Group 8
Data Storage and Transmission Improvements to Camera Traps

Prepared by:
Caide Spriestersbach
Hamish McKenzie
Jasveer Pooran
Kauthar Du Toit

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

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jasveerpooran K. Du Toit

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Chapter 1

Introduction

1.1 Background

The client, Kyle Walker, is an ornithologist from the FietzPatrick Institute who focuses on studying Marshall Eagles in the Kruger National Park. His research primarily relies on images collected from camera trap technology installed at the top of trees where the Marshall Eagles nest. The camera trap he currently uses is the Browning Trail camera, which captures high-resolution images of the raptors for analysis of their feeding habits and nesting activities.

Once the camera trap is set up, it remains in place, continuously collecting data for an extended period. The client accesses the camera trap only after several days, typically spanning over 100 days. The camera is programmed to capture images every 5 minutes, requiring a significant storage system to accommodate the large volume of data until retrieval. However, the client faces difficulties in the data collection process. Since the camera trap is positioned at the top of a tree, he must climb the tree to retrieve the stored data. Moreover, there is a risk of data loss due to environmental factors or destructive animal activities, resulting in the loss of months' worth of research.

The research location, the Kruger, is known for its harsh environmental conditions, including extreme temperatures over an extended period. To withstand these unfavorable conditions, the client's camera trap system is designed to be dustproof and waterproof. Additionally, due to the long research duration, the system requires a power-efficient battery system to provide a consistent power supply for the camera's operation.

In light of these challenges, the client has requested an upgrade to his current camera trap technology or a complete redesign of the system to address these issues effectively.

1.2 Problem Statement

Monitoring birds in remote areas is a challenge due to dated methods of data collection, processing and retrieval. The researchers at the Fitzpatrick Institute, with a focus on raptors and birds of prey, need a reliable and modern way to capture, process and retrieve significant data like the temperature of the birds and the eating habits of observed avian species.

1.3 System Requirements

The upgrade and redesign of the client's current camera trap system must address all the challenges he faces during his research in the Kruger National Park. The redesigned system specifically targets the issue of having to climb a tree for data collection. Therefore, one of the crucial system requirements is the transfer of data from the camera trap at the top of the tree to a data collection point at the bottom. This eliminates the need for tree climbing and simplifies the data collection process. Wireless technology should be employed for this purpose to avoid the risk of damage to wires by animals residing in the Kruger.

The redesigned system should capture images at regular intervals to facilitate continuous monitoring of the raptors, which is the focus of the research. Additionally, it should possess motion detection capabilities to identify periods of raptor activity in the nest. Data loss poses a significant challenge for the client, as it can result in the loss of months' worth of research. Hence, the system should incorporate backup storage or security measures to ensure data integrity in the event of system interference. The client also requested the storage of ambient temperature readings to aid him in his research.

Given the harsh weather conditions at the research location, it is crucial for the system to have a dustproof and waterproof casing. The casing should also withstand temperature fluctuations and high heat conditions typical of the Kruger. Subtlety and size are important considerations in the system design to avoid drawing attention from larger animals and minimize disruption to the raptors' natural activities.

The power system must sustain the operation of the camera trap for the entire 100-day duration without being excessively power-consuming. Overall, the system is expected to enhance functionality and improve upon the existing camera trap technology.

1.4 Scope & Limitations

Scope

This project focuses on the development and integration of four distinct subsystems: Power Circuitry & Base Station Housing, Image Transmission & Camera Trap Enclosure, Raspberry Pi and Web Server, and Sensing and Image Storage. The primary objective is to create a comprehensive solution that addresses the challenges associated with remote monitoring of martial eagles' feeding habits, particularly the inaccessibility of their tree-top nests. The system incorporates low-powered camera traps equipped with advanced sensing capabilities and efficient data processing functionalities. By enabling remote access at the base of the tree and collection of high-definition wildlife images and videos and related sensor data, the system facilitates detailed analysis on how martial eagles' feeding behaviors are influenced by changing temperatures.

Limitations

Despite its advancements, the system has certain limitations. Firstly, the positioning of the camera traps in tree tops may still present challenges in terms of installation and maintenance, although it eliminates the need for researchers to physically climb tall trees. Additionally, the system's effectiveness may be

Table 1.1: Report Contribution Table

Section Name	Contributor Name	Student Number
Section 1 - Sensing and Image Storage	Kauthar Du Toit	DDTKAU001
Section 2 - Image Transmission & Camera Trap Enclosure	Jasveer Pooran	PRNJAS002
Section 3 - Power Circuitry & Base Station Housing	Hamish McKenzie	MCKHAM002
Section 4 - Raspberry Pi and Web Server	Caide Spriestersbach	SPRCAI002

influenced by environmental factors such as extreme weather conditions, which can impact image quality and sensor performance. The system's range for wireless data transfer is also subject to limitations, depending on the signal strength and obstacles present in the surrounding area. Furthermore, while the system incorporates a suite of sensing functionalities, it is important to note that certain complex behaviors and interactions of martial eagles may require additional specialized sensors or manual observations. The integration of sensing devices into a shared database with the lamp server is an initial exploration in this system, merely touching the surface. The primary focus of was to establish a proof of concept. However, given additional resources, increased budget and timeframe, we anticipate that these inherent limitations can be effectively addressed and rectified.

1.5 Report Outline

The report has been broken down into individual sections completed by the authors and can be seen in the table below.

Chapter 2

Literature Review

2.0.1 Subsystem Breakdown

1. Sensors

This subsystem will include the sensing elements for the camera traps; a camera device that is able to snap images of the birds nest, a sensor to detect movement which will enable snapshots to be taken, and a temperature sensor for the birds. The motion detector must automatically trigger the camera system to capture images at a predetermined interval or based on certain conditions, such as when the birds are active or when there is movement in the nest. The camera sensors should also be in focus at all times and positioned to capture usable image data. The temperature sensor system (Infrared Thermography or Passive Integrated Transponder) should be able to detect the temperature of the birds and their surrounding environment. The data from these sensors would be collected by the data acquisition system and stored for later analysis.

2. Data Collection and Processing

This unit deals with accessing image acquisition devices, such as cameras, to collect image data for storage in a database or file system that is secure and accessible. To further improve the system, further processing of this data will be done in order to effectively categorise image data by date, time, type of animal observed and other relevant data. The subsystem would, therefore, also include development of software or algorithms which can process image and temperature data to extract useful information and identify patterns or anomalies. The aim would be to encode this information in the filename to promote ease of access for the researcher by reducing the dataset originally taken in. Consequently, the data storage system would need to handle large volumes of data, and should be impervious and protected from environmental factors such as thunderstorms and strong wind.

3. Data Transmission

This subsystem deals with the infrastructure that is required to send data from the camera trap to the base station. Both wireless and cable methods could be used for this transfer. Wi-Fi, radio communication, and cellular networks are examples of wireless transmission technologies, while USB and Ethernet connections are examples of wired transmission technologies. Further development will reveal which method would be most appropriate to provide a secure and reliable system which maintains data; with minimal losses during the transfer process. The design of antennae, leveraging the power of raspberry pi units and developing or leveraging existing communication protocols would be the basis for this subsection.

4. Power

The power system aims to provide low power consumption capabilities in an effort to limit the need for battery replacements. This system leverages the sunny environment by using solar panels, rechargeable batteries, or a combination of both as a power supply. The system would also involve meeting power requirements of the cameras, sensors, the data storage and processing facility and other equipment used to capture images and temperature data. The design must include functionality to minimize power consumption and extend the life of the power source. This might involve using energy-efficient devices and implementing power-saving modes when possible. Further development would also include a power management system that regulates the voltage and current supplied to the devices. The system also includes a backup power source to ensure uninterrupted operation in case of power failure or other disruptions.

5. Base Station-Camera Trap System Structure

This small subsection will essentially involve selecting casing for our equipment and other protective materials for the exterior of other subsystems. This will include using camouflage casing that is both hardy and robust. The camera trap needs to have little impact on nesting habits of the avian species, so the design needs to be small and sturdy. The base station, however, can be bulky but it must be designed with consideration of the weather conditions, and curious animals that may disrupt the setup.

2.1 Introduction

The population of the protected Martial Eagles in South Africa is currently declining. To provide reliable reasoning for this decline, it is vital to research the role of protected areas and species-specific threats to the eagles. The purpose of this literature review is to investigate the current methods and hardware used to monitor eagle nests and the feeding habits of the birds. The review will focus on how camera traps can be used to complete this task, investigate various ways to determine the body temperatures of birds and ways to store and transmit valuable image and video data. Through this literature review, we want to understand better the technologies implemented to study these majestic eagles.

2.2 Camera Traps

Raptors are surveyed and monitored in a number of ways. Ornithologists undergo roadside, cliff nest, ground nest, and tree nest surveys amongst other research projects. Tree nest surveys can be achieved by inspecting the contents of the nest after it has been located. Researchers try to walk to a point of higher elevation from where they can gain a better perspective and observe the nest from above. An aluminium stick or nest pole can also be used to attach a mirror to observe the nest from above.[1] These methods are used to indicate whether the nests are empty and can then be used as a research point. If necessary, the tree has to be scaled by the researcher, with aluminium extension ladder being the best method to accomplish this apart from physically climbing the tree. Vehicles with the ability to get through the rough terrain have to be used to transport this equipment however, and this can cause destruction to the environment and allow harmful forces access to a route to the nests. Once camera

High end (US $ 550–1000)	**Mid range** (US $ ~450)	**Low end** (US $ <250)
Reconyx PC800/850/PC900/950 IR white LED flash, 0.3 s	Reconyx HC500/550, HC600 IR flash, 0.3 s	Bolymedia Scoutguard SG560D white IR flash + Xenon flash, 2 s
Pixcontroller Raptor IR flash, 1 s	Uway UM562 IR flash, 1.7 s	UWAY UV532 IR flash, 1.3 s
Digitrap Xenon white flash, 1 s	Welthar multipir H320 triple PIR sensor, IR flash, 1 s	UWAY UV535 IR no glow flash, 1.3 s
Pixcontroller DigitalEye 12.1 Trail Camera IR and Xenon white flash, trigger speed not available	Spypoint FLA dual Xenon white and IR LEDS flash, 0.45 s	UWAY UM535 IR no glow flash, 1.3 s
Buckeye Cam X7D/X80 IR flash, 2 triggers in 0.1 s		Moultrie M80 or M100 IR flash 1.6 or 1.7 s
Buckeye Cam Orion IR flash, 0.2 s		Cuddeback Attack IR and Xenon flash, 0.25 s

Figure 2.1: Price range of camera traps [4].

traps are placed in the nests, depending on the systems used, the trees would have to be regularly climbed to maintain and retrieve research. These camera traps are remote cameras that automatically take pictures of wildlife, and hence lower the level of disturbance caused by humans when researching and monitoring.

Camera traps are widely used in the conservation and monitoring industry as they provide a look into secluded areas such as nests and allow for non-invasive monitoring of the raptors. These cameras obtain important data such as predator identification, parental care and nesting behaviour for raptors, as well as foraging, daily activity patterns, scent marking and habitats for larger animals ."Camera traps (i.e. cameras that are remotely activated via an active or passive sensor; hereafter referred to as CTs) offer a reliable, minimally invasive, visual means of surveying wildlife that substantially reduces survey effort" [2].

The types of cameras used vary broadly based on the priorities of the researchers. Commercially available video cameras are low cost and record in real time but they operate for short periods of time and are not made for extended use in harsh environmental conditions. The simplicity and low cost, however, make them well suited for behavioural studies where subsampled time periods are standardised among nests [3]. Still-frame cameras are often used to identify feeding habits of the raptors and possible predators. This type of camera mostly operates under the control of a trigger (mechanical or infrared) and is therefore not viable for continuous raptor monitoring. Trail cameras integrate passive IR triggers and cameras into one system and are made for long-term operation in these environments. These cameras are not constantly running and are therefore energy efficient and can run off simple household batteries. The devices, being in remote areas, require protection from the environment and are therefore housed within a PVC cap to prevent moisture. The cameras are prepared to be as unobtrusive as possible and alterations are often made to the camera lenses, lighting, or settings to allow for this. The cost price of the cameras vary based on specific use case, shown below:

In the past, camera traps required separate devices for the camera and triggering mechanisms. They relied on an animal breaking an infrared beam to trigger the camera and take a photo. However, advancements in technology over the last 20 years have led to self-contained units that include sensors and cameras. Nowadays, most camera traps utilise a passive infrared sensor (PIR) to detect differences in heat and motion between the subject and background temperature. They also use an infrared/LED flash array to illuminate the target area.[4] The camera traps are preferably as non-invasive as possible so as to not tamper with the natural habitat of the raptors. The cameras are therefore usually positioned at a distance of 1 to 4m away from the nest. The security measure of the camera can vary from survey to survey and depends on the surrounding habitat. Various methods are used to install these cameras as outlined in a research paper: "mounted on a tripod or wooden dowel, attached to thin (-1-4 cm) branches with a spring-loaded metal clip, or affixed to a tree trunk with brown duct tape or with a custom-made cargo strap... sometimes joined multiple 30-m BNC cables using female-female BNC couplers prior to climbing to the nest... camera was attached to the limb of the nest tree, 0.4-0.5 m above the nest, using camouflaged plastic cable ties. For all mounting methods, we sprayed the extension cable and exposed camera wires with Ropel®, a nontoxic chemical, to deter wildlife from damaging them" [3].

It can be seen that the mounting method has to be as inconspicuous and camouflaged as possible, so as to not disturb or attract animals (including predators of the raptors). Security and positioning of the camera is important as a location too close to the nest can cause out-of -focus imagery with details that are hard to analyse and capture. Large amounts of data can therefore be lost with insufficient preparation of camera stability and protection. The additional equipment therefore includes: batteries, SD Cards, Security Boxes, Python Cables. Concealment and Camouflage Tape, Mounts, and Bait-holders [5].

The data often recorded on the site sheet are the site of camera placement, the project name, site code, camera code, and date. 'Most modern camera traps allow a label to be programmed that is visible on all images taken. We recommend that the site name is programmed as the label, thus ensuring that every photo has the site name visible with time and date.' [5] The data collected by the cameras are most often stored on SD cards. The data can then be downloaded using an SD card reader to an external hard drive. This process can be completed in approximately 1 hour for two people at a raptor nest, and minimization of contact time with the raptor nesting area becomes a priority when changing the battery and memory card. Cables and connectors allow the systems to be powered and serve as a form of data transmission when working with video data and recorders. "The distance between the camera and its associated recording equipment and power supply should be great enough to allow researchers to download data and exchange batteries without flushing adult birds from the nest or inciting alarm calls from adults attending nestlings" [3]. Cables of different lengths are frequently used in order to reduce the proximity of the recording equipment from the nests and allow for minimal disturbance. The use of cables introduces a factor of signal degradation however, as damage occurs to these transmission lines when the environmental conditions get more severe. Chemical deterrents are placed on the cables to reduce the chance of animals gnawing on them. The cables are also protected by aluminium tape or buried. Gloves can be worn by researchers to reduce scent and mineral deposition. Measures are taken to protect these transmission cables but damage is inevitable. Some researchers therefore look to other options to transfer the data. As seen in table below, although SD card usage is most prominent amongst researchers, other viable options of data storage and transmission exist.

2.3 Power Systems

Browning Trail cameras, like the ones used currently by the Fitzpatrick institute, come standard with a 12V Direct Current connector on the bottom of the camera. This power port allows for direct charging of the traps internal AA sized batteries or for powering the trap externally.[6] Browning also sell complimentary accessories for their cameras that use this 12V port, such as their trail camera

Storage Method	Description	Pros	Cons
SD Card	A small memory card inserted directly into the camera trap	Easy to use, inexpensive	Limited storage capacity, risk of losing or damaging card
External Hard Drive	A portable hard drive used to transfer and store data from the camera trap	Large storage capacity, reusable	Requires additional equipment, risk of losing or damaging hard drive
Cloud Storage	Data is uploaded to an online storage service	Accessible from anywhere, can store large amounts of data	Requires reliable internet connection, may have subscription fees
Wireless Transfer	Data is wirelessly transferred from the camera trap to a nearby device or server	No need for physical access to the camera trap, can be automatic	Requires reliable wireless network, may have technical limitations
On-Board Memory	Data is stored directly on the camera trap's internal memory	No need for additional equipment, can be lightweight	Limited storage capacity, risk of losing or damaging camera trap

Table 2.1: Storage methods for camera traps

power pack, which can double the battery capacity of a trail camera, and the solar camera power pack, which constantly charge the camera trap enabling it to run indefinitely.[7]

In a study of Bearded Vultures in the Pyrenees of Northern Spain, in the early 2000s, used Solar panels and wind turbines to power their camera based monitoring systems. These solar systems were placed on the flat tops of cliffs above the nesting birds and used long cables to power the cameras hidden within the vulture nests. This implementation was ultimately successful, the batteries could power the camera and signal transmission apparatus for 3 to 4 days on their own and the addition of the solar panels allowed the whole system to fully recharge within three hours. This allowed the researchers to successfully monitor the breading habits of the vultures without disturbing them. However, the system did leave room for improvement, the researchers did note that wind turbines proved more successful in recharging the systems on northern facing cliffs (where there was less sunlight) and allowed the system to recharge at night time enabling infra-red camera systems to be used.[8]

Solar panels are also an effective means of powering remote trail cameras as there is little evidence that they negatively effect the behaviour of various bird species. However, birds may confuse large solar arrays as bodies of water and fly into the panels injuring themselves. [9]

2.4 Base Stations

Researchers do not currently appear to use any form of base station placed near their camera traps to house large external batteries, and storage devices. Instead the approach of networking cameras appears to be more popular. These networked cameras are small and are low power allowing them to run without intervention for up to 3 months, they can also transmit data up to 200m away. These cameras then transmit data back to a central router to be uploaded to the internet. [10] The problem with this system is that the router needs to be near enough to the camera traps whilst also maintaining an internet connection, this unfortunately limits its applications in remote areas.

In the few cases that base stations have been used reliability proves to be a key issue. Water damage and animal interference, small mammals chewing through cables, appear to be the main issues affecting base station operation. [8] However, there appears to be little research into how larger mammals specific to an African context would interact with the base stations.

2.5 Data Transmission

2.5.1 Transfer Protocol to Base Station

In the exciting world of bird nest surveillance, cameras are an integral component in a researcher's toolkit to relate the effects of rising temperatures on the eating habits (and consequently physiology) of raptors and other avian species. Secure footage storage is one of the most crucial aspects of this camera surveillance system. There are several ways to store camera footage, including wired and wireless methods.

2.5.2 Secure Digital Card (SD card)

A popular method of data storage for surveillance media is onboard SD cards. Media is captured by the camera and directed to the SD card which stores data using non-volatile flash memory (retains data even after the device is switched off). The flash memory is organised into blocks, which are further divided into pages [11]. Each page can store a certain amount of data, typically 512 bytes or more. When an image or video is captured, the data is processed and written to the SD card as digital files created by the onboard camera logic system. The image data is typically stored in a compressed format such as JPEG. The SD card has a file system that organises the data and makes it easy for the camera or device to access it. The SD card can be inserted into a card reader to view photos on a computer or any other suitable device. The photos can then be accessed, edited, or shared. This storage method is a basic strategy researchers investigating avian species employ to store their image data.

2.5.3 Wired Network Video Recorder

This is a specialised device that can store video footage from cameras on a hard drive. A network video recorder (NVR) is designed to work with IP cameras that transmit digital video footage over an Ethernet network. The NVR behaves like a central hub that collects and manages the video footage from multiple cameras [12].To store video footage using an NVR, you first need to connect your cameras to the NVR using a wired network cable. Once the cameras are connected, the NVR will automatically detect them and start recording the video footage. The NVR can be configured to record continuously or based on specific triggers such as motion or sound detection. Animal surveillance benefits from this strategy as unnecessary footage is not being recorded when a bird is not at the nest, for instance. You can easily access and view the footage from any camera that is connected to the NVR. Additionally, an NVR can automatically backup footage to a remote location, ensuring important footage is not lost, and researchers can monitor multiple locations from a central hub.

2.5.4 A Wireless Network Video Recorder

Some products on the market use flash card formats with WiFi radios to enable automatic content transfer from the local storage to a network storage device. However, there are some drawbacks, such as the camera shutting down while the card still transfers data. An alternative approach is to upload content to a mobile wireless Network-attached storage (NAS) device. Once the content is transferred to local network storage, it can be uploaded to other storage networks, such as personal cloud storage devices. Home NAS devices are becoming more accessible, allowing direct access without external

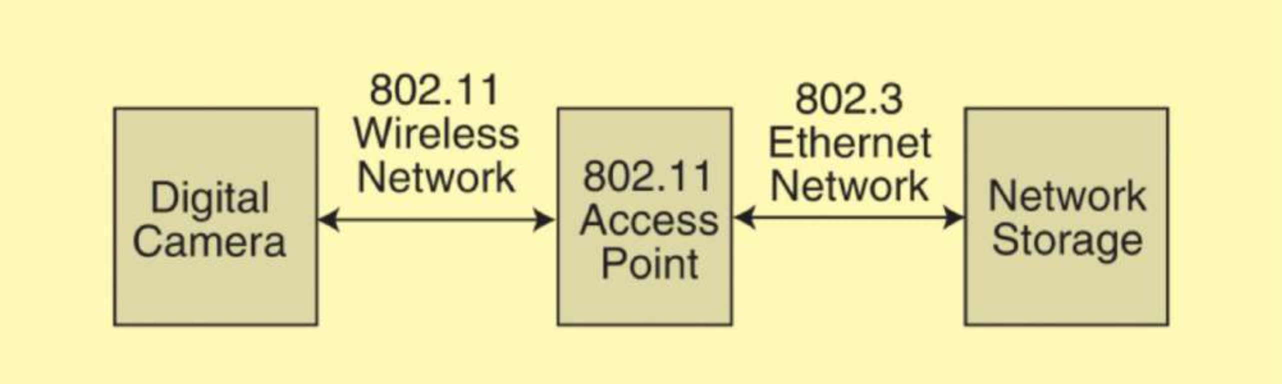


Figure 2.2: Overview of Wi-Fi Storage System [13]

authentication from a connected client and enabling users to create their own ‘cloud storage’ at home. Researchers could benefit from this implementation as it provides an efficient means to store large quantities of data in a separate, nearby storage facility instead of being stored within the camera unit only [13].

2.5.5 WiFi Transfer

Radio waves are used by WiFi enabled cameras to communicate audio and video data to a receiver, which could be a computer, a hybrid digital video recorder, or an application on a smartphone. The information is then kept on a disk or in the cloud and accessible from the same device. WiFi is effective in short-range transmission, but it can lead to signal dropouts when utilising cameras that are connected to a hub several metres away. While this may not be the case for most applications whereby storage units can be located nearby, users in areas that do not have stable internet connectivity will not benefit from this implementation. However, wireless cameras can work without the internet depending on how the camera interfaces with its control source. For instance, a simple setup could involve an access point located between the digital camera and network storage. The camera is paired with the storage that is connected by Ethernet to the access point which ensures reliable transfer of image data packets to the storage device with timestamps. The idea is that all pictures and video clips would be instantly transferred to a local storage directory, without the need for a storage card. Raducan et al. [13] suggests a 32-MB cache is sufficient for live video capture at 720p HD, provided you have an 802.11n connection (which supports up to 300 Mbps of rated theoretical bandwidth under best-case conditions).

2.5.6 Raspberry Pi Based Network Video Recorder

This system is essentially a cheaper alternative to a traditional wireless NVR system consisting of: one Raspberry Pi microprocessor acting as a hub with a hard drive and a camera connected to a Raspberry Pi. The aim for such a system is to allow footage to be stored and monitored through the hub. All devices are connected to the local network, and the camera is accessible via the hub using a browser on your computer (or any other device connected to the local network). The figure 2.3 below shows a high-level overview of the project. In this figure, we see that the cameras, the computer and the Raspberry Pi are all connected to the same network. The cameras each send image data wirelessly to the hub and this is then stored on the hard drive through a wired connection. The live feed can be

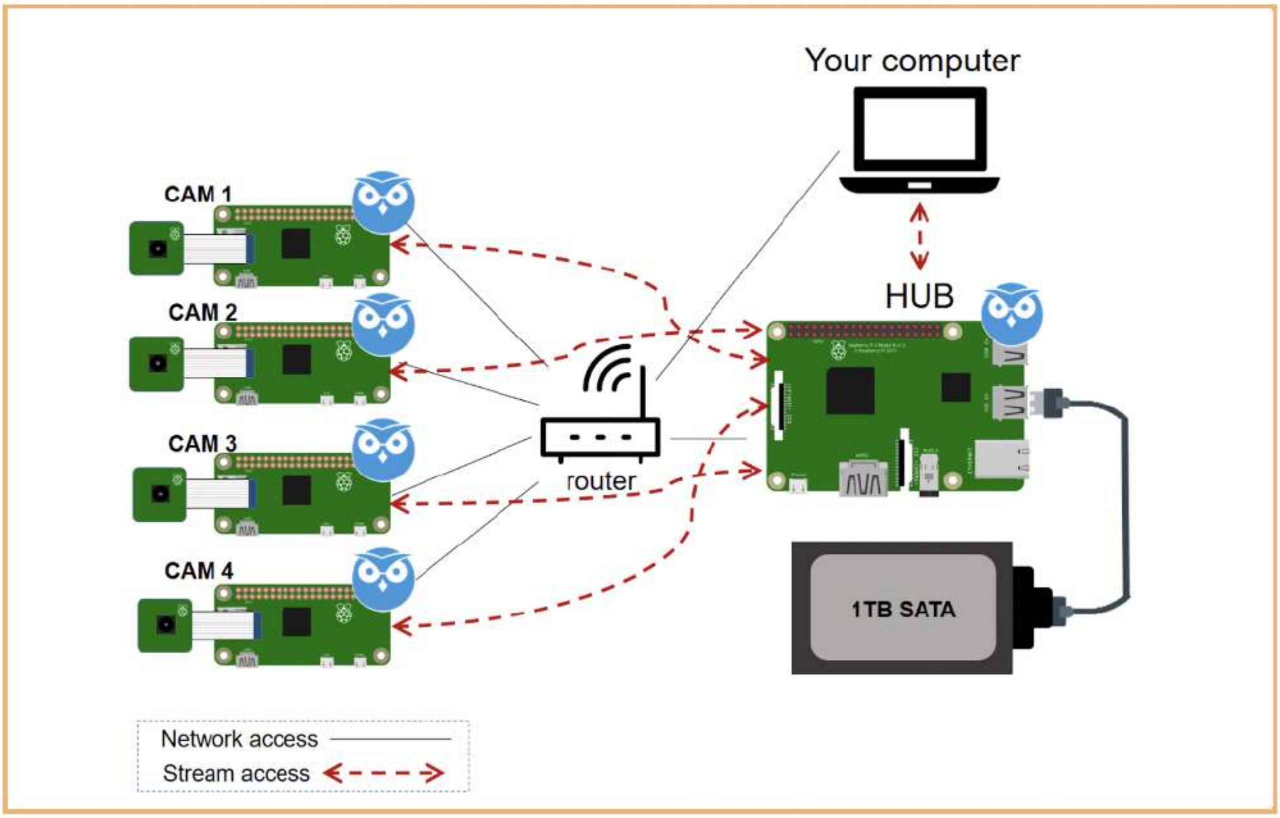


Figure 2.3: Overview of Raspberry Pi NVR [14]

accessed through you computing device which is also connected to the hub. Researchers can benefit from an implementation like this as it provides a setup-and-go system, whereby data will be stored as long as all components are powered ON and running. The researchers will merely need to connect to the same network as the component devices in the system and interface with the chosen Raspberry Pi OS system. The author of this implementation used MotionEyeOS [14]

2.6 Monitoring Body Temperature

Birds' body temperature can vary due to various factors such as their circadian cycle, nutrition, thermal biology, metabolic rate, pathology, and emotional state [15]. Consequently, closely monitoring body temperature is important in physiology, behaviour, and ecology research. The mechanics behind measuring the bird's temperature raises the following questions: What does 'body temperature refer to? How can body temperature be measured effectively? What is the most appropriate location to measure body temperature depending on the specific metabolic function or research purpose?[16]

Traditionally, rectal temperature measurement is one method for measuring body temperature, which is assumed to reflect body core (internal) temperature. However, the surface temperature may be equally important since physiological and environmental factors can influence it [17]. Although it is difficult to measure temperature in freely moving or wild animals, various techniques for measuring internal temperature can be used, including thermometry, implanted loggers or transmitters, and non-invasive peripheral temperatures methods such as subcutaneous (under the skin) tags or infrared thermography [15]. The choice of technique depends on the type of research region of interest, the impact on the wildlife, and other logistical factors like cost. One needs to also determine which body region is suited for temperature measurements and the timescale required for these temperature readings [18]. Furthermore, quantitative metrics like the precision and response time of the sensor ought to be selected to reflect the rate of change of temperature at the site (located on the body of the bird). The choice of measurement sites may be constrained to invasive methods appropriate for each study species.

2.6.1 Internal Temperature Measurement Techniques

Thermometry

Rectal thermometry is a common method of measuring body temperature in medical and ecological settings, but it has limitations. While it is fast, affordable, and minimally invasive, it only provides a cross-sectional temperature sample, and subjects must be captured and handled during sampling, which can cause stress-induced hyperthermia and peripheral cooling [19]. It is best suited for studying cross-sectional data in relatively inactive animals or animals in confined spaces. However, it can't be used to study how an animal's body temperature responds to changes or how it changes over time when the animal is free to move around.

Surgical Implants

The use of intraperitoneal and intra-abdominal implants for long-term studies of body temperature regulation in animals is common. These devices, data loggers or radio transmitters, require surgical implantation and provide valuable insights into the thermal biology of free-ranging animals. Although surgical implantation requires anesthesia and may carry a risk of mortality, careful monitoring and post-surgical recovery can mitigate these risks. Data loggers typically integrate a thermistor, real-time clock, and internal memory for storing temperature, time, and date at user-defined intervals. It can be implanted or externally attached and store temperature, time, and date data, but heart rate loggers are also necessary to observe body temperature [20][21]. Implantable data loggers are suitable for long-term studies but require recapture for data retrieval, which can be difficult for some species. Technological solutions, such as telemetry collars, can help overcome this issue [22]. Radio transmitters can also be implanted in animals and will continuously transmit data without requiring the recapture of the animal. They are effective in remote recording of body temperature in free-ranging animals over long periods. Care must be taken to avoid disturbing natural behaviours during tracking.

2.6.2 Peripheral Temperature Measurement Techniques

Passive Integrated Transponder (PIT)

Passive Integrated Transponder (PIT) tags are small, temperature-sensitive transponders that provide a unique identification number and temperature data when injected under an animal's skin. They were originally developed for veterinary applications but have since been used to study body temperature profiles in wild birds and mammals [23]. Implantation is not painful and does not result in bleeding or later inflammation, at least not in birds. Since PIT tags are also small and lightweight, they are suitable for implantation in small animals without the need for general anaesthesia or analgesia. They are biologically inert and can remain active throughout the animal's life. However, unlike transmitters or data loggers, PIT tags do not transmit or store data but require an electromagnetic field from a receiving unit to collect data. This means that the subject and the receiving station need to be in close proximity, generally up to 0.3 metres. Secondly, if multiple transponders are within the same field (e.g., roosting animals), they are limited to animals that generally move alone. These downsides would affect large animals that tend to travel in groups the most and would not be a viable technique for temperature monitoring.

Interpretation of temperature data must be taken with caution when implanted in different body regions, as the temperature readings may vary. PIT tags may be more appropriate in captive or field settings where subjects can be contained within the field of the receiving unit or attracted to the receiver by other means.

Skin Temperature Measurement

This is a commonly used and moderately non-invasive method for animal temperature sampling. This method involves fitting subjects with an externally attached radio transmitter attached to a small skin area after trimming or removing part of the plumage or fur. Data loggers can also be mounted to radio collars or securely glued to the skin with epoxy. They will provide reliable, high-resolution data on skin temperature fluctuations over long distances if the transmitters are in proper contact with the skin [17]. However, the proximity of the attachment to the skin can cause temperature variation, and environmental conditions can influence skin temperature. Additionally, the size of instruments is limited to 1-5% of body mass for birds or bats and 10% for non-flying animals to minimise the impact of the device on the animal.

Infrared Thermography

The use of infrared thermography (IRT) is a non-invasive method that allows for the measurement of body temperature patterns in freely moving animals. IRT can quantify the thermal characteristics of different body surfaces and changes in heat loss from various body areas since infrared radiation is released by all surfaces with a temperature over zero Kelvin (0 K) [24]. Other sampling methods are not as capable in achieving the same results as IRT. It is particularly useful in endotherms with thin fur or feathers to investigate regional heterothermy. However, IRT only measures surface temperature, and changes in internal temperature must be measured using other techniques. Attempts have been made to correlate IRT surface temperature measurements with core body temperature, but they are only sometimes a reliable predictor of core temperature. Nonetheless, it may be possible to detect stress responses by measuring the temperature around the eyes or other exposed skin areas using IRT [25][26].

In summary, Nord et al. [23] compared two non-invasive methods for measuring the body temperature of unrestrained great tits: subcutaneously implanted PIT tags and temperature-sensitive radio transmitters attached supracutaneously (above skin). These methods were employed to evaluate their suitability in assessing ecologically relevant questions (relating to these birds) under various environmental conditions. Both methods were suitable for measuring peripheral body temperature in small, unrestrained birds, but caution must be taken when using them interchangeably without proper validation. The chosen method should consider factors such as temporal and spatial resolution, expected body temperature range, and behaviour of the study species. Further research is needed to better understand how temperature changes in different body parts respond to various factors, and technological advances will continue to improve temperature measurement in the field.

2.7 Data Processing

While the use of modern technology for monitoring and observing animals in the wild has grown, one of the technologies – the microcomputer can greatly aid the field researchers. The microcomputer is a versatile low-power, compact computer which can perform a variety of tasks at a low cost. A particular brand of microcomputer which has an open-source, modifiable operating system is the Raspberry Pi. The Pi has shown tremendous potential in environmental monitoring applications [27]. The Pi has many features which may be of benefit to researchers such as 40 General-purpose Input/Output (GPIO) pins, four USB ports, and a built-in wireless chip [28]. These features mean that the researchers are able to collect, store, upload, and process the data from multiple sensors.

Raspberry Pis have been used in artificial cavities to record the behaviour of birds, such as the Acorn Woodpecker. "The recording and uploading of video allowed the researchers to study woodpecker breeding behaviour with minimal disturbance and reduced observer effort" [27]. It is also noted by McBride that an important step to demonstrate the capabilities and usefulness of the Pi is to attach various sensors, so that while the Pi collects video or image data, it can attach sensor data such as temperature, wind speed, and humidity. This allows researchers to understand the behaviour of the birds and their reactions to micro-climates.

The researchers purchased 5 Raspberry Pi 3 model B devices, along with other accessories like SD cards and Raspbian operating system. They tested different combinations of sensors, cameras, and solar panels so that each of the 5 units was unique and had different build prices. A python program was written to capture and collate the data. The researchers then placed all the equipment (housed in a waterproof container) outside nearby to a feeding station to observe and monitor the birds behaviour.

Each device was deployed for 44 days, which took a photograph every 10 seconds for a period of 3 hours. Amongst the other metadata collected, 96% of the images were deemed usable. It was also deemed that the unit which contained the cheapest temperature sensor was the only unit which differed significantly from the controlled temperature.

From this it was discovered that while there was no noticeable difference between the expensive and cheaper cameras used, which suggests that users can opt to use a cheaper camera for their projects. It was also found that the temperature sensors could accurately measure and record the micro-climate in which the units were placed.

The researchers conclude that Raspberry Pis show immense promise in remotely and simultaneously collect behavioural and environmental data to further the understanding of the avian field. They also note that due to the high functionality of Raspberry Pis there is a space for further study and progression of the technology to be applied in other fields.

2.8 Conclusion

Much literature on avian observation has been published, especially regarding the technological systems used to monitor them. The development of camera traps is unique for each species researchers observe, and care is taken to create systems that are non-invasive and provide adequate data on the subjects occupying the observed nests. The current setup of camera traps is sufficient in gaining vast amounts of valuable data for researchers, albeit the technology behind some of the components in this system needs to be updated. To this effect, efficient methods were explored for improving power usage of camera traps, recording temperature changes in avian species, transferring image and video data from camera units to storage devices, and processing this data to provide valuable indicators for researchers. Moreover, the literature explored did not provide a comprehensive camera trap system that aims to simplify the journey of avian observation from setting up camera traps to retrieving usable data remotely. The literature suggests that some systems may have remote access to data built-in but lack consideration for the setup process and vice versa. Furthermore, many current camera trap systems do not leverage intelligent data processing techniques that help reduce the amount of raw data initially obtained. Overall, the hardware currently in place for avian research performs the required tasks, but can be improved upon to make the data collection process more efficient.

Chapter 3

Section 1 - Sensing and Image Storage

Prepared by Kauthar Du Toit (DDTKAU001)

3.1 Introduction

The client, Kyle Walker, currently utilizes camera trap technology to assist him in his research on raptors in the Kruger National Park. These camera traps provide high-resolution images, enabling detailed analysis of feeding habits and nest activities. However, the high cost of the current camera traps poses a challenge when conducting research on numerous raptor nests. Additionally, the client has expressed concerns about the reliability of the timestamping on the images. Another issue he faces is the lack of temperature data, as he lacks a device to obtain this information. The Kruger, where the camera trap system is located, experiences temperatures ranging from 5 to 45 °C. Given that temperature significantly influences bird behavior, obtaining accurate temperature readings is crucial for the client's research. Furthermore, data loss can occur due to environmental factors and animal interference in the Kruger, which is another concern for the client.

In light of these challenges, the client has requested a redesign or update of the existing camera trap technology. The redesign should incorporate a timing system, temperature data gathering capabilities, and ensure data integrity. The design process involved employing previously learned design strategies and following a thorough building and testing procedure to ensure a reliable system. Cost efficiency was also a consideration in selecting components, given the budget constraints. The final design aimed to improve upon the client's current technology, providing reliability, efficiency, and meeting all research requirements. Furthermore, the design took into account subtlety and size, ensuring that the system would not interfere with the raptors' habits and typical activities as it would be situated near their nests. Throughout the design process, all of the client's requests were carefully considered and addressed.

3.2 Design Choices

The design process was a rigorous process and involved considering the clients requirements and specifications to make component and functionality decisions.

3.2.1 Requirements

Listing the requirements for the system were a key step before developing the product. The requirements are as listed below.

1. **RC01:** Image capturing system
   Rationale: The client's research focuses on Raptor Surveillance in which he monitors these animals via images taken at regular intervals. The client's research data is currently solely based on images captured.

2. **RC02:** Timing system
   Rationale: Images require timestamping with a timing system so that the client may keep an organised database of the times in which certain events (such as feeding) have occurred. This also allows the data collected to be kept in an orderly and consistent manner.

3. **RC03:** Motion detection
   Rationale: The client often experienced periods of "dead time" in the data collected. The dead time were periods in the images collected where no activity occurred. Motion detection functionality allows the system to capture more data in periods with increased activity and therefore reduces these dead time periods in the data collected.

4. **RC04:** Temperature detection
   Rationale: The client requested ambient temperature data to improve his research. The temperature data should occur at the position of image capturing as the temperature should relate to the images captured.

5. **RC05:** Additional data storage
   Rationale: The client experienced data loss due to environmental or animal interference. An additional data storage system can be used to ensure no research is lost

6. **RC06:** Low cost
   Rationale: The low budget of the research performed requires the use of cost effective and affordable components

Specifications

The specifications are considered when making component selection choices as well as ensuring the final product meets the client's wishes. The derived specifications are as listed below.

1. **DS01:** The client uses the images for research and data collection and therefore requires a good quality camera. The images need to be stored in JPEG form to be stored on the SD card with a size of approximately 1mb to ensure no low resolution images while also not exceeding storage limit.
   Requirement: RC01

2. **DS02:** The timing system needs a reliable Real Time Clock module with no internet access as the system will be placed in the Kruger National Park. The RTC module needs the ability to interface with the camera module as it will timestamp the images. The timing system has to be formatted with the date and time in hours, minutes, and seconds.
   Requirement: RC02

3. **DS03:** Motion has to be detected within a minimum of 0.5 meters to monitor nest activity. The sensor needs to interface with the system via GPIO pins and will have to operate with 5V

supplied by the power system. The ability to detect motion every 2 minutes should be accounted for.
Requirement: RC03

4. **DS04:** The ambient temperature of the Kruger National Park ranges between 5 and 40 °C over the year. The temperature sensor should be able to register temperatures between 0 to 50 °C to account for fluctuations and should have a +-2 °C accuracy. The sensor should operate on 5V from the power supply and should connect via GPIO pins to the system.
Requirement: RC04

5. **DS05:** The ambient temperature of the Kruger National Park ranges between 5 degrees and 40 degrees over the year. The temperature sensor should be able to register temperatures between 0 degrees and 50 degrees to account for fluctuations and should have a +-1 degree accuracy. The sensor should operate on 5V from the power supply and should connect via GPIO pins to the system.
Requirement: RC05

6. **DS06:** The storage system should be easily removable by the client and should store images of 1mb size for a minimum of 100 days to allow for maximum uninterrupted data collection.
Requirement: RC06

Design Process and options

ESP32cam board

The formation of the redesigned camera trap required the use of the ESP32CAM board to act as the image capturing component. The ESP32CAM board has a 32-bit Low-Power Dual-Core with onboard 520KB SRAM and external 2MB PSRAM. The component also has versatile uses, such as streaming and saving photos on the onboard microSD card in JPEG format. The component allows for camera support of two camera types, OV2640 and OV7670. The camera used in this project is the OV2640, connected to the ESP32 microcontroller, which can be controlled by code inserted on the microcontroller, allowing for integration with additional sensors. However, the camera can be easily changed to allow for a camera with better quality to be added to the system, enabling the user to capture well-defined images for raptor monitoring research.

This board was chosen because it can be powered by a 5V voltage source, making it ideal for being powered by the battery subsystem designed for the project. The typical power consumption is 180mA at 5V, allowing the board to operate for a long period of time with low power consumption, as required by the client. The Bluetooth and WiFi capabilities of this component provide further incentives, as data can be transferred without the use of wires. This is essential for a system situated in the Karoo, where wires can easily break due to animal or environmental interference. The component is suitable for the Karoo environment as it has a safe operating temperature range of -20 to +85 °C. Additionally, the component weighs only 20g, making it ideal for placement on a tree branch, and its small dimensions allow for the design of a discrete system that will not attract the attention of raptors or their predators.

The downside of the ESP32CAM board is its limited GPIO pins. The board contains 16 pins, but the majority of them are used for camera and SD card functionality or flashing and debugging the system. Adding peripherals can be a challenge when using the board to its full capacity (with the camera and SD card), as these pins become unavailable. The limited peripheral interfacing pins reduce the functionality of the system, as additional sensors cannot be added when no more pins are available.

The operation design of the initial system was done in a methodical approach.

- The Arduino IDE was used to write and flash the system code to the ESP32 microcontroller, as it provides an easy-to-use environment with a serial monitor to observe the operation of the system during the design and testing process.
- To meet the client's requirement for image capturing ability, the ESP32CAM board was fitted with the OV2640 camera, which offers reasonable quality at a cost-effective price.
- The camera system was updated with the ability to wirelessly stream images to an access point, the Raspberry Pi, using the ESP32's WiFi capabilities, as the system required the transfer of images from the top of the tree to the base of the tree. WiFi was chosen over Bluetooth because it provides higher speed capabilities and is superior for transferring large files such as images.
- These images were then loaded onto the Raspberry Pi LAMP server and could be stored in external memory for use by the client.

microSD card

To meet the requirement of a backup storage system, the camera images from the ESP32CAM board were stored on a separate storage system from the base station Raspberry Pi storage system. The ESP32's onboard microSD card was chosen as the storage device over an external microSD card adapter module. The external module required the addition of 4 extra pins along with 2 pins for voltage and ground, which made the design incompatible with the limited pins on the ESP32. The onboard SD card option was favored in the design process as it did not require any additional pin connections to the board. The operation of image storing was implemented by flashing code to the ESP32.

- Code was created to capture images at regular intervals of 10 minutes. The images were then written to the SD card for storage.
- A 32GB microSD card was inserted into the TF card slot. This size SD card was chosen as it allowed 32,000MB of images to be stored over the duration of operation. The OV2640 camera images were roughly 100KB, but with higher quality images, image sizes of 1MB could allow the SD card to store 32,000 images. With a frequency of 1 image every 10 minutes, and thereby 144 images per day, the system could store new images for over 200 days. The client intends to leave the system to operate for long periods of time, making this 200-day image storage duration ideal.

Real Time Clock

Real-Time Clock (RTC) components operate with 3V and I2C pins, allowing the user to add timing functionality to a system. The component has a built-in battery and continues counting once the initial time has been provided, supplying 24-hour time with a full calendar. The client required timestamps on the captured images, and the use of an RTC PCF8563 I2C module seemed ideal, as the time data would not be affected if the ESP32 entered deep sleep mode or experienced power failures. Initially, connecting the RTC by connecting the RX and TX pins to GPIO pins on the ESP32CAM board proved successful during the testing stages. However, upon addition of the camera and SD modules, it presented challenges to the design. The limited GPIO pins on the ESP32CAM board left no space for further I2C pin additions, preventing the connection of the external RTC. Further research revealed that the ESP32CAM board contained an internal RTC that could be utilized by installing the library on Arduino. The internal RTC time is set to an initial time value in the code and continues counting after the ESP32 is supplied with power. The drawback, however, is that the ESP32 cannot be powered off, which decreases its power-saving abilities. Once the onboard RTC module on the ESP32CAM was accessed, the images being saved to the microSD card could be time stamped with the date and time of the ESP32CAM board. The client could then have access to stored timestamped images as required. These images are stored on the top of the tree, and if any interference or data loss occurs at the base station, they will serve as a backup data storage system.

Passive Infrared Sensor

As the client's research focuses on raptor monitoring, it was essential to add a motion detection system to the design for capturing images when raptors were detected. Various sensors are available for motion detection, including Microwave Sensors, Ultrasonic Sensors, Vibration sensors, and Passive Infrared Sensors. Since the system would be placed in the non-isolated Kruger National Park, it was crucial for the system to distinguish between non-critical motion, such as leaves or other natural occurrences, and critical motion, such as raptor or predator movement. Passive Infrared Sensors are electronic sensors that measure Infrared light radiated from objects in their field of view. These sensors can detect the heat energy emitted by animals, enabling differentiation between animal and non-animal motion activity in the nests. Therefore, the Passive Infrared Sensor (PIR) was chosen as the motion detection sensor to detect the presence of birds or their predators.

The motion detection sensor was interfaced with the system and the code altered to allow for its operation.

- For this project, a PIR sensor detector module operating on 5V, but capable of being powered by supplies up to 12V, was used. This component was connected to the 5V power supply with a small typical power consumption of 65mA, making it ideal for our design.
- The digital PIR emits a HIGH or LOW signal from the data line, which can be connected to the GPIO 13 pin on the ESP32CAM board.
- The trigger mode of the component can be set to single-event trigger or repetitive trigger. Since the system required single-event triggers, where any activity in the nest would register as motion and result in a single HIGH signal read by the microcontroller, this mode was chosen.
- The potentiometer on the component could be adjusted to increase or decrease the time delay of the sensor reading signal. An increased time delay was implemented to ensure the microcontroller could read the pin over a longer period.
- The PIR sensor was then integrated with the camera and storage functionality on the ESP32CAM board. Under typical operation, the camera was set to capture images at 10-minute intervals. When motion was detected by the PIR, the image interval was reduced to 5-minute intervals for

a short period of time before reverting back to its 10-minute interval. This allowed the system to capture more images during periods of increased nest activity, providing the client with fewer images of no activity and minimizing the amount of 'dead' data to sift through.

- All these images were stored on the SD card with timestamps, as mentioned previously.

The addition of the motion detection sensor enhanced the functionality of the system and provided the client with an efficient data collection process.

Temperature Sensor

Temperature sensing is vital for researchers like our client, and it was one of his requirements for the designed system. A wide range of temperature sensors exists, but they can be categorized as contact and non-contact sensors. Contact temperature sensors require direct contact with the object being measured, while non-contact temperature sensors measure the radiation emitted by the heat source. Non-contact sensors were chosen for this project because attaching any sensing components to the raptors would interfere with their natural activity. The client also specifically requested recording and storing ambient temperature readings to enhance his research process.

Among the various temperature sensors available, the BME680 and DHT11 components were found to be most suitable for the system. The BME680 component measures temperature in the range of -40 to 85 °C with a precision of 1 °C Celsius. It operates at a voltage of 3 to 5V and has a current consumption of 5mA, making it easy to interface with the power module. Additionally, the BME680 also measures VOCs (Volatile Compounds) in the air, as well as pressure and humidity. On the other hand, the DHT11 component measures temperatures in the range of 0 to 50 °C with an accuracy of 2 °C. It operates at voltages of 3 to 5V with a maximum current consumption of 2.5mA. While both components are suitable, the DHT11 was chosen because it operates with a single signal pin, whereas the BME680 requires I2C capabilities. The limited GPIO pins on the ESP32 board would make interfacing the BME680 pin a challenge. Although the DHT11 has a smaller temperature range, it still fits the specifications as the temperature in the Kruger National Park fluctuates between 5 to 45 °C.

The DHT11 temperature sensor was therefore interfaced with the camera and PIR module by connecting the signal pin to GPIO pin 16 on the ESP32. However, problems arose during testing as the GPIO pin used for the temperature sensor was found to interfere with the onboard microSD card module, impacting the system's ability to store images. To resolve this issue, the GPIO pin was changed to pin 0 on the ESP32. However, pin 0 is used by the ESP32 for code flashing during the microcontroller programming process. Therefore, the system code was first flashed to the board before connecting the temperature sensor to obtain accurate data readings. The temperature and humidity data provided by the sensor are stored in a text file on the microSD card of the esp32cam board, along with a timestamp from the internal RTC. The client can then retrieve the SD card from the system to access the time stamped images captured by the camera, as well as the text file containing temperature and humidity readings.

3.3 Prototype Design

The final design consisted of four components: an ESP32CAM board with an OV2640 camera, a 32GB microSD card, a PIR sensor, and a DHT11 temperature and humidity sensor. The OV2640 camera connects directly to the ESP32 board, while the PIR sensor utilizes GPIO pin DO13 and the DHT11 utilizes GPIO pin DO1. The microSD card fits directly into the onboard TF card slot for operation. The system was initially built on a breadboard and later transferred to a veroboard during the prototype phase.

Table 3.1: Component Information

Reference	**Common name**	**Unit Price**	**Manufacturer**
DFR0602	ESP32 cam board	R192.57	DFRobot
9MPIRHC-SR501	PIR Motion Detection sensor	R59.95	DIY Electronics
9MDHT11	DHT11 Temperature sensor	R89.95	DIY Electronics
9SDCARDM32GBK	32GB microSD card	R159.95	DIY Electronics

The operation of the final system is as follows:

- The system enters a state of full operation upon connecting the power pin to a 5V power supply from the power subsystem.
- Images are captured at regular intervals of 10 minutes under typical operation.
- When motion activity occurs by any animals, such as the raptors moving in the nest, the PIR detects the motion and outputs a HIGH signal. The image capturing interval then changes to a duration of 5 minutes for 3 image capturing cycles before reverting back to the 10 minute interval. This is to allow for more data gathering when activity occurs in the nest.
- The images captured by the system are written to the microSD card for storage and can then be retrieved by the client. The images stored on the SD card are time stamped with the date and time stored as the image title.
- Temperature and Humidity readings are retrieved by the DHT11 sensor and stored in a text file along with the time on the microSD card every time an image is captured.
- The system also sends regular images via WIFI to the Raspberry pi at the base of the tree for ‘base station’ storage. This allows the client to not have to climb to the top of the tree to collect his data.

The system therefore allows for storage of images and temperature data on a microSD card which can be used by the client in his research. This storage system occurs at the top of the tree. As the Raspberry Pi system stored images at the base of the tree, if any data loss occurs at the base station, the client will not experience any research loss due to this backup storage system.

The wiring diagram for all the systems components and interfacing can be seen below.

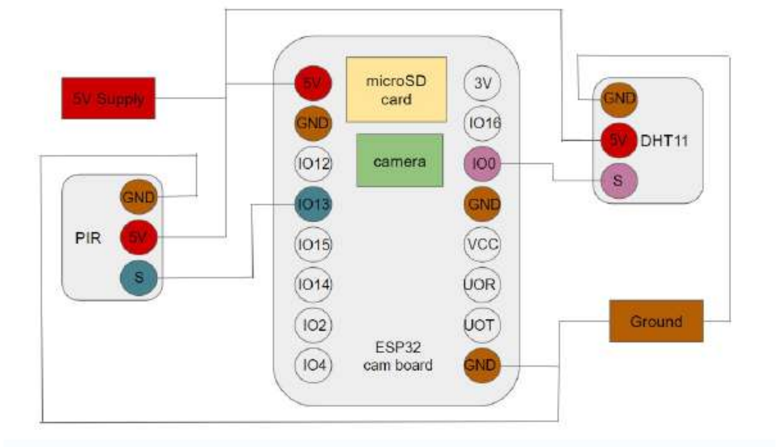
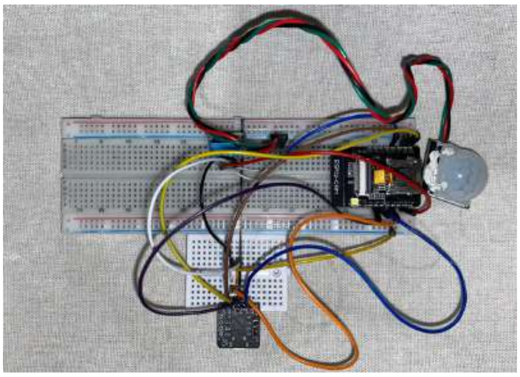
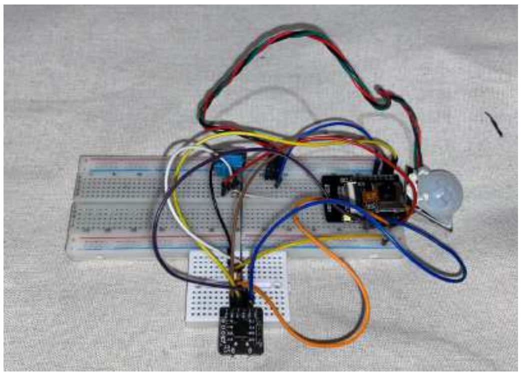


Figure 3.1: Wiring Diagram

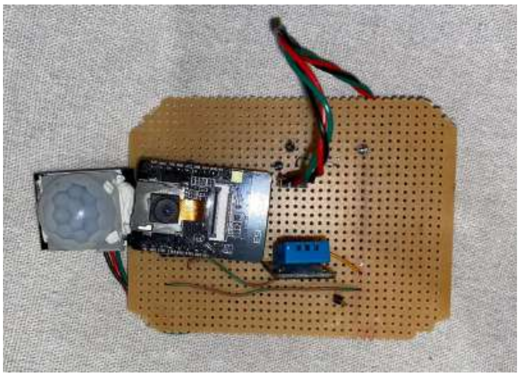
The final prototype design can be seen below on both the breadboard and Vero board stage of implementation. The breadboard power supply of 5V can be obtained by plugging into the usb port on the FTDI module. The Vero board power pin needs a connection to a 5V power supply coming from the power module of the system.



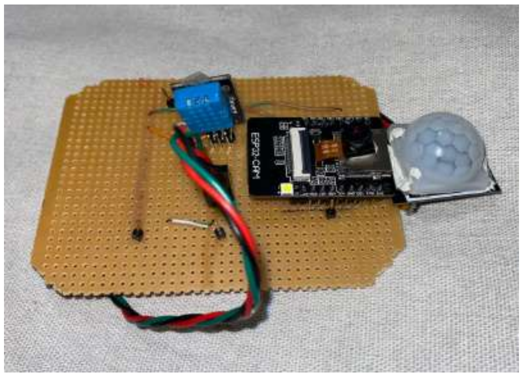
(a) Breadboard top view



(b) Breadboard side view



(c) Vero Board top view



(d) Vero Board side view

Figure 3.2: Final Prototype

3.4 Testing and Results

The prototype must be put through a series of tests to validate performance. The results are analysed for reliability of system operation.

3.4.1 Acceptance Test Protocols

The Acceptance Test Protocols (ATPs) are a series of tests that must be performed before confirming the design for the client. The ATPs are as listed below.

1. **DS01:** The system must be in operation consistently for a full day with no interference to allow it to capture a minimum of 144 images. The image quality for each picture should be analysed to ensure no image experience distortion or dead pixels. No image distortion or decrease in quality over extended run time should be confirmed.
   Specification: DS01

2. **DS02:** The system should be in operation for an hour with no motion interference. The interval of image capturing should be timed and confirmation of a new image every 10 minutes should be obtained. The interval should have an accuracy of +-10 seconds.
   Specification: DS01

3. **DS03:** The system should be connected to a serial monitor with the internal Real Time Clock results displayed. The system should then be in operation for 3 hours, with constant monitoring of the RTC values. The values should be consistent when compared to an external timer. Accuracy is required and no variation can be allowed as this could lead to a time delay build up.
   Specification: DS02

4. **DS04:** The system should be operated for a duration of 6 months. The images captured should be viewed and the timestamping checked for discrepancies in the timing system to ensure that all the images are time stamped correctly with no deviation in the timing system with the increase of operation duration.
   Specification: DS02

5. **DS05:** The system should be in operation and motion should occur at a distance of 0.5m, 0.7m, and 1m. The effect of the motion detection on the system should be confirmed for all three cases.
   Specification: DS03

6. **DS06:** The system should be placed in an environment with temperature conditions of 5 to 45 °C. Motion should occur in the presence of the system and expected PIR operation should be validated with no effect of the external temperature conditions.
   Specification: DS03

7. **DS01:** The system should be placed in temperature conditions ranging from 0 to 50 °C. The temperature readings obtained by the system should be validated against a reliable external thermometer to within 2 °C of accuracy.
   Specification: DS04

8. **DS01:** The system should be in operation for a minimum of 100 days before checking the SD card to ensure that it had not reached storage capacity. No data loss should have occurred and all images should meet the quality standard.
   Specification: DS05

9. **DS01:** Images should be captured by the system and stored on the SD card. The images should be validated to be stored correctly and be under 1mb in size as to not exceed storage capacity for the operation duration.
   Specification: DS05

3.4.2 Practical Tests

The breadboard prototype was connected to a power source, and testing was performed on the system. The components were individually tested to confirm their operation and functionality. Subsequently, the full system was put into operation and tested to validate that it performed as expected.

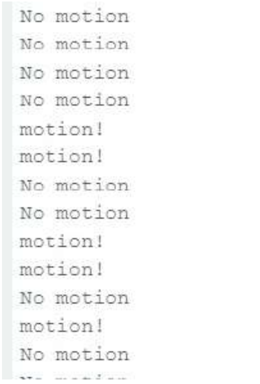
The PIR sensor was tested for motion detection by connecting the board to a serial monitor. A hand was waved in quick motion before it at distances ranging from 0 to 2m. The sensor successfully detected rapid motion at close range. However, as the distance increased, the accuracy of motion detection decreased. A distance of 1.5m was determined to be the maximum reliable distance for accurate results. Beyond the 1.5m mark, motion detection results were inconsistent. The serial monitor below displays the motion detection results.

Next, the DHT11 temperature sensor was tested for accuracy and reliable temperature readings. The sensor was placed in a neutral environment, and the results were displayed on the serial monitor. The sensor was then exposed to a heat source, and it was observed that the temperature increased without any sensing delay. The humidity values were tested by blowing onto the sensor and monitoring for an increase in sensor readings. Overall, the sensor operation proved reliable and produced the expected results which can be seen below.

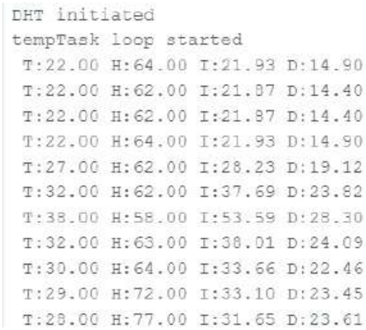
Finally, the full system was put into operation mode. When no motion occurred, the serial monitor displayed ‘slow pictures,’ indicating that images were captured every 10 minutes. When motion was detected within the range of the PIR sensor, the image capturing frequency was changed to 5 minutes for the duration of 3 images, before reverting back to the 10-minute interval. These images were successfully saved on the microSD card along with timestamps. Consequently, the system works as expected and produces reliable results.

When accessing the microSD card data, an SD card reader should be utilised. The figures below depict the images stored in the time stamped form on the SD card. These images are of decent quality and are stored in order as they are captured.

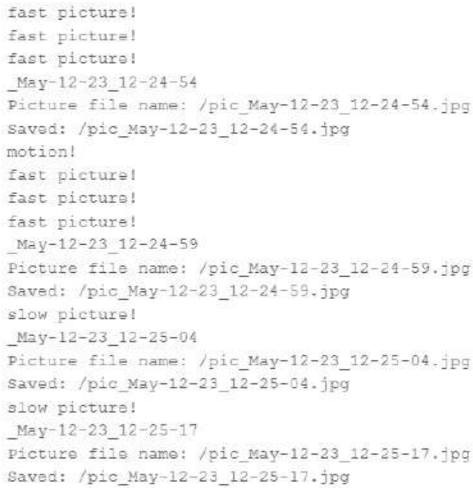
The camera takes a few minutes to intialise and the first 2 picutes may be distorted. The figures below show the configuration process effect on image quality, and the final image quality result as stored on the system.



(a) PIR serial monitor test

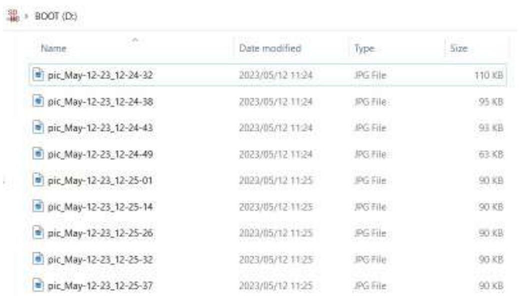


(b) Temperature sensor serial monitor test

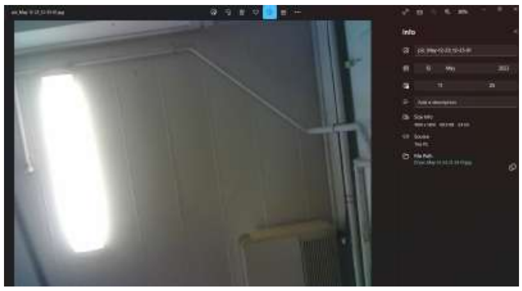


(c) Image storage with PIR serial monitor test

Figure 3.3: Protoype System Tests



(a) MicroSD card image storage



(b) An image retrieved from the microSD card

Figure 3.4: Image Storing System

(a) Camera initializing image result

(b) Camera initialzing image result

(c) Final camera image result

Figure 3.5: Camera configuration distortion

3.5 Conclusion

The design process involved numerous instances of trial and error, with system additions made based on the client's specifications. The system was initially designed on paper before progressing to the prototype phase. Throughout this phase, the prototype underwent changes to address functionality and component limitations. The final design was a redesigned camera trap model based on the ESP32 cam board. It incorporated temperature sensing, motion detection, and image storage capabilities to support the client's research. Despite the redesigned system's image quality not reaching the standard of the original system, replacing and improving the camera can be easily accomplished without a significant increase in the budget. The system ensures data integrity and easy access through a simple microSD card reader, thus mitigating the risk of data loss. Additionally, the system is designed to operate reliably for over 100 days, which aligns well with the client's typical research duration. In conclusion, the final design exhibited reliable performance during testing, while remaining cost-effective and fulfilling all the client's functional requirements.

Chapter 4

Section 2 - Image Transmission & Camera Trap Enclosure

Prepared by Jasveer Pooran (PRNJAS002)

4.1 Introduction

This section of the report provides an overview of a subsystem within a wildlife monitoring system encompassing two critical components: wireless image data transfer from a camera trap to a Raspberry Pi and the design of a weatherproof enclosure to house the camera and sensors perched at the top of the tree. The purpose of this subsystem is to help address the current challenges associated with remote monitoring of martial eagles' nests to better understand feeding habits in different temperature conditions. Currently, researchers have to climb up a tree both to install the camera trap and retrieve data by dismounting SD cards from the camera units. This method necessitates arduous tree climbing, creating inherent challenges in terms of safety, time efficiency, and data accessibility. By employing wireless data transfer and a robust enclosure for its components, the system aims to enhance data collection efficiency while ensuring the protection of sensitive electronic equipment in varying environmental conditions. By enabling wireless, efficient data collection from tree-top nests, the subsystem contributes to the broader academic goal of advancing scientific knowledge and facilitates conservation efforts for the preservation of martial eagles and their natural habitats.This subsystem provides a pivotal means of acquiring crucial insights into the species' behavior, fostering a deeper understanding that is essential in formulating effective conservation strategies aimed at safeguarding this majestic species.

4.2 Wireless Data Synchronization

4.2.1 Design Process

Requirements

The following requirements outline the necessary functionalities and features of the Wireless Data Synchronization System:

1. **RC01:** Seamless and reliable data transfer
   Rationale: The data synchronization system must enable smooth and dependable transfer of captured images from the camera trap to the Raspberry Pi base station. It should establish a

wireless communication link that ensures consistent and uninterrupted data transfer, eliminating the need for physical retrieval of the images.

2. **RC02:** Data integrity and security
   Rationale: The system must prioritize the integrity and security of the transmitted data to maintain the accuracy and confidentiality of the collected information. It should implement measures to safeguard the data during transmission and prevent unauthorized access or tampering.

3. **RC03:** File handling and synchronization
   Rationale: Must include a file handling system that facilitates effective synchronization and storage of data between the camera trap's SD card and the Raspberry Pi. It should employ multi-threading capabilities to monitor for newly created files and synchronize them promptly.

4. **RC04:** Reliable data storage on the Raspberry Pi
   Rationale: Ensures dependable data storage on the Raspberry Pi's storage medium. This guarantees that researchers can access and analyze the captured images for further study and analysis without the need to physically climb the tree and retrieve the data.

Specifications

The following specifications are presented herein, derived from the comprehensive analysis of design requirements:

1. **DS01:** The data synchronization system must have a minimum data transfer rate of 0.4MB/s to ensure smooth and timely transfer of captured images from the camera trap to the Raspberry Pi base station. The system should employ robust wireless communication protocols to ensure reliable and uninterrupted data transfer, minimizing the risk of data loss or corruption during transmission.
   Requirement: RC01

2. **DS02:** The system shall implement authentication using a secure key-based mechanism to ensure the confidentiality and integrity of the collected information.
   Requirement: RC02

3. **DS03:** The synchronization process shall have a maximum latency of 3 seconds.
   Requirement: RC03

4. **DS04:**The system shall store JPEG images with lossless compression in a local directory on the user's machine.
   Requirement: RC04

4.2.2 Prototype Design

The Wireless Data Synchronisation Subsystem aims to enable seamless and efficient transfer of captured images from the camera trap to the Raspberry Pi base station. This subsystem consists of three main components: the camera trap, the Toshiba WiFi SD card, and the Raspberry Pi Zero W with SD card. The camera trap, specifically the Browning Trail Camera, is responsible for capturing images, while the Toshiba WiFi SD card facilitates wireless transfer of these images to the Raspberry Pi. The

Raspberry Pi acts as the logic behind the base station, receiving and storing the images for further processing and analysis.

This SD card creates its own WiFi network, which the Raspberry Pi connects to. The camera trap is equipped with this WiFi SD card, allowing it to transmit captured images wirelessly to the Raspberry Pi. The wireless transfer is achieved through the integration of the software package [29] designed, which provides an easy-to-use abstraction of the FlashAir API.The design choices made in creating the Wireless Data Synchronisation Subsystem prioritize reliability, ease of use, and wireless connectivity. By integrating the software package, the system benefits from the comprehensive functionalities provided, including file synchronization and mirroring between the camera trap and the Raspberry Pi's chosen directory.Furthermore, the selection of the Browning Trail Camera as the camera trap ensures high-quality image capture, while the Raspberry Pi Zero W, known for its compact size and low power consumption, serves as an efficient base station for receiving and storing the images. Consequently, the system reduces the need for physical intervention, and enhances the overall monitoring process.

Software Architecture

This software tool facilitates convenient utilization of the Toshiba FlashAir wireless SD card. Operating as a library, the implementation offers a user-friendly means of communicating with FlashAir SD card. The package encompasses two command line utilities: flashair-util empowers users with the capability to synchronize and mirror files and directories between the local file system and the FlashAir SD card, while flashair-config enables users to configure the settings of the FlashAir SD card. The code uses multi-threading to monitor for newly created files in both the local and remote directories and synchronize them in the specified direction. The type of synchronisation the user requires is handled by the type of command entered by the user in the terminal as demonstrated in Table 4.1.

The FlashAir tool interacts with the FlashAir SD card using the HTTP protocol. In the context of the FlashAir tool, HTTP is utilized to communicate with the FlashAir SD card, which acts as an HTTP server. The tool sends HTTP requests to the FlashAir SD card, specifying the desired operations and parameters. The FlashAir SD card, in turn, processes these requests and sends back HTTP responses with the corresponding results.

The following details how the FlashAir tool leverages HTTP protocol for the final solution:

- Request Methods: The tool uses two main HTTP request methods: - GET: Used to retrieve information or resources from the FlashAir SD card. For example, retrieving file listings, getting device information, or deleting files. We can also download image files in this way to the local machine. - POST: Used to send data to the FlashAir SD card. In this case, the tool uses it for uploading files to the FlashAir SD card.

- Request Parameters: The tool includes additional parameters in the HTTP requests to provide specific instructions or data to the FlashAir SD card. These parameters (as demonstrated in Table 4.1) are sent as part of the query string or as POST data, depending on the request type.

- Response Codes: After receiving an HTTP request, the FlashAir SD card processes it and generates an HTTP response. The response contains a status code indicating the success or failure of the operation. The tool examines the response status code to determine the outcome of the requested operation.

- Request-Response Cycle: The FlashAir tool running on a machine follows a typical request-response cycle. It prepares an HTTP request, sends it to the FlashAir SD card, waits for the corresponding HTTP response, and then processes the response to handle the result or extract relevant data.

HTTP provides the foundation for communication between the FlashAir tool running on the local machine and the FlashAir SD card. It allows the tool to interact with the device, perform operations like uploading and deleting files, and retrieve information from the device over a network connection.

Setup

For our use on the raspberry pi, the setup is achieved in this way:

- Establish a headless configuration for the Raspberry Pi Zero by installing the Raspbian operating system and enabling SSH capabilities, allowing remote access without a monitor or keyboard.
- Access the Raspberry Pi Zero through a Secure Shell (SSH) connection by using the command 'ssh yourpiname@raspberrypi.local' and entering the password created during the setup process. The default password for the Pi user is typically set as 'pi', and the Pi device is commonly named 'admin.'
- Insert the Toshiba WiFi SD card into the camera and allocate sufficient time for the card to initiate its autonomous WiFi network.
- Establish connectivity between the Raspberry Pi Zero and the WiFi network generated by the WiFi SD card. Connect to the wifi manually as you usually would. This is typically performed only once on setup, as subsequent connections will automatically be handled by the tool.
- Install the necessary tool, 'tfatool,' on the Raspberry Pi Zero by executing the command 'python -m pip install tfatool.' This tool enables the transfer of images from the WiFi SD card to the Raspberry Pi Zero.
- Once we have changed the directory we are in to the one where the tool is installed. Execute the appropriate command from the provided table to initiate the transfer of images from the WiFi SD card to the desired location on the Raspberry Pi Zero. Ensure that you are familiar with the directory path where you intend to store the transferred images.
- Once the images are successfully transferred to the Raspberry Pi Zero, proceed to store or process them according to your specific requirements.

We can now use the tool with the specified commands in Table 4.1 to interact with the FlashAir SD card as neccessary.

Table 4.1: Action and Command

Action	Command
Command to list all directories on SD Card	`flashair-util -l`
Command to list all contents in a folder on SD Card	`flashair-util -l -r DCIM/100JLCAM`
Command to sink local (-d) and remote directory (-r) indefinitely (-s)	`flashair-util -s -r DCIM/100JLCAM -d ./camera -j`
Command to sync last image (-S)	`flashair-util -S time -n 1 -r DCIM/100JLCAM -d ./Desktop/camera -j`
Monitor FlashAir for new JPEG files only, download to ./Desktop	`flashair-util -s -j -d /home/Desktop/Photos`
Monitor local directory for new files, upload to FlashAir SD Card	`flashair-util -s -y up`
Monitor a local and remote directory for new files, sync them	`flashair-util -s -y both`
Download the ten most recent images to a local folder then quit	`flashair-util -S time -d images/new/`
Upload all files created in 2023 and afterwards	`flashair-util -S all -t 2023`
Download files created between Jan 23rd and Jan 26th	`flashair-util -S all -t 1-23 -T 01/26`
Sync files (up AND down) between local and remote directories created this afternoon	`flashair-util -S all -t 12:00 -T 16:00 -y both`
Download files created after a very specific date/time	`flashair-util -S all -t '2023-1-25 11:38:22'`
List files on FlashAir created after a certain time	`flashair-util -l -t '1-21-2023 8:30:11'`
Change FlashAir network SSID	`flashair-config -wifi-ssid myflashairnetwork`
Show FlashAir network password & firmware version	`flashair-config -show-wifi-key -show-fw-version`

4.2.3 Testing and Results

Tests Run On System

1. **T01:** Place a test image file on the camera trap's SD card. Initiate the data synchronization process. Verify that the image file is successfully transferred at a speed of 0.4MB/s or greater and stored on the Raspberry Pi. Repeat the test with multiple image files to ensure consistent and uninterrupted data transfer.
   Specification: DS01

2. **T02:** Attempt to access the transferred image file from an unauthorized device or user. Verify that the system denies access and implements appropriate security measures to prevent unauthorized access.
   Specification: DS02

3. **T03:** Create a new image file on the camera trap's SD card. Monitor the synchronization process on the Raspberry Pi. Verify that the newly created image file is promptly synchronized and transferred to the Raspberry Pi. Repeat the test with multiple new image files to ensure the system can handle concurrent synchronization tasks.
   Specification: DS03

4. **T04:** Transfer multiple test image files within a few seconds of each otther from the camera trap to the Raspberry Pi. Verify that all transferred image files are successfully stored on the Raspberry Pi's storage medium. Attempt to access and view the stored image files from the Raspberry Pi. Verify that the stored image files can be accessed and viewed without any issues.
   Specification: DS04

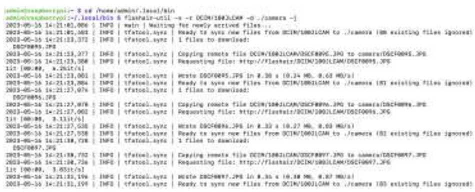
Acceptance Test Procedures

1. **AP01:** The image files are transferred from the camera trap to the Raspberry Pi without any errors or data loss.The transfer rate meets or exceeds the specified minimum rate of 0.4MB/s. The system maintains a stable wireless communication link throughout the data transfer process.
   Test: T01
   Result: Passed

2. **AP02:** The transferred image file is sent successfully without corruption despite having multiple

(a) Camera, Data Cable and WiFi SD Card

(b) Raspberry Pi Zero



(c) Raspberry Pi Setup with Tool Waiting for Images

(d) Pictures Taken on Camera Are Stored On Raspberry Pi

Figure 4.1: Working Wireless Data Synchronisation System

users connected to SD card. The system also successfully detects and prevents unauthorized access to the transferred image file (by those without wifi password).
Test: T02
Result: Passed

3. **AP03:** The system promptly detects and synchronizes (infinitely) newly created image files from the camera trap's SD card. The synchronization process has a maximum latency of 3 seconds. The system can handle concurrent synchronization tasks without any data loss or synchronization conflicts.
Test: T03
Result: Passed

4. **AP04:** All transferred image files are reliably stored on the Raspberry Pi's storage medium without any loss of data.The stored image files can be accessed on the Raspberry Pi and the pictures indeed match what was captured.
Test: T04
Result: Passed

4.3 Weatherproof Enclosure for Sensors

4.3.1 Design Process

Requirements

The following requirements outline the necessary functionalities and features of the enclosure:

1. **RC01:** Robust protection against environmental factors

Rationale: The enclosure must provide strong protection against environmental factors such as dust, water, and other potential hazards. It should have an IP55 certification, ensuring resistance to dust ingress and protection against low-pressure rainstorms. This safeguards the camera trap and associated electronics, ensuring their functionality and reliability in outdoor environments.

2. **RC02:** Convenient access and maintenance
   Rationale: The enclosure design should prioritize easy access to the internal components and ports of the Raspberry Pi. The design should allow for simple maintenance, setup, and connectivity.

3. **RC03:** Modular design
   Rationale: The enclosure should support modular upgrades, enabling the system to incorporate additional features or sensors as needed. This promotes adaptability and scalability of the wildlife monitoring system, accommodating changes in research requirements.

4. **RC04:** Temperature regulation
   Rationale: The enclosure should incorporate effective temperature regulation mechanisms, such as ventilation or insulation, to prevent overheating or damage to the enclosed sensors under extreme temperature conditions.

5. **RC05:** Anti-vandalism features
   Rationale: The design should include anti-vandalism measures to protect the enclosure and sensors from tampering or unauthorized access, ensuring data integrity and system security.

6. **RC06:** Compliance with regulatory standards
   Rationale: The enclosure shall be constructed using materials that are free from hazardous substances such as lead, mercury, and cadmium, in compliance with the Restriction of Hazardous Substances (RoHS) directive.

7. **RC07:** Aesthetics
   Rationale: The enclosure must seamlessly integrate into the natural surroundings. To this effect, only neutral colours should be used to cover the enclosure. It must also be small enough to not become an impediment to the nature that surrounds it. Ideally, the enclosure should not be larger than 130x90x40mm.

Specifications

The following specifications are presented herein, derived from the comprehensive analysis of design requirements:

1. **DS01:** The enclosure shall achieve a minimum IP55 certification, demonstrating its ability to withstand dust and low-pressure rainstorms.
   Requirement: RC01

2. **DS02:** The enclosure design shall provide convenient access to the internal components and ports of the Raspberry Pi. It shall feature clip and hinge openings that allow for easy maintenance and setup. The material used for the enclosure should still enable wireless connectivity, preferably

plastic.
Requirement: RC02

3. **DS03:** The enclosure shall support modular upgrades, enabling the addition of extra features or sensors. The enclosure design shall ensure adaptability and scalability by accommodating at least two additional modules or sensors.
Requirement: RC03

4. **DS04:** The enclosure shall incorporate effective temperature regulation mechanisms to ensure the optimal operating conditions for the enclosed sensors. The temperature inside the enclosure shall be maintained within ± 2 degrees celsius of the ambient temperature to prevent overheating or damage to the sensors.
Requirement: RC04

5. **DS05:** The enclosure design shall incorporate anti-vandalism features to protect against tampering or unauthorized access. The enclosure shall provide a mechanism to attach a lock to. The enclosure shall also be constructed using durable materials with a minimum thickness of 2 millimeters, capable of withstanding impact forces from small animals without compromising the integrity of the enclosure or sensors.
Requirement: RC05

6. **DS06:** The enclosure shall incorporate effective temperature regulation mechanisms to ensure the optimal operating conditions for the enclosed sensors. The temperature inside the enclosure shall be maintained within ± 2 degrees celsius of the ambient temperature to prevent overheating or damage to the sensors.
Requirement: RC06

7. **DS07:** The enclosure shall incorporate effective temperature regulation mechanisms to ensure the optimal operating conditions for the enclosed sensors. The temperature inside the enclosure shall be maintained within ± 2 degrees celsius of the ambient temperature to prevent overheating or damage to the sensors.
Requirement: RC07

4.3.2 Prototype Design

The enclosure is an integral component of the system, providing protection to the camera trap and associated sensors deployed in remote locations like Kruger National Park. The design of the enclosure is an integral part of the whole project. It protects the components used to solve the challenges associated with data collection experienced by researchers conducting avian research. This section will deal with explaining the enclosure design chosen, its alignment with requirements and specifications, and the design choices made to achieve a reliable option for component housing.

The camera trap enclosure functions as a weatherproof housing for sensors, thus providing protection against environmental elements like rain and curious animals. It incorporates a motion-sensitive (through PIR) wildlife camera trap, which captures high-definition photos and videos of wildlife. The enclosure enables wireless data transfer from the camera trap to the Raspberry Pi base station, where the data is processed and stored for further analysis. This design enables the easy connection of internal components for setup and maintenance. It features a full, durable plastic design so that the enclosure is secure against shock and wireless communication is not affected by thick physical material.

The enclosure is designed to withstand various environmental conditions, addressing the challenge of positioning the camera trap in tree tops. The use of durable materials with a minimum thickness of 2 millimeters ensures its resilience against impact forces from small animals. This design choice complies with requirement DS07, which mandates the enclosure's ability to withstand such forces without compromising its integrity or the sensors' functionality. Additionally, the enclosure's unique triangulated design provides full protection to the internal electrical components, shielding them from the elements and meeting one of the IP55 certification requirements (DS01). However, we have not yet tested if the design is impervious to dust. Currently, there is no openings besides the holes for the camera and PIR sensor. For future design, if sealed correctly with epoxy and marine seal for good measure, the design could prevent some destruction due to dust. We also suggest covering the camera trap with a thorn bush to deter any curious animals visiting the tree. Additionally, the configuration can be securely fastened utilizing the handles located on the back cover, easily facilitating the attachment of a belt if deemed necessary. If this is not an option, there is also provisions made for a camera tripod stand which can be securely fastened to the lower section of the enclosure. A handle was also included at the top to allow for easy transportation or as another means to help mount the enclosure onto a tree branch.

The enclosure also features a clip and hinge openings, offering easy access to the internal components and ports of the Raspberry Pi. This design choice satisfies requirement DS02, ensuring convenient maintenance, setup, and potential upgrades without the need for extensive disassembly. Furthermore, the enclosure incorporates a bulky lower and upper half, allowing the integration of at least two additional modules or sensors, supporting the system's modular upgradability as required by DS03. The design does include an insert to conveniently separate the internals from both halves. Interestingly, the design is also protected against tampering or unauthorized access since it is equipped with a padlock loop, allowing users to attach a lock to secure the enclosure, thereby meeting the requirement of DS05. This design choice enhances the system's security and ensures the integrity of the data collected by the camera trap. The material used for the enclosure is plastic, enabling unimpeded wireless connectivity as specified by RC02. This selection ensures that the wireless communication capabilities of the Raspberry Pi and other IoT sensors are not compromised. The enclosure's design allows seamless data transfer between the camera trap and the base station without interference. For temperature regulation, it was decided to use silicon sachets to help with humidity in the enclosure, white paint was meticulously applied to the interior surfaces, while an exterior coating in green was used. This was done to reflect sunlight and reduce the absorption of heat from the surroundings. Some available insulation (foam) was provided in the enclosure to help absorb some heat.

This design was inspired by existing camera traps utilised in the industry [30]. It allowed for a smooth integration with other subsystems as it provided adequate space (130x90x40mm) for the specific electronic devices required for this application. A software tool called Fusion360 was used to create modifications to suit our client's needs.

4.3.3 Testing and Results

Tests Run On System

1. **T01:** Expose the enclosure to controlled dust conditions and verify that no dust particles penetrate the enclosure. Simulate low-pressure rainstorms by subjecting the enclosure to water spray from various angles and intensities. Inspect the enclosure for any signs of dust infiltration or water damage.
Specification: DS01

2. **T02:** Open the enclosure using the clip and hinge openings provided. Verify that all ports and internal components of the Raspberry Pi are easily accessible without the need for excessive disassembly. Close the enclosure and ensure that it securely holds the Raspberry Pi in place.Repeat the open-close process multiple times to assess the durability of the clip and hinge mechanisms.
Specification: DS02

3. **T03:** Identify and select two additional modules or sensors compatible with the enclosure. Install the chosen modules or sensors into the enclosure alongside the existing components. Verify that the enclosure can accommodate the additional modules without compromising its structural integrity or the functionality of the existing components. A temperature sensor can be used for this test.
Specification: DS03

4. **T04:** Validate the effectiveness of the temperature regulation mechanisms within the enclosure. Procedure. Place the enclosure in a controlled environment with a known ambient temperature. Measure the temperature inside the enclosure. Gradually increase and decrease the ambient temperature while monitoring the enclosure's internal temperature. Ensure that the temperature inside the enclosure is maintained within ± 2 degrees Celsius of the ambient temperature throughout the test.
Specification: DS04

5. **T05:** Attempt to tamper with the enclosure or gain unauthorized access by applying force or manipulation. Assess the enclosure's ability to resist tampering and unauthorized access. Drop a small weight (1.5Kg) on the enclosure to see if the plastic cracks to allow access. Verify that the lock mechanism functions properly and securely attaches to the enclosure. Inspect the enclosure for any signs of damage or compromise after the test.

Acceptance Test Procedures

1. **AP01:** No dust particles should penetrate the enclosure during the dust exposure test. The enclosure should prevent water ingress during the simulated low-pressure rainstorms. There should be no signs of dust infiltration or water damage on the internal components after the test.
Test: T01
Result: Passed

2. **AP02:** The clip and hinge openings should provide easy and smooth access to the internal components and ports of the Raspberry Pi. All ports and internal components should be easily

reachable without the need for excessive disassembly. The enclosure should securely hold the Raspberry Pi in place when closed. The clip and hinge mechanisms should withstand repeated opening and closing without significant wear or damage.
Test: T02
Result: Passed

3. **AP03:** The enclosure should accommodate at least two additional modules or sensors alongside the existing components. The structural integrity of the enclosure should not be compromised by the presence of the additional modules. The functionality of the existing components and the added modules should not be negatively affected by their integration within the enclosure.
Test: T03
Result: Passed

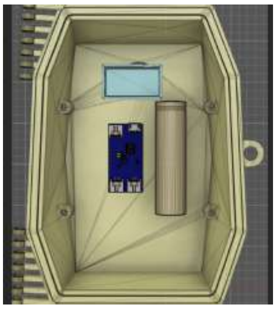
4. **AP04:** The temperature inside the enclosure should be maintained within ±2 degrees Celsius of the ambient temperature throughout the test. The temperature regulation mechanisms should effectively dissipate heat and prevent overheating of the enclosed sensors. There should be no signs of excessive heat buildup or damage to the sensors during the test.
Test: T04
Result: Failed. While the external system did not deform within temperature ranges of 30-50°C, we could not reliably say that the methods used on the Raspberry Pi did much to reduce the internal temperature of the enclosure.

5. **AP05:** The enclosure should resist tampering and unauthorized access attempts. The lock mechanism should securely attach to the enclosure and prevent unauthorized opening. The enclosure should remain intact and show no signs of compromise or damage after the test.
Test: T05
Result: Passed

4.4 Conclusion

The design process for the Wireless Data Transfer Subsystem and the Weatherproof Enclosure successfully fulfilled the client's requirements and specifications, presenting an effective and dependable solution for remote monitoring of wildlife habitats. The implementation of Wi-Fi SD card technology in the Wireless Data Transfer Subsystem facilitated seamless wireless communication between the camera trap and the Raspberry Pi-based base station. This eliminated the need for manual tree climbing and enabled convenient data collection and transmission. The subsystem achieved the objectives of easy setup, reliable data transfer, and does have compatibility with the Lamp Server for efficient data storage, but this could not be achieved since we used a very basic Raspberry Pi model. The Weatherproof Enclosure was crafted to meet the challenges posed by outdoor environments and safeguard the enclosed equipment. Its modular design allowed for future expansions, ensuring adaptability and scalability. While, the enclosure did not provide adequate temperature regulation, we believe this can be later fixed in the near future. Interestingly, the design managed to hold its own against attempts to crack the case when locked. The enclosure's aesthetic aspects were also addressed, seamlessly integrating it into the natural surroundings.Through the fulfillment of the client's needs and the adherence to

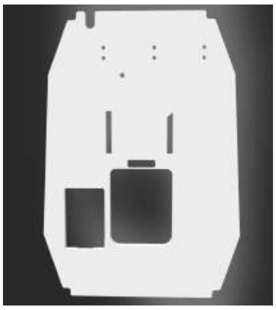
(a) Front View



(b) Housing of Power Components (sample components similar in size)

(c) Handles at back used for mounting

(d) Bottom Fastener (applied horizontally across bottom case)



(e) Insert for Mounting Sensors atop Bottom Case

(f) Clips Used to Fasten Enclosure

Figure 4.2: 3D Model of Enclosure

(a) Front View

(b) Back View

(c) Housing of Power Components

Figure 4.3: Completed 3D Prototype of Enclosure

specified requirements and specifications, the Wireless Data Transfer Subsystem and the Weatherproof Enclosure provide a comprehensive solution for remote wildlife monitoring. The successful integration of these components equips researchers with a reliable and user-friendly tool to gain valuable insights into the natural world they so desire to protect.

Chapter 5

Section 3 - Power Circuitry & Base Station Housing

Prepared by Hamish McKenzie (MCKHAM002)

5.1 Introduction

The importance of housing and powering various components of our solution is paramount. Without effective housing the components would be left exposed to the animals and unpredictable weather of the Kruger Park most certainly damaging and breaking them. Without power, the essential circuitry for the camera trap and base station would cease to function, rendering the whole project useless. Therefore, this chapter of the report investigates these crucial modules.

This chapter of the report is divided into three main sections: Camera Trap Power Module, Base Station Power Module, and Base Station Housing. Each section explores the design process and decisions behind its respective module, with the objective of designing a fully functioning prototype. Furthermore, each section will also provide future improvements and ideas to the design of the overall project with the long term goal of creating a deployable camera trap to study African Martial Eagles.

5.2 Camera Trap Power Module

5.2.1 Design Process

Requirements

The functional requirements of the camera trap power circuitry were determined based on several constraining factors. Mainly, the fact that the system has to be stored in a small unobtrusive housing, as to not disturb the birds being observed, which has to be placed a top a tree many metres above the ground. This system must power the entire camera module for multiple months at a time since the trap is effectively inaccessible when the birds are in the nest. Therefore, using this knowledge the following requirements were created:

1. **RC01:** The system must be able to power the ESP32 cam module, temperature sensor, humidity sensor, and PIR sensor.

2. **RC02:** The system must power a Browning Extreme Spec Ops Camera.

3. **RC03:** The system must have an operating lifespan that exceeds 6 months.
4. **RC04:** The power module must be small enough to fit within the constraints of the camera trap housing
5. **RC05:** The module must be light enough to be carried up a tree and strapped onto a tree branch.

Specifications

Specifications for the camera trap power module were then derived from the corresponding module requirements 5.2.1.

1. **DS01:** The power module must have a 5V, 500mA output.
   Requirement: RC01
2. **DS02:** The power module must have a 12V, 1A output.
   Requirement: RC02
3. **DS03:** The system must be able to recharge via a 12V Solar Panel.
   Requirement: RC03
4. **DS04:** The module must fit within 130x90x40mm.
   Requirement: RC04
5. **DS05:** The module's weight must be less than 500g.
   Requirement: RC05

Power Calculations

It was important to calculate the power consumption of all the various components in the system in order to accurately estimate the battery life of the device. This will allow us to choose the most cost effective battery solution, and validate our specifications outlined above 5.2.1. Tables 5.1 & 5.2 detail the power consumption of the individual components that are powered by the system and how long various batteries would be able to power these components for respectively.

Table 5.1: Power Consumption of Various Components

Device	Mode	Voltage (V)	Current (mA)	Power (W)
ESP 32 Cam	Deep Sleep	5	6	0.03
	Modern Sleep	5	20	0.10
	Light Sleep	5	6.7	0.034
	Flash on	5	310	1.55
	Flash off	5	180	0.90
	Wi-Fi transfer minimum	5	240	1.20
	Wi-Fi transfer maximum	5	800	4.00
Browning Extreme Spec Ops	Resting	12	0.08	0.00096
	Daytime	12	588	7.06
	Night-time	12	797	9.56
	Average*	12	3.9	0.047
DHT11 Temperature Sensor	Average	5	0.2	0.001
DHT11 Temperature Sensor	Maximum	5	1	0.005
PIR Sensor	Typical	5	0.05	0.00025
Total	Maximum Power Draw			13.66
	Typical Power Draw			1.25
	Minimum Power Draw			0.032

*The average current draw of the Browning Extreme Spec Ops trail camera assumes that the camera takes 144 photos in a day, one every 10 minutes, and that half of these pictures take place at night.

The estimated battery life was calculated using the formula $t = 10 \times \frac{A}{P}$, where t is the time in hours, A represents the battery capacity in Amp Hours, and P denotes the power consumption in Watts.

Table 5.2: Battery Lifespans for Various Battery Sizes

Device	**Mode**	**800mAh Battery Lifespan 14500/ rechargeable AA cell (Hours)**	**12000mA Battery Lifespan 8×Duracell non-rechargeable AA** (Hours)**	**2200mAh Battery Lifespan 18650 cell (Hours)**
ESP 32 Cam	Deep Sleep	266.67	NA	733.33
	Modern Sleep	80		220.00
	Light Sleep	235.29		647.05
	Flash on	5.16		14.19
	Flash off	8.88		24.44
	Wi-Fi transfer minimum	6.66		18.33
	Wi-Fi transfer maximum	2		5.50
Browning Extreme Spec Ops	Resting	8333.33	125000	22916.67
	Daytime	1.13	16.99	3.11
	Night-time	0.83	12.55	2.30
	Average	170.21	2553	468.08
DHT11 Temperature Sensor	Average	8000	NA	22000
DHT11 Temperature Sensor	Maximum	1600		4400
PIR Sensor	Typical	32000		88000
Total	Maximum Power Draw	0.58		1.61
	Typical Power Draw	6.4		17.6
	Minimum Power Draw	250		687.5

**The 8×Duracell AA are the built in battery pack of the Browning Extreme Spec Ops camera.

Batteries

The design process taken when choosing the various types of batteries for the system mainly revolved around deciding whether to make the system with rechargeable or non-rechargeable batteries.

While Non-rechargeable (primary) cells do have a higher energy density due to their lack design compromises to enable charging, they were deemed unfavourable of their fixed window of operation until the batteries die. On the other hand rechargeable (secondary) cells when paired with a solar panel or other renewable charging source would be able to run almost indefinitely minimising maintenance and disturbances to the animals being studied.

The costs of the various approaches were considered, with secondary cells and their respective charging circuitry costing less, R539 Vs R3000, when compared to primary cells. This cost estimate is based on the assumption that the primary cells would have to power the system for at least 6 months, this would take approximately 360×AA batteries. In contrast, the secondary cells would only have to power the system continuously for two days due to the implementation of solar charging.

Charging and Voltage Regulation

The charging circuitry of the camera trap power module is extremely important, without it the system would only be able to run for approximately 56 hours on three 18650 cells. Therefore, it is important that the charging circuitry used is efficient and reliable. The charging circuitry also has the job of protecting the battery and camera trap circuitry from any electrical damage.

Using this knowledge various all in one charging and battery management circuits were considered for the project. “The Solar 14500 Power Management Board” from Waveshare [31] was eventually chosen for its wide range of features and reasonable price. The board features that were desirable in our context are its ability to operate at high temperatures (up to 85°C), its wide solar panel input voltage range (6-24V), its battery management features (under-voltage lockout, and overcharging cutoff), and its ability to output regulated 5V 1A.

However, due to shipping delays the originally chosen “The Solar 14500 Power Management Board” did not arrive in time resulting in the “CN3065 - 1A Lithium Battery Charging Board” [32] being used instead. Unfortunately this board does not have the same suite of features at the Solar 1500 Power Management Board, missing the under-voltage lockout and voltage regulation.

The “HKD DC/DC BOOST ADJ MOD 5-35V 4A” [33] was originally intended to boost the output of the 5V output to 12V to allow for the Browning Trail Camera to be powered. However, due to the shipping delay of the charging board, the board was instead used to boost the 3.7V from the 18650 Li-ion battery to a regular 5V to power the ESP32 Cam board and sensor suite.

5.2.2 Prototype Design

For the prototype design, the “HKD DC/DC BOOST ADJ MOD 5-35V 4A”, “CN3065 - 1A Lithium Battery Charging Board”, and an 18650 Li-Ion cell were used. The components were connected together to form a rough prototype for testing. The prototype can be seen in figure 5.1.

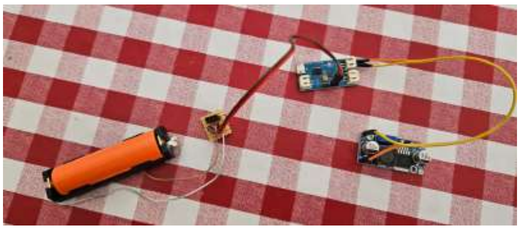


Figure 5.1: Prototype Camera Trap Power Module

5.2.3 Testing and Results

Acceptance Test Protocols

1. **ATP01:** The module must be powered by its own battery cells for 30 minutes. During this time the voltage regulator output must be measured by a digital multimeter.
   Pass Case: The output voltage of the regulator, as displayed by the multimeter, is $5 \pm 0.1V$.
   Specification: DS01

2. **ATP02:** The module must be powered by its own battery cells for 30 minutes. During this time the voltage regulator output must be measured by a digital multimeter.
   Pass Case: The output voltage of the regulator, as displayed by the multimeter, is $12 \pm 0.1V$.
   Specification: DS02

3. **ATP03:** The terminal voltage of the systems battery will be measured with a multimeter. Then a 12V DC voltage source is applied to the solar charging module, to simulate a solar panel being attached to the system for 60 minutes. After which the battery's terminal voltages will be measured by a multimeter.
   Pass Case: The battery terminal voltage must have increased by a minimum of 0.1V.
   Specification: DS03

4. **ATP04:** The power module will be inserted into the 3D printed camera trap housing, see Chapter 4.
   Pass Case: The power module fits within the housing.
   Specification: DS03

5. **ATP05:** The power module will be placed onto a scale and the reading will be taken.
   Pass Case: The scale measurement must not exceed 500g.
   Specification: DS04

Results

The system successfully passed ATP01 when tested, successfully outputting 5.00V. However, due to shipping delays the original solar charging board ordered did not arrive in time resulting in the system failing ATP02. The system failed ATP03 as the CN3065 charging board is not able to accommodate a 12V input. However, when a 5V input was applied the battery charged successfully. When the system was assembled fully it was discovered that the power module successfully fit inside the housing with a single 18650 cell, and room for two more cells. Therefore, it passed ATP04. When weighed the module was measured at $72g$. However, this was with just one 18650. The theoretical weight with three 1860 cells was calculated to be $162g$. Therefore, the system passed ATP05.

5.2.4 Final Design

Future Improvements

The future design of the module could be greatly improved from the current prototype iteration. Firstly, the addition of the solar charging board [31] would allow the system to complete ATP02 and would allow for more battery management features. However, the end goal would be to consolidate all of the modules into a single printed circuit board simplifying the design and assembly of the module. Lastly, adding a further two 18650 cells and an actual solar panel to the system are a must as this will allow it to operate to its full potential.

5.3 Base Station Power Module

5.3.1 Design Process

Requirements

The functional requirements for the base station power module revolve around the module powering the Raspberry Pi web server for an extended period of time. Since the module is placed on the ground it is accessible when the ornithologists collect the data from the system. Therefore, the batteries inside the housing can be replaced, and any other maintenance carried out. Using this knowledge the following requirements were created:

1. **RC06:** The system must be able to power the Raspberry Pi Microprocessor.
2. **RC07:** The system must be able to operate for extended periods of time without intervention or maintenance.
3. **RC08:** The power module must be small enough to fit within the base station housing.

Specifications

Specifications for the base station power module were then derived from the module requirements 5.3.1.

1. **DS06:** The power module must have a 5V, $500mA$ output.
   Requirement: RC06
2. **DS07:** The power module must have a replaceable battery system.
   Requirement: RC07
3. **DS08:** The system's battery life must last more than 6 months.
   Requirement: RC07
4. **DS09:** The module must fit within 140x140x40mm.
   Requirement: RC08

Table 5.3: Power Consumption of Various Components

Device	**Mode**	**Voltage (V)**	**Current (mA)**	**Power (W)**	**1000mAh Battery Lifespan (Hours)**	**12000mA Battery Lifespan 8x Duracell non-rechargeable AA (Hours)**
Raspberry Pi Zero W	Idle	5	260	1.3	7.6	92.30
	Stressed	5	370	1.85	5.4	64.86
	Average	5	336	1.68	5.95	71.42
Arduino Uno	Deep Sleep	5	0.57	0.0028	3571.42	42857.14
	Modified Arduino*	5	0.0308	0.0001	100000	1200000
Total	Maximum Power Draw			1.853	5.39	64.75
	Typical Power Draw			1.68	5.95	71.42
	Minimum Power Draw			1.3	7.6	92.3

Power Calculations

*The modified Arduino would have its voltage regulator and led removed to save on power draw [34].

Batteries

Since the system is accessed semi-regularly to collect the data from the unit primary cells were chosen for the base station power module. The cells chosen are regular AA sized alkaline batteries, these are readily available even in remote areas such as the Kruger National Park.

Non-rechargeable cells also require less circuit complexity due to the lack of charging circuitry. This allows us to bring down the cost of the base station considerably. With the primary cell implementation of 8×AA batteries and the voltage regulation circuitry, the system will cost R141.04.

Battery Life Extension

The calculations in table 5.3 show that the system battery life will only last a maximum of 92.3 hours. This would result in the system failing to meet the design specifications, specifically DS03.

Therefore, the system's battery life needs to be extended. To achieve this an Arduino uno and real time clock (RTC) were added to the system. The arduino is placed in sleep mode waking up and checking the time from the RTC every hour. If the desired time is detected the arduino will turn a general input output pin high turning on a relay and switching on the Raspberry Pi microprocessor. After 15 minutes the Arduino will switch off the relay and go back to sleep.

Using this implementation the battery life of the system was estimated to be extended from 71.42 hours to over a year.

5.3.2 Prototype Design

For the prototype design the L7805CV 5V voltage regulator was used for its ability to supply large amounts of current, widespread availability, and low cost. The system also used the "BMT RELAY BOARD 1CH 5V" [35] for the relay. The prototype can be seen in figure 5.3b.

5.3.3 Testing and Results

Acceptance Test Protocols

1. **ATP06:** The module must be powered by its own battery cells for 30 minutes. During this time the voltage regulator output must be measured by a digital multimeter.
   Pass Case: The output voltage of the regulator, as displayed by the multimeter, is $5 \pm 0.1V$.
   Specification: DS06

2. **ATP07:** The power module will be inserted into the 3D printed camera trap housing, see Chapter 5.4.
   Pass Case: The power module fits within the housing.
   Specification: DS09

Results

The system successfully passed ATP06 when tested, successfully outputting 5.00V. The system also successfully fit within the prototype housing, see figure 5.3b. Therefore, the system passed ATP07.

5.3.4 Final Design

Future Improvements

For an improved future design of the system consolidating the various modules, the relay, RTC, and voltage regulator onto a printed circuit board is certainly advised. This would improve the layout of the circuitry and minimise the chance of any wires from disconnecting potentially compromising the entire circuit. We would also recommend adding a second bank of 8×AA batteries to further improve battery life.

5.4 Base Station Housing

The base station housing is tasked with keeping the Raspberry Pi web server and its respective power module, see section 5.3, isolated from its surrounding environment.

5.4.1 Design Process

Requirements

Since the system is to be deployed in remote sections of the Kruger National Park, it will have to survive inclement weather, inquisitive animals, and a barrage of insects. Using the context of the housing the following requirements were produced:

1. **RC09:** The housing must be able to protect the internal circuitry from outside weather conditions

2. **RC10:** The housing should not allow insects to make their way inside to the electronics and nest potentially damaging the functionality of the module.

3. **RC11:** The enclosure should be robust enough to survive any small interactions from inquisitive wild animals.

4. **RC12:** The Raspberry Pi must still be able to communicate through Wi-Fi with the camera trap above.

5. **RC13:** Heat from the components inside must be effectively dissipated from the housing ensuring efficient operation.

Specifications

Specifications for the housing were then derived from these requirements. These were the derived specifications:

1. **DS07:** IP65 rating, dust-tight and protection against water jets.
   Requirement: RC09 & RC10

2. **DS08:** The enclosure must withstand being dropped from 1 metre.
   Requirement: RC11

3. **DS09:** The enclosure must withstand temperatures in excess of 40°C.
   Requirement: RC09

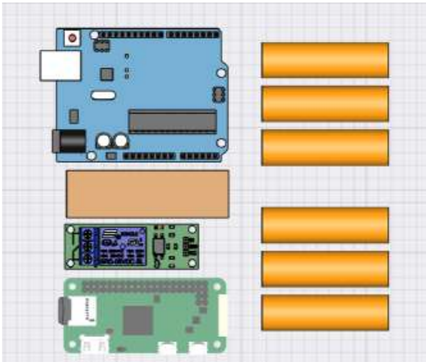
4. **DS10:** The Raspberry Pi's Wi-Fi signal is detectable from 15 metres away whilst the Pi is sealed within the housing.
   Requirement: RC12

5. **DS11:** The housing must keep the raspberry Pi processor from exceeding 80°C while operating the web server in a 40°C environment.
   Requirement: RC13

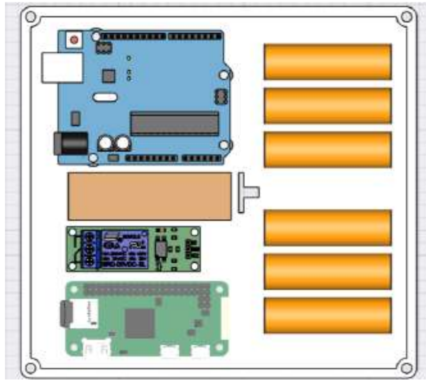
5.4.2 Housing Modelling

The housing was designed and modelled using a 3D computer aided design tool called Shapr3D. The process began first by importing all the measurements of the various internal components and deciding on a basic internal layout. A basic box shape of dimensions 150×160×40mm was then drawn around these components with screw holes added in the corners to allow for the lid to be securely attached. Mounting posts were then added to secure the various circuit boards and batteries within the housing. A Rudimentary lid design was then created.

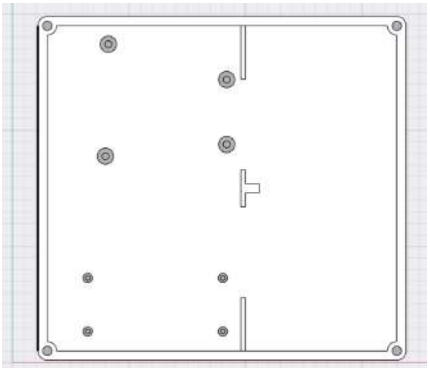
The following figure 5.2 highlights the various processes in designing the enclosure.



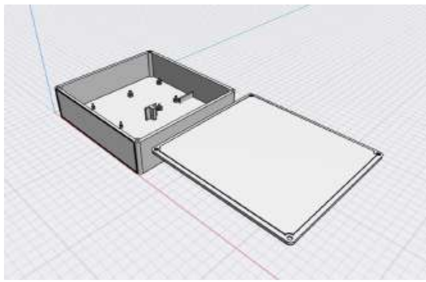
(a) Internal Components Layout



(b) Top View of Housing with Internal Components



(c) Internal Component Mounting Points Added



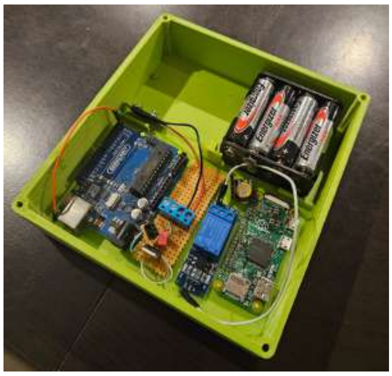
(d) Lid and Housing 3D View

Figure 5.2: Base Station Housing Design Process

5.4.3 Prototype Design

For the prototype design the housing was 3D printed using Polylactic Acid (PLA) filament. PLA was chosen for its low melting point, high strength, and low thermal expansion making it excellent for quick 3D printing. The 3D model seen in figure 5.2d was then printed on the University of Cape Town's Prusa Mini 3D printers. Due to load-shedding concerns the housing was printed at 200% speed, this unfortunately resulted in poor print quality on the sides and bottom of the housing box, seen in figures 5.3c & 5.3a.

(a) Top View of Prototype Housing



(b) Prototype Housing with Internal Components

(c) Side View of Prototype Box

Figure 5.3: Base Station Housing Prototype

5.4.4 Testing and Results

Acceptance Test Protocols

Following the development of the specifications, 5.4.1 acceptance test protocols (ATP's) were developed.

1. **ATP08:** The enclosure will be sprayed water jet, 12.5 litres per minute, for at least 3 minutes. [36]
   Pass Case: No water may be detected inside.
   Specification: DS07

2. **ATP09:** The enclosure will be dropped from a measured height of 1m. The test must be repeated three times
   Pass Case: The enclosure must not break in any way.
   Specification: DS08

3. **ATP10:** The enclosure will be placed into a 50° environment for four hours to simulate the harsh conditions of the Kruger.
   Pass Case: The enclosure may not deform in any way.
   Specification: DS09

4. **ATP11:** The Raspberry Pi will be sealed inside the housing and will output a Wi-Fi network allowing the user to access the web server.
   Pass Case: A Wi-Fi reciever must be able to detect and connect to the network from 15 metres away.

Specification: DS10

5. **ATP12:** The Raspberry Pi will be sealed inside the housing and will be running the webserver. The housing will then be placed inside a 40°C environment for 30 minutes. During this time the Raspberry Pi system on a chip's (SoC) temperature will be read from its built in temperature sensor.
Pass Case: The raspberry Pi SoC's must not exceed 80°C during this time, this indicates thermal throttling.
Specification: DS11

Results

After the tests outlined above, 5.4.4, were conducted the following results were concluded. The system unfortunately failed ATP08 as water was detected inside after testing was concluded. This is most likely due to the poor print quality affecting the seal between the lid and box. The system suffered a catastrophic failure, figure 5.4, when ATP09 was tested prohibiting further testing.

Figure 5.4: Housing After Testing ATP09

5.4.5 Final Design

Future Improvements

The results from the various test conducted to the housing, see 5.4.4, highlighted the design flaws of the system. Therefore, for future versions it is recommended to construct the base station housing out of metal. This would greatly improve the housing's durability as well as its heat dissipation. The addition of a rubber seal around the lid would also allow for manufacturing tolerances to be larger while still keeping the IP65 rating.

5.5 Conclusion

In conclusion the goals of the chapter have been successfully achieved. The exploration behind the design process of each respective module yielded favourable results with working prototypes being developed. Furthermore, lessons were learnt throughout the design process and testing resulting in improvements in key areas being identified for each section.

The testing of the camera trap power module yielded favourable results however, due to uncontrollable shipping delays this section was missing full functionality. Similarly, the base station housing was also missing full functionality with the housing failing its ATPs. However, the lessons learnt in this section provided excellent future design guidelines. Lastly, the base station power module ended up fully completing its test protocols. Even so, this still yielded key areas for improvement namely the packaging of the module. This lays the groundwork for future work, with the end goal of creating a deployable camera trap to study African Martial Eagles being well within reach.

Chapter 6

Section 4 - Raspberry Pi and Web Server

Prepared by Caide Spriestersback (SPRCAI002)

6.1 Introduction

This report presents the design choices, prototype design, and testing results of a subsystem developed for wildlife monitoring. The subsystem combines the Raspberry Pi Zero W and the ESP32 Cam board to capture wildlife images at predefined intervals and transmit them wirelessly for further processing. The report provides an overview of the design choices, including the selection of hardware components and the setup of the Raspberry Pi and auto hotspot feature. It also discusses the integration of the ESP32 Cam board and the image storage mechanism using the Raspberry Pi's microSD card. Furthermore, the report describes the setup of the LAMP web server stack for hosting a user-friendly interface to access and manage the captured images. The prototype design section explains the hardware integration of the ESP32 Cam board and the Raspberry Pi Zero W, as well as the software implementation for image capture, processing, and transmission. Lastly, the report presents the limitations of the subsystem and proposes future improvements, such as upgrading to a more powerful hardware platform for real-time object detection and enhancing the web server performance.

6.1.1 Requirements and Specifications

Requirements

The functional requirements of the Raspberry Pi and web server were determined based on the specific needs and constraints of the project. The main consideration was reliability of this system as it is the backbone for the other functionalities of the project.

The following requirements were therefore created:

1. **RC01:** The web server which is hosted on the Raspberry Pi must be functional.
2. **RC02:** The system must exhibit high reliability and seamless operation throughout its functionality.
3. **RC03:** The network settings on the Raspberry Pi shall be properly configured to ensure reliable connectivity and functionality of the auto hotspot feature.

4. **RC04:** The system shall be able to wirelessly transmit images.

5. **RC05:** The system shall be able to capture images.

Specifications

The requirements were then used to determine the following specificaitons:

1. **DS01:** The web server must have a basic Graphical User Interface (GUI) and be easy to navigate via links.
   Requirement: RC01

2. **DS02:** The system should be able to react to changes in front of the camera and still be able to function correctly.
   Requirement: RC02

3. **DS03:** The Raspberry Pi's network settings shall be configured to ensure smooth operation and connectivity, including setting up the Wi-Fi connection, configuring IP addresses, and enabling the auto hotspot feature.
   Requirement: RC03

4. **DS04:** The system shall include mechanisms to wirelessly transmit data at intervals to the web server.
   Requirement: RC04

5. **DS05:** The system will be able to capture images which are clear and high quality.
   Requirement: RC05

6.2 Design Choices

6.2.1 Raspberry Pi Setup and Auto Hotspot Feature

The Raspberry Pi Zero W was selected for its affordability and suitability for the application. It offers a 64-bit Arm Cortex-A53 CPU clocked at 1GHz and 512MB of LPDDR2 SRAM, providing sufficient processing power for the project. Additionally, the Pi Zero W includes 2.4GHz 802.11 b/g/n wireless LAN and Bluetooth 4.2 capabilities, enabling wireless connectivity. It incorporates a microSD card slot for storage and has 40 GPIO pins for interfacing with external devices.

One important consideration for the project was the operating temperature of the Raspberry Pi. The Pi Zero W can operate in temperatures up to 70°C, which is particularly relevant for the deployment in the Kruger National Park where temperatures can exceed 40°C/104°F. With this capability, the Raspberry Pi can withstand the harsh environmental conditions and ensure reliable operation in the park. It is crucial to have a system that can function effectively even in high-temperature environments to maintain the stability and longevity of the Raspberry Pi during its deployment.

To set up the Raspberry Pi, the chosen operating system was Raspberry Pi OS Lite (32-bit). This lightweight and efficient operating system was selected to optimize resource usage in the resource-constrained environment of the project. Raspberry Pi OS Lite does not include a Graphical User

Interface (GUI), which further reduces resource consumption and enhances performance. The operating system was burned onto a durable ADATA 16GB microSD card, which is waterproof, antistatic, and capable of operating in temperatures up to 85°C, ensuring the storage medium's reliability even in demanding conditions.

The 2.4GHz 802.11 b/g/n wireless LAN capability of the Raspberry Pi Zero W is essential for setting up the access point. This feature allows the Raspberry Pi to act as a router, facilitating the connection for the ESP32 Cam board to transmit information to the Raspberry Pi.

To implement the auto hotspot feature on the Raspberry Pi, a tutorial provided by RaspberryConnect (Auto Hotspot Tutorial) was followed. This tutorial offered step-by-step instructions for configuring the Raspberry Pi as an auto hotspot, allowing for seamless switching between a known Wi-Fi network and an access point. The tutorial provided valuable insights into monitoring Wi-Fi connection status and implementing the necessary scripts for automatic switching.

To ensure smooth operation and connectivity, specific network settings were configured on the Raspberry Pi. This involved setting up the Wi-Fi connection, configuring IP addresses, and enabling the auto hotspot feature. Key configurations included:

- Setting up the Wi-Fi connection: The Raspberry Pi was configured to connect to a known Wi-Fi network when available, providing access to the internet and other network resources.
- Configuring IP addresses: The network interfaces and IP addresses were configured to enable seamless switching between the access point mode and the known Wi-Fi network mode.
- Enabling the auto hotspot feature: The necessary modifications were made to the Raspberry Pi's settings to allow it to dynamically switch between the access point mode and connecting to a known Wi-Fi network.

By carefully configuring these network settings, the Raspberry Pi was able to maintain reliable connectivity and facilitate the desired functionality of the auto hotspot feature.

To ensure the robust and reliable operation of the Raspberry Pi setup and the auto hotspot feature, several design considerations were taken into account. These included:

- Implementing error handling mechanisms: The code was designed to handle potential errors or unexpected scenarios, such as network disconnections or failures in the auto hotspot switching process.
- Monitoring network connectivity: The system was equipped with mechanisms to monitor the stability and availability of the network connection, allowing for proactive responses to network issues.
- Considering potential failure scenarios: Contingency plans were put in place to address potential failure scenarios, ensuring that the system can recover and continue functioning even in adverse conditions.

By incorporating these robustness and reliability considerations, the Raspberry Pi setup demonstrated resilience and maintained consistent performance, contributing to the overall success of the project.

6.2.2 ESP32 Cam Board Integration and Image Storage

The ESP32 Cam board plays a crucial role in capturing and transmitting images in our project. It is a compact module equipped with an ESP32 microcontroller and boasts important features such its WIFI image upload support, its ability to support OV2640 and OV7670 cameras, which provides both processing power and wireless connectivity capabilities. The board boasts impressive feature, the ones of interest is its full compliance with WiFi 802.11b/g/n/e/i and Bluetooth 4.2 standards and can operate at temperatures up to 85°C. The integration of the ESP32 Cam board involves the following steps:

- Hardware setup: The ESP32 Cam board needs to be properly connected to the Raspberry Pi. This typically involves connecting the camera module to the board and establishing the necessary connections in the code uploaded to the ESP board via a FTDI chip.
- Software configuration: To utilize the ESP32 Cam board, specific software libraries and dependencies need to be installed on the Raspberry Pi. These libraries enable communication and control between the Raspberry Pi and the ESP32 Cam board.

In our project, we need a reliable method to store the images captured by the ESP32 Cam board. To achieve this, we utilize the storage capabilities of the Raspberry Pi, specifically the microSD card. The process involves:

- Mounting the microSD card: The Raspberry Pi should be configured to recognize and mount the microSD card for storing the captured images. This typically requires configuring the file system and ensuring the microSD card is properly detected on system start-up.
- Image storage format: Consideration should be given to the format in which the images are stored on the microSD card. Choosing a suitable format, such as JPEG, can help balance image quality and file size.
- File organization: It is important to establish a logical and organized file structure for storing the images. This ensures easy retrieval and management of the captured images during further processing or analysis.

By integrating the ESP32 Cam board and implementing an effective image storage mechanism, we can capture and store images seamlessly within our system. This allows us to leverage the images for subsequent analysis, object detection, or any other desired processing tasks.

6.2.3 LAMP web server Setup

The LAMP stack, comprising Linux, Apache, MySQL, and PHP, was chosen as the web server solution for its compatibility with the Raspberry Pi and its ability to handle image uploads from the ESP32 Cam board. This widely used combination of open-source technologies provides a robust and scalable platform for hosting dynamic websites and web applications.

Linux, as the operating system, ensures optimal performance and resource utilization on the Raspberry Pi while offering stability, security, and extensive software support. Apache, the leading open-source web server software, efficiently handles HTTP requests and facilitates communication between the ESP32 Cam board and the Raspberry Pi.

MySQL, a powerful open-source relational database management system, stores and manages the captured image data, enabling seamless access to images. PHP, a popular server-side scripting language, is used to develop the dynamic web application for handling image uploads and interacting with the MySQL database.

By leveraging the architecture and components of the LAMP stack, our web server solution provides a solid foundation for scalability, reliability, and security. This combination of well-established technologies ensures efficient image storage and management within the project.

6.3 Prototype Design

6.3.1 System Overview

Our system is designed to monitor wildlife using a combination of a Raspberry Pi and an ESP32 Cam board. The Raspberry Pi serves as the central controller, while the ESP32 Cam board captures images and communicates wirelessly.

The system captures wildlife images at predefined intervals using a timer-based approach. The ESP32 Cam board captures the images and transmits them to the Raspberry Pi for further processing.

The Raspberry Pi would ideally perform object detection on the captured images to identify wildlife objects of interest. The detected objects are recorded and stored for further analysis.

An auto hotspot feature enables the system to operate in areas without existing network infrastructure. The Raspberry Pi dynamically switches between acting as an access point and connecting to known Wi-Fi networks for reliable data transmission, this allows the researcher to remotely access the Raspberry Pi and make modifications if necessary.

A web server is integrated into the system, providing a user-friendly interface for remote access to the captured images. Users can navigate through the images, retrieve specific images based on date and time, and delete images if the researcher deems the image unnecessary.

This subsystem offers an automated and wireless solution for wildlife monitoring, combining image capture, object detection, and data transmission capabilities.

6.3.2 Hardware Integration

Our subsystem combines the ESP32 Cam board and the Raspberry Pi Zero W to enable image capture and wireless transmission for wildlife monitoring. The integration of these components involves connecting and configuring them to work together seamlessly.

The ESP32 Cam board, as described in the tutorial [37], is known for its camera compatibility and wireless connectivity features. Using the steps outlined in the tutorial, we connected the camera module to the ESP32 Cam board and configured it to capture images efficiently. The board's WiFi capabilities allow for wireless transmission of the captured images to the Raspberry Pi Zero W.

The Raspberry Pi Zero W, acting as the main processing unit of our subsystem, receives the transmitted images from the ESP32 Cam board. Following the guidance provided in the tutorial [38], and performs image processing tasks using software algorithms. These algorithms enable functions such as image filtering, object detection, or image enhancement to extract meaningful information from the captured images. In the case of our prototype, no filtering or object detection or image enhancement was performed. The unprocessed images are then stored for later analysis and processing.

To physically implement the subsystem, we securely mounted the ESP32 Cam board into its housing and the Raspberry Pi Zero W within a protective enclosure, ensuring environmental protection as mentioned in the tutorial [37]. This enclosure safeguards the components against dust, moisture, and physical damage. We also ensured stable and reliable operation by carefully connecting the power sources to both components, adhering to the tutorial's recommendations [37][38].

6.3.3 Software Implementation

The software implementation of our subsystem relies on the integration of the ESP32 Cam board and the Raspberry Pi Zero W, utilizing the capabilities of both devices for efficient image capture, processing, and wireless transmission. To enable image capture and transmission, we followed the tutorial provided by Random Nerd Tutorials [37]. This tutorial guided us through the setup of the ESP32 Cam board, including configuring the camera module and establishing a connection to the Raspberry Pi Zero W via Wi-Fi. By following the steps outlined in the tutorial, we were able to ensure seamless communication between the ESP32 Cam board and the Raspberry Pi Zero W.

Additionally, we utilized the tutorial from RaspberryConnect [38] to implement the auto hotspot functionality on the Raspberry Pi Zero W. This tutorial provided the necessary steps to configure the Raspberry Pi Zero W as an access point, allowing for direct connections with other devices without the need for an existing Wi-Fi network. This feature proved to be essential in our wildlife monitoring system, enabling remote access to the Raspberry Pi Zero W and facilitating the transmission of captured images.

By leveraging the expertise shared in these tutorials, we successfully integrated the ESP32 Cam board and the Raspberry Pi Zero W, harnessing their combined power to capture, process, and transmit images wirelessly. This software implementation forms a crucial component of our subsystem, facilitating efficient data flow and enabling real-time monitoring and analysis of wildlife activities.

6.3.4 Limitations and Future Improvements

One of the limitations of my subsystem is the inability to implement real-time object detection on the Raspberry Pi Zero due to its ARMv6 architecture. Object detection requires significant computational power, which the Raspberry Pi Zero's ARMv6 processor lacks. Despite my best efforts, I encountered technical limitations that prevented me from executing object detection algorithms on the Raspberry Pi Zero. This limitation hinders the ability of the subsystem to store only the relevant images that contain animals and discard the images that do not contribute to our wildlife monitoring goals.

To address this limitation and enhance the capabilities of our system, I propose upgrading to a more powerful hardware platform, such as the Raspberry Pi 4. The Raspberry Pi 4 offers a higher-performance

ARMv7 or higher architecture, providing the computational resources necessary for real-time object detection. With real-time object detection, the system would be able to selectively store images that contain animals, filtering out irrelevant images and optimizing storage capacity.

Moreover, the more powerful Raspberry Pi 4 would also enable me to enhance the performance of our web server. With a faster processor and increased memory, my system could handle larger numbers of concurrent requests, improve response times, and provide a more robust and efficient user experience.

Additionally, the integration of the hardware components and functionalities developed by other team members into one comprehensive system would be facilitated by the Raspberry Pi 4's enhanced capabilities. Combining the power management system, data transmission capabilities, and sensor integration with the improved processing power of the Raspberry Pi 4 would result in a more integrated and cohesive wildlife monitoring system.

In conclusion, upgrading to the Raspberry Pi 4 would address the limitation of ARMv6 architecture, enabling real-time object detection, improved web server performance, and the integration of multiple functionalities. These enhancements would allow me to store only relevant images containing animals, discard unnecessary images, and create a more comprehensive and efficient wildlife monitoring system.

6.4 Testing and Results

This section focuses on my individual contribution to the project, which involves implementing the subsystem that combines the ESP32 Cam board and the Raspberry Pi Zero W for image capture and wireless transmission in wildlife monitoring. My role encompasses efficient image capture, wireless transmission, and web server functionality. I conducted thorough testing and evaluation to assess the performance of my contribution and its alignment with the project objectives.

To evaluate the effectiveness of my subsystem, I designed a set of Acceptance Test Procedures (ATPs) that target specific functionalities. These ATPs define objectives and corresponding test procedures to evaluate the performance of my contribution. The tests cover image capture, wireless transmission, web server functionality, access point and Raspberry Pi boot configuration, and system reliability.

Through comprehensive testing, analysis, and evaluation, I assessed the performance of my subsystem against each ATP. This evaluation includes a detailed assessment of its capabilities, as well as an examination of its strengths, limitations, and potential areas for improvement.

In the upcoming sections, I present the ATPs, the employed test procedures, and the corresponding results and analysis. This comprehensive overview provides insights into the achieved performance of my individual contribution to the project.

6.4.1 Acceptance Test Procedures

1. **ATP01** Objective: Image Capture

   Test Procedure: Verify that the ESP32 Cam board successfully captures high-quality images using the camera module.

   Expected Outcome: Clear and well-defined images are captured and stored for further processing.

Specification: DS05

2. **ATP02** Objective: Wireless Transmission

   Test Procedure: Validate the wireless transmission functionality between the ESP32 Cam board and the Raspberry Pi Zero W.

   Expected Outcome: Images captured by the ESP32 Cam board are wirelessly transmitted and received by the Raspberry Pi Zero W without data loss or interference.

   Specification: DS04

3. **ATP03** Objective: Web Server Functionality

   Test Procedure: Evaluate the web server functionality implemented on the Raspberry Pi Zero W.

   Expected Outcome: The web server successfully serves a user-friendly interface, allowing users to access the captured images and perform basic operations, such as viewing, downloading, and managing the images.

   Specification: DS01

4. **ATP04** Objective: Access Point and Raspberry Pi Boot Configuration

   Test Procedure: Verify the successful setup and configuration of the access point on the Raspberry Pi Zero W, ensuring that it automatically creates a Wi-Fi hotspot when no existing network is available.

   Expected Outcome: The Raspberry Pi Zero W functions as an access point, allowing other devices to connect to it and access the web server interface. The access point should be automatically activated upon booting the Raspberry Pi Zero W.

   Specification: DS03

5. **ATP05** Objective: System Reliability

   Test Procedure: The test involved evaluating the subsystem's reliability and stability under normal operating conditions. It focused on verifying that the system functions reliably and quickly, without encountering critical failures or performance degradation during regular usage.

   Expected Outcome: The subsystem demonstrates reliability and stability, operating smoothly and responsively without experiencing significant delays or errors.

   Specification: DS02

6.4.2 Results and ATP Validation

ATP01: Image Capture

The objective of this test is to verify that the ESP32 Cam board successfully captures high-quality images using the camera module. The test involved capturing multiple images using the ESP32 Cam board and storing them on the web server for further processing. The expected outcome was clear and well-defined images to be captured and stored for further processing.

The test was performed, and the ESP32 Cam board successfully captured a series of high-quality images. A screenshot of the web server interface displaying the captured images is provided below:

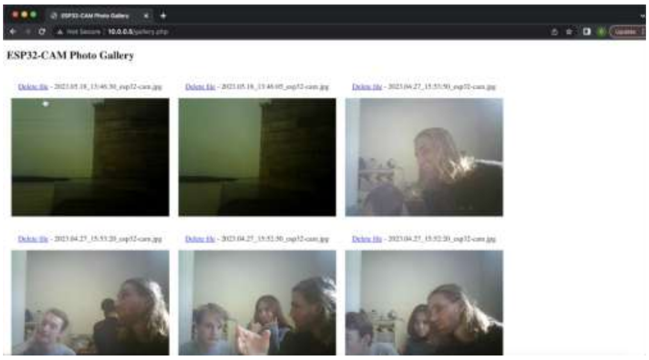


Figure 6.1: Screenshot of web server showing images taken by the ESP32 Cam board

The captured images demonstrate the capability of the ESP32 Cam board to produce clear and well-defined visuals. Each image represents a snapshot taken by the camera module and highlights the effectiveness of the image capture functionality within the system. These images serve as valuable inputs for subsequent analysis and processing stages.

By successfully fulfilling **ATP01**, the system confirms its ability to capture high-quality images, which is crucial for the overall functionality and effectiveness of the wildlife monitoring system.

ATP02: Wireless Transmission

The objective of this test is to validate the wireless transmission functionality between the ESP32 Cam board and the Raspberry Pi Zero W. The test involved capturing an image using the ESP32 Cam board and wirelessly transmitting it to the Raspberry Pi Zero W. The successful reception of the image by the Raspberry Pi Zero W without data loss or interference was verified. I expect the images captured by the ESP32 Cam board to be wirelessly transmitted and received by the Raspberry Pi Zero W without data loss or interference.

The test was performed, and the wireless transmission functionality between the ESP32 Cam board and the Raspberry Pi Zero W was successfully validated. A screenshot of the Arduino IDE displaying the successful transmission of an image is provided below:

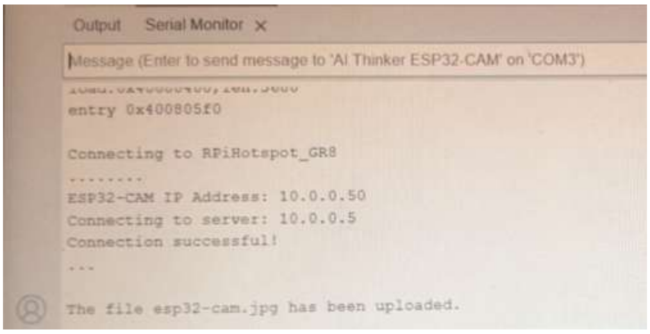


Figure 6.2: Screenshot of Serial Monitor showing successful operation

The screenshot clearly demonstrates the successful wireless transmission of an image from the ESP32 Cam board to the Raspberry Pi Zero W. The transmitted image was received without any data loss or interference, confirming the robustness and reliability of the wireless communication between the two components.

By meeting **ATP02**, the system verifies its ability to wirelessly transmit captured images, which is essential for remote monitoring and data transfer in the wildlife monitoring system.

ATP03: Web-server Functionality

The objective of this test is to evaluate the web server functionality implemented on the Raspberry Pi Zero W. The test involved accessing the web server interface hosted on the Raspberry Pi Zero W and verifying its functionality. The web server should serve a user-friendly interface that allows users to access the captured images and perform basic operations, such as viewing, downloading, and managing the images. I expect the web server successfully serves a user-friendly interface, allowing users to access the captured images and perform basic operations, such as viewing, downloading, and managing the images.

The test was performed, and the web server functionality implemented on the Raspberry Pi Zero W was evaluated. A screenshot of the graphical user interface (GUI) showcasing the web server interface is provided below:

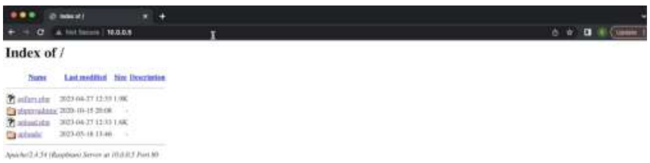


Figure 6.3: Screenshot of showing the web server graphical user interface

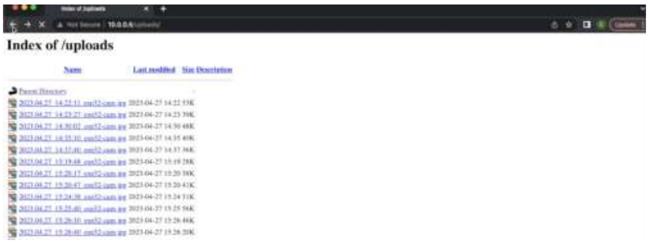


Figure 6.4: Screenshot of showing the images being stored in uploads

The screenshots demonstrate the successful implementation of the web server functionality. The web server interface provides a user-friendly platform where users can access the captured images. It offers features such as image browsing, downloading, and management options, enabling users to interact with the stored images conveniently.

By meeting **ATP03**, the system ensures that users can easily access and manage the captured images through the web server interface. This functionality enhances the usability and accessibility of the wildlife monitoring system, allowing users to effectively analyze and utilize the collected data.

ATP04: Access Point and Raspberry Pi Boot Configuration

The objective of this test is to verify the successful setup and configuration of the access point on the Raspberry Pi Zero W. The access point should automatically create a Wi-Fi hotspot when no existing network is available. The test involved booting up the Raspberry Pi Zero W and verifying that the access point is automatically activated. Additionally, connecting to the access point from another device and accessing the web server interface to confirm its functionality. I expect the Raspberry Pi Zero W to function as an access point, allowing other devices to connect to it and access the web server interface. The access point should be automatically activated upon booting the Raspberry Pi Zero W.

The test was performed, and the successful setup and configuration of the access point on the Raspberry Pi Zero W were verified. The following screenshots demonstrate the achieved outcomes:

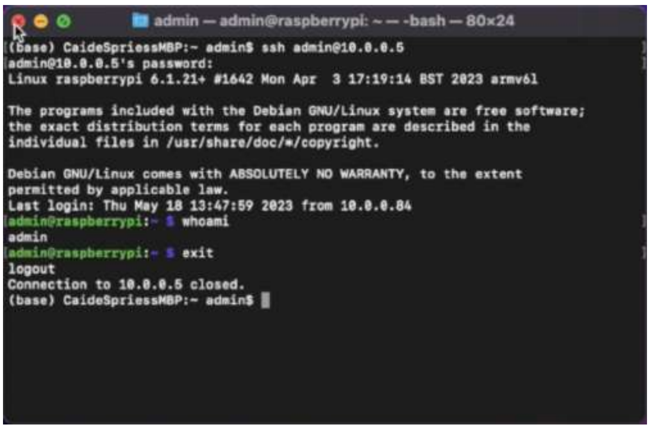


Figure 6.5: Screenshot of showing the SSH Connection to Raspberry Pi Zero W

The screenshot shows a successful SSH connection to the Raspberry Pi Zero W, indicating that the device is operational and can be accessed remotely.

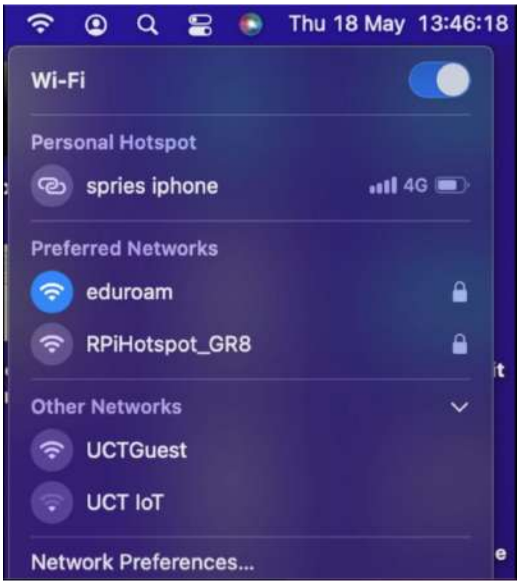


Figure 6.6: Screenshot of showing the Access Point being detected in Wi-Fi list

The screenshot displays the access point created by the Raspberry Pi Zero W, which appears in the list of available Wi-Fi networks. This indicates that the access point functionality is functioning correctly.

By successfully meeting **ATP04**, the system ensures that the Raspberry Pi Zero W functions as an access point, automatically creating a Wi-Fi hotspot when no existing network is available. This allows other devices to connect to the Raspberry Pi and access the web server interface, providing seamless connectivity and access to the wildlife monitoring system.

ATP05: System Reliability

The objective of this test is to assess the reliability and stability of the subsystem. The test involved evaluating the subsystem's reliability and stability under normal operating conditions. It focused on verifying that the system functions reliably and quickly, without encountering critical failures or performance degradation during regular usage. I expect the subsystem to demonstrate reliability and stability, operating smoothly and responsively without experiencing significant delays or errors.

The subsystem exhibited excellent reliability and stability during testing, performing reliably and responsively. The following screenshots provide evidence of meeting ATP 5:

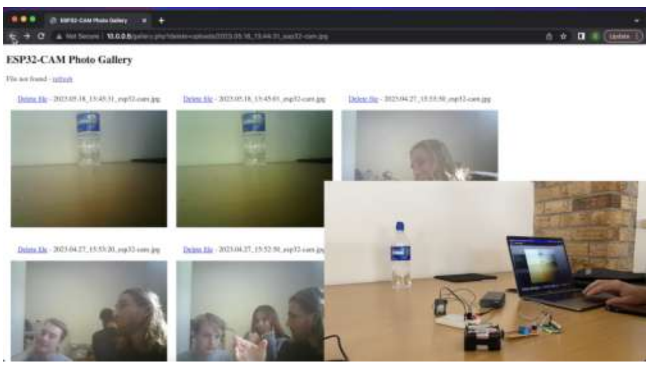


Figure 6.7: Screenshot of showing a Live Demo - Image Upload

In this screenshot, the live demo showcases the subsystem's full functionality. The camera captures an image that includes a bottle, and the system successfully processes the image, resulting in the bottle images appearing on the web server. This demonstrates the reliability and stability of the system's image processing functionality.

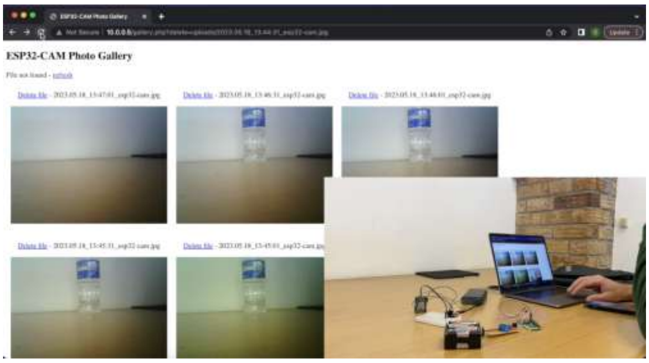


Figure 6.8: Screenshot of showing a Live Demo - Non-Bottle Image Upload

In this screenshot, the live demo demonstrates the system's ability to upload images that do not contain a bottle. By removing the bottle from the scene and capturing a new image, the system successfully uploads the image to the web server. This showcases the reliability and stability of the system's image upload functionality.

By successfully meeting **ATP05**, the subsystem demonstrates its reliability and stability. The system functions smoothly and responsively, allowing users to quickly interact with the web interface, process images efficiently, and upload images without encountering delays or errors. This reliability ensures the efficient operation of the wildlife monitoring system, providing users with a seamless experience and facilitating the capture, analysis, and management of images in a reliable manner.

6.5 Conclusion

The developed subsystem for wildlife monitoring successfully combines the Raspberry Pi Zero W and the ESP32 Cam board to capture and transmit wildlife images wirelessly. The design choices, including the selection of hardware components and setup of the Raspberry Pi and auto hotspot feature, were carefully considered to ensure reliability and functionality in high-temperature environments. The integration of the ESP32 Cam board and the image storage mechanism using the Raspberry Pi's microSD card provides a seamless solution for capturing and storing images. Additionally, the implementation of the LAMP web server stack enables remote access to the captured images through a user-friendly interface.

However, the subsystem has limitations, particularly the inability to perform real-time object detection on the Raspberry Pi Zero W due to its ARMv6 architecture. To address this limitation and enhance the system's capabilities, an upgrade to a more powerful hardware platform, such as the Raspberry Pi 4, is proposed. The Raspberry Pi 4 would enable real-time object detection, improve web server performance, and facilitate the integration of other functionalities developed by team members. Testing and evaluation of the subsystem demonstrated its effectiveness in meeting the desired objectives, and future improvements would further optimize the system's performance and functionality for wildlife monitoring.

Chapter 7

Conclusions

The aim of this project was to consolidate our various design methodologies and differences to develop an engineering solution to the various problems faced by the ornithologist Kyle Walker. Kyle studies the endangered African Martial Eagle and their feeding habits. He completes through the use of camera traps placed observing the eagle's nests. While this system works, it is a laborious process with the nesting trees having to be scaled each time Kyle wishes to retrieve the data. Therefore, we sought to make this process easier.

The report first explored existing solutions in the literature and their relevance to our specific proposed solution. The report was then split into four main sections each headed by a different group member explaining their contributions to the solution. These sections outlined how our solution was designed and implemented and explain the functionality reached.

In summary, the camera trap we designed was able to capture and transmit images from its housing to the web server hosted on the Raspberry Pi web server. The camera trap module was successfully designed such that human interactions be limited to installation and removal. The group also explored the viability of a Wi-Fi SD card transmission method to the web server. This method also proved successful. The web server also proved a success, being easily accessible from any device with Wi-Fi connectivity, allowing for the easy management of the photographs taken.

These improvements will allow for Kyle Walker to access his data without needing to climb any future trees. Therefore, the project was deemed a success, achieving the goals set out from the start. We look forward to seeing what the future holds for our project and for group 8 as a whole.

Chapter 8

Recommendations

The recommendations presented in this report aim to enhance and optimize the overall performance and functionality of the wildlife monitoring project. These recommendations focus on addressing limitations, increasing efficiency, and expanding the capabilities of the system. Implementing these recommendations will contribute to the development of a more robust and comprehensive wildlife monitoring solution.

To enhance the sensing functionality, we recommend the RFROBOT Firebeetle 2 instead of the ESP32 Cam board. The Firebeetle 2 provides more General Purpose Input Output (GPIO) pins, enabling additional sensing capabilities such as temperature. By utilising the Firebeetle 2, images can be stored onboard on an SD card before being transmitted to the web server. This feature was not achievable due to limited memory space on the ESP32 Cam board and is required for the deep sleep configuration where the Raspberry Pi is switched on and off.

To enhance the camera trap housing's waterproofing and structural integrity, we propose using a resin-based 3D printer. This technology offers improved durability and protection against environmental factors. Incorporating heat reduction padding within the camera trap housing will aid in the regulation of temperatures and thus safeguarding internal components.

Developing a PCB circuit that consolidates all camera trap's power systems will simplify the overall design and improve efficiency. Although a 12V, 1 Amp support did not arrive in time due to shipping delays, it is essential to include to ensure adequate power for the system.

To aid in heat dissipation and increase durability, it is recommended to construct the bottom housing using metal materials. Ensuring the bottom housing is watertight is crucial to protect internal components from water damage and main the system's functionality.

Upgrading to a more advanced Raspberry Pi, ideally a Raspberry Pi 4, will enable object detection to be done on the captured images. This feature can facilitate more efficient storage by automatically purging images that do not contain animals. A more powerful Raspberry Pi allows for the creation of a comprehensive server that consolidates all the mentioned functionalities in the above report into one system. This setup will make all necessary information easily accessible via the website, hosted on the web server.

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