capabilities:

- When there is motion detected in the nest, the system will take a picture and record the temperature and humidity at the time the picture was taken – this data will be saved to an SD card on the camera module.

- The camera has the ability to move its frame of view.

- These functionalities will be controlled via a webserver, where it will be possible to view and edit the contents of the SD card, download the contents of the SD card onto a laptop or cellphone via a local network produced by the camera module (ESP32-CAM). The angular position can also be controlled from the webserver, via seven buttons each with different position options.

- This entire system will function off a power module that contains a battery charged by a solar panel, combined with a module to provide: Reverse polarity protection, Overvoltage protection, Short-circuit protection and voltage regulation. This ensures that all the equipment in the tree is protected if anything had to go wrong with the battery.

This solution (the entire system) mitigates the need for Dr. Chris Vennum to carry heavy gear when walking from the nearest road to the wildlife site. Once on the site, it is no longer required to climb the tree to retrieve the SD card and re-adjust the camera, this can now be done wirelessly via the webserver from the bottom of the tree. In this way, many of Dr. Vennum's previous problems have been solved. This subsection involves the design, building and testing of a data collection system and a system to control the angular position of the camera. The data collection system needs to be able to detect motion, take a picture and measure the temperature and humidity when motion is detected. The angular position control system needs to have the ability to adjust the angular position of the camera on command. This subsection is to be integrated with chapter 4. This will allow the latest temperature and humidity readings to be viewed on a webserver, where the angular position of the camera can also be controlled. The actual storage of data, and the platform from which the data can be retrieved is not covered in this subsection.

3.2 Theory

Limited theory is required to understand the content of this report. However, some knowledge is required. The following is the schematic for a typical non-inverting operational amplifier setup:

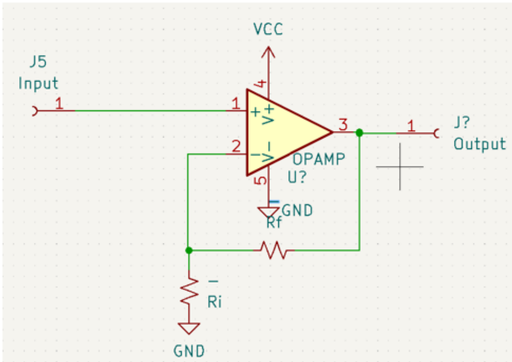

Figure 3.1: Non-Inverting operational amplifier configuration

The above figure has the functionality of amplifying the Input voltage by a factor 'A', and this amplified signal is realised at the Output. 'A' is calculated with the following formula: A=1+Rf/Ri . Hence the selection of the resistors is very important. The operational amplifier is powered via rails, and its output cannot exceed the voltage that it is supplied. For example, If Vcc = 5V, then the maximum output possible from the system would be 5V or 0V, no matter what the input or gain value is. This is known as the operational amplifier's saturation level. The resistors in this configuration dissipate power. As such, if their power ratings are too small, they could blow and create an open circuit. To calculate the power they dissipate, the voltage divider rule needs to be utilized. Since the power dissipated by a resistor is equivalent to : P= V*V/R . . . [1] , where V is the voltage drop across the resistor. The voltage divider rule can be used to calculate the voltage drop across each resistor:

V_(drop,Rf)=V_out-V_out (Ri/(Ri+Rf)) . . . [2]

V_(drop,Ri)=V_out (Ri/(Ri+Rf)) . . . [3]

These voltages can be used in the power equation to determine the power dissipated in each resistor.

Terminology: PWM – Pulse width modulation. This is a signal with a set period, however, within each period, the signal is pulled from a low level (generally 0V) to a high level (generally 3.3V) for a set time, to create a pulse. The width of this pulse as a percentage of the width of the period is known as the duty cycle.

IC - Integrated Circuit

Servo Motor – Servo Motors are components designed to control the angular position of objects. Their precision and high torque capabilities make them ideal for rotating objects to their desired position. The motor does this by receiving a PWM signal at one of its pins. This signal indicates the position to which the Servo Motor should rotate to.

3.3 Design Choices

The design process of this subsection begins with defining what needs to be achieved from this subsection followed by the design thinking, part choices, the expected performance of the system, and lastly the first design is realised.

What needs to be achieved from this subsection: This subsection revolves around the effective collection of data. The data being collected comes in the form of pictures, temperature and humidity readings at the time that the picture was taken. All this data is desired at the time when motion is detected in the nest. The camera will be placed in a tree in the Kalahari. The idea behind a Motion Sensor governing the data collection is that Dr. Chris Vennum is interested in photographing birds/tracking birds, and since he cannot be in the tree constantly or monitoring a camera feed 24/7, it is ideal for data to be collected when there is movement in the bird's nest as there is a very good chance that this indicates that the bird(s) is/are in the nest. Dr Vennum indicated that it was a tough and unsafe task to climb up the tree and adjust the cameras position, hence, the camera position control part of this subsection was created. If desired, Dr Vennum can shift the area that the camera frame covers. It should be noted that the idea behind this functionality is not to move the camera constantly, as this will disturb the wildlife environment. Rather, it should be used as a tool to fine tune the position of the camera frame without having to climb up the tree. As highlighted in the introduction, the functionality of this subsection will be controlled via a local webserver, not covered in this subsection. This negates the need to climb the tree every time a camera adjustment is desired, rather, the angular position of the camera can be controlled from the webserver at the bottom of the tree.

Design Thinking: Following what needs to be achieved by this subsection, the design thinking process was started. First, a microcontroller with a camera had to be selected. The selection of this part could not be based solely off the needs of this subsection, as this microcontroller would have to have the ability to facilitate the creation of a webserver from which the data collected would be retrieved. Together with the author of chapter 4, the ESP32-CAM part was chosen. It has a camera, Wi-Fi module, plenty of GPIO pins for the use of multiple sensors and storage in the form of an SD card. This part was included in the design thinking section as it wouldn't be possible to continue with this without first working with the author of chapter 4 and deciding on a part that would meet the needs of both subsections. It was quite clear at this point that sensors would be needed, namely, a Motion Sensor and Temperature and Humidity Sensor. These sensors would need to be used as one would expect, the Motion Sensor should send a signal to the camera and Temperature and Humidity Sensor for a picture to be taken and the accompanying temperature and humidity readings to be recorded. To control the angular position of the camera, a motor would need to be utilised, more specifically, a motor that is proficient at angular position control. A Servo Motor would therefore be ideal, as it rotates to an angular position defined by a pulse at its PWM pin and has a greater torque output when compared to other low powered DC motors. Since the motor is being used to move an object in an environment that is very effected by wind and rain, a higher torque is desired, to ensure that wind or rain does not hinder the movement of the camera.

Part Choices:

ESP32-CAM: It is known at this point that the ESP32-CAM was not chosen based solely off the needs of this subsection, but here are the reasons that it works for this subsection: It has 10 GPIO pins – This is important as GPIO pins are needed for the Motion Sensor, Temperature and Humidity Sensor and Servo Motor. As such at least 3 GPIO pins are needed. There should be a few extra for other subsections to make use of. It has a Camera. It has an onboard SD card – this could be useful for storing data in between data retrievals.

PIR Motion Module - HC-SR505: The current camera being used by the user is placed within 2m from the nest, and the HC-SR505 has a 3-meter sensing range. It runs off a 4.5-20V supply and has a very small quiescent current 60 micro-Amperes. This results in a low power consumption of: $60\times10\hat{(}-6)$ (5V)=0.3mW. It has a working temperature of between -20 and 80 degrees Celsius, which is perfect as the temperatures in the Kalahari are not as extreme. Most importantly it is very easy to use, it is a small IC (Integrated-Circuit) with 3-pins for Power, Ground and Output. The output is either “High”/3.3V or “Low”/0V, which is very easy information to process in the microcontroller. The dimensions and weight of this part, and of all the parts for that matter are important, as the motor is going to have to rotate the camera but given the nature of the environment in which this system will be implemented, it is very possible that the motor will have to rotate the entire circuit, and hence the lighter and smaller each part is, the better. The HC-SR505, is a small, lightweight component, weighing less than 50 grams. The power submodule of this project supplies 5V, and since the HC-SR505 can operate off a 5V power rail, it fits the 5V constraint.

Humidity and Temperature Sensor – DHT11: The DHT11 is a small, lightweight 4-pin device, with 2-pins for Power and Ground, 1-pin for data transmission and the last pin is null in this case. It allows for the measurement of temperatures between 0 and 50 degrees Celsius. It requires a power supply of 3-5V, and consumes 0.5mA when measuring the temperature and humidity, 0.2mA on average and 100 micro-Amperes when on standby mode. This means that in the worst case, it will be consuming: $0.5\times10\hat{(}-3)$ A(5V)=2.5mW of power, which shows that it consumes very little power, even in the worst case possible. This part also fits the 5V constraint.

HKD Micro Servo MG90 90D: This is the Servo Motor that is to be used control the angular position of the camera. This has a Power pin, Ground pin and a PWM (Pulse Width Modulation) pin. The PWM pin accepts a PWM signal, which tells the Servo Motor how far to turn and in which direction. This component can turn a maximum of 90-degrees, which could be translated into 45-degrees in either direction if 45-degrees is defined as a neutral position. The camera already has a 120-degree frame, which means, a 45-degree rotation in each direction will be enough for the camera to cover everything in front of it (it will have 210-degree vision). It operates off 4.8-6V which once again fits the constraint of a 5V supply limit and consumes current based off the load its driving. In a no-load situation, it will draw roughly 70mA, the finished system is anticipated to be lightweight, and hence it is not expected for the Servo Motor to consume much more current than this. However, this still means that the servo consumes roughly 0.35W, making it a relatively power-hungry component. The power submodule of this section has made provision for this by opting for a larger battery, and charging said battery via a solar panel.

The tests to be performed will now be defined, along with what will be considered as an acceptable test performance (ATP) for each test:

Test 0 – Test 0 is performed to ensure that all the components being used for this subsection are functional. First the Motion Sensor will be powered, and its output pin scoped. The expected output is 3.3V when motion is detected, and 0V when no motion is detected. The Servo Motor will be powered, and its PWM pin will be supplied by a signal generator to give the relevant pulse. The Servo Motor is expected to go to position "90 degrees" when given a 2ms pulse within a 20ms period, turn left to "0 degrees "when that pulse is changed to 1ms and go to its centre position "45 degrees" when the pulse is 1.5ms. The Temperature and Humidity Sensor is first tested in Test 1, this was done as the initial test for it would have been very similar to the test it gets in Test 1. Acceptable test performance for Test 0 is for both the Motion Sensor and Servo Motor to behave as expected.

Test 1 – Test 1 revolves around the test of the Motion Sensor/Temperature and Humidity Sensor module. When the Motion Sensor is triggered, the camera must take a picture and the temperature and humidity readings must be read from the Temperature and Humidity Sensor. An acceptable test performance will be that a picture is taken, and temperature and humidity readings are printed to the serial monitor when motion is detected. Please note that it is not expected for the picture to be saved on the SD card, rather just that the camera captures a picture.

Test 2 – Test 2 revolves around the Servo Motor. Code will be written and uploaded to the ESP32-CAM board, instructing the Servo Motor to change its angular position. The code will tell the Servo Motor to change its position from 0 degrees to 45 and then 90 degrees with a delay between each change. An acceptable test performance will be that the servo turns to the correct position each time.

Test 3 – Test 3 revolves around the integration of this subsection with chapter 4. As highlighted in the introduction, the position of the camera is to be controlled via the webserver, and the latest temperature and humidity readings should be available. This test includes ensuring that when a position is selected on the webserver, the Servo Motor rotates to that position, and that when temperature and humidity readings are requested from the webserver, they do appear on the server. This test falls in this subsection since the control of the Servo Motor and Temperature and Humidity Sensor fall into this section. While the webserver code was not written in this section, assistance was provided to the webserver module to ensure that the code used to control the Servo Motor and read the Temperature and Humidity Sensor was functional.

Design: Most of this design occurs in the code on the ESP32-CAM, however there is a some required circuitry to get everything working. The circuitry just involves connecting the sensors and Servo Motor to the ESP32-CAM in a safe and effective manner. The proposed circuitry for this is shown below:

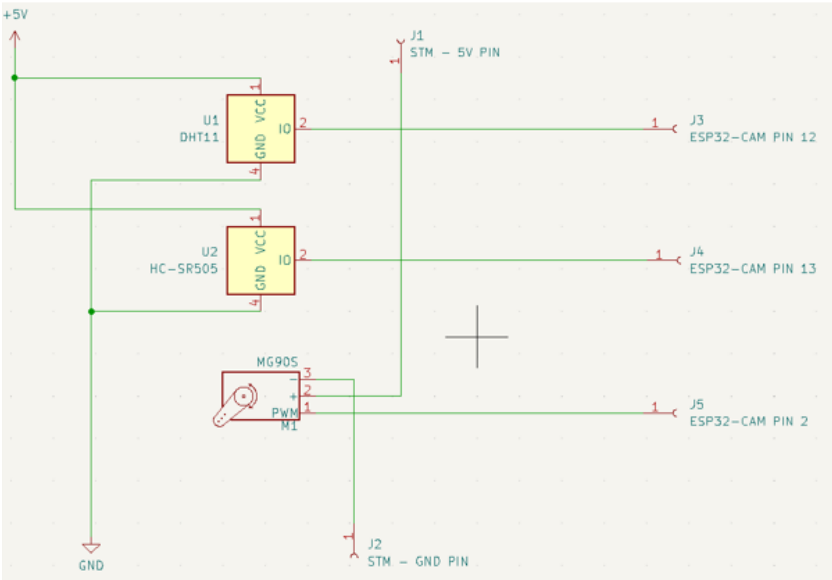

Figure 3.2: Proposed design

Explanation: The Motion Sensor IC has very simple implementation. It needs power (VCC and ground) and its third pin is the output. The output goes to a logic high when motion is detected, and a logic low when no motion is detected. In this case, the output of the Motion Sensor (HC-SR505) is connected to pin 13 of the ESP32-CAM. The Temperature and Humidity Sensor (DHT11) has similar implementation, except it has 4 pins (one of the pins is a no connect so it is not shown in the schematic), but it also requires power (VCC and ground), and its pin 2, is the pin from which the ESP32- CAM will read the temperature and humidity. Pin 2 of the DHT11 is connected to ESP32-CAM pin 12. The Servo Motor (MG90) has VCC and ground pins, and its last pin is labelled "PWM". This is because this Servo Motor changes its angular position depending on the pulse it receives from the ESP32-CAM. It should be noted at this stage that the ESP32-CAM is being powered through an STM Discovery Board. The Servo Motor is also powered from the STM Discovery Board. The reason for this is that the ESP32-CAM and the STM Discovery Board have a common ground, and the pulse being sent to the Servo Motor is with reference to the ESP32-CAM's ground, and hence the Servo Motor needs to be powered from the same rails as the ESP32-CAM, so that the correct pulse can be realised at its PWM pin. The PWM pin of the Servo Motor is connected to pin 2 of the ESP32-CAM. This was the extent of the circuit design at this point in the project. Test 1 Code:

```
void loop() {
  camera_fb_t * fb = NULL;
  delay(3000);
  if (digitalRead(12)==HIGH){ // If motion is detected enter this loop
      delay(2000);
      Serial.println("Motion detected"); // Print "Motion detected"
      fb = esp_camera_fb_get();  // Capure a picture with the ESP32-CAM
      if (fb) {
         Serial.println("Camera capture success");  //Print "Camera capture success"
         esp_camera_fb_return(fb);
         delay(1000);
      }
      else if(!fb) {
       Serial.println("Camera capture failed");    // If the camera capture failed, print a failure statement
      }
      mySensor_t sensorData;
      sensorData.temperature = dht.readTemperature(); //get temperature reading
      sensorData.humidity = dht.readHumidity(); //get humidity reading
      Serial.print("T = ");
      Serial.print(sensorData.temperature); // print " T = (current temperature)
      Serial.println(" degrees");
      Serial.print("Humidity = ");
      Serial.print(sensorData.humidity); // print "Humidity = ( current humidity)
      Serial.println(" %");

  }
  else if (digitalRead(12) == LOW){
    Serial.println("No motion detected");  // If no motion is detected, print "No motion detected"
  }
}
```

Figure 3.3: Test 1 code

This code (to be flashed to the ESP32-CAM) simply checks if the Motion Sensor detects motion. If it does, a picture is taken, temperature and humidity readings are retrieved, and messages are sent to the serial monitor along the way to check whether each stage was successful. For example, if motion is detected, the serial monitor will read “Motion detected”, then if a picture is captured successfully the serial monitor will read “Camera capture success”, and if temperature and humidity readings are retrieved, the monitor will display these values. If motion is not detected, code was written to display “No motion detected” to the serial monitor. This code is in the form of a loop, so it will repeat itself.
Test 2 Code:

```
void loop() {
delay(1000);
myservo.write(0); // turn servo to angular position 0 degrees
delay(1000);
myservo.write(45); // turn servo to angular position 45 degrees
delay(1000);
myservo.write(90 );// turn servo to angular position 90 degrees
  }
```

Figure 3.4: Test 2 code

This code sends a signal to the pin which the Servo Motor is connected to, telling it to turn to different angular positions. In this case, the Servo Motor would start at 0 degrees, delay for 1 second, then turn to 45 degrees, delay for 1 second, then turn to 90 degrees and this would repeat.

Test 3 – The code for Test 3 is very long and will therefore not be included here. It should be noted that the code for Test 3 was merely aided by this subsection, via providing libraries and code to control the Servo Motor and the Temperature and Humidity Sensor. The code that was provided by this subsection for this test was limited to:

- The libraries used for the Servo Motor and the Temperature and Humidity Sensor which were:

- The DHT library from Adafruit
- The ESP32Servo library by Kevin Harrington
- The code used to initialise and control the components:

```
Servo myservo;  // create servo object to control a servo
void setup() {
  myservo.attach(2);  // Assigns pin 2 to the servo
}
myservo.write() // Tells the servo what angular postion to adjust to
```

Figure 3.5: Supplied Sevro Motor code

```
typedef struct {
  float temperature;
  float humidity;
} mySensor_t; //defining floats for storing the sensor data

#define DHTPIN 13  //Initialising the DHT11 to pin 13
#define DHTTYPE DHT11 // defining DHT type
DHT dht(DHTPIN, DHTTYPE); //creat dht object

dht.begin(); // beginning the dht object

mySensor_t sensorData; //create sensordata object
sensorData.temperature = dht.readTemperature(); //get temperature reading
sensorData.humidity = dht.readHumidity(); //get humidity reading
```

Figure 3.6: Supplied Temperature and Humidity Sensor code

The functions and objects seen in this code where utilised in the webserver code to ensure that the Servo Motor could be controlled via the webserver and Temperature and Humidity Sensor values could be displayed to the webserver .

3.4 Preliminary Tests and Results

Before the final design, preliminary tests needed to be run on the current design. Hence the tests outlined earlier in this document were run on the current design.

Test 0: Test 0 was successful, first the Motion Sensor was connected to a power supply (+5V and Ground) and its output was scoped with a multi-meter. When the sensor was left for a while, the reading on the multi-meter dropped to 0V, but when a hand was waved over the Motion Sensor, the reading shot up to 3.33V, which meant that the Motion Sensor was operating as expected. Then the Servo Motor was connected to power (+5V and Ground), and its PWM pin was connected to a signal generator, whose output was set to a pulse of 2ms of magnitude 5V. This caused the Servo Motor to swivel. The pulse was then changed to 1.5ms, and this caused the Servo Motor to swivel left by roughly 45 degrees. Lastly the pulse was set to 1ms, and this caused the Servo Motor to swivel counter-clockwise by a further 45 degrees. This meant that the Servo Motor was operating as expected.

Test 1: Test 1 was unsuccessful! Motion was successfully detected, and a picture was successfully captured when motion was detected, however, the Temperature and Humidity readings were "nan", representing "not a number". After debugging the circuit, it was determined that the Temperature and Humidity Sensor was faulty. A snippet of the output is shown below:

```
Motion detected
Camera capture success
T = nan degrees
Humidity = nan %
No motion detected
No motion detected
No motion detected
No motion detected
No motion detected
Motion detected
Camera capture success
T = nan degrees
Humidity = nan %
```

Figure 3.7: Preliminary Test 1 results

Test 2: Test 2 was also unsuccessful. What was noticed first was that the Servo Motor was not changing its angular position. At this point the output of the ESP32-CAM's pin was scoped. It was found that it was sending a pulse of the correct width (1ms, 1.5ms, 2ms respectively), however, the magnitude of the pulses were 2.9V rather than the required 5V. Simply put, the ESP32-Cam was not capable of providing enough power to drive the servo motor, and hence it was determined that the output of the ESP32-CAM's pin 2, would need to be amplified before being sent to the PWM pin of the servo motor. Since Test 1 and Test 2 failed, it was pointless at this stage to run Test 3, as it required that the sensors and Servo Motor were operational.

3.5 Final Design

The following figure shows the schematic of the final design:

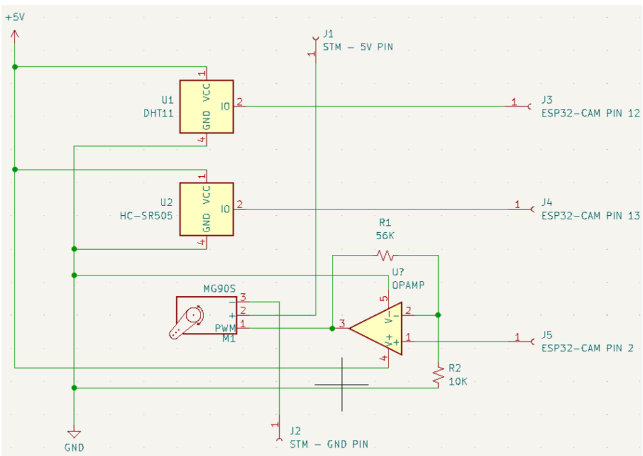

Figure 3.8: Final design schematic

To solve the issues found in the preliminary testing stage, the following changes were made: A Temperature and Humidity Sensor that was known to working was put into the circuit. A simple non-inverting operational amplifier circuit was added to boost the signal being sent to the Servo Motor. The operational amplifier chosen was the LM358, due to its fast response rate, its slew rate is: 0.3 V/s . This means that since the slew rate is in the micro-seconds range it would not corrupt the signal being sent to the Servo Motor as it is in the milli-seconds range. The operational amplifier was powered with rails of 5V and 0V. This was acceptable as it was expected to output either 5V or 0V. In fact, the gain of the circuit was chosen such that the saturation feature of the LM358 came into play. Resistor values were chosen to make the gain of the operational amplifier to be 6.6V/V. This meant that without the saturation effect of the LM358, the output of the system would be either: 2.9V * 6.6 = 19.14V or 0V. But since the operational amplifier is powered from 5V and 0V rails, the circuit can physically only output either 5V or 0V. The current consumption of a LM358 averages around 0.7mA, meaning that in this use case, it will consume 0.7×10ˆ(-3) (5V)=3.5mW. In terms of the power dissipated in the resistors, the formulas 1,2 and 3 can be utilized. This yields:

V_(drop,R1)=4.25V

V_(drop,R2)=0.75V

P_(d,R1)=0.32mW

P_(d,R2)=0.05mW

Hence, the resistors chosen were rated at 125mW as they were the resistors with the lowest power rating available. The total power consumed by this circuit is equal to the voltage supplied to the circuit multiplied by the current drawn from the circuit. This is equivalent to the addition of the power consumed by each component. In this case the power consumption of this circuit is:

P=0.3mW+2.5mW+0.35W+3.5mW+0.32mW+0.05mW=356.67mW

This shows that the circuit being used to control the sensors and the Servo Motor is light on power when compared to the rating of the battery which is in the KiloWatts range. Everything else in the circuitry design was kept constant. This final design was soldered onto a piece of Veroboard:

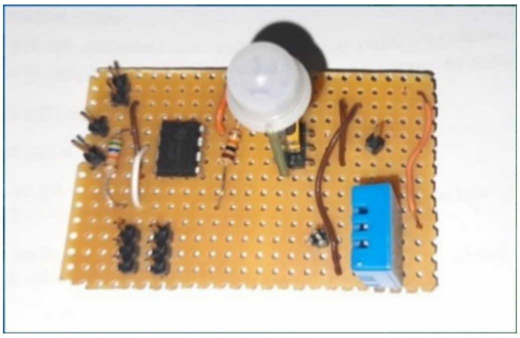

Figure 3.9: Final soldered circuit

The IC with a dome shape at the top is the Motion Sensor (HC-SR505), the blue component is the Temperature and Humidity Sensor (DHT11), and the operational amplifier circuit is seen on the top left of the figure. The Servo Motor is connected to the board via the pin headers.

3.6 Testing and Results

The tests were then rerun on the final design. Test 0 was not rerun as that test was successful, and no changes were made to the circuitry concerning that test. Test 1: The second and final run of test 1 was successful! Motion was successfully detected when a hand was waved above the Motion Sensor, this was followed by the camera successfully capturing a picture and acceptable Temperature and Humidity readings being sent to the serial monitor. The serial monitor output is shown below:

```
No motion detected
Motion detected
Camera capture success
T = 22.60 degrees
Humidity = 48.00 %
Motion detected
Camera capture success
T = 22.60 degrees
Humidity = 48.00 %
No motion detected
No motion detected
No motion detected
No motion detected
Motion detected
Camera capture success
T = 22.60 degrees
Humidity = 48.00 %
No motion detected
```

Figure 3.10: Final Test 1 results

Due to the time pressured nature of this project, this test was not run in a different environment, hence the Temperature and Humidity readings were constant as can be seen in Figure 3.10.

Test 2: Test 2 was successful for the final design! The Servo Motor was moving as commanded. Unfortunately, there is no way to show these results without the use of a video. However, a video of the Servo Motor working was put into the presentation. The fact that Test 1 and Test 2 were passed means that the Temperature and Humidity Sensor and the Servo Motor circuit was functional. This is a pre-requisite for Test 3, as Test 3 simply involves the control of these two components.

Test 3: Test 3 for the final design was successful. Seven possible positions for the Servo Motor were defined on the webserver:

1 -Neutral.

2 -15 degrees right of neutral.

3- 30 degrees right of neutral.

4-45 degrees right of neutral.

5-15 degrees left of neutral.

6-30 degrees left of neutral.

7 – 45 degrees left of neutral.

Neutral was defined as the Servo Motor taking an angular position of 45 degrees, this allowed it to rotate 45 degrees to the left and 45 degrees to the right since it has a 90-degree swivel constraint. All these positions were tested, and the Servo Motor obeyed the command sent from the webserver.

Unfortunately, short of inserting a video, the results cannot be shown. However, a video of this working is in the PowerPoint presentation that was used on the 19th of May. In terms of displaying the latest temperature and humidity readings, this was also successful and an image of the displayed values on the webserver page is shown below:

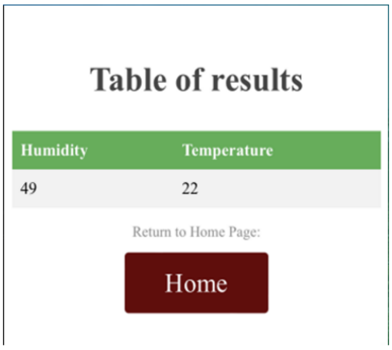

Figure 3.11: Test 3 results

3.7 Flaws in the system

Unfortunately there was two flaws this system. While the ESP32-CAM had enough GPIO pins to support the use of multiple sensors, it required all of these GPIO pins to mount the SD card. This meant that the ESP32-CAM could not save information to the SD card while simultaneously reading/writing information from/to any sensors or components attached to its GPIO pins. Hence, while both saving to the SD card and the use of the sensors and the Servo Motor was successful, these operations can not be done at the same time. The second flaw regards the Motion Sensor which was very sensitive, which may lead to many false triggers.This may fill up the onboard SD card with unnecessary information very quickly.

3.8 Conclusion and Recommendations

The purpose of this section was to implement a Motion Sensor, such that when motion is detected a picture is taken on the ESP32-CAM and the reading from the Temperature and Humidity Sensor is recorded. Furthermore, a Servo Motor was to be implemented in such a way that when the user desires, they can change the angular position of the camera. All of this was achieved in this report and hence this subsection is deemed a success. Please note that while the webserver was mentioned in this subsection, the only help that was provided by this subsection of the report was ensuring that the code and libraries used for the control of the Servo Motor and Temperature and Humidity Sensor was functional. The recommendation for this project is to add a ESP32 DEV board onto the design. This board has enough GPIO pins that all of them are not necessary to mount the SD card. This would mean that the all the components connected to the GPIO pins would still be functional, while still being able to save information to the SD card. In layman's terms, by adding an ESP32 DEV board to the design the entire system would become functional. To combat the consequences of a very sensitive Motion Sensor, it is recommended to introduce a filtering algorithm. That analyses each picture taken and deletes any pictures that do no contain the desired features.

Chapter 4

ESP32 Initialization and User Interface

This chapter within the report has been authored by Ethan Meknassi (MKNETH002), representing exclusive contribution to this subsection of the design.

4.1 Introduction

The entire system involves the development of an innovative camera trap system utilizing an ESP32 camera module embedded within a nest. This camera trap system provides a diverse range of functionalities aimed at capturing and analyzing birds effectively while minimizing disruptions to their environment.

This subsection focuses on the initialization and implementation of the ESP32 camera system, which is equipped with a camera, a motion detector, temperature and humidity sensors, and a repositioning mechanism. This submodule involves the development of software that enables the integration of these functionalities into the system.

At the core of this submodule lies the initialization of the ESP32 camera as a whole, ensuring all its fundamental functions are properly established. It will also discuss how the hardware components will interact each other to create a functional and efficient system. To enable precise positioning of the camera within the tree, a servo motor is incorporated into the module. By utilizing the servo motor, the camera can be adjusted to an optimal angle, facilitating accurate and efficient wildlife observation. Consequently, it becomes crucial to initialize the servo motor within the ESP32 camera and define various functions that allow for effective camera positioning which is the task of this submodule.

The second critical component of this subsection involves the development of a user interface, which enables users to access and utilize the diverse functionalities offered by the camera trap system. This user interface is created through the establishment of a web server within the ESP32 camera.

By developing software that integrates these features, the camera trap system becomes a powerful tool for capturing and analyzing bird behavior while minimizing disruptions to their environment. Through the use of webserver, the user is able to access and utilize these functionalities wirelessly.

4.2 Design Choices & design process

The primary decision of utmost importance revolved around the development of a user interface that would enable users to access and utilize the various functionalities of the system. Multiple options were considered for user interaction. One option involved using a console with a screen to display the functionalities and allow user interaction. Another option was to implement a controller with buttons that would send signals to the module for operating different functionalities. However, the final decision, reached by the group, centered around employing a wireless connection.

In this approach, the module would establish its own network or 'webserver' that users could connect to using their smartphones or other devices. Once connected, users would gain access to all the data stored in the camera trap module, enabling them to download the data onto their own devices. Users would also be able to activate all system functions, such as capturing images, adjusting the camera's position, and accessing data. The implementation of a webserver also allows users to connect to the camera trap module from a significant distance away from the tree. This minimizes disruption to wildlife and species while ensuring accurate and effective data retrieval.

Regarding hardware selection, the design team opted to utilize an ESP32 Camera microcontroller for the system. Although a Raspberry Pi was initially considered, the ESP32 Camera module was chosen due to its user-friendly interaction and relatively low cost. The ESP32 Camera comes equipped with a built-in WiFi module, facilitating the creation of a web server. This feature aligns with the design team's preferences, as it allows users to wirelessly access and interact with the system's functionalities. Wireless interaction and data gathering are critical elements of this design solution. Additionally, the abundance of online resources and past projects available for the ESP32 camera influenced its selection, simplifying software development and implementation of desired functionalities. Consequently, the ESP32 Camera microcontroller, with its WiFi module capabilities and integrated camera module, was chosen for the camera trapping system.

In terms of the system's memory, the utilization of a SD card is a logical choice, driven by various factors that give SD cards an advantage over alternative storage methods for such a system. The primary factor is its seamless compatibility with the ESP32 Camera, which features a dedicated SD card slot for storage. This integration significantly reduces complexity, as the SD card can be easily mounted onto the ESP32 camera module, simplifying storage implementation. Furthermore, SD cards offer a high storage capacity in a compact and portable form. Considering the handling of images and other files, it is essential to consider the memory system's capacity, as images can occupy substantial space, and the objective is to store as many as possible. Additionally, SD cards exhibit excellent durability and reliability over prolonged periods. They can endure extreme temperatures and moisture, making them highly suitable for the system's design, particularly when deployed in a harsh desert environment. SD cards serve as an optimal memory solution for a camera trap system, facilitating effortless data retrieval, robust performance under demanding environmental conditions, and seamless integration with an ESP32 camera microcontroller.

Another crucial decision made by the design team pertained to the implementation of camera positioning for the module. Two potential solutions were evaluated. The first option involved displaying a live stream of the camera's view on the ESP32 Camera's webserver, which users could wirelessly access and view on their phones. This live stream would feature buttons to rotate the camera. The second option involved capturing and storing pictures on the SD card, which users could view through the web server interface. Camera repositioning would be achieved using a motor controlled by buttons on the ESP32 Camera's web server. The design team selected the second option for several reasons. Firstly, implementing a live stream monitoring system is complex. Furthermore, the live stream consumes a considerable amount of power, which is inefficient for the battery-powered ESP32 Camera. The second choice allowed for the implementation of an interface where users could view and download pictures stored on the SD card. Lastly, a live stream would not be practical when the cameras are set up and left in trees for monitoring purposes.

The code utilized in the design was based on open-source resources and incorporated snippets from online tutorials. Refer to reference [21], [23], [23] and [24].

4.2.1 Acceptance Test Procedures

The subsequent sections present the Non-functional Specifications and Functional Specifications of this submodule, each denoted by IUISS-x, representing the initialization and user interface specification.

Non-functional Specifications

No.	Specification Description	Acceptance Criteria
IUIS-1	The hardware expenditure should not exceed a threshold of R500.	The total cost of the bill of materials for this submodule must not exceed R500.
IUIS-2	The selected hardware should possess compact dimensions to facilitate its installation within a tree as a camera trap.	The dimensions should be less than 10x10cm.
IUIS-3	The hardware should also be prioritizing minimal weight to ensure portability of the device.	The weight of the hardware should not exceed1kg.
IUIS-4	The software employed must adhere to an open-source model, providing users with all the requisite permissive licenses for unrestricted utilization.	The cost for the software must be free with all permissive licenses.
IUIS-5	The web server should be accessible to users from their devices, located at the base of the tree or a sufficiently distant location to minimize disturbance to wildlife.	The user must access the webserver from about 5-10 meters
IUIS-6	The storage capacity of the system must be substantial enough to accommodate a significant volume of pictures for storage purposes.	The storage capacity must be of at least 16Gb.

Table 4.1: ESP32 initialization and user interface non-functional specifications with their respective acceptance criteria.

Functional Specifications

No.	Specification Description	Acceptance Criteria
IUIS-7	The pertinent data captured by the camera trap, such as the images files, should be stored on the SD card for preservation and retrieval.	Pictures must successfully be saved on the SD card
IUIS-8	The data stored on the SD card can be wirelessly accessed by the user via the web server.	The web server presents the directory structure of the SD card, displaying the image and files available on the SD card.
IUIS-9	Users have the capability to retrieve the data stored on the SD card.	The data on the SD card can be viewed and downloaded onto the user's phones from the webserver.
IUIS-10	Even when the webserver is not operational, the relevant data and pictures should continue to be stored on the SD card to ensure their preservation and availability.	The system continues to function and save data when the webserver is not up.
IUIS-11	Real-time sensor values must be made accessible to the user through the web server, providing up-to-date data reflecting the current moment.	The user must access the latest temperature and humidity sensor values from the webserver.
IUIS-12	The web server must promptly and seamlessly respond to user inputs without any noticeable delay or congestion in transmission.	Upon the user selecting a functionality on the web server, it should be executed immediately and without delay.
IUIS-13	The web server should facilitate wireless camera rotation, enabling users to remotely adjust the camera's orientation.	An interface enabling the camera rotation using the webserver.
IUIS-14	The user interface is designed to be intuitive, easy to comprehend, and user-friendly, ensuring a straightforward experience for users.	The webserver interface is clear and easy to navigate through.

Table 4.2: ESP32 initialization and user interface functional specifications with their respective acceptance criteria.

4.3 Final Design

The final system design is a result of the decisions made during the design process. The submodule is responsible for initializing all the required software on the ESP32 camera and creating a functional user interface in the form of a webserver. This webserver enables users to access and utilize all the system's functionalities such as the capturing a photo and saving it on the SD card, rotating the camera, accessing the current temperature and sensor values and viewing, downloading and deleting the files on the SD card.

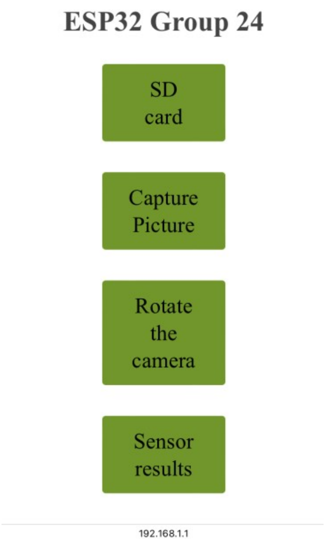

Figure 4.1: Screenshot showing the main page of the webserver

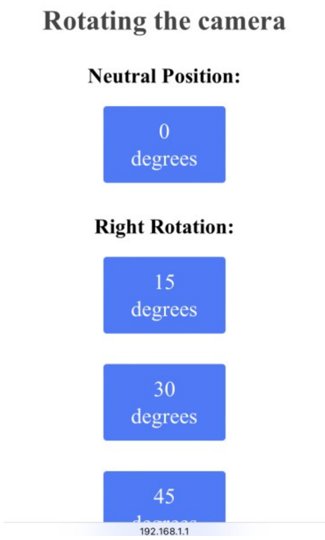

Figure 4.2: Screenshot showing the servo motor user interface of the webserver

Figure 4.1 depict the appearance of the webserver interface and its main page. The main page consists of four distinct buttons, each serving a different function.

Clicking on the SD card button redirects the user to a new page displaying the contents of the SD card which can be seen later on figure 4.7. From this page, users have the option to view, download, or delete the stored pictures. The first button on the main page enables users to capture real-time images using the camera. These pictures can be viewed by clicking on the appropriate button. In addition to manual picture capture, the system is also equipped to automatically take pictures when motion is detected. The accompanying temperature and humidity readings are gathered and stored in a text file, accessible via the webserver's first button.

The third button, labeled 'Rotate the camera', leads to a separate page, as depicted in Figure 4.6. This interface provides users with buttons to control the angular rotation of the camera. The 'Neutral Position' button centers the camera at 0 degrees. Additionally, there are three buttons on each side for 15, 30, and 45-degree movements, allowing users to adjust the camera position to the right or left. Figure 4.6 only shows a snippet of the interface. There are 7 buttons, 3 for each side and 1 neutral position button.

```
void setup() {
  WRITE_PERI_REG(RTC_CNTL_BROWN_OUT_REG, 0); //dis

  // Serial port for debugging purposes
  Serial.begin(115200);
  WiFi.softAP(ssid, password);
  WiFi.softAPConfig(local_ip, gateway, subnet);
  Serial.print("Camera Ready! Use 'http://");
  Serial.print(WiFi.softAPIP());
  Serial.println("' to connect");
  delay(100);
  server.begin();
  Serial.println("HTTP server started");
```

Figure 4.3: Code snippet of the initialization of the Webserver

The ESP32 camera employs Arduino code to initiate the webserver. The code snippet depicted in Figure 4.3 encompasses the webserver's initialization and includes the requisite lines of code for its setup. The code also encompasses variable initialization for specifying the network name and the password necessary for server authentication.

```
String SendHTML(){
  String ptr = "<!DOCTYPE html> <html>\n";
  ptr +="<head><meta name=\"viewport\" content=\"width=device-width, initial-scale=1.0, user-scalable=no\">\n";
  ptr +="<title>WebServer</title>\n";
  ptr +="<style>html { font-family: Bahnschrift SemiLight Condensed; display: inline-block; margin: 0px auto; text-align: center;}\n";
  ptr +="body{margin-top: 50px;} h1 {color: #444444;margin: 50px auto 30px;} h3 {color: #444444;margin-bottom: 50px;}\n";
  ptr +=".button {display: block;width: 80px;background-color: #3498db;border: none;color: black;padding: 13px 30px;text-decoration: none;
  ptr +=".button-on {background-color: #3498db;}\n";
  ptr +=".button-on:active {background-color: #2980b9;}\n";
  ptr +=".button-off {background-color: #690;}\n";
  ptr +=".button-off:active {background-color: #2c3e50;}\n";
  ptr +="p {font-size: 14px;color: #888;margin-bottom: 10px;}\n";
  ptr +="</style>\n";
  ptr +="</head>\n";
  ptr +="<body>\n";
  ptr +="<h1>ESP32 Group 24</h1>\n";
  ptr +="<p></p><a class=\"button button-off\" href=\"/seepic\">SD card</a>\n";
  ptr +="<p></p><a class=\"button button-off\" href=\"/picture\">Capture Picture</a>\n";
  ptr +="<p></p><a class=\"button button-off\" href=\"/rotate\">Rotate the Camera </a>\n";
  ptr +="<p></p><a class=\"button button-off\" href=\"/table\">Sensor results </a>\n";
  ptr +="</body>\n";
  ptr +="</html>\n";
  return ptr;
}
```

Figure 4.4: Code snippet showing the HTML software development for the main page

The Arduino code snippet shown in Figure 4.4 demonstrates the initialization of the main page HTML on the ESP32 camera. It includes the initialization of various buttons and defines the destinations to which each button leads. There are additional HTML initialization codes not shown here that are used for setting up other pages accessible from the main page.

```
void loop(){
    if (digitalRead(12)==HIGH){
      capturePhotoSaveSD(); //takes a picture and saves it on SD card
      Serial.println("Motion detected");
      sensorData.temperature = dht.readTemperature();
      sensorData.humidity = dht.readHumidity();
      Serial.print("T = ");
      Serial.print(sensorData.temperature);
      Serial.println(" degrees");
      Serial.print("Humidity = ");
      Serial.print(sensorData.humidity);
      Serial.println(" %");
  }
  else if (digitalRead(12) == LOW){
    Serial.println("No motion detected");
  }
  server.send(200, "text/html", Table(sensorData.humidity, sensorData.temperature));
}
```

Figure 4.5: Code snippet showing the initialization of the sensor and the triggering of the camera as well as the information being sent to the HTML interface

Figure 4.5 illustrates the software initialization that enables the system to capture and save a picture on the SD card whenever the motion sensor is triggered. Additionally, it records the temperature and humidity values at the time the picture is taken and sends them to the webserver.

```
void gotoRotate(){
  server.send(200, "text/html", Rotate());
}

void neutral(){
  server.handleClient();
  myservo.write(45);
  server.handleClient();
  server.send(200, "text/html", Rotate());
}
```

Figure 4.6: Code snippet showing the initialization of servo system with the webserver

The provided Arduino code snippet,displayed in figure 4.6,demonstrates the initialization and operation of the servo motor with the ESP32 camera. The neutral position is set when the parameter of the **myservo.write()** function is set to '45', causing the motor to remain stationary. To rotate the servo motor either left or right, the same code is utilized by changing the value within the range of 0 to 90 degrees. A value of 0 corresponds to the leftmost rotation of the motor, while 90 represents the rightmost rotation. When the corresponding button is pressed on the webserver, the function is activated, adjusting the angular position of the system.

A critical aspect of the design that needs to be addressed is the limitation of available GPIO pins on the ESP32 camera microcontroller during the initialization of the SD card. Due to the utilization of all GPIO pins for the SD card initialization process, there are insufficient pins remaining for the initialization of the sensors and the servo motor. Consequently, the system's functionalities cannot operate simultaneously as intended.

While the design and software development are correct and encompass all the required functionalities, it is necessary to consider an alternative module to the ESP32 camera. One possible solution is to employ an ESP32 Dev board, which shares similar costs and meets the necessary ATPs. However, incorporating an external camera module alongside the ESP32 Dev board would be essential to achieve the desired functionality.

By utilizing an ESP32 Dev board with an additional camera module, the design can accommodate all the functionalities simultaneously, as the ESP32 Dev board offers a sufficient number of GPIO pins.

4.4 Testing and Results

4.4.1 Results

The submodule requires specific hardware components, namely the ESP32 camera and an SD card. The ESP32 camera microcontroller is priced at R175, while the SD card costs R75. The combined cost of these components totals R250. The ESP32 camera microcontroller measures 5.44x2.79cm and weighs 0.1kg. In comparison, the weight of the SD card is negligible at 0.01kg [25].

For the initialization process, open-source software was selected, which is freely available. The chosen SD card has a storage capacity of 16GB, enabling it to accommodate a substantial number of pictures.

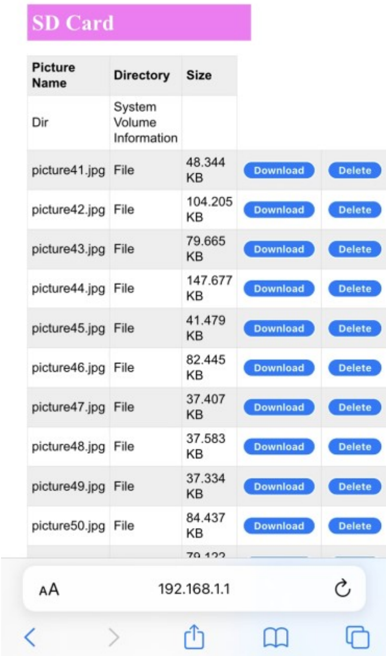

Figure 4.7: Screenshot of the webserver showing the directory of the SD card

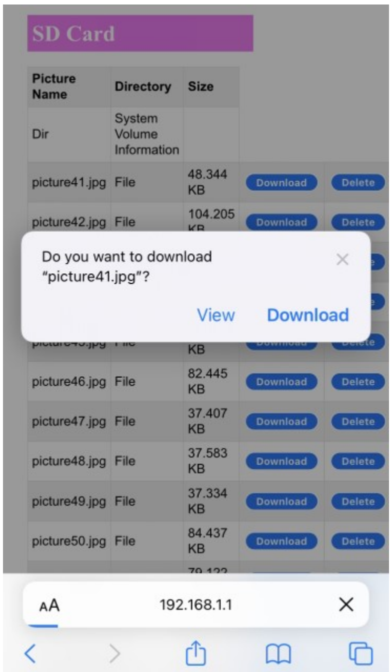

Figure 4.8: Screenshot showing the pictures are viewable and downloadable from the webserver

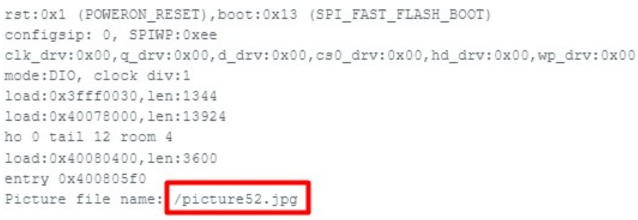

Figure 4.9: Screenshot of the serial monitor after a picture was taken and saved onto the SD card

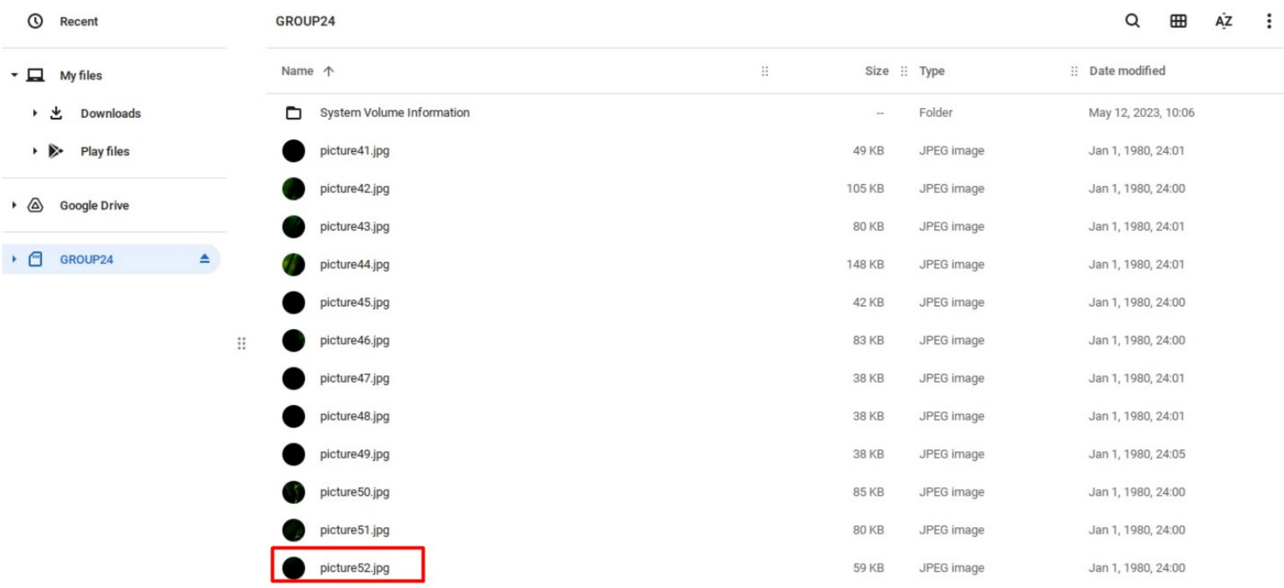

Figure 4.10: Screenshot of the SD card directory on a computer's GUI

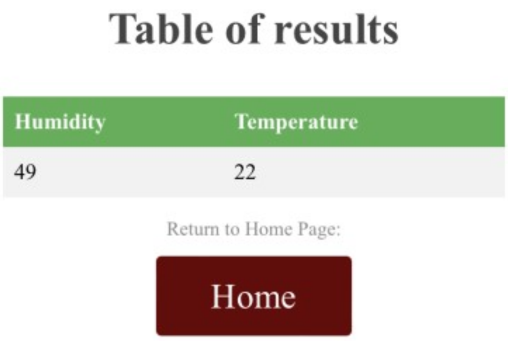

Figure 4.11: Screenshot of the current temperature and humidity sensor values on the webserver

Upon the successful capture and storage of a picture on the SD card, the serial monitor displayed relevant information. Figure 4.9 provides a visual representation of the displayed details on the serial monitor following the picture capture process. Pictures were also successfully taken when the webserver was turned off. Each picture was assigned a unique file name and securely stored on the SD card, as depicted in Figure 4.10.

In addition to the serial monitor, the webserver user interface allowed users to access the directory of the SD card. Figure 4.7 showcases the webserver interface, allowing for the comparison of the directory on the SD card with the directory on the computer. Notably, the webserver interface granted users the ability to view and download the stored pictures, as shown in Figure 4.8.

The webserver provided access to real-time sensor data, such as temperature and humidity, which are displayed in tabular form. These values corresponded to the current conditions in the room during the recording. Figure 4.11 showcases this functionality, presenting the sensor values in a clear and organized manner.

Furthermore, the servo motor promptly responded to inputs received from the webserver, accurately positioning itself to the desired angular position. The system exhibited immediate responsiveness when users interacted with its functionalities, indicating a seamless transmission process without any noticeable delays.

The user interface of the system was found to be user-friendly and intuitive. The buttons and controls are easy to comprehend, ensuring a straightforward user experience. This aspect is exemplified in the final design section, where the intuitive nature of the buttons is evident.

4.4.2 Non-Functional Specifications ATP testing

Specification No.	Test Procedure	Acceptance Criteria	Test result
IUIS-1	Perform a comprehensive calculation of the bill of materials (BOM) for the specified submodule.	The total cost of the bill of materials for this submodule must not exceed R500.	The cost analysis for the components of this section amount to a total cost of R250. This test is passed.
IUIS-2	Determine the dimensions of the ESP32 camera in centimeters.	The dimensions should be less than 10x10cm.	The ESP32 Camera dimensions are 5.44x2.79cm. The test is passed.
IUIS-3	Determine the weight of the ESP32 camera in kilograms.	The weight of the hardware should not exceed 1kg.	The ESP32 camera and the SD card together amount to 0.11kg. The test is passed.
IUIS-4	Calculate the costs associated with the software and the permissive licenses.	The cost for the software must be free with all permissive licenses.	The software used was open-source and therefore cost R0. The test is passed.
IUIS-5	Perform a range test on the webserver by trying to connect to it from different distances.	The user must access the webserver from about 5-10 meters	The webserver was still accessible when the ESP32 camera was 10 meters from the device. The test is passed.
IUIS-6	Determine the capacity of the SD card.	The storage capacity must be of at least 16GB.	The SD card used held a storage capacity of 16GB. The test is passed.

Table 4.3: Assessment of the acceptance tests and the results for the non-functional specifications

4.4.3 Functional Specifications ATP testing

Specification No.	Test Procedure	Acceptance Criteria	Test Result
IUI-7	Utilizing the web server, an image is captured and subsequently the SD card is verified to determine whether the picture has been successfully saved or not.	Pictures must successfully be saved on the SD card.	The picture taken using the webserver was saved on the SD Card. This test is passed.

IUI-8	The webserver's displayed page, presenting the files on the SD card, is compared with the actual contents of the SD card using a computer.	The web server presents the directory structure of the SD card, displaying the image and files available on the SD card.	The contents displayed on the web server page were found to be identical to the contents observed on the computer and each file was present with the correct size. This test is passed.
IUI-9	From the web server's display page, files are viewed and downloaded. The downloaded files are subsequently compared with the files on the SD card to check if they are identical.	The data on the SD card can be viewed and downloaded onto the user's phones from the webserver.	The files downloaded from the webserver were found to be identical to the ones are the SD card. This means the downloading was done successfully. This test is passed.
IUI-10	The web server is deactivated by removing its initialization, and subsequently, it is checked whether pictures are still being taken when motion is detected despite the webserver being turned off.	The system continues to function and save data when the webserver is not up.	The system continued to capture pictures upon detecting motion, despite the web server being turned off. These newly captured pictures were successfully saved on the SD card. The test is passed.
IUI-11	Upon pressing a button on the web server, it is checked whether the temperature and humidity sensor values are displayed. Subsequently, it verified these values are accurate by comparing them to the actual temperature and humidity measurements in the room.	The user must access the latest temperature and humidity sensor values from the webserver.	When the button was pressed, the latest temperature and humidity sensor readings were displayed on the webserver. These values were almost identical to the measurements in the room. This test is passed.

IUI-12	The various functionalities of the system have been implemented, and the delay between clicking a button on the web server interface and its corresponding reflection in the system is recorded.	Upon the user selecting a functionality on the web server, it should be executed immediately and without delay.	There was almost no delay between clicking a button on the webserver and having its associated reflection on the system. The response was immediate. The test is passed.
IUI-13	The webserver interface for controlling the servo motor, and consequently the camera, is tested to ensure the functionality and accuracy of each button.	An interface enabling the camera rotation using the webserver.	The relevant buttons on the webserver led to the rotation of the servo motor accurately. The test is passed.
IUI-14	The comprehensiveness and difficulty of the webserver interface was evaluated.	The webserver interface is clear and easy to navigate through.	The interface is focused on simplicity, and user-friendliness. The test is passed.

Table 4.4: Assessment of the acceptance tests and the results of the functional specifications

4.5 Conclusion and recommendations

The initialization and implementation of the ESP32 camera module and its user interface involved the software development necessary for integrating system functionalities. This submodule focused on ensuring proper interaction between hardware components. Specifically, it established communication between the sensors and the ESP32-cam, as well as between the servo motor and the ESP32-cam. Additionally, a webserver user interface was developed to provide users with access to required functionalities and data retrieval. The webserver enabled users to capture pictures, access sensor data, view, download, and delete files on the SD card, and adjust the camera's angular position using the servo motor. Overall, the initialization of the ESP32 camera and its webserver was successful. All system functionalities were appropriately initialized and operated correctly. The webserver was designed with user-friendliness in mind to facilitate ease of use for all these functionalities. The functional and non-functional design specifications acceptance procedure tests (ATPs) were met, ensuring an efficient and accurate system.

Regarding system issues and recommendations, a significant problem arises from the inability of all functionalities to work simultaneously due to the SD card's pin requirements, which exhaust all available GPIO pins on the ESP32. To address this issue, it is recommended to employ a different microcontroller that offers a greater number of available pins. An ESP32 Dev board can be used, as it possesses identical functionalities to the ESP32 camera but offers additional GPIO pins, allowing for simultaneous functionality of the entire system. The only additional requirement would be to attach an extra camera module to the ESP32 Dev board.

Chapter 5

Electrical Protection

This chapter within the report has been authored by Leseli Matsoso (LSSMAT001), representing exclusive contribution to this subsection of the design.

5.1 Introduction

5.1.1 Overview

In many electronic applications, the creation and deployment of effective voltage conversion circuits as well as protection circuitry are crucial. For electrical devices to operate reliably and safely, a precise control step-down from a higher voltage to a lower voltage level must be used, as well as the incorporation of appropriate protection features. This section of the report therefore provides research to offer a thorough analysis of the design and construction of a hybrid system circuit board that reduces the voltage from a bigger and more powerful supply unit to low level of power to enable functionality as the very first step of protection measures as well as specific protection methods appropriate in power handling and distribution. The circuit designed is appropriate for a variety of applications and projects but has been adopted in this design of a camera trap specifically to protect an ESP32 camera, servo motor, and sensors which include humidity, temperature, and motion sensors.

5.1.2 Objective

The main goal of this subsystem of the project is to create a step-down circuit that is extremely efficient, dependable, and capable of producing a stable, regulated direct current (DC) supply of 5V and 3.3V outputs from a 12V lithium battery while also incorporating vital protective measures to protect the attached components. The circuit includes devices for protecting against over-voltage, reverse polarity, short circuits, ultra-low voltage dropout, and over-current. The risk of damage from voltage fluctuations, improper polarity, and fault circumstances is reduced by these protection mechanisms, which also safeguard the circuit's longevity and integrity and that of the devices it supplies within the camera trap.

In this section, we will delve into the detailed design considerations and implementation steps of the step-down circuit. Each protection feature will be discussed individually, providing insights into their importance and selection of appropriate components. Furthermore, we will explore the interfacing aspects of the circuit with the power source, an ESP32 micro-controller camera and servo motor, elucidating the connection diagram and control logic.

The acceptance test points to confirm the circuit's performance and functioning will also be defined in this section of the report. These tests will assess the stability and accuracy of the voltage output, the activation and response of the over-voltage protection, the operation of the reverse polarity protection, the effectiveness of the short circuit protection, the efficiency of the ultra-low voltage dropout, and the efficiency of current limiting.

This subsystem strives to provide a dependable and adaptable solution for many electronic projects by designing and implementing the circuit outlined with complete protective features and taking into account the unique requirements of interfacing with the ESP32 camera and servo motor in particular so as to ensure the robustness and integrity of our camera trap. The circuit design, implementation procedures, test results, and suggestions for future enhancements will all be thoroughly examined in the parts that follow in this section of the report.

5.2 Design Process

The overall design process for this subsection followed requirements analysis procedure which entailed identifying functional and non-functional circuit requirements, exploring design choices and component selections based on identified choices and ultimately performance optimisation via acceptance test procedures.

5.2.1 Requirements

Functional requirements

- Voltage Regulation
  The circuit should be able to safely, accurately and efficiently step down input power to required level of two input levels required to power the ESP32 camera, servo motor and sensors
- Over-voltage protection
  Detect and prevent voltage levels above a specified threshold from reaching sensitive components or circuits. Disconnect the power source or activate protection devices to redirect excessive voltage to avoid
- Under-voltage protection
  The under-voltage protection is aimed at protecting the power supply from over-draining the battery and let it recharge to sufficient level hence protecting its lifespan.
- Over-current Protection
  To avoid excessive current flow that can result in overheating, damage, or fire risks, monitoring and control of current levels should be achieved. To stop the current flow, turn on safety feature put in place such as circuit breakers, fuses, or current-limiting devices to isolate the power supply from the overall system.
- Short circuit protection
  In case of short circuits, which happen when an unintentional low-resistance route is formed between conductors in the load, isolate the power supply unit from the load thus rendering it

powerless to avoid excessive current flow, component damage, and fire risks, that is, quickly interrupt the circuit.

- Reverse polarity protection
  Protect circuits from connections with reverse polarity, which occur when the positive and negative terminals are accidentally switched.By cutting the circuit or stopping the passage of reverse current, protect components or equipment from damage.

- Thermal protection
  Monitor temperature levels to prevent overheating and damage to components. Activate sleep mode or thermal shutdown to let the components cool down to maintain safe operating temperatures.

Non-functional requirements

- Reliability
  The protection circuitry should be highly reliable, ensuring consistent and accurate detection and response to fault conditions. It should minimize false trips or failures to activate the protection mechanisms during actual fault events.

- Safety
  The safety of people and equipment should be given priority by the protective circuitry, which should act quickly in dangerous situations. It should abide by pertinent safety norms and standards, such as those governing electrical safety.

- Response time
  Fast response times from the protective circuitry are necessary to quickly identify and address fault conditions. The response time should be within acceptable limits to prevent damage or injury.

- Scalability
  The protection circuitry should be scalable, allowing for the expansion or modification of the electrical system without compromising protection effectiveness. It should be adaptable to accommodate changes in load capacity, circuit configuration, or system upgrades.

- Environmental conditions
  The protective circuitry must be built to withstand and perform effectively in the anticipated environmental conditions, including temperature and humidity. Environmental elements that can impair performance or jeopardize safety should not be able to harm it.

- Power Efficiency
  In order to maximize energy efficiency and save operating expenses, the protection circuitry should reduce power consumption and losses, that is, it should prioritize energy conservation without compromising the effectiveness of protection mechanisms.

5.2.2 Specifications

By adhering to the following specifications, the circuit can be designed, implemented, and tested to meet the intended functionality, performance, and safety requirements of the ESP32 camera trap system.

- Voltage Regulation
  The circuit should be able to handle input of 12V to ensure compatibility with proposed power supply unit and step it down to two output voltages of 5V [?] and 3.3V [?]
- Over-voltage protection
  The system should prevent voltage levels above a threshold of 5.5V to accommodate sensors used, The 3.3V output should be constantly at 3.3V with 0.2V headroom allowable.
- Under-voltage protection
  To avoid the power supply from over-draining the battery, the protection circuit should disconnect the battery if it falls below 9.6V.
- Over-current Protection
  Current should be limited to 0.5A to avoid excessive current that can damage the rest of the system.
- Short circuit protection
  In case of short circuits, disconnect load from the power supply unit.
- Reverse polarity protection
  Protect circuits from connections with reverse polarity, when the positive and negative terminals are switched, by cutting the circuit or stopping the passage of reverse current to protect components or equipment from damage.
- Thermal protection
  Monitor temperature levels to prevent overheating above 40 degrees Celsius.

5.2.3 Acceptance test procedures (ATPs)

- Voltage Conversion Test:

  Apply a 12V input voltage from a lithium-ion battery or equivalent DC source to the circuit. Measure the output voltage to verify that it remains stable at 5V within an acceptable tolerance range. A second output of 3.3V should also be obtained, measured and verified from same 12V input source.
- Over-voltage Protection Test:

  Apply an input voltage higher than the specified overvoltage threshold. Verify that the protection circuit activates and effectively limits the output voltage to a safe level, preventing damage to the components

- Reverse Polarity Protection Test:
  Connect the input voltage with reversed polarity. Confirm that the circuit detects the reversed polarity condition and prevents current flow remaining off, ensuring the system's safety.
- Short Circuit Protection Test:

  Introduce a short circuit in the output terminals of the circuit. Verify that the protection circuit detects the short circuit and quickly interrupts the current flow, protecting the components from excessive current.
- Ultra Low Voltage Dropout Test:

  Reduce the input voltage gradually and monitor the circuit's behavior. Confirm by measurement that the circuit maintains stable output voltages of 5V and 3.3V until the input voltage drops below the specified ultra low voltage dropout threshold.
- Current Limiting Test:

  Apply a load that exceeds the maximum rated current of the circuit. Ensure that the circuit activates the current limiting mechanism to restrict the output current to a safe level, preventing overheating and component damage
- Performance and Stability Test:

  Operate the circuit under normal operating conditions for an extended period. Monitor the output voltage stability, temperature levels, and overall performance to ensure reliable and consistent operation

5.2.4 Design choices

Voltage regulation

The primary means of stepping down DC to Dc voltage identified were through use of voltage dividers [**?**], linear regulators and switching regulators especially the buck converter switching regulators. With the voltage divider being on the worst case applicable to this project the linear and switching regulators are compared and contrasted in the following table [**?**].

Table 5.1: Linear voltage regulator vs Buck converter

Comparison metric	Linear regulators	Buck converter
Cost	Low	High
Efficiency	Mostly low	Usually high up to 95%
Output power	Generally several watts and highly depends on thermal design	Large power possible
Noise	Low noise	Switching noise avoidable by choosing high switching frequency
Design	Simple	Complicated
Parts count	Few parts count	More external parts required
Heat generation	Considerable amount of heat	Low heat generation

Converter was deemed more effective for this project and thus used as the choice of design.

Over-voltage and reverse polarity protection

For reverse polarity and reverse polarity protection, design choices were found to be very similar with minimal variations based on simplicity and complexity. Explored choices were: a simple diode circuit to provide current flow in one direction with a blocking diode of high peak inverse voltage to aid reverse blocking. Another design option considered was a MOSFET transistor and diode protection circuit which is relatively cheap and easy to build providing the best efficiency as MOSFETs are voltage controlled devices. Last design choice considered was a MOSFET and gate driver circuit which was deemed not only expensive but highly complex for the appliction as most features of the gate driver remain unused.

Short circuit protection

The design considerations in for this protection measure also differed in choosing whether to use voltage controlled or current controlled devices, being MOSFET transistors and bipolar junction transistors with the overall circuitry implementation similar. The BJTs as current controlled devices were deemed better suited to this application hence used as the choice of design.

All other protection measures not discussed above were catered for as inherent features of regulator chosen.

5.3 Final Design

The final design incorporates a comprehensive protection system to ensure reliable and safe operation. This includes a robust reverse voltage protection and over-voltage protection mechanism, implemented using a P-channel MOSFET (IRF9530n) and a 9.1V Zener diode. These components are cascaded in series with the LM2576HVS-5.0 buck converter, which serves as the primary voltage regulation stage. The buck converter efficiently steps down the 12V input from the power supply to a stable 5.0V output at port 1. The buck converter was chosen for its current limiting capabilities as its able to limit current drawn to a maximum of 3A but operates at 500 mA at normal load conditions. The buck-conveter is also fixed ensuring it will provide a constant 5V. It also features a thermal shutdown protective measure to prevent the circuit from overheating though at the cost of itself[?]. The internal circuitry to provide further evidence as to motivation behind selecting this component as the final design component is shown in figure 5.1 below.

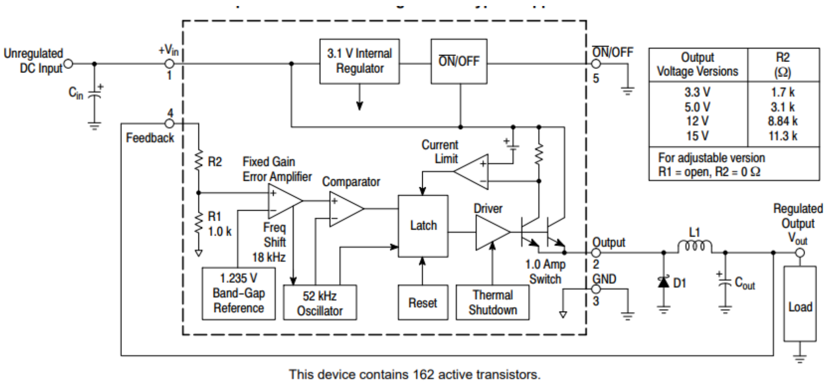

Figure 5.1: Buck converter internal circuitry and external connections

To further enhance the versatility of the design, a secondary voltage regulation stage is implemented using a linear regulator (HT7533-1). This stage provides a clean and regulated 3.3V output at port 2. Both output ports are connected in parallel to facilitate simultaneous power delivery to multiple devices. The motivation in this secondary conversion stage to use a linear regulator is because of its relatively cheap cost and relaibility in low power level applications as discussed in table 5.1 prior.

To ensure the protection of the circuit and connected devices, a dedicated short circuit protection circuitry is integrated. This protection circuit utilizes NPN BJTs (TIP42C) to monitor the output ports and swiftly respond to any potential short circuit conditions. In the event of a short circuit, the protection circuitry acts promptly to disconnect the power supply from the load by providing a safe path of electrical flow and prevent damage to the circuit components.

The circuit schematic of the design, as well as the physical implementation on a Veroboard, is illustrated figures 5.2 and 5.3 below. The schematic showcases the arrangement of the components and their interconnections, while the Veroboard layout demonstrates the practical realization of the design. The soldered implementation on the Veroboard ensures the proper connection and reliable functioning of the circuit.

Please refer to the figures below for the detailed circuit schematic and the soldered implementation on Veroboard.

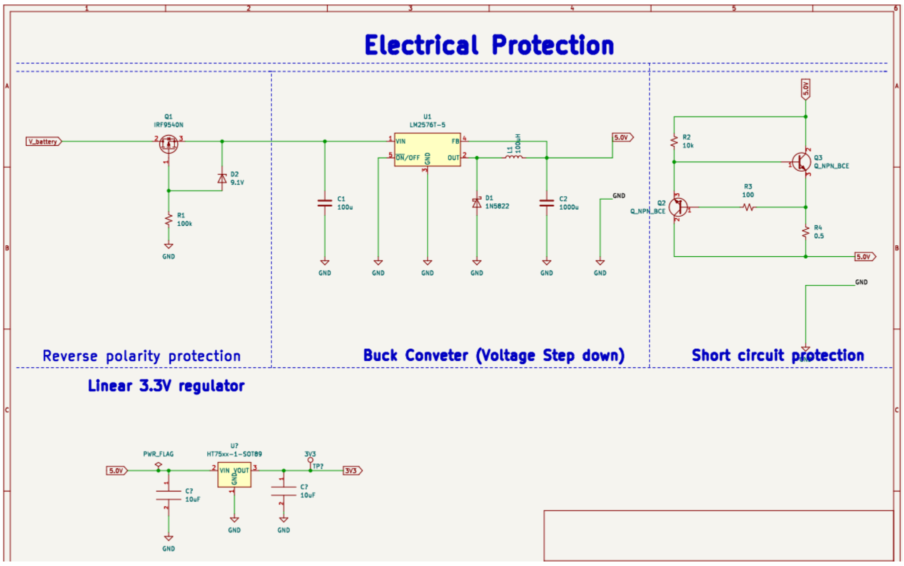

Figure 5.2: Electrical protection design schematic

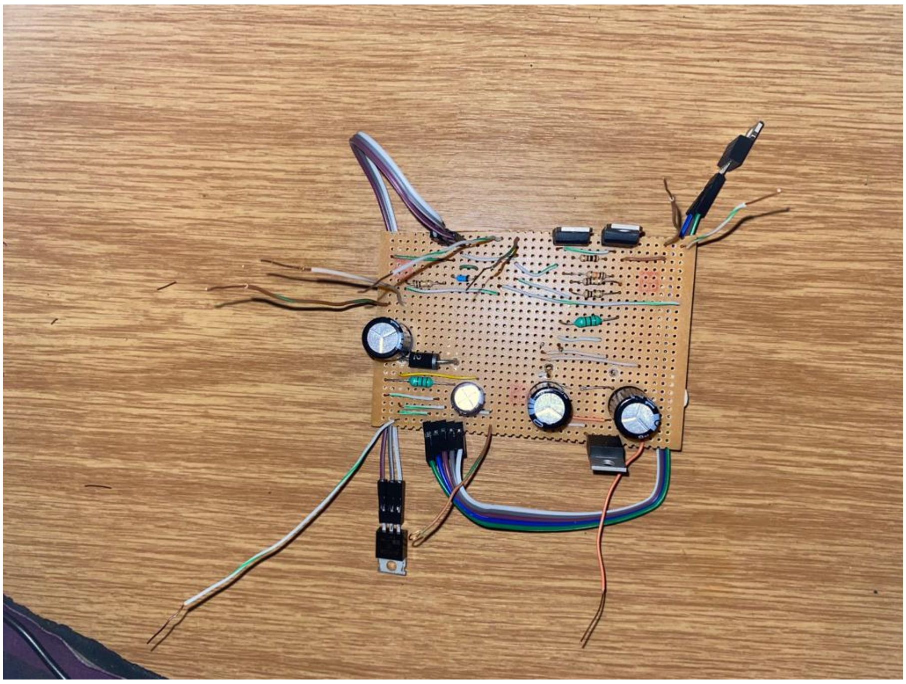

Figure 5.3: Electrical protection on veroboard

The creativity to connect jumpers and only have the regulator on the them is to allow easy changing in case of its failure and also to avoid triggering the thermal shutdown which compromises the regulator.

The combined efforts of the reverse polarity protection, overvoltage protection, voltage regulation stages, and short circuit protection circuitry make the final design robust, efficient, and reliable. These features provide an optimal solution for stepping down the 12V input voltage from the power supply to the desired 5.0V and 3.3V output voltages, ensuring the safe and stable operation of the connected devices.

5.4 Testing and Results

Following the various design choices was the building of final design in kiCAD to ensure proper connection and interface with other sub-modules. The kiCAD schematic was followed to built the solution on a bread-board for testing and finally soldering on veroboard once all tests complete which also followed an intensive continuity test before powering up to protect the circuits from possible short derived from soldering.

To ensure the functionality, performance and safety of the electrical protection board, the distinct sections of the system were taken through rigorous testing procedures. The following tests were performed:

Voltage Regulation:

The buck converter system was subjected to varying load conditions, ranging from minimum to maximum specified values as per datasheet [?]. The output voltage at port 1 (5.0V) and port 2 (3.3V) was measured using a bench digital multimeter. The measurements were taken at different load levels to verify that the output voltage remained within the specified tolerance limits. Figures 5.4 and 5.5 show the consistence of the buck converter subjected to different inputs of the bench supply to simulate the power supply.

Figure 5.4: Voltage regulation of low input

Figure 5.5: Voltage regulation of high input

The buck converter system demonstrated excellent voltage regulation characteristics, with the output voltages consistently maintained within the desired range under various load conditions.

Efficiency:

The efficiency of the buck converter system was assessed by measuring the input power and output power. The input power was calculated by multiplying the input voltage and input current. The output power was calculated by multiplying the output voltage and output current. The efficiency was then calculated as the ratio of output power to input power, multiplied by 100%. The measurements revealed that the buck converter system achieved high efficiency, typically above 90%, indicating effective power conversion and minimal power loss.

Reverse Polarity Protection:

The reverse polarity protection circuit, consisting of a MOSFET (IRF9530n) and a Zener diode, safeguards the system against damage caused by reversed input polarity. This protection mechanism prevents incorrect voltage polarity from reaching the buck converter and other components, ensuring their longevity and reliability.

Over-voltage Protection:

The Zener diode in the over-voltage protection circuit acts as a voltage clamp, limiting the output voltage to a safe level. This prevents excessive voltage from being supplied to the connected devices, protecting them from potential damage due to voltage surges or spikes.

Short Circuit Protection:

The short circuit protection circuitry, utilizing NPN BJTs (TIP42C), actively monitors the output ports for short circuit conditions. In the event of a short circuit, the protection circuitry promptly detects the excessive current and disconnects the power supply to prevent component damage and ensure user safety.

5.5 Conclusion

Finally, the design and implementation of the voltage step-down circuit using the LM2576-5.0 buck converter, as well as other different protective mechanisms, have proven to be successful in delivering the necessary functionality, efficiency, and safety. The buck converter system efficiently reduced the power supply's 12V input voltage to a stable and controlled 5.0V output at port 1, while simultaneously generating a secondary 3.3V output at port 2 via a linear regulator.

Through rigorous testing, the buck converter system exhibited excellent voltage regulation characteristics, maintaining the output voltages within the specified tolerance limits under varying load conditions of the sensors used in the ESP32 camera trap. The system demonstrated high efficiency, achieving efficient power conversion with minimal power loss. It also displayed excellent response times and stability during load transients, ensuring reliable performance even under load changes.

There is definitely huge room for improvement on this system with the very first recommendation being to implement this design on a PCB instead of a veroboard to make it more compact and light in weight hence easier to interface with the rest of the design. A proper thermal protection measure that does not rely on compromising the general functionality of the circuit could be adopted considering costs and application needs. For this solution in particular proper female headers could be used in place of the jumpers and would render the system easy to handle as the length of jumpers seems to be unnecessarily long altering the circuit size. interfacing with a digital system to clearly identify and define failure points or reasons of failure in a case whereby one of the protection measures has been triggered would also prove to be a crucial addition to the circuit to further enhence its robustness.

Overall, the testing results demonstrated the excellent performance, efficiency, reliability, and safety of the electrical protection system as all ATPs were achieved and accounted for. The system met the specified voltage regulation requirements, showcased high efficiency, and exhibited robustness in handling load transients. Additionally, the reverse polarity protection, over-voltage protection, and short circuit protection, ensured the safety and protection of the circuit components and connected devices, enhancing the overall reliability of the ESP32 camera trap system.

Chapter 6

Battery level monitoring

This chapter within the report has been authored by Masasa Melato (MLTMAS021), representing exclusive contribution to this subsection of the design.

6.1 Introduction

6.1.1 Background

Power source refers to any device, system, or means that provides electrical energy or power to other devices or systems. Power sources convert one form of energy into electrical energy to meet the power requirements of various applications. A power supply is a crucial component in electronic systems that converts electrical energy from a source into the desired voltage and current required to power electronic devices. Every power source must obtain the energy it supplies to its load, as well as any energy it consumes while performing its tasks[1].The source of energy is 12V lithium battery which is charged by a 12V 2W solar panel.There is a charging module between the solar and the battery that protect , monitors and regulate the battery voltage and current. Power source should be able to provide enough power for camera trap to work.

6.1.2 Objectives

The main purpose of this subsection is to be able to create power source for camera trap using a battery and a solar panel.This power source will provide an extended operational period for the system without requiring the user to manually recharge the battery.The battery charging,monitoring and regulation circuits that will be built on this subsection only focuses on the charging between the solar and the battery. Benefits of solar energy include the lack of pollution and lower costs[26].Otherwise, on sunny days, the solar panel may produce more energy than the battery can handle, which can damage the battery.

In the context of the camera trap system, it is noteworthy that the power source serves as the main provider of energy every time the system operates. This consistent and reliable power supply ensures the continuous functionality of the camera trap system, enabling it to capture and record images or videos as intended. Consequently, it is imperative that this subsystem possesses an extended lifespan to ensure uninterrupted operation and maximize the system's longevity and effectiveness. The project was tested for several times and the results was quiet near to what's expected which in return, it shows that the power supply was successfully made. . The camera trap system derive their power from the source every time it works. Ideally this subsystem should have a lifespan that is longer.

6.2 Design Choices

6.2.1 Power source

Depending on the particular requirements and needs, there are several factors to take into account when selecting a source of power. This includes,availability compatibility, reliable power delivery, energy efficiency,safety,long-term reliability and costs. A power supply that doesn't provide reliable or clean power can cause any number of problems, including instability that can be hard to pin down. In fact, a failing power supply can often cause other problems such as random resets and freezes that can otherwise remain mysterious[2]. ESP32 and servo motor are the two components that needed the power supply.

The following options for power supply of ESP32 and mg90s servo motor were considered:

Power over Ethernet (PoE): The ESP32 board that supports Power over Ethernet, can be power using an Ethernet cable connected to a PoE switch or injector. This method eliminates the need for a separate power supply as the power is provided through the Ethernet cable itself

Solar Power and batteries: Batteries provide DC power and can be easily replaced or recharged as needed. For applications where a continuous and renewable power source is desired, solar panels can be used to power both ESP32 and mg90s servo motor. Solar power setups typically involve a solar panel, a charge controller to charge the battery and regulate the voltage from solar to a lithium battery,and a battery to provide power to the ESP32 and servo motor

Servo Controller: Another option is to use a dedicated servo controller. Servo controllers are designed to provide power and control signals to multiple servo motors. They often have built-in power regulators and can handle higher current requirements

Wind Power: Wind power utilizes the kinetic energy of wind to generate electricity. Wind turbines convert the rotational motion of wind-driven blades into electrical energy through generators. Wind power is a renewable energy source and but is commonly used in large-scale wind farms

USB Power: The ESP32 boards often come with a micro USB or USB-C connector, allowing you to power the device directly from a USB port. This is a convenient option if USB power source readily available, such as a computer, USB wall charger, or power bank

Selecting the best power supply ensures the stable and efficient operation of the devices, protects components, and provides long-term reliability[27].

6.2.2 Health monitoring

Monitoring the health of a solar charging system for a battery is essential to ensure its optimal performance and longevity,to monitor the health of a battery, there are several different methods and techniques that can be developed.

Battery Voltage Monitoring: Monitoring the voltage of the battery is a fundamental aspect of assessing its health. Voltage readings can indicate the state of charge and help identify any abnormalities. Regular voltage measurements can provide insights into the battery's capacity and detect issues such as overcharging, undercharging, or a failing battery. An LEDs monitor can be used to check the level of the voltage in the battery and the voltages can be measured using Arduino.

Data Logging and Analysis: Implementing a data logging system to collect and analyze the monitoring data over time can provide insights into the long-term health and performance trends of the battery. By tracking parameters such as voltage, current, temperature, and SOC, patterns or anomalies can be identified, allowing for timely maintenance or troubleshooting actions.

By employing these monitoring techniques, solar charging systems can ensure the health and longevity of batteries, optimize charging efficiency, detect and prevent potential issues, and maximize the overall performance of the solar energy system

6.2.3 User requirements

The requirements are based on the problem Chris Vennum faced. Chris Vennum is a Bird Researcher who needs a way to manage remotely, to avoid going to too often which may disrupt the species and the equipment used is not always adequate. The requirements for this subsection are based on the problem he faced which include the walk from the road to the site often.

After considering the user requirements,several power source supply and health monitoring methods were eliminated,the different processes of power sources and the health monitoring circuits were taken into consideration and the conclusion was made.This section is about power generation,so the user need a power system that can survive for several days without charging it. A solar and a lithium battery that provide DC power and can be easily replaced or recharged as needed was found to be a suitable method of power generation.To save costs and to avoid complexity, the simple LED monitoring circuit was built and the aduino was used to the voltages.Lastly, the protection circuit between the battery and solar was also implemented.

6.3 Final Design

6.3.1 Technical specifications

The proposed solution was to place the system in the tree with the pictures taken every time motion is detected in the nest,the temperature and humidity readings are recorded every time a picture is taken and a servo motor controls the angular position of the camera.The system is controlled using a web server and the power source. There is enough sunlight in the Kalahari to supply the solar panel.

Solar specifications

Table 1: power specification and their ratings

type of module	rating
max power(W)	14
Tolerance 3Operating Temperature(℃)	-40℃ —85℃
Open Circuit Voltage(V)	13.38
Maximum Power Voltage (V)	12
Maximum Power Current(A)	1.2
Short Circuit Current(A)	0.31
Module Efficiency	11
Solar Cell Efficiency	18
Series Fuse Rating	10
Terminal Box	IP65
Maximum system voltage (V)	DC1000

-Bypass diode minimizes the power drop by shade.

-Waterproof Perfect for grid applications

-Pro-duct guarantee 5 years. -The conversion efficiency of solar cell is above 18

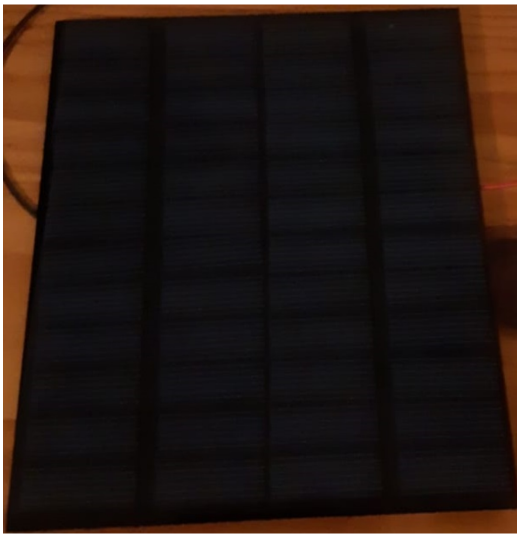

figure1:solar panel

The first step taken in the design process was configuring what the measurements that were going to be taken to characterize the solar panels. With the solar panel placed in the open sun with proper orientation, the open circuit characteristics of the solar panels in an ideal environment can be measured. With those results, a 10Ω resistor is inserted to determine the power characteristics supplied only by the solar panel. The operating manual provided with the system suggested an output voltage of 12V.[28]

Battery specifications

Table2: Perfomance characteristics

voltage(V)	12.6 V 14.8 V
Number of cell	6
Design Life	5 YEARS
max power	98wh
max.current	1.2
capacity	2.6Ah
3%of capacity declined per month at	20℃(average)

figure2: battery

A 12V/1.2A lithium battery that provide DC power and can be easily replaced or recharged.Again, it has high Energy density,Long Cycle Life,Low Maintenance,No Memory Effect,Wide Temperature Range, and fast charging.

To estimate the working time of a 12V lithium battery, the power consumption of the device was determined system .The battery's capacity (in watt-hours) was divided by the power consumption to get an approximate working time.The servo motor and esp32 needed to be powered.

Monitoring specifications

Charging module (BMT XH-M603 DIG BAT CONT 12V-24V)

- Model: XH-M603
- Input Voltage: DC 10-30V
- Output current: 20A
- Display Precision: 0.1V
- Control Precision: 0.1V
- Output Type: direct output
- Voltage Tolerance: +/-0.1V

- Application Fields:12-24V storage battery

- Battery Types: Lead-acid batteries for solar power conversion, nickel-cadmium batteries, nickel-metal hydride batteries, lithium-ion batteries, polymer batteries, Car battery, electric car battery

figure3:XH-M603

The lithium charger battery control offers the following functions: Automatic control circuit connection, Automatic charging and power off, Real-time voltage monitor, Auto save setting, ST core chip LM2596 switch voltage regulator Using method: Set Starting Voltage-in normal display voltage state,press the button will display start charging voltage;long press for 3s the digital tube will flash: you can start or stop button to set starting up charge voltage value. Set Stop Voltage-in normal display voltage state,press the button will display stoping charge voltage;long press the button for 3s the digital tube will flash;you can start or stop button to set stoping charge voltage value. Factory Reset- in power on state press the start/stop button at the same time,digital tube will display 888;that represents factory reset settings.

Battery level monitoring
4 LEDs(3 red with voltage drop of around 2 volts and 1 green with voltage drop of about 3v)
4 Resistors(1000ohm)

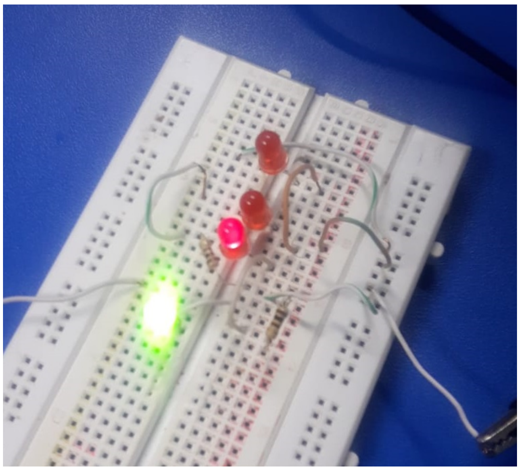

figure4:LEDs circuit

Monitoring the voltage by using simple LEDs is the most effective and simple method.The 4 LEDs represents the voltage percentage, when all LEDs are on, the battery is fully charged(at 12V) , when 3

LEDs are on, the battery is on a range from 75% to 100%(9V-12V),not including 100%full,it is half full when 2 lEDs are on as shown on the diagram.When 1led turns on, the battery just reached 25% and when there is no LED that is on, the battery is below 25% (0-3 volts,but less than 3)

6.4 Testing and Results

6.4.1 Battery Level Monitor

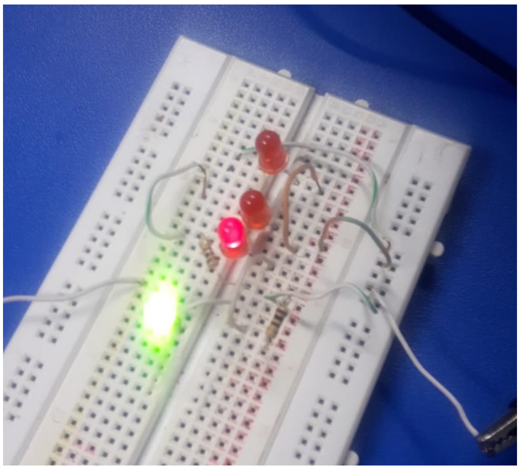

Figure5

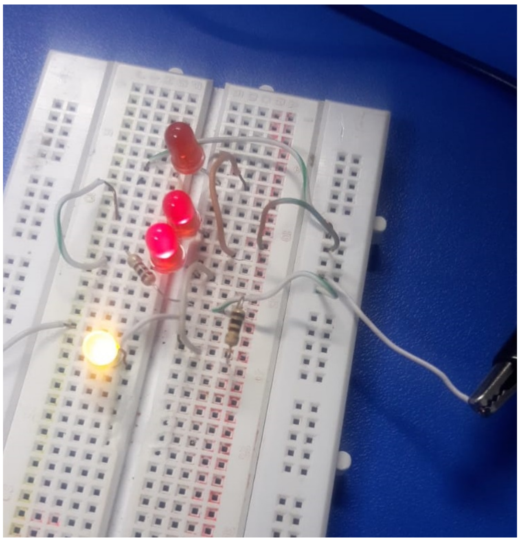

Figure6

figure 5 shows the two LEDs that are on which implies that the battery reached half of charging (6-9v range but did not reach 9 volts) . Figure 6 shows the battery level on range from 9 to 12 but less than 12.

The following code was used to program aduino

‘if (inputvoltage < 3 inputvoltage >= 0.00)
digitalWrite(2, HIGH);
delay (30);

digitalWrite(2, LOW);
delay (30);

else if (inputvoltage < 6 inputvoltage >= 3)

LEDfunction(2);

else if (inputvoltage < 9 inputvoltage >= 6)

LED$_{f}unction(3);$
$elseif(inputvoltage < 12inputvoltage >= 9)$
$LED_{f}unction(4);$"

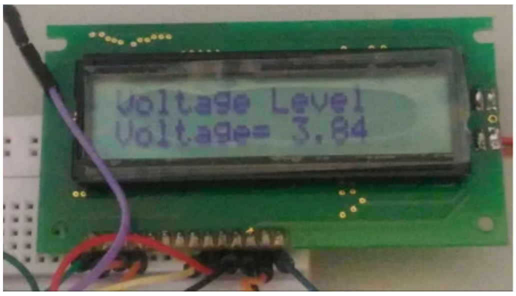

figure7

The results are shown on the LCD on figure 7 above.

A 25ohm resistor was connected across the Battery Connection Leads, where the measured output voltage was about 0.2V. The measured current was negligible. Both the charging and charged lights were on during this test. Considering this data, it is concluded that charge controller must sense the necessary output voltage that it needs to supply. Because the resistor is not providing this reference, the supplied voltage and current are relatively s

6.5 Conclusion and recommendations

Several additions to expand this experiment were suggested to provide more insight into the physical functionality of the system. A module for the system could be created to test the system under certain conditions. The module would include several screen filters to see what impact a lower level of light will have on the system. Also, thermal couples can be attached to each side of the solar panel to measure the temperatures in front of or behind the solar panel, as it has been observed that there is a strong trend between temperature and output efficiency . A more advanced version of this module can include a mechanism to control the orientation and angle of the solar panel to ensure the maximum amount of light input[29].

This report began with a comprehensive design and implementation details of PV based battery charger system which issued to charge lithium battery. The solar panel size needs to keep a 12V battery charged largely depends on the specific batteries wattage, voltage, amp-hours — and, of course, energy consumption.[29] In summary, the project achieved the goals that were set out, by designing and demonstrating the Experimental prototype of PV based battery charging module and health monitoring.

Chapter 7

Conclusions and recommendations

The objective of this project was to design, develop, and deploy an advanced camera trap system that enables an innovative approach to image capture. The camera trap system was created by utilising a ESP32 camera module monitoring a nest, resulting in a highly capable tool for photographing and studying bird behavior while minimizing disruptions to their natural habitat. The system incorporates several key features, including a camera module, motion detection capabilities, temperature and humidity sensors, and a repositioning mechanism. All of these functionalities are seamlessly integrated into the ESP32 camera module. To ensure reliable and uninterrupted operation, the entire system is powered by a 12V lithium-ion battery, which can be conveniently recharged using a solar panel. Moreover, the power module of the system is equipped with robust electrical safeguards, enabling the camera trap to be safely used in harsh environments, such as desert conditions.

This report started with an introduction providing an overview of the entire system and relevant background information pertaining to the project. The identified issues encountered by the client with their previous camera trap system were addressed through a problem statement, highlighting the limitations of the existing design, such as budget constraints and a strict deadline.

Chapter 2 consisted of a literature review, which encompassed comprehensive research on camera traps and potential solutions explored by the design team. This section also delved into investigating methods for safely powering an autonomous system in challenging environmental conditions such as a desert.

The design phase was subsequently divided into four subsections: Sensor and Servo Motor control, ESP32 camera and user interface initialization, electrical protection, and power monitoring.

The Sensor and Servo Motor control submodule, in chapter 3, focused on developing the necessary circuitry for Servo Motor operation and sensor functionality. The key achievement of this section was enabling the system to capture an image upon detecting motion in the nest, while also implementing a temperature and humidity sensor. The Servo Motor circuitry was also designed and established.

The ESP32 camera and webserver initialization submodule, in chapter 4, involved developing software components for the system. This included initializing the ESP32 camera, interfacing with sensors and the motor, and creating a user interface in the form of a webserver. The webserver allowed users to wirelessly access all system functionalities and retrieve data produced by the system.

The electrical protection submodule, in chapter 5, encompassed the implementation of safety within the system, such as reverse polarity protection, over-voltage protection, short circuit protection, and voltage regulation. This submodule ensured that the integration of the battery into the system was both suitable and safe, delivering sufficient power to each component.

Lastly, the power monitoring chapter focused on monitoring the power consumption of the system.

Overall, the system effectively resolves the client's issues, allowing bird researchers to set up the camera trap once and subsequently adjust the camera's angular position using the servo motor wirelessly using the webserver. Data collected by the system is saved on the ESP32 camera's SD card, which can be wirelessly accessed by the user from the base of the tree. This minimizes disruptions to wildlife and eliminates the need for constant tree climbing.

However, despite meeting all required acceptance test procedures (ATPs), the system has some fundamental flaws. It is unable to function simultaneously due to limitations in the ESP32's GPIO pin configuration. Additionally, the motion sensor's sensitivity is excessively high, resulting in some collected data being unusable for the user.

7.1 Future Work and Recommendations

Based on the objectives set by the design team and the results achieved, some recommendations and future ideas for this project are presented.

7.1.1 Hardware recommendations

To address the flaws associated with the ESP32 camera module, the following recommendations are proposed:

1. Replacement of ESP32 Camera Microcontroller: Consider substituting the ESP32 camera microcontroller with an ESP32 Dev Board. This alternative microcontroller should be compatible with the existing software developed for the system. By utilizing the ESP32 Dev Board, it may be possible to overcome the limitations of the GPIO pin configuration, enabling simultaneous functioning of the system.

2. Integration of Raspberry Pi with External Camera Module: Another solution is to incorporate a Raspberry Pi along with an external camera module. This setup offers the advantage of having more GPIO pins available, which provides greater flexibility for software development and system functionality. By leveraging the Raspberry Pi's capabilities, the limitations posed by the ESP32 GPIO pins can be circumvented, allowing for concurrent operation of the system.

By implementing either of these recommendations, it should be possible to resolve the issues related to the ESP32 camera module and enhance the overall performance and functionality of the camera trap system.

7.1.2 Software recommendations

To address the issue of collecting excessive and less useful data due to the sensitivity of the motion sensor, the following recommendations are proposed:

1. Implementation of a precise Motion Sensor: Consider replacing the current motion sensor with a different model that offers higher precision and sensitivity control. By utilizing a more accurate motion sensor, the system can minimize unnecessary detections, resulting in a reduction of data collected. This not only saves space on the SD card but also ensures that the data captured is more relevant and useful for the user.

2.Integration of Filtering Methods with ESP32 Microcontroller: Implement filtering methods within the ESP32 microcontroller to improve the data quality. One approach is to develop a filtering algorithm that removes pictures and associated sensor values where no bird is detected. By implementing this filtering method, the system can discard irrelevant data, providing the user with a more focused dataset.

3. Application of Machine Learning Techniques: Employing machine learning algorithms, a robust model can be developed to effectively discern the presence of birds within images. The model's training dataset would comprise both bird-inclusive and bird-exclusion instances. By training this model, the system can accurately identify the existence of birds within the given frame of the camera trap. Consequently, the system would proceed to capture the corresponding image and gather pertinent sensor data.

Chapter 8

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