Wildlife Monitoring in the Kalahari: System for Observing Twilight Activities of Fork-tailed Drongos

GROUP 22

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Abstract

This report details the development of an innovative wildlife monitoring system designed to study the twilight activities of Fork-tailed Drongos in the arid Kalahari. Our design integrates infrared camera traps with a robust power management system capable of operating in remote and harsh environments. This system aims to address the limitations of current wildlife monitoring technologies, which suffer from rapid battery depletion and unreliable performance, hindering effective data collection. By implementing a solar-powered energy solution and enhancing camera trap technology, this project seeks to provide reliable, continuous monitoring without the need for frequent maintenance. The outcomes expected from this project include improved observational capabilities of Fork-tailed Drongos during twilight periods.

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Abbreviations

Arm Advanced RISC Machines

CSI Camera Serial Interface

GUI Graphical User Interface

IR Infrared

PIR Passive Infrared

RADAR Radio Detection and Ranging

RAII Resource Acquisition Is Initialization

RISC Reduced Instruction Set Computer

SBC Single Board Computer

SCP Secure copy protocol

SFML Simple and Fast Multimedia Library

SSH Secure Shell

STL Standard Template Library

TCP Transmission Control Protocol

XML Extensible Markup Language

Chapter 1

Introduction

1.1 Background

This project focuses on the integration of technology to enhance the observation and study of wildlife, particularly through the use of camera traps in the study of Fork-tailed drongos in the Kalahari. The project is designed to interface closely with stakeholders like Ben, a PhD student under Dr. Susan Cunningham and Dr. Tom Flower, who is studying how Fork-tailed drongos mitigate the challenges of breeding in the extreme temperatures of the arid Kalahari.

1.2 Objectives

The primary objective of this project is to develop a reliable, cost-effective, and efficient wildlife monitoring system using infrared camera traps. The system aims to capture detailed footage of Fork-tailed drongos' twilight activities, specifically focusing on their feeding behavior and the predation risks at varying temperatures. Enhancements in camera reliability, battery life, and overall data quality are central to achieving this objective, enabling comprehensive behavioral studies of drongos and potentially other species in similar environmental conditions.

1.3 System Requirements

The system must be capable of extended autonomous operation in harsh, remote environments with minimal maintenance. It should provide high-resolution images and videos, operate efficiently across a range of temperatures, and feature robust data storage and transmission capabilities. The design must also ensure ease of deployment and retrieval, with consideration for the ecological impact on the surveyed wildlife.

1.4 Scope & Limitations

This project is limited to the technological aspects of wildlife monitoring systems. While the design aims to be broadly applicable to various environmental conditions, the primary testing and implementation will focus on the arid regions inhabited by Fork-tailed drongos. Budgetary constraints, technological limitations, and environmental regulations may also restrict certain design aspects, such as the choice of materials and technologies used.

1.5 Report Outline

The report begins with a literature review outlining the problem and background behind the project. Subsequent chapters detail the design process for each submodule, including the power, camera and sensing, mechanical housing, and graphical user interface submodules. Each of these chapters outlines the rationale behind design choices, the integration of subsystems, and the methods used for testing and validation. The report concludes with chapters on conclusions and recommendations. Additionally, a bibliography and appendices are included.

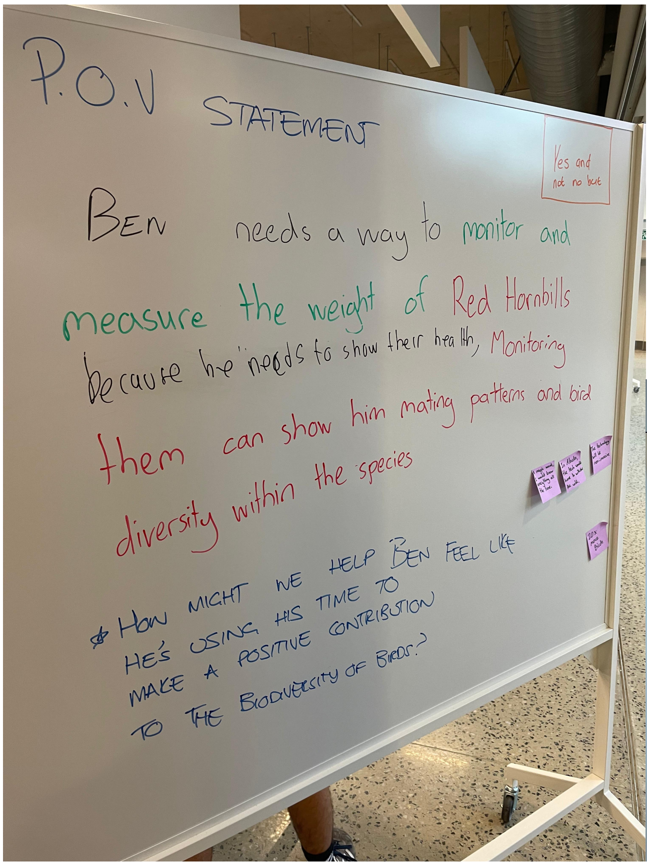
1.6 D-School

1.6.1 Activities

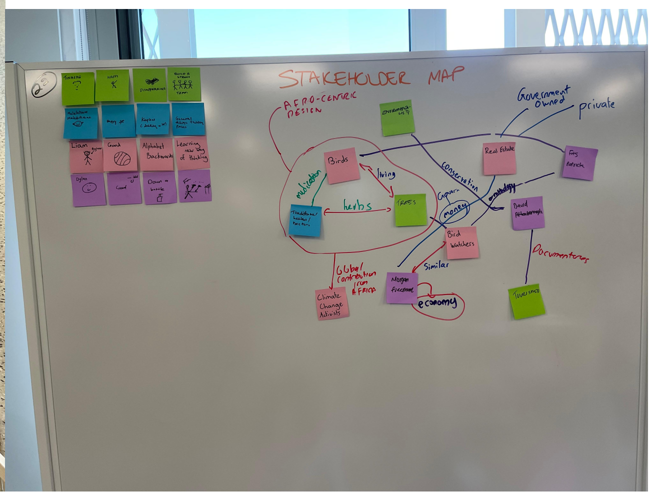
Over two 6-hour sessions at the Design School, we honed our abilities and knowledge essential for creating products that truly meet user needs and are designed with the user in mind. Our journey began with mastering the art of defining problems, delving deep to uncover the underlying motivations behind our clients' requirements. Through collaborative mini-interviews, we explored various scenarios, gaining insights into our clients' perspectives.

Subsequently, we crafted problem statements that encapsulated these insights, refraining from rushing to solutions prematurely. The second session featured presentations by researchers from the FitzPatrick Institute, shedding light on field research methodologies, motivations, and encountered challenges. Leveraging our acquired skills, we dissected problems, formulated multiple statements, and devised a range of solutions.

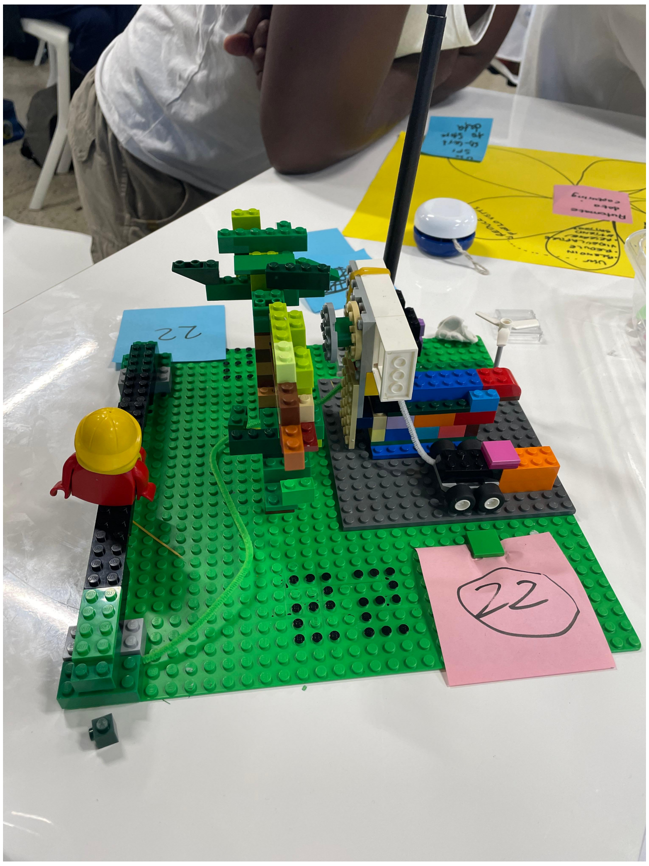
The accompanying figures offer glimpses into the collaborative work we engaged in during these sessions.



(a) Forming a problem Statement



(b) Stakeholder Map



(c) Prototyping

Figure 1.1: D School Activities

1.6.2 Design Choices

For development of efficient and low cost power system different DC-DC converters, power panels and batteries were considered. Additionally, variety of SBCs, cameras and motion detection methods were evaluated in order to have a reliable camera system. A comprehensive set Graphical User Interface (GUI) libraries were also investigated so that user friendly GUI can be developed. Finally, different materials and designs of housing system were considered so that portable and well ventilated housing system can be developed.

1.6.3 Choosing One (or fusing multiple into one)

Exploring multiple design ideas allows us to gather insights into their strengths and weaknesses. By considering different perspectives, we can identify the pros and cons of each idea and incorporate them into a refined final design. The collective benefits of multiple ideas while mitigating their individual limitations, allows us to obtain an optimal solution that meets the requirements resulting in a final design that is more robust, efficient, and innovative.

1.6.4 Brief description of each subsection

- **Power Submodule:** Provides continuous, stable power using a solar-charged battery system, ensuring the device operates autonomously in remote environments.
- **Housing Submodule:** Encases the electronic components in a protective housing that supports both functionality and durability under field conditions.
- **Camera and Sensing Submodule:** Captures high-quality images and data using advanced sensors and camera technology, optimized for low-light conditions and remote monitoring.
- **Graphical User Interface Submodule:** Manages data reception between the field device and a computer, enabling remote access to data and providing analytics.

Chapter 2

Literature Review

2.1 Problem Statement

Ben Murphy from the Fitzpatrick Institute is conducting a study on the Fork-tailed Drongo, focusing on their twilight feeding activities. The research is hampered by geographical and logistical challenges. The birds inhabit remote and hard-to-access locations, making data collection difficult. Further complicating the study are the limitations of the current camera traps. These devices, outdated and unreliable, suffer from rapid battery depletion, which impacts the continuous collection of data during crucial twilight periods. Additionally, the high replacement costs are prohibitive, limiting the ability to update the technology or deploy additional cameras. Ben needs an energy-efficient and cost-effective method to effectively document the Fork-tailed Drongos' twilight feeding behavior.

2.2 Introduction

The observation of bird activities presents numerous challenges, particularly when documenting specific behaviors such as the twilight feeding routines of Fork-tailed Drongos. This literature review delves into the technological and methodological advancements within wildlife research, focusing primarily on camera trapping and its applications in studying avian species. It evaluates the effectiveness, limitations, and innovations in camera technology, alongside considerations of animal behavior and environmental impact, aiming to provide an insightful framework for overcoming the challenges faced by researchers like Ben. The review further explores the intersection of wildlife activity with various light sources and the implications for filming under twilight conditions. Additionally, this review explores innovative solutions in the realms of power storage and supply, which are crucial for the sustainability of battery-powered camera traps. This review will examine advancements in DC-DC converters and Battery Management Systems (BMS), highlighting emerging technologies aimed at enhancing efficiency and reliability in energy storage systems. These developments hold particular significance for camera trapping in remote areas, where researchers must contend with limited access to power grids. By synthesizing findings from a diverse range of studies, we aim to offer a comprehensive understanding of the challenges and potential solutions for capturing these elusive twilight behaviors.

2.3 Advancements and Considerations in Camera Trap Technology for Wildlife Research

Camera trapping represents a cornerstone methodology in wildlife research, offering a non-invasive window into the natural behaviors and patterns of various species. This section synthesizes current research and developments in camera trap technology, emphasizing their application, innovation, and associated challenges within the field of wildlife monitoring.

2.3.1 Technological Features

Camera traps have become indispensable tools in wildlife studies, offering researchers valuable insights into the behaviors and populations of various species. The evolution of camera trap technology from film-based systems to digital equipment has revolutionized the field, providing researchers with more efficient and versatile options for data collection. Early automated camera trap systems, as described by Trolliet et al. [1], were instrumental in studying activity patterns, intra-community interactions, and populations of large carnivores.

One of the crucial considerations when choosing digital camera trap equipment is its characteristics, which significantly impact the types and quality of data collected. Trolliet et al. [1] emphasized the importance of features such as trigger speed, detection zone, recovery time, nighttime capability, battery consumption, cost, and picture resolution. Trigger speed, for instance, dictates the camera's ability to capture fast-moving animals, with faster trigger speeds resulting in higher detection rates. Additionally, the detection zone, defined as 'the zone covered by the camera's infrared beam in which movement can be detected' [1], width and depth play a vital role in determining detection rates, and the number of pictures taken per event [1]. Trigger speeds of existing models range from 0.197 seconds (Reconyx HC500 model) to 4.206 seconds (Stealth Cam Rogue IR model) [1]. Moreover, cost and additional features such as burst mode and video recording further influence camera trap selection. Despite the advantages of high-resolution images for individual identification, factors such as sensor size also impact picture quality and should be carefully evaluated [1]. Nighttime capabilities are essential for studying nocturnal species, with infrared cameras being favored due to their discreetness as mentioned by Trolliet et al. [1] 'Infrared light emitted by a series of Light Emitting Diodes (LEDs) allows the camera to take black-and-white pictures' [1] adding to that 'the most discrete and best solution to avoid scaring wildlife is to use a camera with a 'no-glow' ... These cameras function in the same way as normal infrared cameras, shooting black and white pictures, but using LEDs that emit no visible light at all' [1].

The Trailmaster camera system represents a notable example of a reliable and versatile camera trap system, offering 'portability, weatherproof construction, programmability, and high-quality photographs' [2]. Its ability to produce permanent records electronically makes it invaluable for research applications, enabling long-term monitoring of wildlife with minimal labor costs [2]. 'Researchers can adapt it to a variety of uses such as monitoring burrows, tree cavities, nesting birds, or suspected wildlife crossings or travel corridors' [2]. Research carried out by Swann et al. [3] further compares the trail master to other cameras furthering the exploration of features to consider. The study highlights the significance of the camera's detection zone in capturing target species. Wider zones increase the likelihood of capturing large animals across a broader area, but also lead to more 'false triggers' [3] from animals outside the camera's field of view (e.g., TrailMaster 500). Conversely, narrow zones minimize false triggers but may miss smaller animals or those positioned outside the narrow detection area (e.g., CamTrakker) [3]. The authors Swann et al. [3] emphasize selecting a camera system based on the target animal size. Some systems are more adept at detecting smaller creatures, while others excel at capturing larger ones (e.g., DeerCam performs well for smaller animals compared to TrailMaster 1500). Camera sensitivity plays a crucial role. Higher sensitivity settings are more likely to capture smaller animals or those at a distance, but also increase false triggers from factors like heat or small animals near the flash zone (e.g., Buckshot RTV and Scout) [3].

2.3.2 Limitations and Pitfalls of Camera Traps

While camera traps are invaluable tools for wildlife research, they are not without their limitations. Camera traps face two significant issues:

1. **False Positives:** These occur when camera traps are triggered without the presence of the target animal. False positives can significantly impact the efficiency and accuracy of wildlife monitoring, caused by non-target movements such as wind, rain, or changes in temperature and light. This can lead to rapid memory storage filling, battery life depletion, and an increase in the time and resources needed for data processing. According to Newey et al., [4], high numbers of false positives were recorded, especially in exposed sites, likely due to moving vegetation and varying temperature changes detected by the camera's passive infrared sensors. This shows the importance of careful camera placement and setting adjustments to minimize such occurrences.

2. **False Negatives:** These represent instances where the camera fails to capture an image when the target animal is present, leading to an underestimation of species presence or abundance. Factors contributing to false negatives include inadequate sensor sensitivity, incorrect camera placement, and environmental conditions that mask animal heat signatures or movements. Newey et al. [4] highlighted that a significant proportion of animal activities were not detected by the cameras, highlighting the necessity for validating camera trap performance under the specific conditions of the study to avoid biases in data collection.

2.3.3 Innovations in Camera Trap Technology

Traditionally, camera traps have been useful for wildlife research, offering a non-invasive way to monitor animals. However, researchers have faced limitations due to the need to physically retrieve data from the traps,‘ uncertainty involving storage capacity of SD cards and battery life’ [5]. According to a study by Laughlin et al. [5], the cellular transmission offers significant advantages. It can reduce the amount of time spent visiting cameras in person, which translates to less time in the field and more time spent analyzing data. This technology could also be crucial for addressing technical problems with the traps or data collection process more quickly [5]. On the other hand, the authors, Laughlin et al. [5] found that transmission efficiency can be significantly lower in forested areas compared to open spaces. This suggests that researchers may need to carefully consider the landscape where they plan to deploy camera traps [5]. Overall, cellular transmission technology represents a promising advancement in camera trapping. While some limitations exist, researchers can leverage this innovation to improve wildlife research efforts [5].

Another study by Nazir et al. [6] addresses the issues faced by researchers in the limited use of user control offered by camera traps. Researchers often struggle with pre-programmed functions that may not suit their specific research questions. WiseEye, 'a user-customizable open source camera trap platform' [6] tackles this issue head-on by utilizing a Raspberry Pi single-board computer as its core. This allows for user-defined programming, essentially transforming the camera trap into a blank canvas for researchers to tailor its operation to their exact needs [6].WiseEye's innovation goes beyond simple customization. It introduces the revolutionary concept of 'confirmatory sensing' [6]. This goes a step further than the standard Passive Infrared (PIR) triggers used in most camera traps. While PIR sensors are effective, they can be susceptible to false positives – images triggered by wind, swaying branches, or other non-target movements. WiseEye integrates additional confirmation methods, such as radar or pixel change detection. These work in conjunction with the PIR sensor, ensuring an image is only captured when the actual movement of an object is confirmed. This significantly reduces the number of irrelevant images cluttering the data set, saving researchers countless hours during post-processing [6]. The effectiveness of WiseEye is not just theoretical. Studies have shown it demonstrably reduces both false positive and negative image captures compared to commercially available camera traps. This translates to a cleaner, more focused data set that allows researchers to delve deeper into their wildlife investigations [6]. WiseEye represents a paradigm shift in camera trap technology. By offering user-customizable platforms, confirmatory sensing for improved data quality, and user-defined metadata for efficient processing, WiseEye empowers researchers to collect more meaningful data with less wasted time and effort. This open-source innovation holds immense potential to propel wildlife research and conservation efforts forward [6].

While camera traps have revolutionized wildlife research by providing invaluable insights into the natural world, their effectiveness hinges on careful consideration of technological features, placement strategies, and the landscape. Continuous innovation and methodological refinement are crucial in leveraging the full potential of camera traps for conservation and research efforts, ensuring that data collection is both efficient and representative of true wildlife behaviors and populations.

2.4 Behavioral Patterns of Fork-tailed Drongos

Fork-tailed Drongos exhibit a range of intriguing behavioral patterns, particularly in their feeding strategies and vocal mimicry. These behaviors not only highlight their adaptability but also their impact on the ecosystems they inhabit.

2.4.1 Feeding and Foraging Ecology

The Fork-tailed Drongo demonstrates a versatile diet predominantly consisting of insects, with grasshoppers, butterflies, and termites. In a detailed study by Okosodo et al. [7], it was found that these birds consume an impressive 86.6% insect and 14.4% plant species, highlighting their role as insectivorous predators within their ecosystem.

2.4.2 Habitat Utilization

The study conducted by Okosodo et al. [7] also sheds light on the Fork-tailed Drongo's habitat utilization. They predominantly occupy secondary forests, which provide the highest amount of food materials (63%), followed by farmlands (25%) and developed areas (12%). This distribution of habitat usage reflects the bird's adaptability and the potential influence of different land use types on their foraging behavior and diet.

2.4.3 Vocal Mimicry and Kleptoparasitism

One of the most fascinating aspects of the Fork-tailed Drongo's behavior is its use of vocal mimicry in kleptoparasitism. Tom Flower's [8] comprehensive research reveals that these birds not only use their species-specific alarm calls to deceive other species but also mimic the alarm calls of other species to scare them away and steal their food. This deceptive strategy shows a complex behavioral adaptation that allows Fork-tailed Drongos to exploit the anti-predator responses of other species for their benefit.

The effectiveness of this strategy is further highlighted by the fact that the structural components of both the species-specific and mimicked false alarm calls are indistinguishable from true alarm calls, making the deception highly convincing [8]. This behavior not only underscores the cognitive capabilities of the Fork-tailed Drongo but also illustrates the dynamic interactions within their ecosystem, where vocal mimicry plays a critical role in their survival and feeding strategy.

In conclusion, this review of Fork-tailed Drongos' behavioral patterns, particularly their feeding habits and habitat preferences, not only enhances our understanding of their ecological role but also provides practical insights for effective observation techniques, like optimal timing and positioning of cameras, aiding in the precise capture of their twilight activities.

2.5 Impact of Different Light Sources on Wildlife Activity

The interplay between light sources and wildlife, particularly avian species, has become a significant concern amidst growing urbanization. This section delves into the myriad ways in which different lighting types—natural, infrared, and artificial—affect bird behavior and overall wildlife activity. By examining the repercussions of urban lighting on avian life cycles and behaviors, this section of the review aims to underline the critical balance between natural and anthropogenic light exposure in wildlife habitats.

2.5.1 Effects of Various Light Sources on Bird Behavior

Adams et al. [9] with many other research articles and studies, put forward strong evidence that avian behaviour is closely linked to sources of light [9]. This becomes a major issue as wildlife habitat areas and migration corridors are being overrun with urban development as outlined by Stephen Ambrose [10]. A critical point highlighted in Ambrose's research is that urban development threatens wildlife, particularly through increased risk of collisions with buildings and disorientation of birds. Ambrose's research further reveals that artificial light at night (ALAN) can have other implications such as immunological, metabolic, reproductive, and cognitive processes, which correlates with the findings in a study conducted by Tahajjul Taufique. According to a study titled '*Artificial Light at Night, Higher Brain Functions and Associated Neuronal Changes: An Avian Perspective*', "ALAN has negative impacts on various territorial behaviors in wild birds, including reproduction, singing, migration, and sleep" and "has detrimental impacts on learning, memory, mood, and exploration in multiple laboratory investigations" [11], emphasising the significant effects light has on wildlife birds. From this research, we can clearly see how chances of survival are significantly decreased when their markers of behaviour are negatively impacted by artificial sources of light. However, the research suggests not all light has negative effects.

Natural Light

Most wildlife, including birds, are diurnal and are most active during daylight hours. Natural sunlight regulates their circadian rhythms, influencing their feeding and mating patterns [11, 12]. In addition, different species may exhibit preferences for specific times of the day depending on their ecological niche and adaptations, according to Taufique. Moreover, Vincent Cassone published a study titled "Avian Circadian Organization: A Chorus of Clocks" which mentions, "there are several observations that tentatively link clock gene expression with avian rhythmic behavior" [12]. Casson implies that bird behaviour is put out of sync from their natural time keeping processes when artificial light at night is present. The Fitzpatrick Institute studies many bird species and underscores that the Fork-tailed Drongo feed their chicks in the twilight period of the day. This poses as a threat to filmers such as Ben Murphy who is interested in monitoring the feeding process, as it only occurs after sunset. This means that alternative unobtrusive filming methods may need to be used to monitor these Fork-tailed Drongos to keep them in sync with their natural time keeping processes.

However, nocturnal species, such as owls, are active during the night and rely on moonlight for visibility during foraging and hunting. Linley et al. [13] suggests that moon phases can affect their activity levels, with brighter nights typically seeing increased activity, due to the increase of activity from prey [13]. Ben Murphy from The Fitzpatrick Institute says that Fork-tailed Drongo chicks are hunted by owls at night approximately two hours after twilight. This is important as Ben Murphy is interested in the predation of Fork-tailed Drongo chicks, which occurs at night. This means that there is very little visible light available for standard filming techniques, and so, a different means of data capture must be utilized without using flash photography.

Infrared Lighting

Cilulko et al. stress that infrared lighting (thermal imaging), which is invisible to many animals, can be used for nocturnal wildlife observation without causing disturbance [14]. Cilulko et al. [14], expresses "thermal imaging techniques support safe and non-invasive measurements and the acquisition of results that cannot be obtained by any other method". Infrared cameras allow researchers to study wildlife behaviour at night without interfering with their natural activities. This is critical for wildlife observation, as the data captured shows birds in their natural habitat, undisturbed by artificial filming techniques.

Artificial Light

Artificial light in urban areas, such as streetlights and building illumination, can disrupt the natural behaviour of birds. According to Taufique, light pollution can interfere with navigation, migration, and feeding patterns [11]. In line with the aforementioned, a study conducted by Eckhartt and Ruxton, concludes that artificial light may also attract insects, which in turn can affect bird foraging behaviour as the balance of the ecosystem is disrupted [15]. Insects are drawn to the light, which attract predatory birds. This has a severe consequence on insect populations which affects wildlife across the ecosystem including many bird species. Intense artificial lighting, such as floodlights and spotlights used for filming can startle and disturb wildlife. This is well said in Guynup's article about the negative effects flash photography can have on owls, "This causes brief 'functional blindness', a glowing afterimage that affects the ability to see and recognize objects" [16]. It can also cause overall stress levels to rise and with repetition can lead to temporary or permanent displacement from their habitats [16]. Thus, it is essential to avoid the use of intense artificial lighting.

In summary, the impact of light sources on wildlife, especially birds, is profound and multifaceted. The disruption caused by artificial lighting not only affects avian behavior but also has broader ecological consequences. This necessitates a concerted effort toward understanding and mitigating the adverse effects of light pollution, underscoring the importance of sustainable urban planning and wildlife conservation strategies.

2.6 Solutions for Storage and Power Supply

This section explores innovative solutions in the realm of power storage and supply, crucial for the sustainability of battery-powered applications. With a focus on advancements in DC-DC converters and Battery Management Systems (BMS), the literature presents emerging technologies aimed at enhancing efficiency and reliability in energy storage systems. These developments hold particular significance in the context of portable electronics, IoT devices, and renewable energy systems, where power efficiency and management are paramount.

2.6.1 DC-DC Converters

Battery-powered applications often require voltage reduction, a task commonly handled by the buck converter [17]. However, the suitability of buck converters diminishes in low-power scenarios due to the substantial overhead associated with the size of the inductor and its control mechanisms [17]. Elhebeary and Yang [17] have emphasized the unsuitability of buck converters for low-power applications, despite their widespread use, citing the notably low-efficiency LDO regulators as a potential alternative. In response to these challenges, Kim et al. [18] propose an innovative solution: a two-step digital pulse width modulation (DPWM) combined with a low-power self-tracking zero current detector (ST-ZCD) high-efficiency buck converter. This novel approach addresses the control overhead inherent in traditional buck converters while also improving overall efficiency [18]. The integration of DPWM and ST-ZCD not only mitigates control overhead but also enhances efficiency, making it a promising solution for low-power applications. With a peak efficiency of 91.5% and a quiescent current of just 130 µA, this converter represents a significant advancement [18]. These findings underscore the importance of continually exploring and innovating in power conversion technologies, especially in the context of energy-efficient and low-power applications.

The research by Elhebeary and Yang [17] serves as a reminder of the challenges inherent in traditional power conversion methods. Their critique of LDO regulators highlights the need for solutions that balance efficiency and practicality in low-power scenarios. Conversely, the work by Kim et al. [18] showcases the potential of novel approaches such as DPWM and ST-ZCD in overcoming these challenges.

By addressing the limitations of traditional buck converters, the advancement of power conversion technologies, particularly in battery-powered applications can be accelerated. These developments have significant implications for various industries, including portable electronics, IoT devices, and renewable energy systems.

IoT applications often require a boost or buck-boost if WiFi is utilized, as RF (radio frequency) transceivers demand a voltage greater than that provided by the battery [19]. Traditional boost converters, however, exhibit issues such as discontinuous and pulsating current, which not only diminish efficiency but also exacerbate output voltage ripple concerns [20]. In contrast, the single-mode double clock timing (DCT) controlled M-KY converter addresses these drawbacks with its commendable efficiency of 80% within a current range spanning from 6 µA to 100 mA [20]. Furthermore, the M-KY converter offers a simplified zero current detection (ZCD) design, enhancing its appeal in IoT applications [20].

Moreover, advancements in converter design, exemplified by the single-inductor dual-input triple-output buck-boost (SIDITOBB) converter, are making strides in addressing efficiency and power consumption concerns [21]. This innovative converter introduces a clock-less shortest power path (CSPP) control strategy, significantly enhancing efficiency while minimizing power consumption [21]. Such developments mark crucial progress in the realm of power conversion technology, particularly for wildlife monitoring in remote areas where energy efficiency and compactness are paramount.

2.6.2 Battery Management System (BMS) for Li-ion batteries

Battery Management Systems (BMS) are indispensable components for maintaining optimal performance and longevity of lithium-ion batteries, particularly in applications where accurate State of Charge (SOC) indication is crucial. SOC indication, which tracks the present charge level of a battery, serves as a fundamental aspect of BMS functionality, ensuring that the battery operates within safe limits and provides reliable power output [22]. In scenarios where batteries serve as the primary power source, precise SOC measurement becomes even more critical to prevent potential damage caused by overcharging or discharging beyond safe limits [22]. While traditional methods such as impedance spectroscopy have been employed for SOC estimation, their practicality in portable devices is limited due to factors such as complexity and resource requirements [22]. Addressing this challenge, Jeong et al. [22] propose the Instantaneous Linear Extrapolation (ILE) algorithm, which offers a convenient and efficient solution for SOC estimation in IoT applications. By modulating battery current to estimate electromotive force, the ILE algorithm provides accurate SOC indication while minimizing computational overhead, making it well-suited for resource-constrained devices [22].

Furthermore, while model-based SOC estimation methods are known for their accuracy and robustness, they often come with high computing costs, which may be prohibitive in certain IoT applications [23]. These methods rely on complex mathematical models and algorithms to predict SOC based on various battery parameters and operating conditions [23]. As a result, they require significant computational resources, which may not be available on low-power microcontrollers commonly used in IoT devices [23]. In contrast, Radle circuit-based SOC estimation offers a cost-effective alternative that is well-suited for deployment on low-power microcontrollers [24]. By leveraging the simplicity and efficiency of Radle circuit design, SOC estimation can be achieved with minimal computational overhead, making it an attractive option for IoT applications in remote and resource-constrained environments [24]. This approach has the potential to enhance the reliability and accessibility of SOC estimation in a wide range of IoT applications like monitoring birds in Kalahari.

State of health (SoH) is another vital indicator for battery management systems, particularly concerning lithium-ion batteries. While charging feature-based SoH estimation offers stability and controllability, extracting features can be challenging, especially in cases of partial charging [25]. To address this, a linear cycle counting algorithm has been proposed, showing promising results in SoH estimation [26]. This algorithm represents a significant advancement in the field, providing a potential solution to the challenges associated with SoH assessment.

The advancements discussed in this section offer promising directions for the future of power storage and supply solutions. As technology continues to evolve, the potential for more efficient, reliable, and environmentally friendly energy systems becomes increasingly achievable. This progression is not only vital for the technological advancement of portable and IoT devices but also plays a crucial role in promoting sustainability and reducing the environmental impact of energy consumption.

2.7 Conclusion

The intricacies of documenting the twilight activities of species like the Fork-tailed Drongos pose significant challenges for researchers. This literature review has highlighted the critical role of advanced camera trapping technology and innovative solutions in overcoming these obstacles. Through the exploration of various studies, we have identified key considerations in camera technology, animal behavior, and environmental impacts that are essential for conducting effective wildlife research. The review underscores the necessity of integrating technological advancements with a deep understanding of ecological principles. This synergy is crucial for enhancing the accuracy, efficiency, and ethical conduct of wildlife monitoring. For researchers like Ben, embracing these innovations, particularly advancements in power storage and supply like efficient DC-DC converters and robust Battery Management Systems (BMS), is paramount. These advancements are especially significant for camera trapping in remote locations with limited access to power grids.

By maintaining ethical and environmental standards while utilizing these technological advancements, researchers like Ben can capture the elusive behaviors of Fork-tailed Drongos and similar species. This knowledge not only expands our understanding of these fascinating creatures but also informs conservation efforts to protect them and their habitats.

Chapter 3

Power Subsystem

We Need To Start Investing More In Solar Energy...But It's Not Just Going To Happen Overnight

—*Unknown*

This section was completed by Dylan Kuming, KMNDYL001.

3.1 Introduction

The Power module is designed to power the entire system which includes a Raspberry Pi, light sensor as well as a camera. Since this system will be deployed in the Kalahari, which experiences extreme conditions, the power module needs to be robust and sustainable. Current systems rely on rechargeable batteries that deplete quickly and need frequent manual replacement. This submodule addresses these limitations by integrating a solar panel to charge a battery system, enabling the device to operate autonomously in this remote location for extended periods. This solar solution enhances system reliability, reduces the need for frequent human intervention, and supports the project's ecological goals by minimizing environmental impact.

3.2 User Requirements

The Power Supply Unit (PSU) is designed to power essential electronic devices autonomously in remote areas. The following table lists the user requirements:

Table 3.1: User Requirements of the Power Module

Label	User Requirement	Refined by	Verification
UR1	The system must operate continuously for at least one week without maintenance or battery replacement.	FR1, FR4	ATP1, ATP5
UR2	The power system must be easy to replace and simple to use.	FR2, FR3	ATP2, ATP3, ATP4

3.3 Functional Requirements

This table outlines the key functionalities of the Power Supply Unit (PSU), essential for operating camera traps and other devices reliably in remote wildlife conservation settings:

Table 3.2: Functional Requirements of the Power Module

Label	Functional Requirement	Refines	Refined by	Verification
FR1	The PSU must efficiently convert solar energy to electrical power to charge the battery.	UR1	DS1	ATP1
FR2	The PSU must include protective measures to prevent battery damage.	UR2	DS2	ATP2, ATP3
FR3	The PSU must provide a clear and accurate indication of the battery charge level.	UR2	DS3	ATP4
FR4	The PSU must supply regulated and stable power to devices in the system.	UR1	DS4	ATP5

3.4 Design Specifications

The Design Specifications define how the Power Supply Unit (PSU) will meet the functional requirements through its construction, components, and operation. The PSU is designed to provide reliable, efficient, and continuous power supply to devices in remote wildlife conservation areas.

Table 3.3: Design Specifications of the Power Module

Label	Design Specification	Refines	Verification
DS1	Using the CN3791, a standalone 4A Li-ion battery charger IC with MPPT functionality, the PSU will charge a 3.7V Li-ion battery using a 10W monocrystalline silicon solar panel.	FR1	ATP1
DS2	Battery protection includes a XT60 connector to prevent reverse polarity, a glass fuse for over-current/ short circuit protection, and an over-discharge protection circuit which uses a LM358 Op Amp.	FR2	ATP2, ATP3
DS3	The PSU will provide a visual indication of the battery charge level using a series of LEDs that reflect different charge levels.	FR3	ATP4
DS4	The PSU will use a boost converter to step up the 3.7V output from the Li-ion battery to a regulated 5V supply for the other devices in the system. The boost converter will be built around the 555 timer IC, driving an IRFZ44N N-Channel MOSFET for efficient power conversion.	FR4	ATP5

3.5 Acceptance Test Procedures

The Acceptance Test Procedures (ATPs) ensure that the Power Supply Unit (PSU) adheres to the design specifications through a series of tests. Each test is designed to validate a specific aspect of the PSU's performance and reliability in its operational environment.

Table 3.4: Acceptance Test Procedure of the Power Module

Label	Refines	Description
ATP1	DS1	*Solar battery charger test:* Test the battery charging circuit using a test bench to simulate varying solar conditions. Confirm with a multimeter that the output voltage of the battery charger consistently holds at 4.2V.
ATP2	DS2	*Overcurrent protection test:* This test checks the PSU's ability to handle overcurrent conditions with a glass fuse rated at 5A. The test verifies that the fuse blows when currents exceed 5A, ensuring protection against short circuits and overcurrent situations.
ATP3	DS2	*Overdischarge protection test:* Evaluate the PSU's capability to prevent battery overdischarge using an LM358 OpAmp. This test checks that the circuit disconnects the load when the battery voltage drops below 3V, thereby protecting the battery and enhancing its longevity.
ATP4	DS3	*Battery level test:* This test assesses the accuracy of the PSU's battery level indicator, which uses multiple LEDs to represent various charge levels. The procedure involves sequentially discharging the battery to confirm that each LED deactivates at the designated voltage thresholds.
ATP5	DS4	*Boost converter test:* Assess the functionality of the boost converter circuit that uses a 555 timer IC to generate PWM signals. This test evaluates the converter's efficiency in stepping up the voltage from 3.7V to 5V, ensuring it can effectively power the other devices in the system.

3.6 Design Choices

This section evaluates various design alternatives for the Power Module subsystem and justifies the final selections based on critical criteria such as cost, technical maturity, ease of manufacturing, implementation, ease of testing, reliability, and maintenance costs.

3.6.1 Power Supply Options

Three power supply configurations were evaluated: battery only, solar power only, and a battery charged using a solar panel. The table below summarizes their comparative analysis based on key criteria.

Table 3.5: Comparison of power supply options

Criteria	Battery Only	Solar Power Only	Battery Charged by Solar
Cost	Low (ZAR 75–160)	High (ZAR 100–300)	High (ZAR 175–460)
Reliability	Low (until battery depletes)	Medium (daytime only)	High (daytime and nighttime if battery is charged)
Implementation	Easy (plug-and-play)	Moderate (requires setup)	Moderate (complex setup)
Maintenance	High (frequent changes)	Low (minimal upkeep)	Low (rare intervention)

A battery Charged by solar was chosen due to its high reliability and low maintenance requirements. This system converts solar energy into electrical energy to charge a battery, allowing uninterrupted operation which is crucial for deployments in remote areas where regular maintenance is challenging.

3.6.2 Battery selection

After deciding the PSU would utilize a battery charged by solar energy, specific rechargeable batteries were compared for their suitability. Four battery types were contrasted based on their specifications and costs from Communica.

Table 3.6: Comparison of specific battery options

Criteria	Li-ion	NiMH	Lead-Acid	Li-Poly
Voltage (V)	3.7	1.2	12	3.7
Capacity (mAh)	800	2000	1200	1100
Cost (ZAR)	75.84	77.05	95.00	160.00
$\frac{\textbf{Energy Density}}{\textbf{Price}}$ $(\frac{\textbf{mWh}}{\textbf{ZAR}})$	10.55	25.97	12.63	6.88
Size	small	small	medium	small
Lifespan	Long	Medium	Short	Long

Based on the comparative analysis, the 3.7V Li-ion battery was chosen for its favorable balance between cost, energy density, size, and lifespan. It offers a high energy density per price unit, making it economically viable for long-term deployment without sacrificing performance or lifespan.

3.6.3 Solar Battery Charger IC Selection

A critical component in the power module is the solar battery charger IC. This component must efficiently manage the charging of the battery using the power harvested from the solar panel. To select the most suitable IC, three options were compared: the CN3791, the CN3065, and the BQ24650. The comparison is based on price from JLCPCB, the inclusion of Maximum Power Point Tracking (MPPT) functionality, input voltage range (V_{in} range), output voltage (V_{out}), and charge current capabilities.

Table 3.7: Comparison of solar battery charger ICs

IC	Price (USD)	MPPT	V_{in} Range (V)	V_{out} (V)	Charge Current (A)
CN3791	0.5565	Yes	4.5 to 28	4.2	4
CN3065	0.8190	No	4.4 to 6.6	4.2	0.8
BQ24650	2.0475	Yes	5 to 28	4.2	10

The CN3791 was chosen for its balance of cost, MPPT functionality, wide input voltage range, and suitable charge current. While the BQ24650 offers a higher charge current, its significantly higher price does not justify the added benefit for this application. The CN3065, lacking MPPT, is not as efficient in power management, making it less suitable for variable solar intensity conditions.

3.6.4 Solar Panel Selection

Choosing the right solar panel is crucial for the efficiency and reliability of the power module. Three different solar panels were evaluated based on their price from Takealot, power output, physical size, maximum power voltage (V_{mp}), and maximum power current (I_{mp}). The selection aims to optimize power delivery while maintaining cost-effectiveness and compatibility with the solar charger IC specifications.

Table 3.8: Comparison of solar panel options

Criteria	10W Monocrystalline	3.2W Multifunctional	3.5W Bright Sun
Price (ZAR)	295	299	108
Power (W)	10	3.2	3.5
$\frac{\textbf{Power}}{\textbf{Price}}(\frac{\textbf{mW}}{\textbf{ZAR}})$	33.90	10.70	32.41
Size (mm)	244 x 350 x 17	160 x 250 x 25	150 x 260 x 20
Max Power Voltage (V)	17.8	6	6
Max Power Current (A)	0.57	0.53	0.58

After reviewing the options, the 10W Monocrystalline solar panel was selected for its higher power output and optimal voltage compatibility with the CN3791 solar battery charger IC, which needs a higher input voltage for effective MPPT functionality. Despite being slightly more expensive than the Bright Sun panel, the 10W panel offers a better power-to-price ratio and is better suited for providing sufficient power under varying light conditions. Its size and output parameters are ideal for the intended deployment, ensuring a reliable energy supply for extended periods with minimal maintenance.

3.6.5 Battery Charger with MPPT Function

After opting for a battery charged by solar for the power supply, and choosing to go with the 3.7V Li-ion battery, 10W Monocrystalline solar panel, and the CN3791 solar battery charger IC, the next step was making the circuit for the battery charger. The CN3791, a standalone 4A Li-ion battery charger featuring Photovoltaic Cell Maximum Power Point Tracking (MPPT), was chosen for its ability to charge the battery efficiently under constant current (4A) and constant voltage (4.2V) modes. Its straightforward design and minimal external component requirements make it particularly suitable for portable and solar-powered applications.

Component Selection for the Battery Charger

Using the typical application circuit and recommendations from the CN3791 datasheet, the following component values were selected for optimal performance:

Table 3.9: Component Selection for the CN3791 Battery Charger IC

Component	Description	Value
Input Capacitors	Electrolytic capacitor for low-frequency filtering ($C_{\mathbf{in1}}$) Ceramic capacitor for high-frequency oscillation suppression ($C_{\mathbf{in2}}$) Ceramic capacitor for high-frequency conditions ($C_{\mathbf{in3}}$)	$C_{\text{in1}} = 10\,\mu F$ $C_{\text{in2}} = 4.7\,\mu F$ $C_{\text{in3}} = 470\,nF$
Output Capacitors	Electrolytic for low-frequency filtering ($C_{\mathbf{out1}}$) Ceramic capacitor for minimizing ripple voltage and load step transients ($C_{\mathbf{out2}}$)	$C_{\text{out1}} = 10\,\mu F$ $C_{\text{out2}} = 4.7\,\mu F$
Inductor	Limit inductor ripple current to 0.3 times the full-scale charge current, considering the switching frequency and input voltage.	$L_1 = 82\,\mu H$
MOSFET	P-Channel MOSFET for efficiency and thermal management, specifications matching the gate drive voltage requirements of the CN3791.	CEM4435A
Diode	Schottky diodes, preventing reverse current flow and minimizing power loss.	SS34
MPPT Resistors	Calculation based on the MPPT functionality, where $V_{\text{MPPT}} = 1.205 \times (1 + \frac{R_3}{R_4})$. Provides accurate tracking of the solar panel's maximum power point.	$R_4 = 3.3K$, $R_3 = 47K$
Sense Resistor	Sense resistor for setting charge current in constant current mode, essential for the charge current control of the CN3791.	$R_{\text{CS}} = 0.05\Omega$

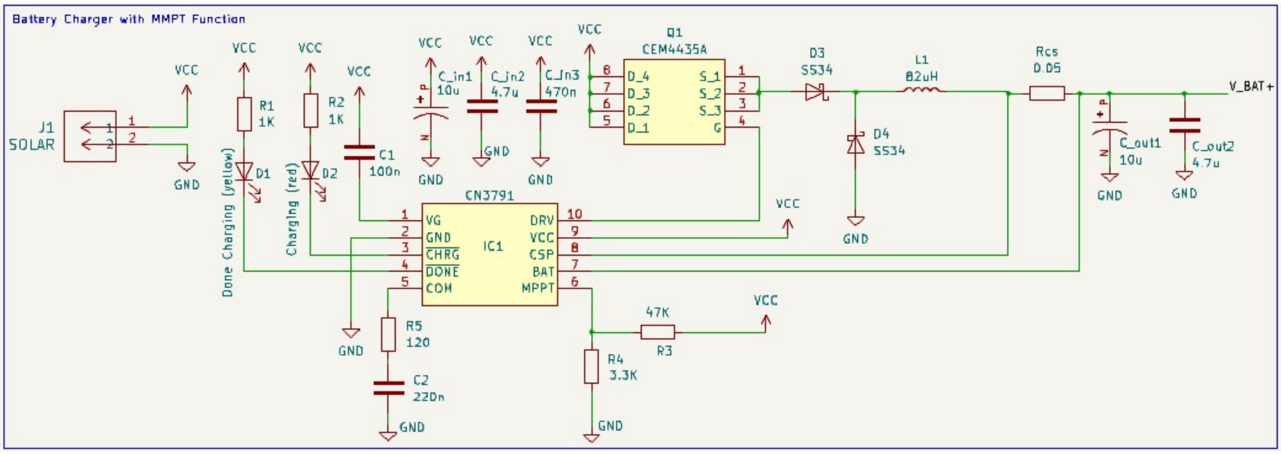


Figure 3.1: Schematic of the Battery Charger with MPPT Functionality

This detailed component integration ensures that the power module maximizes the efficiency of solar energy conversion, providing reliable and sustainable power to charge the battery under varying environmental conditions.

3.6.6 Protection Circuitry

To enhance the longevity and safety of the 3.7V Li-ion battery within the Power Supply Unit, various protection mechanisms were integrated. Instead of using an all-in-one battery protection IC, the protection features were implemented using separate components to provide targeted and efficient safeguards.

The CN3791 charger IC includes several built-in protection features, such as over-voltage protection, under-voltage lockout, and thermal shutdown. To further ensure comprehensive safety of the battery, additional protective measures were added to the system as follows:

(a) Reverse Polarity Protection

An XT60 connector was selected for its capability to prevent reverse polarity connections. Its unique geometric design allows connections only in the correct orientation, thereby protecting the battery and system from potential damage due to reverse polarity. The connector is robust and easy to use, which are critical for ensuring reliability and simplicity in maintenance in field conditions.

(b) Overcurerent/ Short Circuit Protection

A glass fuse rated at 5A was incorporated to provide short circuit protection. This fuse is designed to safely interrupt the power supply in the event of a current over 5A or a short circuit by blowing out, thereby creating an immediate physical barrier against excessive current flow. This straightforward method was preferred over more complex circuit-based solutions due to its reliability, simplicity, and ease of replacement in field applications.

(c) Overdischarge Protection

To enhance battery longevity and safety, an overdischarge protection circuit was implemented using an LM358 operational amplifier. While the CN3791 charger IC includes an under-voltage lockout feature for its own protection, this additional circuit actively monitors the battery voltage and disconnects the load when it falls below a critical threshold of 3V. This helps prevent battery performance degradation and potential system failures without relying on specialized protection ICs.

(i) Circuit Description: As illustrated in Figure 3.2 (right), the overdischarge protection circuit utilizes an LM358 operational amplifier, which is powered by a voltage regulator depicted in Figure 3.2 (left). This regulator converts the voltage from the solar panel into a stable $5V$, which powers the OpAmp. In the overdischarge protection circuit, the battery voltage $V_{\mathrm{BAT+}}$ is scaled down using a voltage divider consisting of resistors R_7, R_8, and R_9, making it suitable for the non-inverting input of the LM358. The reference voltage V_{REF}, set at $2.5V$, is established by a voltage divider using resistors R_{10} and R_{11}, and is connected to the inverting input of the OpAmp. When the scaled-down voltage from the battery $V_{\mathrm{BAT+}}$, after the voltage divider, falls below V_{REF}, the output of the OpAmp turns low, causing MOSFET Q_3 to deactivate. This action leads to Q_2 turning off as well, effectively disconnecting the load from the battery. Capacitor C_8, connected at the output of the OpAmp, provides stability to the circuit by minimizing potential oscillations. The circuit also incorporates hysteresis to prevent erratic switching, which is discussed below in paragraph (ii).

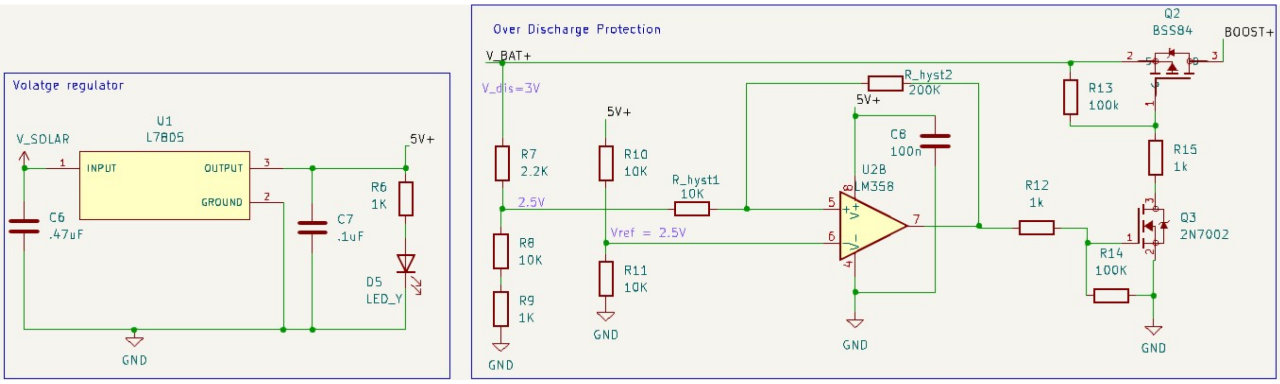


Figure 3.2: 5V L7805 Voltage Regulator Circuit (left) and Overdischarge Protection Circuit (right)

(ii) Hysteresis Implementation: Hysteresis is incorporated to stabilize the circuit and avoid oscillations around the disconnection threshold. This is achieved by adding R_{hyst2}, a resistor connected from the output of the OpAmp back to its non-inverting input.

Equations and Calculations

Given circuit parameters are as follows:

- $V_P = 5V$ (positive supply voltage),
- $V_N = 0V$ (negative supply voltage, or ground),
- $V_{REF} = 2.5V$ (set by the voltage divider of R_{10} and R_{11}),
- Resistance ratio $R = 20$ for hysteresis, determined by $\frac{R_{\text{hyst2}}}{R_{\text{hyst1}}}$.

The calculated threshold voltages and hysteresis are:

Table 3.10: Hysteresis Voltage Calculations for the Over-Discharge Protection Circuit

Name	Formula	Answer
High Threshold Voltage (V_{TH})	$V_{TH} = \left(1 + \frac{1}{R}\right) \times V_{REF} - \frac{1}{R} \times V_N$	2.625V
Low Threshold Voltage (V_{TL})	$V_{TL} = \left(1 + \frac{1}{R}\right) \times V_{REF} - \frac{1}{R} \times V_P$	2.375V
Hysteresis Voltage (ΔV)	$\Delta V = V_{TH} - V_{TL}$	0.25V

Significance of Hysteresis

The hysteresis voltage (ΔV) ensures that the circuit does not toggle erratically near the disconnection threshold. It allows for a clear transition between the load being connected and disconnected, thus avoiding unnecessary stress on the battery and connected components.

(iii) Overdischarge Protection Circuit Advantages: This circuit is crucial for preventing deep discharge conditions in Li-ion batteries, especially critical for systems that operate without frequent monitoring. By leveraging the characteristics of the LM358 OpAmp, the circuit effectively disconnects the load before the battery voltage falls to damaging levels, thereby ensuring both the safety and longevity of the battery.

3.6.7 Battery Level Indicator

For the battery level indicator, the design options evaluated included a digital readout system and a simple LED-based indicator. The chosen solution was an LED-based indicator due to its simplicity, low cost, high reliability, and intuitive visual feedback.

Figure 3.3 presents a simple and effective circuit for indicating the charge level of a 3.7V 18650 Lithium battery, as shown in the schematic. This circuit uses four LEDs that light up to represent different charge levels through a series of resistors and rectifier diodes. The resistors limit current to the LEDs, ensuring safe operation, while the diodes (1N4007 – D_6, D_7, D_8) prevent current backflow and set distinct voltage thresholds for LED activation.

The LEDs indicate the following: red for low (25% and 50%), yellow for 75% charge, and green for full charge. When fully charged (approximately 3.7V), all LEDs light up. As the battery discharges, LEDs extinguish sequentially from green to red, indicating decreasing charge levels. This indicator is easy to assemble, requires minimal components, and integrates well into electronic projects requiring visual battery charge indication.

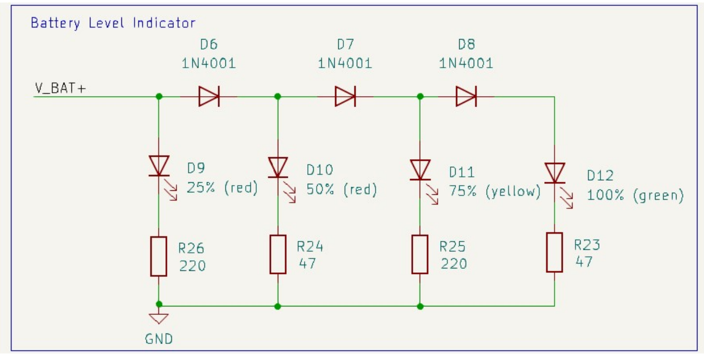


Figure 3.3: 18650 Lithium 3.7V Battery Level Indicator Circuit.

3.6.8 DC-DC Boost Converter

(i) Design Rationale: The project requires a stable 5V power supply to operate a Raspberry Pi, sensor, and camera, all powered by a 3.7V Li-ion battery. To achieve this, a step-up (boost) converter is necessary to meet the voltage requirement efficiently.

(ii) Evaluation of Switching Mechanisms: Table 3.11 presents a comparison of different switching mechanisms used in boost converters, emphasizing their suitability based on cost, complexity, and power efficiency.

Table 3.11: Comparison of switching mechanisms for boost converter

Criteria	Transistor Switch	555 Timer	Microcontroller PWM
Cost	Low	Low	High
Complexity	Medium	Low	High
Power Efficiency	High	High	Medium

Given its low cost, low complexity, and high efficiency, the 555 timer was selected as the switching mechanism for the boost converter. Its straightforward operation and precise voltage control capabilities ensure a stable 5V output, crucial for the connected devices. In contrast, the transistor switch and the microcontroller PWM, while viable options, introduce greater complexity and potential points of failure, making them less desirable for this application where simplicity and reliability are critical.

(iii) Circuit Overview and Component Selection: The boost converter uses a 555 Timer IC configured in astable mode to generate a PWM signal, driving an N-Channel MOSFET which controls the charging and discharging of an inductor, effectively stepping up the input voltage from 3.7V to 5V.

Table 3.12: Boost Converter Circuit Components

Component	Description	Value
555 Timer IC	PWM signal generator	LM555
Inductor	Stores energy	82μH
MOSFET	Switches inductor current	IRFZ44N
Diodes	Directs and blocks current	1N4001, SS34
Capacitors	Voltage stabilization	100nF, 1nF
Resistors	Sets operation frequency	1kΩ, 50kΩ POT

(iv) Circuit Operation and Analysis: The boost converter steps up the voltage by storing energy in an inductor and releasing it at a higher voltage through a diode to the load. The operation cycle begins when the 555 Timer IC outputs a high PWM signal, turning on the MOSFET (Q_4). This allows current to flow through the inductor (L_2), causing it to store energy in the form of a magnetic field. During this phase, the diode (D_{13}) is reverse-biased, and the output capacitor (C_{11}) supplies energy to the load. When the 555 Timer IC's output goes low, the MOSFET turns off, and the magnetic field in the inductor collapses. This rapid change in current induces a voltage across the inductor that adds to the input voltage, forward-biasing the diode (D_{13}) and charging the output capacitor (C_{11}) to a higher voltage than the input.

The duty cycle of the PWM signal, adjusted by the potentiometer (VR1), determines how long the MOSFET is on relative to the off-time. This duty cycle directly influences the average voltage across the inductor, and thus the output voltage. The ratio of the output voltage (V_{out}) to the input voltage (V_{in}) is approximately given by the formula:

$$V_{out} \approx \frac{V_{in}}{1 - D}$$

where D is the duty cycle of the PWM signal.

Other components, such as the diodes (D_{14}, D_{15}), ensure current flows in the correct direction and protect against reverse currents. Capacitors (C_{12}, C_{13}, and C_{11}) are used to filter the voltage and maintain a steady DC level at the output.

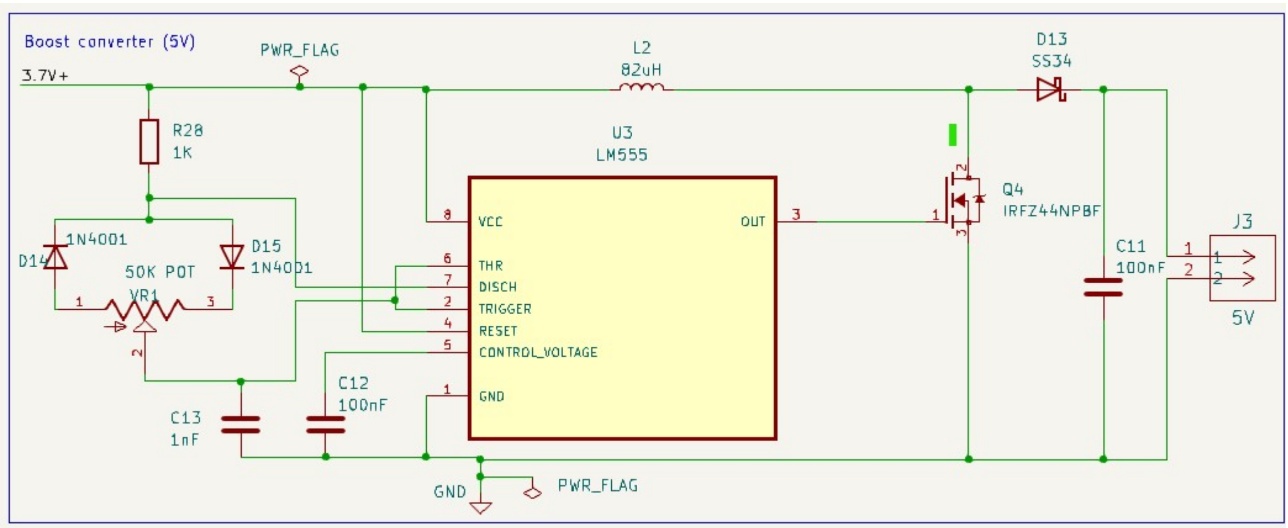


Figure 3.4: Boost converter schematic with 555 Timer IC.

3.6.9 PCB design

Figure 3.5 depicts two PCB iterations. The initial version (on the left), which cost \$144 ≈ R2700 on JLCPCB, exceeded the budget limit of R2000 ≈ \$107. To align with financial constraints, cost reduction strategies were employed, including the use of basic components instead of extended versions, omitting some pre-owned components, switching to through-hole components for self-soldering, and reducing the number of assembled boards from five to two. These adjustments decreased the PCB cost to approximately \$41 $\approx$ R766 (on the right), showing the importance of budget management in design.

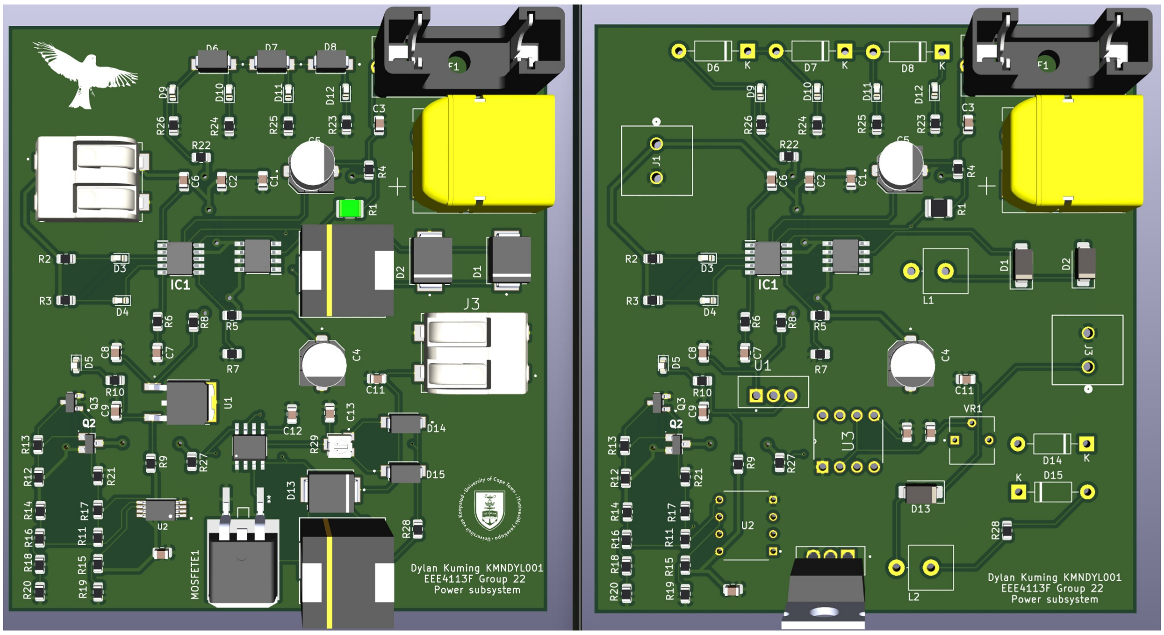


Figure 3.5: PCB Comparison

3.7 Final Design

The final design of the power subsystem is made to ensure reliable operation in remote environments. This section provides a detailed overview of the subsystem, designed to power a Raspberry Pi, light sensor, and camera efficiently.

3.7.1 System Overview

The power module integrates several key features:

- **Solar Panel Integration:** A 10W monocrystalline solar panel is used for efficient solar energy harnessing.
- **Battery Charging System with MPPT:** The CN3791 4A, 4.2V Li-ion battery charger IC optimizes the conversion of solar energy to charge a 3.7V Li-ion battery.
- **Comprehensive Battery Protection:**
  - *Reverse Polarity Protection:* An XT60 connector prevents incorrect connections.
  - *Over-Current and Short Circuit Protection:* A 5A glass fuse provides reliable protection.
  - *Over-Discharge Protection:* An LM358 operational amplifier monitors and controls the battery voltage.
- **Battery Level Indicator:** An LED-based visual indicator provides battery status feedback.
- **Boost Converter:** A 555 timer-based boost converter steps up the 3.7V battery output to 5V.

3.7.2 Circuit Implementation

- **Schematic Layout:** The integration of all components is shown in the power module schematic (see Appendix, Figure A.1).
- **PCB and Setup Configuration:** The final PCB design (see Appendix, Figure A.2) is optimized for cost[1] and performance, with easy assembly and robustness in field applications (see Appendix, Figure A.3).

3.8 Testing and Results

3.8.1 Electrical Characteristics

Table 3.13: Summary of Electrical Tests and Results

Test Component	Specification	Test Condition	Measured Value	Remarks
Solar Battery Charger	4.2V, 4A	Vin = 4.5 to 28V	Vout = 4.2V	Correct after resoldering the PMOS
Overcurrent Protection	Fuse response at >5A	Simulated fault condition	Not tested	Assumed correct based on fuse rating
Voltage Regulator	5V output	Vin = 7 to 28V	Vout = 5V	Regulator functioning correctly
Overdischarge Protection	Cutoff at $\leq$ 3V	Vinput decrease from 3.7V	Cutoff at 3.04V	Cutoff functioning correctly
Hysteresis Test	Reactivation at 3.2V	Vinput increase from 2.7V	Reactivated at 3.2V	Hysteresis prevents toggling
Battery Level Indicator	Indicate battery levels	Variable V_{in}	See details in paragraph (c) of 3.8.2	Operational with adjusted levels
Boost Converter	Output 5V	$V_{in} = 3.7V$	$V_{out} = 5V$	Achieved desired output voltage
Full Circuit Test	Combined functionality	Simulated operational input	All outputs correct	All circuits functional together

3.8.2 Detailed Test Descriptions

(a) Solar Battery Charger

Initially, the output voltage increased with Vin due to incorrect PMOS orientation. After correction, the charger produced a stable 4.2V output across the input range of 4.5 to 28V, which aligns with the specifications, thereby confirming the successful completion of ATP1.

(b) Battery Protection Circuitry

- **Reverse Polarity Protection:** The geometric design of the XT60 connector ensures correct connection orientation, preventing reverse polarity damage without requiring an active test.
- **Overcurrent Protection:** The use of a 5A glass fuse is intended to protect against short circuits by blowing when currents exceed 5A. Active testing was not conducted to avoid equipment risk; however, it is assumed to function correctly based on the specifications of the fuse, effectively verifying ATP2.

[1] For a price list of components used in the power submodule, please refer to the Bill of Materials (BOM) provided in Appendix B.

- **Voltage Regulator Test:** The consistent output of 5V from the voltage regulator is crucial for powering the OpAmp in the overdischarge protection circuit, confirming the reliability of this component.
- **Overdischarge Test:** The successful demonstration of the circuit's ability to disconnect the load at 3.04V aligns with the threshold specifications, validating ATP3 effectively.
- **Hysteresis Test:** The reactivation threshold tested at 3.2V confirmed that the hysteresis prevents the circuit from toggling near the disconnection threshold, further substantiating the robustness of ATP3.

(c) Battery Level Indicator

The indicator successfully displayed different charge levels at various test voltages, providing clear visual feedback on battery status. The LEDs lit and extinguished at the designated voltage levels, thereby verifying ATP4:

- At 3.7V, all four LEDs indicated a 'fully charged' status.
- At 3.2V, three LEDs showed a 'high charge.'
- At 2.5V, two LEDs signaled a 'medium charge.'
- At 2.0V, one LED indicated a 'low charge.'

(d) Boost Converter

Adjusting the duty cycle via the potentiometer achieved the desired 5V output from a 3.7V input, demonstrating the boost converter's effectiveness and confirming ATP5.

(e) Integration Test of the Full Circuit

Upon reassembling the module with 0Ω resistors to reconnect all the sub-circuits, and supplying voltage through the designated inputs simulating real-world conditions, all parts functioned cohesively. Measurements verified that the entire system operated as designed when interconnected, fully validating the integration of all ATPs.

3.8.3 Conclusion

The detailed testing confirmed that the power module, designed with solar energy harvesting, battery charging with MPPT, comprehensive protection mechanisms, and an efficient boost converter, operates as intended and can reliably power the Raspberry Pi, light sensor, and camera with a 5V supply using a 3.7V Li-ion battery that is charged by the solar panel.

Chapter 4

Camera and Sensing Subsystem

LNKMAL001

4.1 Introduction

As fork-tailed drongos show no signs of extinction in Kalahari it is important for researchers like Ben to understand behavioral activities of the Drongos. These activities need to be in visual form. Hence this subsystem focuses on camera and sensing which will help Ben to get accurate and reliable information about behavioral patterns of Drongos around their nests. Moreover, the system will also help to capture foreign objects around the nest.

4.2 Requirements, Specifications Acceptance Test Procedures

4.2.1 User Requirements

UR_1: Reliability : The system must capture all activities around the nest day and night.

UR_2: Cost effectiveness : The camera system needs to be cheap to replace.

UR_3: Power efficiency: The camera system should not deplete batteries too quickly.

4.2.2 Functional Requirements

FR_1: The system must use motion detection or object detection to trigger scene capture.

FR_2: Video capture must be triggered immediately when there is an object around the nest.

FR_3: Camera must allow connection of Fill flash or Infrared (IR) LEDs.

FR_4: Camera system must be able to capture clear images at various light intensities from daylight to twilight.

FR_5: Videos and images filenames must have associated date and time for GUI processing.

FR_6: Captured videos and images must be saved to a directory that can be accessed via Secure Shell (SSH) protocol.

FR_7: Video length and images resolution should be configurable.

FR_8: Camera must have a soft configurable IR filter.

4.2.3 Specifications

S_1: The system uses SBC for interfacing with camera.

S_2: Camera supports 480p to 1080p image resolution and 720p video resolution.

S_3: The system uses image processing based technique to trigger scene capture.

S_4: Images and videos are downloaded using Secure copy protocol (SCP).

S_5: Digital light sensor is used for toggling camera operating modes (daylight or night mode).

S_6: The system consumes 5V and 450mA at maximum.

S_7: Camera has a built-in IR-cut filter.

4.2.4 Acceptance Test Procedures

ATP_1: Confirm that camera can capture images in daylight and night.

ATP_2: Verify that trigger works.

ATP_3: Verify that light sensor reads 0 lux in dark and output increase with increasing light intensity.

ATP_4: Verify that the image filters returns expected output.

4.3 Design Choices and Methodology

4.3.1 SBC

Reduced Instruction Set Computer (RISC) architecture is known for high performance per watt for battery powered devices. Therefore SBC choice narrowed down to two Quad-Core Advanced RISC Machines (Arm) cortex-A53 CPU based SBCs namely Raspberry Pi Zero 2W and Orange Pi Zero 2W. Mali G32 MP2 GPU is superior to VideoCore IV as it supports OpenGL ES 1.0/2.0/3.2, OpenCL

Table 4.1: Comparison between Raspberry Pi Zero 2W and Orange Pi Zero 2W

Aspect	Raspberry Pi Zero 2W	Orange Pi Zero 2W
Processor	RP3A0, Cortex-A53 (64-bit)	Allwinner H618, Cortex-A53 (64-bit)
CPU Speed	1GHz	1.5 GHz
GPU	VideoCore IV	Mali G31 MP2
RAM	512MB SDRAM	LPDDR4:1GB/1.5GB/2GB/4GB
Wi-Fi	2.4GHz 802.11 b/g/n	5GHz 802.11 a/b/g/n/ac
Bluetooth	Bluetooth 4.2 BLE	Bluetooth 5.0
GPIO Pins	40	40
Camera Interface	Camera Serial Interface (CSI)-2	USB
On Board Storage	MicroSD card slot	16MB SPI flash, MicroSD card slot
Power consumption	5V, 350mA	5V, 300mA
Official OS	Raspbian (Debian based)	Orange Pi OS (Arch)
Price	R278.33	R479.00 - R874.00

2.0, Vulkan 1.1 while VideoCore IV only supports OpenGL ES 1.1, 2.0 and optimised version of OpenCL called pocl. This therefore makes orange pi a good option for image processing algorithms which are computationally expensive but can be highly parallelised. Moreover, Orange pi SPI flash is very appealing as it is more reliable and quick to access. Raspbian is based on Debian which is very stable Linux distribution compared to Orange Pi OS which is based on Arch which is a rolling release distribution. Therefore in terms of security, software support, backward compatibility raspbian is superior.While Orange Pi supports Debian, it is not optimised for Orange Pi hence slower performance and it might not have effective support like official OS.

Orange Pi power consumption is lower as it uses LDDR4 RAM hence consumes 0.25W less than raspberry pi but this is based on when all most every peripheral is operating. However, raspberry pi CSI-2 camera interface makes it very attractive as this is compatible with many raspberry pi official cameras and many more from different vendors. While there exists USB cameras for embedded systems in the market, they are not as many as CSI compatible cameras. CSI has higher bandwidth than USB, and it is dedicated specifically for processors and Socs which leads to lower latency compared to general purpose USB. As Ben needs a reliable and easy to replace camera system, Raspberry Pi Zero 2W is better option as it uses stable OS hence a newer version of OS cannot lead to drivers issues or backward incompatibility unlike rolling release Arch of which Orange Pi OS is based on. Also CSI support makes it a more attractive because this allows for a wider range of cameras to choose. Moreover, Orange Pi documentation does not clearly state its overall and peripherals power consumption and 300mA is based on online community reviews. In contrary, Raspberry Pi documentation clearly outlines Raspberry pi Zero 2W power consumption overall and each peripheral power consumption. Based on these features, Raspberry pi Zero 2W was chosen as payload for camera subsystem.Not only does it offer robust features, it is also available at lower cost.

4.3.2 Camera

As Ben needs a camera with night vision capability, there were two options to choose from namely: WS Raspberry Pi Night Vision Camera (IR-CUT) and Raspberry Pi Camera Module V3 (NoIR). The table below illustrates differences in key specifications. WS IR-CUT camera was chosen over Raspberry

Table 4.2: Comparison WS Raspberrry Pi Night Vision Camera (IR-CUT) and Raspberry Pi Camera Module V3 (NoIR)

Aspect	**IR-CUT**	**NoIR**
Sensor	5MP OV5647	11.9MP Sony IMX708
IR-Cut Filter	yes, soft configurable	no
Video Modes	1080p30, 720p45, 480p60	1080p50, 720p100, 480p120
Camera Interface	CSI-2	CSI-2
Diagonal Angle of View	75.6°	75°
Price	R399.90	R526.48

Pi No-IR because it has soft configurable IR-Filter hence it can capture clear images at varying light intensity levels. In contrast, absence of IR-Filter on No-IR makes it unsuitable for day light images which is one of the reasons Ben is looking for alternative solution to the current camera traps. Moreover, WS IR-CUT comes with two high intensity IR-LEDS and LDRs hence LEDs automatically turn on when light intensity drops. While No-IR offers higher resolution and frame rate, 12MP is not appealing as Ben needs a deterministic real time camera system and 12MP pixels will take long to process and consumes a lot of memory. While No-IR is an official raspberry pi camera, ov5747 is well supported on all raspberry boards. Finally, WS IR-CUT is cheaper while offering robust features that meet the project specifications and user requirements.

4.3.3 Bird presence detection or Motion Detection

Motion detection is very important for automatic capture of a scene. As it is vital for this project, Passive Infrared (PIR) and Image Processing based approaches were considered.A PIR sensor is an electronic sensor that measures IR light radiating from objects in its field of view. However, most PIR sensors are for security applications or automatic lighting whereby they detect motion of slowly moving human beings. Not only do they prevail in motion detection of slow moving objects, they are also susceptible to false triggers or can fail to detect motion of small fast moving animal like Drongo. In contrast, there a plenty of image processing algorithms used in motion detection. Background subtraction and Frame differencing are two algorithms that stood out as they assume static camera. Frame differencing is a simple algorithm that works by subtracting two consecutive frames in a video frames or two quick successive photos of a scene and then the difference is thresholded. Background subtraction models the background by capturing the scene of interest without target object presence and then background model is subtracted from the photos from the scene and thresholded. Background subtraction is not ideal for environments with varying light intensity levels but adaptive version updates the background model based on light intensity. However, I considered frame differencing based on consecutive photos as it is not computationally intensive which implies low power consumption.

4.3.4 Software Development Stack

Programming languages

With regards to systems programming C++ and Rust were the options considered. Rust emphasises memory safety, has built-in package manager and build system. Rust also has a built-in concurrency and therefore a very powerful language for high performance applications. However, rust allows unsafe keyword which can bypass compiler strict memory checking rules. In contrary C++ is high performance language that has zero overhead abstractions. Also modern C++, C++11 and following standards use Resource Acquisition Is Initialization (RAII) to mitigate memory leaks through smart pointers which help in automatic memory management. Moreover, Standard Template Library (STL) offers a rich set of algorithms and collections.Also modern C/C++ build tools like CMake and Meson make C++ development even easier.Moreover, Rust ecosystem is relatively new hence it does not have a well established set of libraries. In contrast, C++ has a very mature ecosystem and rich set of libraries like Boost, OpenCV, Simple and Fast Multimedia Library (SFML) and many more. Rust wins in terms of memory safety, build tools, and concurrency. But C++ RAII which is also used in rust helps to solve issue of manual memory management. C++ ecosystem is mature and therefore it was a suitable option over rust.

Python was chosen for camera interfacing as picamera2 is official raspberry pi python binding of libcamera which is camera library for Linux systems.

Library choices

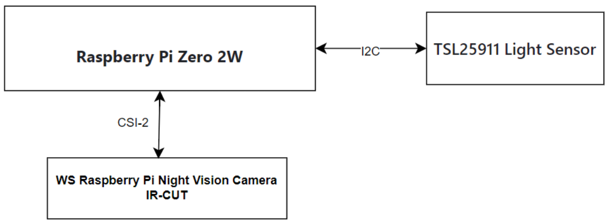
For image processing tasks two libraries were considered namely OpenCV and stb. OpenCV offers rich set of image and video processing libraries. But, it is not well optimised for embedded systems. On the other hand, stb is the header only C library that can be used for reading and writing images to the disk. Since needs Ben a reliable system, performance is a key hence stb was chosen for image processing tasks.

4.4 Subsystem Design

4.4.1 Hardware Design

Figure 4.1 below shows the block diagram of the system. A light sensor is used for toggling the camera mode between normal mode and daylight

Figure 4.1: Block diagram



4.4.2 Initial software Design

Initially the application consisted of two applications, C++ and python application. C++ application was handling all image processing workload and python application was capturing images. The two applications communicated via Transmission Control Protocol (TCP). However this introduced complexity as python TCP routine needed to synchronize with function handling image capturing and also wait for replies from C++ application.

4.4.3 Final Software Design

To mitigate issues with initial design, a more robust approach was taken. In this design, a python binding was created using C++ image processing application, as a result only one main application was required.

4.4.4 C++ Application

This application abstracts image processing routines which are used by python application. This procedures include linearing filtering, thresholding and object detection.

Linear Filtering

Image linear filtering is $2D$ convolution operation whereby a kernel or filter defined as $n \times n$ matrix $\omega(x, y)$ is applied to the $M \times N$ image $f(x, y)$. An n is chosen such that it is odd most of the time therefore there exists an integer b such that $n = 2b + 1$. Let $g(x, y)$ be convoluted image then $g(x, y) = \omega * f(x, y) = \sum_{s=-b}^{b} \sum_{t=-b}^{b} \omega(s, t) f(x - s, y - t)$, where centre coefficient $\omega(0, 0)$ aligns with the pixel location (x, y).This has to be repeated for every pixel. However most kernels are separable hence number of computations can be reduced. For example 3×3 Gaussian kernel is given by: $\omega(x, y) = \frac{1}{16} \begin{pmatrix} 1 & 2 & 1 \\ 1 & 4 & 1 \\ 1 & 2 & 1 \end{pmatrix}$, This kernel can be represented as $\mathbf{v} \times \mathbf{v^T}$, where $\mathbf{v} = \frac{1}{4} \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$. Therefore $g(x, y) = \omega * f(x, y) = (f(x, y) * \mathbf{v}) * \mathbf{v^T}$. For this project, separable kernels like Gaussian and box are used for filtering.

Thresholding

Image thresholding is a transformation whereby a gray scale image is converted to the binary image.It is characterised by transfer function $h(I(x, y)) = \begin{cases} 0 & \text{if } I(x, y) < T \\ 255 & \text{if } x \geq T \end{cases}$, where T is a threshold value. Since the image is a result of subtraction of images ostu's thresholding algorithm has been used as the difference pixels are expected to form bimodal histogram with deep valley between two peaks. This algorithm works by searching a single threshold that minimises intra class variance [27]. Minimising intra-class variance is the equivalent to maximising inter class variance hence the latter was used as it is computationally eased.

4.4.5 Python Application

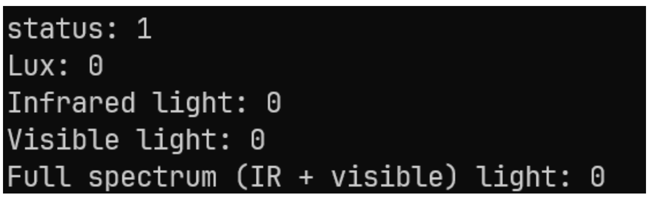
This is the main application of this system. It uses image processing library for motion/object detection. It also handles capturing of images and toggling camera operating mode based on light sensor lux values.

4.5 Testing and Results

4.5.1 TC_1:Light Sensor

The purpose of this test to evaluate if the light sensor reads correct values at varying light intensity levels. The sensor was evaluated at three light intensity level which include complete darkness, medium light and shining a light source to the sensor.

Figure 4.2: Light sensor in darkness



```
status: 1
Lux: 0
Infrared light: 0
Visible light: 0
Full spectrum (IR + visible) light: 0
```

Figure 4.3: Light sensor in medium brightness

```
status: 1
Lux: 54
Infrared light: 2892
Visible light: 88933887
Full spectrum (IR + visible) light: 88935244
```

Figure 4.4: Light sensor in high light intensity

```
status: 1
Lux: 81168
Infrared light: 15538
Visible light: 160117543
Full spectrum (IR + visible) light: 160119986
```

As brightness increases from complete darkness to high light intensity, light sensor values increase from zero to very huge number as seen from Figure 4.2 to 4.4.

4.5.2 TC_2:Camera

This test evaluates if the camera can capture images at night and during the day. Therefore evaluates if IR-CUT filter is soft configurable.Figures below show captured images. Figure 4.5 illustrates that

Figure 4.5: Image captured at daylight

Figure 4.6: Image captured at night

the camera captures clear images during the day. Conversely, Figure 4.6 shows disabling IR filter at night leads to fairly clear image.Figure 4.6 was captured at night in a dark room.

4.5.3 TC_3:Image filtering

In this test, image filtering functions are evaluated which include Gaussian filter, mean filter and converting RGB image to gray scale. Figure 4.7 shows a snippet of code used to evaluate the filters.

Figure 4.7: Filtering test application

```
import image
path = "/home/mlenka/images/"
# original image
img = image.Image(path+"board.jpg")
kernel = [4.5,0,0,0,0,0,0,0,0,0,0]
# gaussian filter output
blur = image.Image(img.width, img.height, img.channels)
# gray
gray = image.Image(img.width, img.height, 1)
# box / averaging
box = image.Image(img.width, img.height, img.channels)
img.filter(blur,kernel,True)
kernel = [1,1,1,1,1,1,1,1,1,1,1]
img.filter(box,kernel,False)
img.to_gray_scale(gray)
# save images to disk
blur.write(path+"board_gauss.jpg")
box.write(path+"board_mean.jpg")
gray.write(path+"board_gray.jpg")
```

Figure 4.8: Image used for filtering

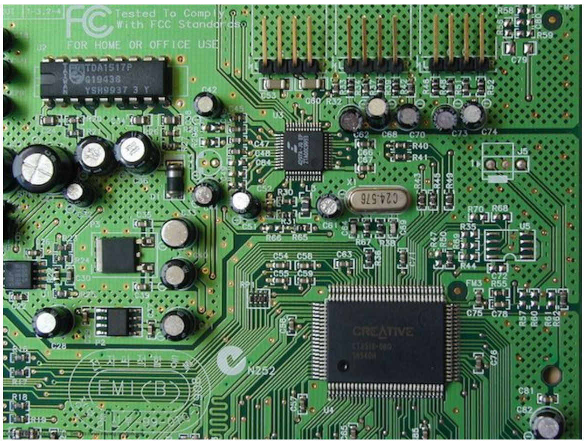
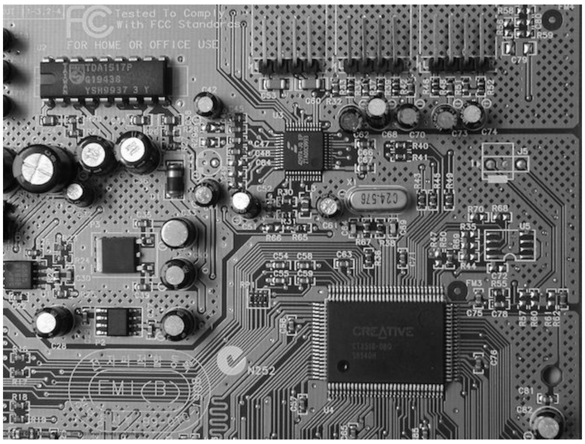


Figure 4.9: Gaussian blurred image

Figure 4.10: Mean blurred image

Figure 4.11: Gray scale image



Figures 4.9 to 4.11 show that all filters outputs are correct, as outputs expected to be blurred are blurred and gray scale image appear as expected.

4.5.4 TC_4:Thresholding and Object detection

In this test camera trigger system is evaluated, that is whether the system can detect object using frame differencing. Figure 4.12 shows the python script used for testing.

Figure 4.12: Object detection test program

```python
    gray.write(path+"board_gray.jpg")
def object_detect():
    # background
    b = image.Image(path + "2024-05-12_12:57:26.jpg")
    # background + object
    f = image.Image(path + "2024-05-12_12:56:10.jpg")

    # gray scales
    b_g = image.Image(b.width, b.height, 1)
    f_g = image.Image(f.width, f.height, 1)
    b.to_gray_scale(b_g)
    f.to_gray_scale(f_g)

    # frame differencing
    diff = image.Image(b.width, b.height, 1)
    b_g.absolute_diff(f_g, diff)

    # thresholding
    obj_th =  image.Image(b.width, b.height, 1)
    diff.otsu_1d(obj_th)
    # save to disk
    obj_th.write(path+"detect.jpg")

    if obj_th.detect():
        print("Object detected")
    else:
        print("No object detected")
```

Images used for testing are illustrated below. Thresholded image and test program output are shown below. From Figure 4.16 and 4.15, it can be seen that canera trigger system is working. Hence the camera can be triggered to capture activity around the bird's nest.

Figure 4.13: Background without object

Figure 4.14: Background with object

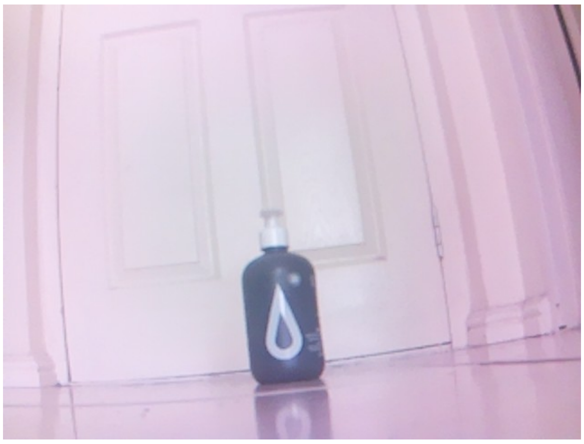
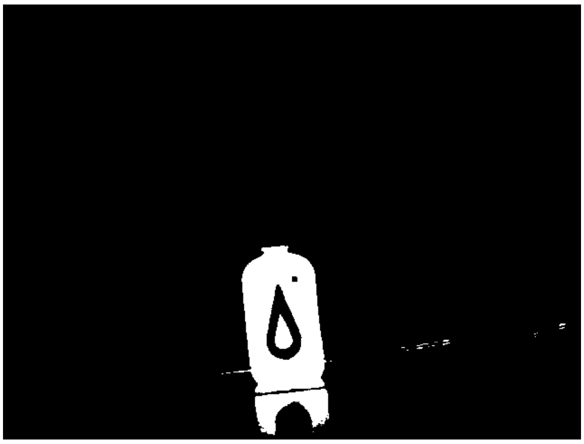


Figure 4.15: Program output

Figure 4.16: Thresholded Image



4.6 ATPs Assessment

Table 4.3 illustrates different Acceptance Test Procedures and their test results. Images were downloaded successfully as shown in GUI section. Moreover, image resolution and video length are soft configurable via Extensible Markup Language (XML) file. Additionally, the system is cost effective as SBC used is cheap and the camera is fairly cheap with robust features. Since SBC is Arm based, the system is concluded to be power efficient, and also the light sensor can be switched on at predawn and sunset. Hence light sensor can be shut down most of the time. Finally, the camera can also capture videos successfully.

Table 4.3: ATPs Assessment

ATP	Requirements	Specification	Test Case	Test Result
ATP_1	**UR_1, FR_2, FR_3, FR_4, FR_8**	**S_7, S_8**	**TC_2**	**Passed**
ATP_2	**FR_1, UR_1**	**S_3**	**TC_4**	**Passed**
ATP_3	**UR_1, FR_1**	**S_5**	**TC_1**	**Passed**
ATP_4	**UR_1**	**S_3**	**TC_3**	**Passed**

4.7 Conclusion and Recommendations

In conclusion, a low cost and reliable camera system design has been successful. With light weight image processing library a system can detect objects efficiently and therefore trigger scene capture. Moreover, the system is easier to maintain as complex C++ library can be interacted with via python script. However, this system can be improved by using PIR, Radio Detection and Ranging (RADAR), and audio sensors together with image processing based approach to make a trigger system more reliable and effective. Also for the system to be responsive in real time, SBC can be paired with microcontroller. Finally most of the specifications and functional requirements have been successfully met.Additionally, this can be made more robust if images can be displayed on website in real time so that the user can help to verify trigger particularly during the day.

Chapter 5

Mechanical Housing Subsystem

This section was completed by Liam Breytenbach, BRYLIA002.

5.1 Mechanical Housing Introduction

The purpose of the mechanical housing is to protect the electrical components from the harsh elements that surround it. This includes dust and rain which could damage and corrode the electrical components over time. The enclosure must be easy for the user to set-up and use as well as be versatile enough to adapt to most environments it could potentially encounter. The design of the mechanical enclosure went through several iterations and diverged into two main ideas. Each of the ideas have figures of merit to consider. Changes throughout the design iterations were prompted by factors such as material, ease of assembly, versatility and airflow.

5.2 User Requirements

The Mechanical Housing is designed to enclose and secure the electrical components of the other subsystems and bring them together as a single product:

Table 5.1: Mechanical Housing User Requirements

Label	**Requirements**
HR-1	The product must be easy to transport
HR-2	The housing must not break in the Kalahari
HR-3	The product must be user friendly
HR-4	The housing must not disturb the wildlife around it
HR-5	The product must be cheap

5.3 Functional Requirements

The Functional requirements outline the key functionalities of the Mechanical Housing outlined in 5.1.

5.4 Design Specifications

The Design Specifications of the Mechanical Housing will detail how the Housing will meet the Functional and User Requirements.

Table 5.2: Functional Requirements

Label	Functional Requirements
HFR-1	All of the components must be able to fit into the housing as a single unit
HFR-2	The housing must be dust proof
HFR-3	Unit must have 6 degrees of Freedom
HFR-4	The product must be coated in an environmentally appropriate material
HFR-5	The product must be within budget

Table 5.3: Specifications

Label	Specifications
HS-1	The housing unit must be 175mm x 100mm x 40mm
HS-2	Unit must easily rotate and translate about the x, y, z axes
HS-3	The solar panel unit must be 375mm x 250mm x 500mm
HS-4	The product must be made of plastic or wood and coated sufficiently
HS-5	The housing must be less than R280

5.5 Requirement Analysis and Design Choices

5.5.1 Dimensions

The design of the housing must accommodate all the components from the Power, Microcontroller, and Sensor Submodules. Placement of these components also must be considered.

5.5.2 User Convenience

The design is made to be as user friendly as possible. This is done in a number of ways.

Ease of Setup

The housing is mounted with two ball and socket joints. This allows the user to set up the camera very quickly and effectively. The bottom of the ball and socket joint is attached to three flexible plates. These plates allow the housing to be attached to a surface with any angle, whether flat or curved. Since the housing is mounted in a tree, screws are used to attach the plates to the trunk, securing the housing for as long as is intended.

Ease of Use

The housing of the Camera, Sensor, and Power Modules is sealed with a retractable lid. This lid is transparent as the design of the PCB allows for the user to observe the battery level indicator and determine whether certain components on the PCB and Camera are functioning as expected. The lid can be easily removed and acts as a solid barrier to the climate surrounding it. As mentioned above, the housing of the camera can be easily adjusted to any desired angle due to the ball and socket joints.

5.5.3 Thermal Considerations

Thermal regulation is a crucial factor when considering the design of the housing. Thermal Regulation falls into two categories.

Active:

This method involves using electricity to lower the temperature of the system. This includes air conditioning systems, fans, or liquid cooling systems. These systems actively remove heat from the device to maintain a desired temperature.

Passive:

This method relies on natural processes or materials to dissipate heat without the need for electricity. This includes strategic design features to maximize natural airflow, insulation to reduce heat transfer, or using materials with high thermal mass to absorb and release heat slowly.

The environment surrounding the mechanical housing ranges from 10-45 degrees. Thermal considerations must be made to accommodate each of the components within the housing. Due to the system attempting to conserve as much power as possible, a passive thermal regulation system is used. Components cannot be stacked on top of one another as this can lead to overheating of the components. There must be adequate airflow through the housing, such that the heatsinks on certain devices are able to function properly.

5.5.4 Cost

The cost of 3D printing is relatively low. Fairly complex designs can be made, which cater for specific needs of the housing subsection. A customized housing can be made using a 3D designer tool (Such as Solidworks) where the user is in complete control of the design. Another viable option is using a wooden frame to house the components. Wood is a very strong substance that is readily available. It is relatively cheap and can be cut, glued and painted to meet the design requirements. A large portion of the housing subsection is 3D printed. Although the strength of a 3D print is sometimes unreliable, the requirements do not need the housing to be unbreakable. Majority of the time, the housing will not be touched or moved. For these reasons, a 3D print using 0.15mm thickness PLA is sufficient for the task. The solar panel is mounted to a wooden structure. The original design consisted of a 3D printed design, however, the size and weight of the solar panel is too large for a 3D print to be successful.

5.5.5 Environmental Considerations

It is important when observing wildlife not to disturb their natural behaviours such as mating, feeding and migratory patterns. This is considered in the design of the housing. The housing is coated to resemble the natural environment around it. It is not too large as to disturb wildlife and the housing itself blends into the bark, leaves and features surrounding it. The hardware supporting the Solar Panel is made of pine wood. Although this is an alien species of flora, pine is not harmful to the species that surround it. Overall the housing takes the wildlife around it into consideration as to not disturb it in any dramatic way.

5.5.6 Design Choices

Housing Design 1

This design aims to reduce the cost and design time to observe Fork Tailed Drongos. It is a simple design that sufficiently houses the electrical components and meets most of the design specifications.

Pros:

- Low Cost.
- Short Design time.
- Relatively small and compact.

Cons:

- Is not user friendly (difficult to set up).
- Can lead to the electrical components overheating.
- Hard to adjust.

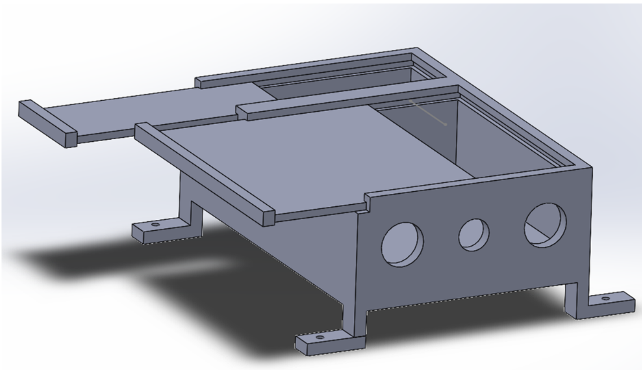


Figure 5.1: Housing Design 1

This design attempts to reduce the size of the mechanical housing. It involves stacking the PCB, Rasbery Pi and Sensor (Separated by insulation). While this design is an elegant solution. The major drawback is overheating of the components as well as visibility of the PCB. The PCB has battery level indicators as well as other indicator LEDs that need to be visible to the user. If the user were to try view the PCB, they would have to dismantle the housing structure to do so.

Housing Design 2

This design is still relatively low cost and is aimed to make the product as user friendly as possible. It incorporates aspects from Design 1, however has an added ball and socket joint that allows the user to position the camera at any angle they desire. Additionally the design is more spread out, allowing the user to view the PCB through the transparent lid present on the top of the housing.

Pros:

- Low Cost.

- User Friendly.
- Can easily be adjusted.

Cons:

- Longer 3D print time.
- Slightly Larger.

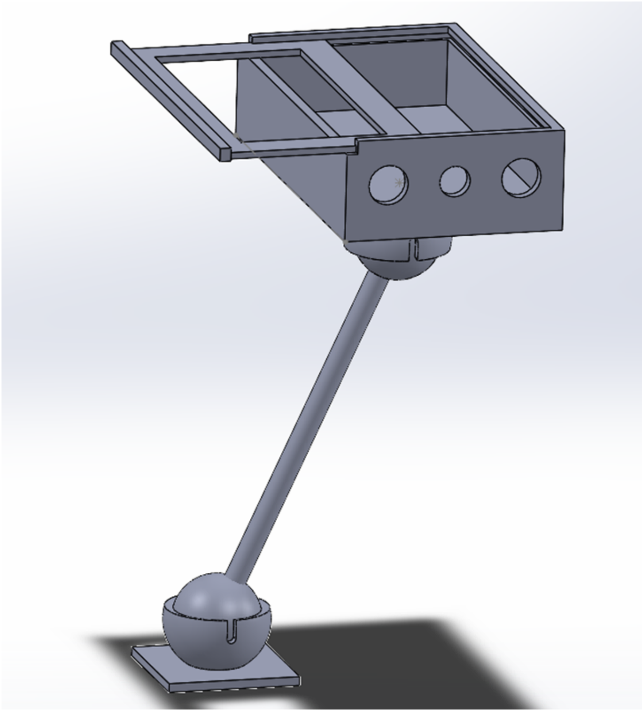


Figure 5.2: Housing Design 2

This design meets all of the design requirements. The components within the enclosure are spread out to reduce overheating. The housing can be easily adjusted to get any angle the user desires. While it is slightly larger than Housing Design 1, it is marginal. Overall Housing Design 2 is a better fit for the design of the enclosure.

Solar Panel Casing Design 1

This design is used to hold the solar panel in place. This is a tricky concept as the solar panel is not attached to the main housing. The main housing will be placed on and around the trunk of a tree. Unfortunately, this means that very little sunlight will reach it. For this reason, the placement of the solar panel needs to be sufficiently far away such that the sunlight is not blocked by the canopy of the tree.

Pros:

- Low Cost.
- Strong.

Cons:

- Too large for 3D printing.
- Cannot be adjusted easily.

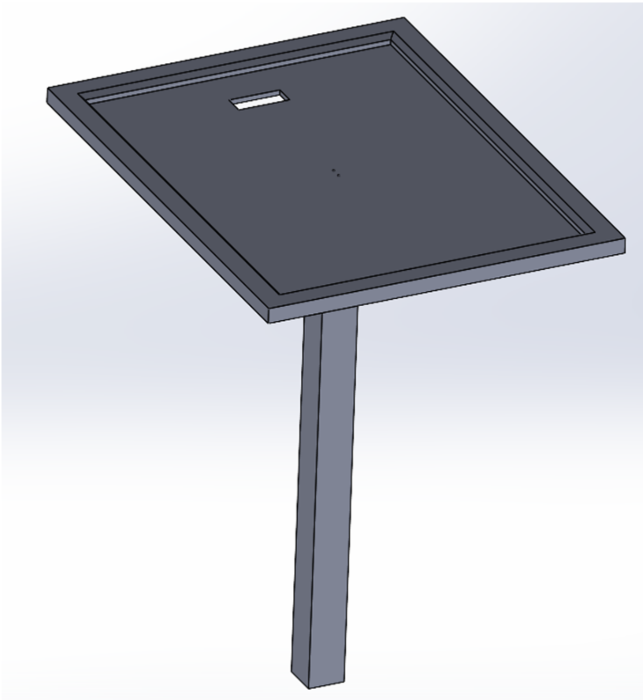


Figure 5.3: Solar Panel Casing Design 1

This design takes into consideration the weight and size of the solar panel. It also considers that the solar panel cannot be attached to the tree itself.

Solar Panel Casing Design 2

This design is also used to hold the solar panel in place. Due to very little sunlight being able to reach it when attached to the tree, the placement of the solar panel must be at a distance from the trunk.

Pros:

- Low Cost.
- User Friendly.

Cons:

- Very Large 3D print.
- Is not strong enough to hold the Solar Panel.

This is a very elegant design that attempts to make the use of the solar panel more user friendly. Unfortunately due to the weight of the solar panel, this design cannot be used as the frictional forces acting on the ball and socket joints overcome it's ability to maintain a fixed orientation. For this

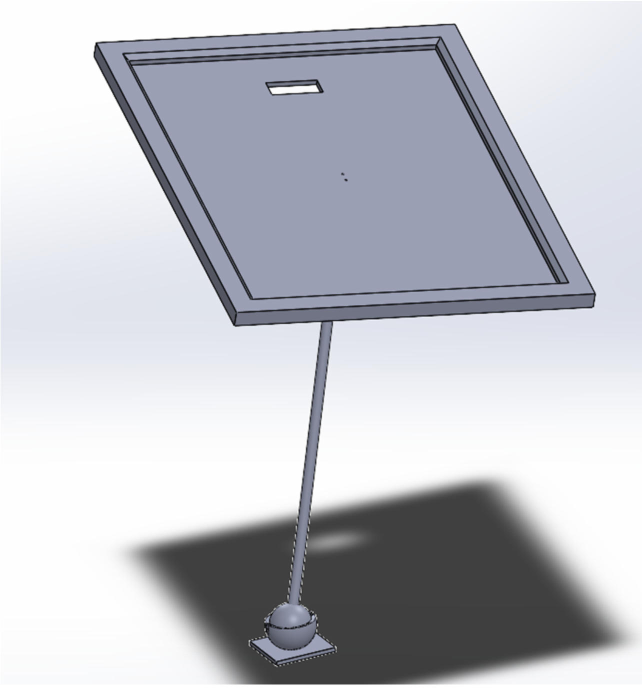


Figure 5.4: Solar Panel Casing Design 2

reason, Solar Panel Casing Design 1 is used as it is strong enough to hold the solar panel in place at a sufficient distance from the tree.

5.6 Final Design

The Final Design of the Mechanical Housing uses the designs from Housing Design 2 [5.5.6] and Solar Panel Casing Design 1 [5.5.6]. A schematic of the internal layout of the placement of electrical components can be seen below.

The housing has been designed slightly larger than is needed to fit the components within. This is to allow easy access to certain components such as the battery, as well as to allow for component replacement if necessary. On the PCB, there are various indicators such as LEDs and battery level indicators. This design allows for the user to observe within the box without dismantling the entire housing.

The Mechanical Housing has been placed in a simulated environment below, to show how the product would look when used in a practical situation.

> **Note:** Note that the cable running from the Solar Panel to the housing has been disguised as the Fork Tailed Drongo can interpret the cable as a snake and can disturb them from their natural behaviour.

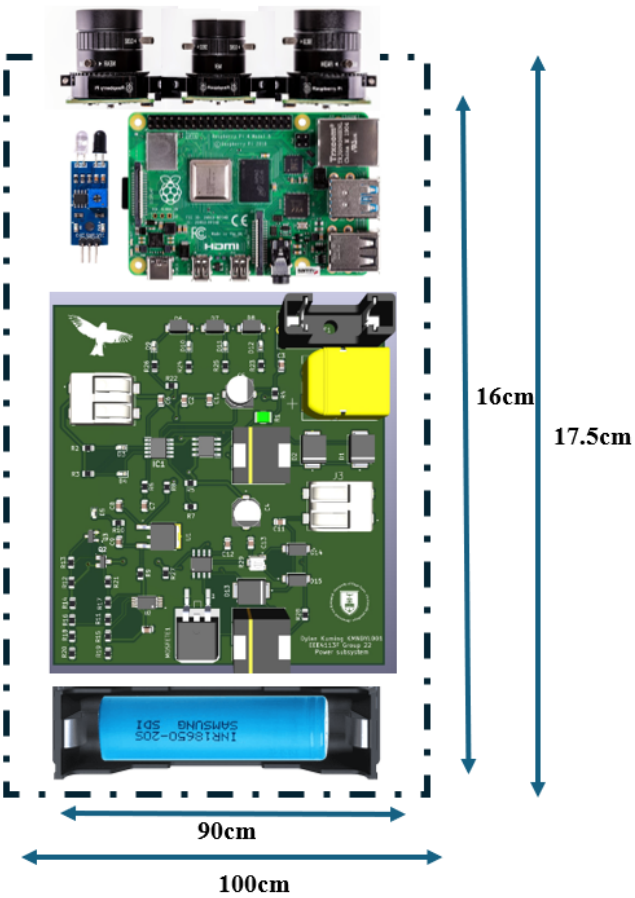


Figure 5.5: Final Design Internal Schematic

Figure 5.6: Final Design in a Simulated Environment

5.7 Testing and Results

5.7.1 Acceptance Test Results

To test the Mechanical Housing subsection, the Functional Requirements and Specifications must be tested.

Table 5.4: Acceptance Test Plan

Label	Refines	Description	Result	Remarks
ATP-1	HFR-1, HS-1	Place all components inside the housing.	Passed	All components can fit into the housing.
ATP-2	HFR-1, HS-3	Place the solar panel on the Solar Panel Casing.	Passed	The solar panel fits securely onto the Solar Panel Casing.
ATP-3	HFR-2	Pour 250g of sand on the housing.	Passed	The housing does not allow sand to get inside the housing.
ATP-4	HFR-3, HS-2	Rotate the housing about the x, y, z axes.	Passed	The housing can rotate about the x, y, and z axes.
ATP-5	HFR-3, HS-2	Translate the housing in the x, y, and z directions.	Passed	The housing can move in the x, y, and z directions.

As can be seen, all of the User Functional Requirements and Design Specifications have been met. From this, the User Requirements have also been achieved.

5.8 Mechanical Housing Conclusion

The Mechanical Housing subsystem plays a vital role in protecting and enclosing the electrical components from the environment while providing user friendly functionality. Through a detailed analysis of user requirements, functional requirements, and design specifications, a Mechanical Housing design has been achieved that meets the subsection's objectives.

Through the design process, two primary housing designs were considered. While Housing Design 1 offers simplicity and cost effectiveness, it lacked user friendliness and thermal regulation capabilities compared to Housing Design 2. Ultimately, the incorporation of a ball and socket joint in Housing Design 2 provided enhanced maneuverability, making it the preferred choice for the final design. Although Solar Panel Casing Design 2 provided greater user convenience, it lacked the necessary strength to secure the solar panel effectively. Consequently, Solar Panel Casing Design 1 was chosen, as it demonstrated the capability to securely hold the solar panel in position.

Through testing, the Mechanical Housing subsystem successfully met all of the user requirements, functional requirements, and design specifications. The acceptance test results confirm the functionality and reliability of the housing design, allowing the Mechanical Housing Subsection to be integrated into the larger project framework.

Chapter 6

Graphical User Interface Subsystem

This section was completed by Tinashe Timba, TMBTIN004.

6.1 Introduction

This submodule details the development of a graphical user interface (GUI) designed specifically for Ben, a researcher dedicated to studying fork-tailed drongos. These birds are known for their interesting behavior and ecological significance, making them a valuable subject for scientific inquiry. The purpose of the GUI is to streamline data collection, processing, and visualization tasks, thereby allowing Ben to focus more on analysis and less on the complexities often associated with field research. This tool is part of a larger system intended to support his day-to-day activities and long-term research goals. By automating routine tasks and simplifying the user experience, the GUI facilitates a more efficient workflow and enhances the overall effectiveness of the research process. This section outlines the requirements gathered from Ben, the design considerations and challenges faced, the solutions implemented, and the testing procedures used to ensure reliability and satisfaction.

6.2 Requirements and Specifications

6.2.1 User Requirements

1. The user interface should be intuitive and easy to navigate for Ben, who has a minimal technical background.

2. The user needs to be able to retrieve data with minimal effort.

3. The program should show relevant information for research purposes.

6.2.2 Functional Requirements

FR_1: The system must be able to download images from a designated network from the camera capturing the Drongo activity.

FR_2: It must be able to specify the download folder on the machine of Ben's choosing.

FR_3: The GUI must be able to display the downloaded images in a scrollable view.

FR_4: It must also view images in a satisfactory size.

FR_5: The GUI must be able to allow the recording of observations about each image for example specific features. It must have the option to save observations along with the specific image.

FR_6: The GUI must be able to display analytics based on the camera footage. It must show the number of images captured in a day and display the history over some time to enable comparison.

FR_7: The GUI must automatically include timestamps on downloaded images.

FR_8: The system must allow Ben to customize GUI settings for example the default download folder and preferred display mode.

FR_9: It must have a settings menu to make these preferences.

FR_10: The GUI must aid in data management.

6.2.3 Specifications

S_1: GUI must be developed using Tkinter or Kivy for a simple and easy-to-use interface.

S_2: OpenCV will be used for image and video retrieval and interaction with the GUI framework.

S_3: Images will be sized 640x480 pixels, which is suitable for basic documentation, or 1280x720 pixels, which is a larger size and good for image quality and file size.

S_4: Images will be in JPEG format, which offers a good balance between image quality and file size.

S_5: The system will receive images via Wi-Fi or Bluetooth from the camera.

S_6: The system must operate without the reliance on an internet connection for image download, storage, and analysis.

S_7: The system must use a simple, one-click download with intuitive folder selection options and download in the background to ensure Ben can continue working while images are retrieved.

S_8: The system must have an explicit scroll feature for inappropriate placements.

S_9: Analytics are to be presented in the form of heatmaps and line charts to provide insights to Ben understandably.

S_10: The GUI must store image names and their observation in a .txt file.

6.3 Design Choices and Methodology

Graphical User Interfaces (GUIs) play a pivotal role in creating user-friendly applications.

6.3.1 Platform

Web App

Web apps can be accessed from any device with an internet connection and a web browser and this promotes ease of use across different devices without the need for installation however Web apps also require a reliable internet connection, which is a limitation in remote or field-based research settings.

Updates and changes can be pushed directly to a server and take effect immediately without requiring user intervention but they might experience latency or slower response times compared to desktop applications, particularly with high data loads, in this case, images of Drongos.

Desktop App

In contrast to Web Apps, Desktop apps offer better performance and more efficient handling of processes and graphics, important for intensive tasks. They can function without an internet connection, making them ideal for fieldwork in remote areas where connectivity is an issue. Unlike web apps, there might be a need to develop multiple versions for different operating systems which might prove to be a challenge unless the right language model is used.

6.3.2 Language

Java

Java is often faster than Python, which can be crucial for performance-intensive applications and programs can run on any device that supports the Java Virtual Machine.Java is known for its robustness, security features, and extensive library of reusable components, which can be useful; in keeping Ben's data safe. However, Java requires more lines of code than Python, which can increase development time which is limited, and the potential for bugs. While Java offers several options for GUI development, such as Swing and JavaFX, these options can be less modern and be more difficult to implement compared to Python's alternatives.

Python

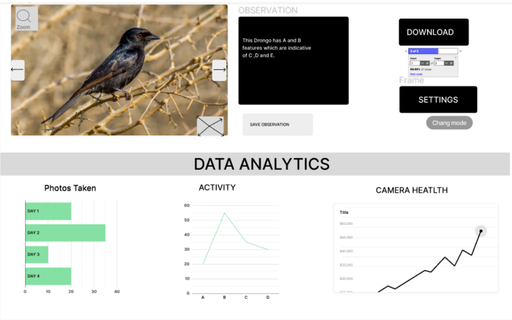
Python's syntax is clear and concise, making it excellent for designing a GUI in a limited time. Python has a lot of libraries, particularly for data handling and GUI development (e.g., Tkinter, PyQt). It also has a large community that provides a wealth of resources, which can be invaluable for solving problems and finding examples of best practices. A disadvantage to note is that Python can be slower than Java, which might be a limiting factor and Python's memory consumption is higher, which might not be ideal for very resource-constrained environments.

6.3.3 Platform and Language Choice

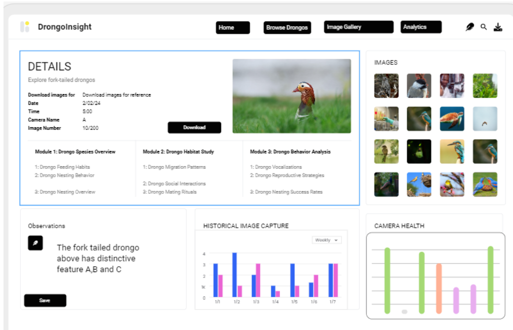
The choice to use Python and make a desktop application was guided by which of the above aligned more with the design requirements and specifications. Python offers several options for building GUIs, each with its own set of features and capabilities. During the initial stages of the project, careful consideration was given to selecting the most suitable libraries for developing the graphical user interface (GUI) component of the system. After evaluating several options, including Kivy and Tkinter, the decision was made based on various factors that align closely with the project's requirements and objectives.

GUI Deign Goals

Layout



(a) Design 1



(b) Design 2

Figure 6.1: Comparative view of Frontend Design options

The images above depict what I aim to build for the GUI interface. The designs are contain all the required functionality. Design 2 is a bit more complex as it offers additonal functionality over and above what is required. Due to time constraints and the fact that this interface is only required for Ben's use , I have chosen to go with the first design.

6.3.4 Tool vs Requirements

This section explores the libraries that could be used for the design of the GUI. These are Tkinter and Kivy.

1. **Downloading Images over a Network** : Tkinter provides support for making network requests using Python's requests libraries. One can create functions to download images from the designated network camera. Kivy also supports making network requests, allowing download images from the camera within the GUI application.

2. **Specifying Download Folder**: Tkinter provides components such as Label and Progressbar that can be used to display download progress. Additionally, it is possible to specify the download folder using Tkinter's file dialog module. Kivy offers similar components for displaying download progress and specifying download folders.

3. **Ability to scroll through images**: Tkinter does not have built-in support for scrolling images but this can be implemented using custom functionality for scrolling by implementing logic appropriate to do so in the form of functions and buttons within the GUI.Kivy offers built-in support for scrolling through its ScrollView widgets.

4. **Recording Observations and Saving Them with Specific Images**: Tkinter provides input widgets such as Entry for recording observations. One can save observations alongside images by storing them in a text file. Kivy offers similar input widgets for recording observations. One can implement functionality to save observations and associate them with specific images.

5. **Displaying Analytics Based on Camera Footage**:Tkinter can display analytics using graphical components such as charts and graphs created with libraries like Matplotlib. One can

generate analytics based on camera footage and display them within the Tkinter application. Kivy can also display analytics using its built-in graphical components. One can create charts and graphs directly within the Kivy application to visualize camera footage analytics.

6. **Allowing Customization of GUI Settings for Ben**: Tkinter can create settings menus and dialogs using its various components and dialog modules.and this can allow Ben to customize GUI settings such as default download folder and display mode within the Tkinter application.Kivy offers similar capabilities for creating settings menus and dialogs. One can implement customization options for Ben within the Kivy application using Kivy's widgets and layout components.

6.3.5 Final Design Choice:

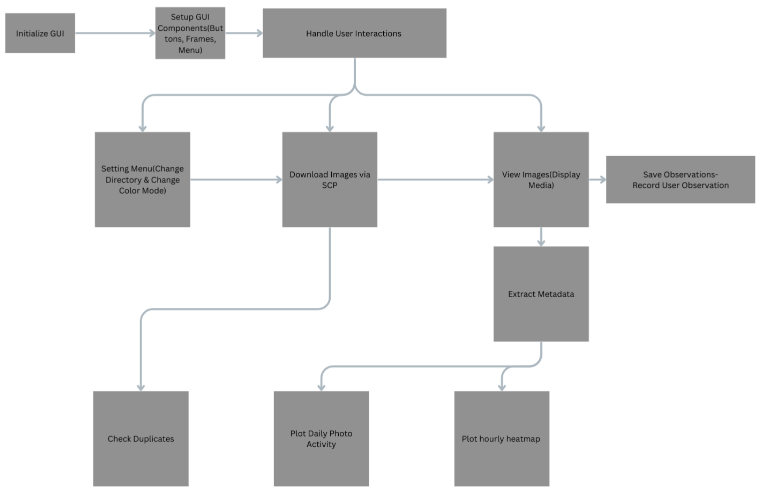


Figure 6.2: Block diagram

The figure 1.3 above outlines the design plan. It provides an overarching view of the GUI. I decided to use an extension of Tkinter called CustomTkinter to develop this . I had intially chosen Tkinter due to its simplicity and ability to provide a simple user interface that would require little guidance for Ben but during the implementation, I realized that the product looked outdated and old which would no be appealing to a user.

(a) Tkinter Frontend Design

(b) CustomTkinter Design

Figure 6.3: Comparison of GUI designs using Tkinter and CustomTkinter

As Custom Tkinter is an extension of Tkinter , the same functionality as described above is applies.

Final Drongo Activity Monitoring System

The final system with all the function implemented is seen belowin figure 6.4.

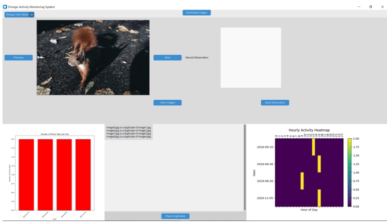


Figure 6.4: Final Graphical User Interface

The front end design was setup by declaring buttons and frames in specific position on the screen as can be seen in the figure 6.5 below.

```python
# Top frame (using CTkFrame)
top_frame = ctk.CTkFrame(root)
top_frame.pack(fill="both", expand=True)  # Fill remaining space

# Frame for displaying images (using CTkFrame)
image_frame = ctk.CTkFrame(top_frame, width=640, height=420)
image_frame.grid(row=0, column=2, padx=10, pady=10, sticky="nsew")  # Grid placement
image_frame.grid_propagate(False) # will stop from resizing


# Bottom frame (using most of the space)
bot_frame = ctk.CTkFrame(root)
bot_frame.pack(fill="both", expand=True)

# Frames within bottom frame
photost_frame = ctk.CTkFrame(bot_frame)
photost_frame.pack(side="left", fill="both", expand=True)

health_frame = ctk.CTkFrame(bot_frame)
health_frame.pack(side="left", fill="both", expand=True)

scrollable_frame = ctk.CTkFrame(health_frame)
scrollable_canvas =Canvas(scrollable_frame)
scrollable_canvas.pack(side="left", fill="both", expand=True)
scrollbar = ctk.CTkScrollbar(scrollable_frame, command=scrollable_canvas.yview)
scrollbar.pack(side="right", fill="y")
scrollable_canvas.configure(yscrollcommand=scrollbar.set)
scrollable_canvas_frame = ctk.CTkFrame(scrollable_canvas)
scrollable_canvas.create_window((0, 0), window=scrollable_canvas_frame, anchor="nw")
```

(a) Frame setup

```python
# Download button (using CTkButton)
download_button = ctk.CTkButton(root, text="Download Images") #, command=download_images
download_button.pack(padx=(10, 0), pady=(0, 10))  # Pack at top with padding


# Scrolling buttons
next_button = ctk.CTkButton(top_frame, text="Next", command=next_image)
next_button.grid(row=0, column=3, padx=10, pady=10)  # Grid placement

prev_button = ctk.CTkButton(top_frame, text="Previous", command=prev_image)
prev_button.grid(row=0, column=0, padx=10, pady=10)  # Grid placement

# Text entry for recording observations (using CTkLabel and CTkEntry)
observation_label = ctk.CTkLabel(top_frame, text="Record Observation:")
observation_label.grid(row=0, column=4, padx=10, pady=10, sticky="w")  # Grid placement, anchor west

observation_entry = ctk.CTkTextbox(top_frame, height=300, width=300)
observation_entry.grid(row=0, column=5, padx=50, pady=50, sticky="ew")  # Grid placement, expand horizontally

# Save button for recording observations (using CTkButton)
save_button = ctk.CTkButton(top_frame, text="Save Observation", command=save_observation)
save_button.grid(row=1, column=5, padx=10, pady=10, sticky="e")  # Grid placement, anchor east
#Settings Menu
# Create a menu bar for settings
options=["Choose Download Directory","Change Color Mode"]
# Creating a settings dropdown (using CTkOptionMenu)
settings_menu = ctk.CTkOptionMenu(root,values=options,command=settings)
settings_menu.place(x=10, y=10)
```

(b) Buttons

Figure 6.5: Details of the GUI components: Frame setup and Buttons

6.4 Testing and Results

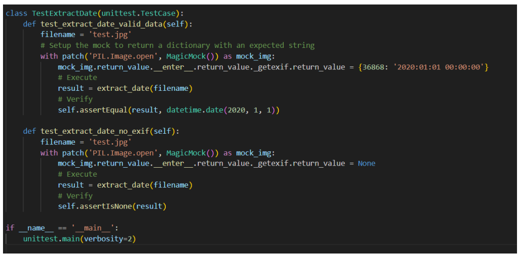
This section presents the tests used to evaluate the functionality of the GUI and determine if it meets the requirements and specifications. The results determine whether the product has been designed correctly in line with what the user wants.

6.4.1 Unit Testing:

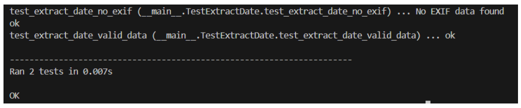
A unit test was developed to test the function for the extraction of meta data which is particularly useful for the analytics tabs .

Extraction_Test

The following code was used to test the extract_date() function:



(a) Unit test 1: Code



(b) Unit test 1: Result

Figure 6.6: Testing and Results of the extract_date() Function

6.4.2 Acceptance Test Procedures

ATP_1: The system must be able to download images from the designated camera network.

Test Steps

1. Go to download section and click the button after specifying download directory .
2. Verify images have been downloaded if the succesul downlad statement has been printed.
3. Check download folder as a final check.

Expected Result:Images are successfully downloaded.

Testing and Result :The images from the raspberry pi were succesfully downloaded as seen below by the terminal output that was expected:

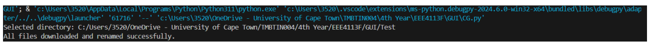


Figure 6.7: Download Successful

ATP_2: Ensure user can specify the download location and view images once the images are in.

Test Steps:

1. Access the settings menu.
2. Set a custom folder location.
3. Verify images have been saved to the specified folder by clicking 'View Images' button.

Expected Result: Images are saved to the specified download folder and can viewed in the GUI.

Testing and Result : The functions being tested here are display_images() function and the operation of choosing a download directory as seen in the code snippets below:

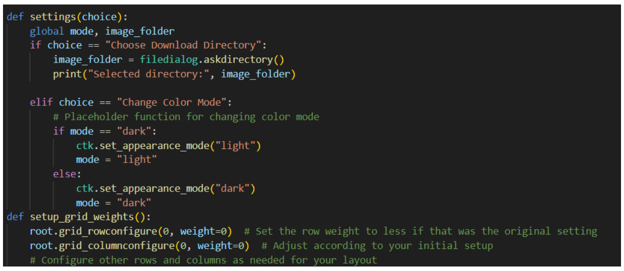


Figure 6.8: Option Menu Design

Figure 6.9: Display Images

Once the GUI was open , the option to chose the download directory was selected. A folder named 'Test' was created. The images from PixelPeeper were added to the folder as a simulation of how they would be placed with download functionality. View images was selected. The figure below shows the process and depicts a successful test.

(a) Creating download directory

(b) Image viewed

Figure 6.10: Steps in Managing Download Directory and Viewing Images

ATP_3: The GUI must provide scrolling in both directions for images and play video.

Test Steps:

1. Open a folder.
2. Scroll through the images.
3. Verify play on click for videos.

Expected Result: Images are displayed in a scroll-able view and user can play videos via a mouse click.

Testing and Result: This ATP serves as a test for the function of the buttons 'Next' and 'Previous' and the play on click functionality for videos.

```
def next_image(event=None):
    global current_image_index
    if current_image_index < len(image_files) - 1:
        current_image_index += 1
        display_media()

def prev_image(event=None):
     global current_image_index
     if current_image_index > 0:
        current_image_index -= 1
        display_media()
```

Figure 6.11: Image Scrolling

```
def display_video(video_path):
    for widget in image_frame.winfo_children():
        widget.destroy()

    cap = cv2.VideoCapture(video_path)
    play = [False]  # Start with video paused

    def toggle_play_pause(event=None):
        play[0] = not play[0]  # Toggle play status
        if play[0]:  # If toggling to play, start the stream
            stream_video()
```

Figure 6.12: Video Play

Once the images were viewable the next and previous buttons were used to browse the image folder. Images were successfully viewed and browsed.Although the video can not be shown in this report, the test is confirmed to have been passed.

ATP_4: Verify that the analytics are displayed and observations are recorded.

Test Steps:

1. View the analytics section of GUI.
2. Check if data is being presented in graph form.
3. Record an observation about the image.
4. Save the image along with observation.

Expected Result: Observations are successfully recorded and saved and clear and understandable analytics are shown .

Testing and Result: There are 3 analytics frames for this GUI.The first show the number of photos taken per day , the second shows duplicates and the third the hourly activity of data capture per day. Images with known timestamps were used.Copies of these images (image1-image4) were intentionally made to show the system's ability to detect duplicates; these images are images6 -8. Therefore the expected data shown should be 2 images for 4 separates date and times and 4 duplicate detections.

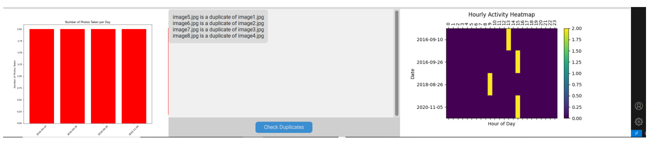


Figure 6.13: Analytics

The code being tested here is seen in the figure below:

```python
def save_observation():

    observation_text = observation_entry.get("1.0", "end-1c")
    if observation_text:
        image_filename = image_files[current_image_index]
        observation_filename = os.path.join(image_folder, "Observations/observations.txt")

        with open(observation_filename, "a") as f:
            f.write(f"Image: {image_filename}\n")
            f.write(f"Observation: {observation_text}\n\n")

        print("Observation saved.")
```

Figure 6.14: Capturing Observation

An observation was captured for images 1 -4 .The observations were successfully captured in a textfile named Observation located in the same folder as the images.

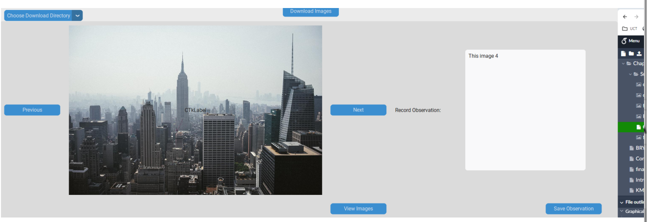


Figure 6.15: Record Observation

Figure 6.16: Observations captured

Figure 6.17: Observations

ATP_5: GUI is capable switching of colour modes.

Test Steps:

1. Navigate to to the options menu
2. Toggle the colour mode of the GUI

Expected Result: The GUI successfully changes modes.

Testing and Result:

(a) Light mode (b) Dark mode

Figure 6.18: Comparison between light and dark modes

ATP_6: Evaluate the usability of the GUI for users with minimal technical background.

Test Steps:

1. Ask a user with limited technical knowledge to navigate the GUI.
2. Observe the user's experience.

Expected Result: The GUI is intuitive and easy to navigate for users with minimal technical background.

Testing and Result The test was conducted with one user who has limited technical expertise. Initially, the user was slightly overwhelmed by the number of buttons but quickly became more comfortable after exploring the GUI. Navigation between different functions like image viewing and downloading was handled well after a brief explanation. However, the user struggled with the correct order in which to use the GUI (selecting a directory and the clicking download) and suggested that a tutorial would be helpful. Overall, while the GUI is largely intuitive, certain features could benefit from additional guidance or simplification to enhance usability for non-technical users.

ATP Summary

Functional Requirement Code	Specification Code	ATP	Result
FR_1	S_1, S_5, S_6	ATP_1	Passed
FR_2,FR_9,FR_8	S_7	ATP_2	Passed
FR_4, FR_3	S_2 S_3, S_4,S_8	ATP_3	Passed
FR_5,FR_6,FR_7, FR_10,	S_9,S_10	ATP_4	Passed
FR_8		ATP_5	Passed

Table 6.1: ATP Results

6.5 Conclusion and Recommendations

The graphical user interface (GUI) designed for Ben meets its primary objective: creating an intuitive, effective tool for his field research on fork-tailed drongos. By addressing user requirements, such as usability and performance, the GUI enables Ben to focus more on data analysis and less on technical setup and issues.The GUI simplifies routine tasks like image downloads and review, allowing researchers like Ben to work efficiently despite a limited technical background.The GUI ensures fast and smooth image downloading, maintaining responsiveness throughout operation. By incorporating features like analytics and scrollable views, the GUI delivers insightful data. Using the settings menu, Ben can easily configure the default download folder, display mode, and other preferences.Comprehensive acceptance tests and unit testing validated the GUI's functionality. The GUI meets its requirements for downloading images, specifying folders, scrolling, playing videos, and providing analytics.

Some recommendations include adding creatung a tutorial to help the user navigate the interface betters. Future versions of the GUI could include improving the interface's aesthetic design. and allowing researchers to create custom layouts or modules tailored to specific research needs, further improving the system's adaptability.Overall, the GUI system effectively serves its purpose, providing a solid foundation for Ben's research and offering room for growth.

Chapter 7

Conclusions

The purpose of this project was to help build the right product for Ben who is studying Fork Tailed Drongos through developing an energy efficient camera trap system coupled with a Graphical User interface capable of operating in a remote environments.The aim was to sufficiently address the challenges faced in studying the activities of the Fork Tailed Drongo in the Kalahari.

This report began with an introduction to the problem set out the background, objectives, system requirements and scope and limitations.

The literature review was followed in Chapter 2 where camera trap technology was extensively discussed. This chapter laid out the foundation for understanding the critical requirements and possible technological improvements in wildlife monitoring that could be applied to our solution.

As seen in Chapter 3, the development of the power submodule has successfully addressed several critical issues associated with wildlife monitoring systems, particularly in the arid and remote environments of the Kalahari. The integration of a solar-powered solution with a robust battery management system has significantly enhanced the reliability and operational lifespan of the camera traps used in the study of Fork-tailed Drongos. The submodule has demonstrated its capability to maintain continuous operation, overcoming challenges related to battery life and device maintenance.

In Chapter 5, the Mechanical Housing design was put forward. Following a thorough assessment, a design meeting all user requirements was achieved. Among two housing designs considered, Housing Design 2, featuring a ball and socket joint for enhanced maneuverability was chosen. Although Solar Panel Casing Design 2 provided convenience, Solar Panel Casing Design 1 was selected for its strength in securely holding the solar panel. Successful testing confirmed the subsystem's compliance with requirements, allowing for it's integration into the project framework. As seen in Chapter 4, a camera system is very reliable and cheap. And therefore has a potential to replace current expensive and power hungry camera traps used by Ben.

Finally in Chapter 6, the development of the GUI was detailed. This subsystem was crucial for ensuring that the technology developed was accessible and usable by researchers in the field, regardless of their technical expertise. The GUI's design considerations were aligned with the need for a simple, intuitive interface that could facilitate complex tasks efficiently.

In summary, the project achieved the goals that were set out, by designing and demonstrating a solution that integrates camera trap technology with a user friendly GUI, powered by a reliable solar powered system.This ensures that Ben can conduct extended studies in the Kalahari with minimal environmental impact and receive reliable data.The system's usability and robustness signifies a great potential if it is deployed in the field.

Chapter 8

Recommendations

Based on the results from testing and discussions the current solution can be improved in the following ways:

Power Module

Based on the outcomes of the power submodule testing, the following recommendations are proposed to enhance the design and functionality:

- **Expand Solar Panel Capacity:** To ensure consistent power supply during low sunlight conditions, it is recommended to increase the solar panel capacity. This will accommodate variations in solar energy availability and improve system resilience.
- **Upgrade Battery Technology:** Investigate the feasibility of using advanced battery technologies such as lithium-sulfur or solid-state batteries, which may offer better performance in terms of energy density and charging cycles.
- **Implement Adaptive Power Management:** Develop a smart power management system that dynamically adjusts power consumption based on the operational mode of the camera traps, thereby optimizing battery usage.
- **Field Testing in Varied Environments:** Conduct extended field testing of the power submodule in various environmental conditions to evaluate its performance and make necessary adjustments before widespread deployment.

Mechanical Housing

- **Larger 3D printers:** Much of the design of the mechanical housing was limited by the size of the 3D printers used. A larger 3D print would allow for larger 3D prints which would benefit the user as the cost of product would decrease from materials used.
- **Test Housing in the real environment:** A true reflection of how the housing will function must take place in it's intended environment (Kalahari). Whilst simulated testing is appropriate, a more comprehensive investigation of the materials used can be conducted.

Graphical User Interface

Based on the final design of the Graphical User Interface the following Recommendations are suggested:

- **Icons**:Replace buttons in text and make use of more intuitive symbols such arrows for scrolling.
- **Additional Frames**:Add a window that displays duplicate images and allows for automatic deletion.
- **Storage:**Include the option of a database to store images rather than on a device.

Camera and Sensing

Based on the final design of the Camera and Sensing system the following Recommendations are suggested:

- **Streaming**:Stream live images and videos captured over a website as the camera library used support streaming.
- **Sensor Fusion**:Use motion sensors together with image processing based trigger to make system more robust.
- **Test the camera system in real environment**: Some algorithms parameters need to be altered based on real time response, hence field deployment will help choosing optimum parameters for such algorithms.

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Appendix A

Power Module Additional Figures

A.1 KiCad Schematic

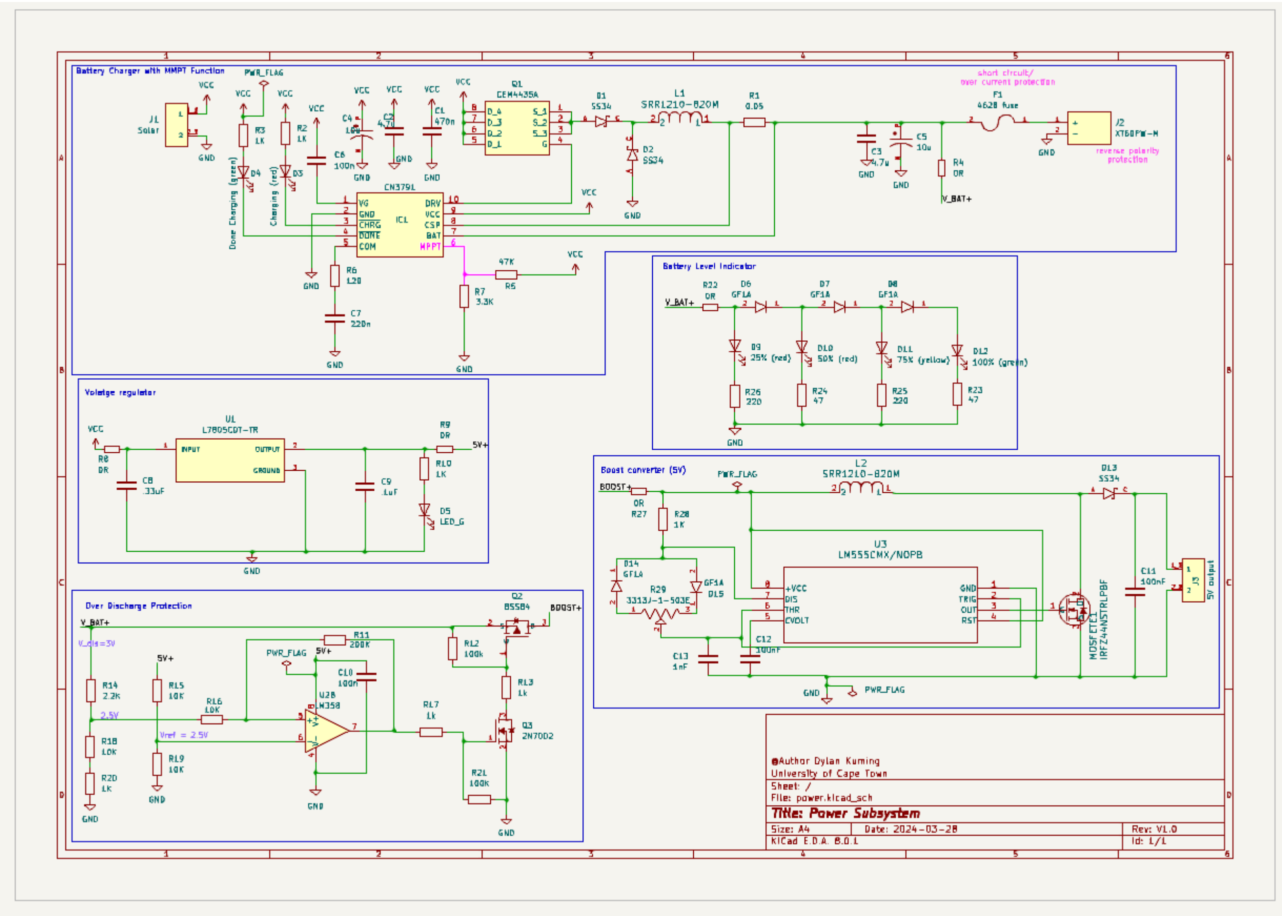

Figure A.1: KiCad Schematic of the Power Module

A.2 Final PCB

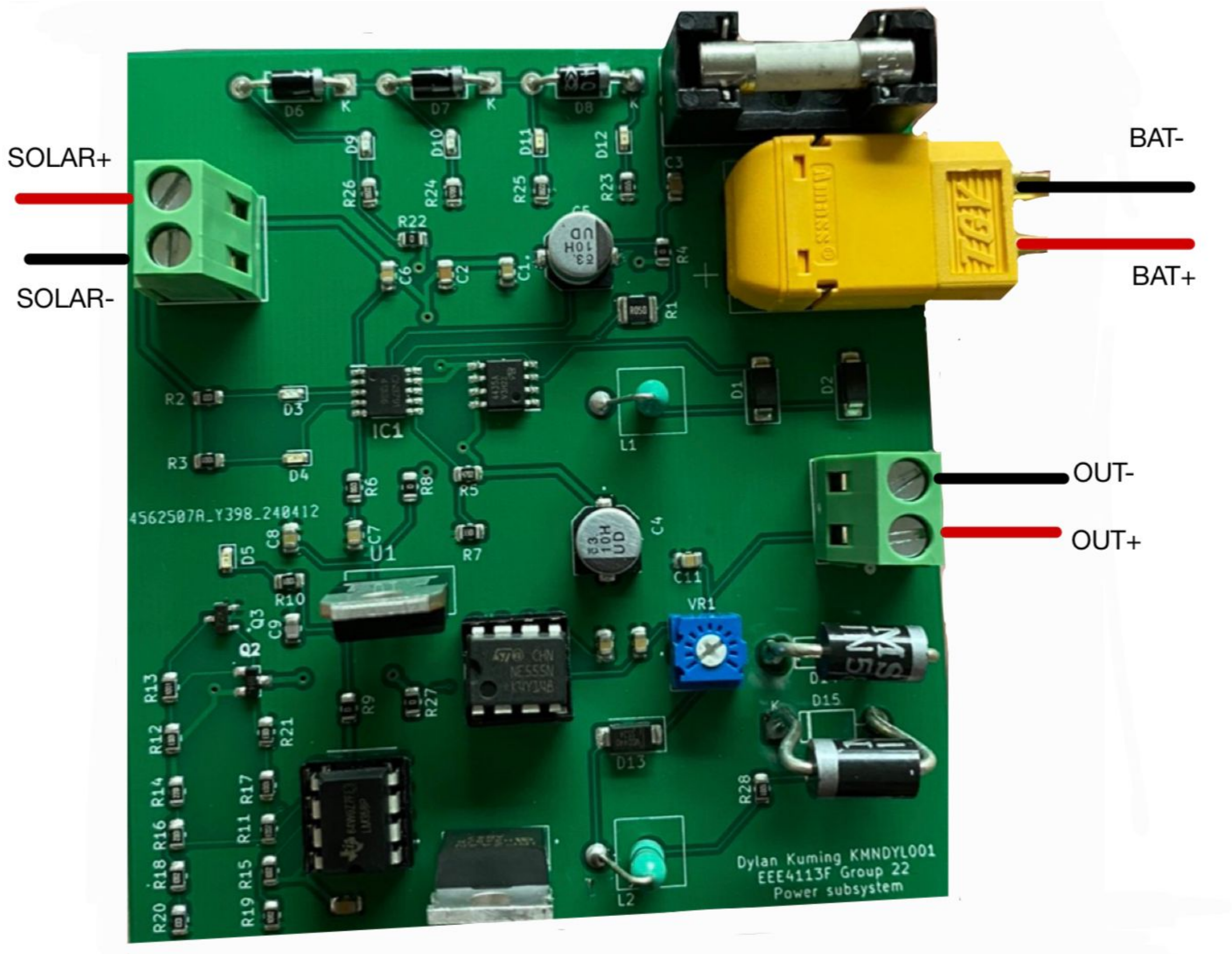

Figure A.2: Final PCB of the Power Module

A.3 Setup

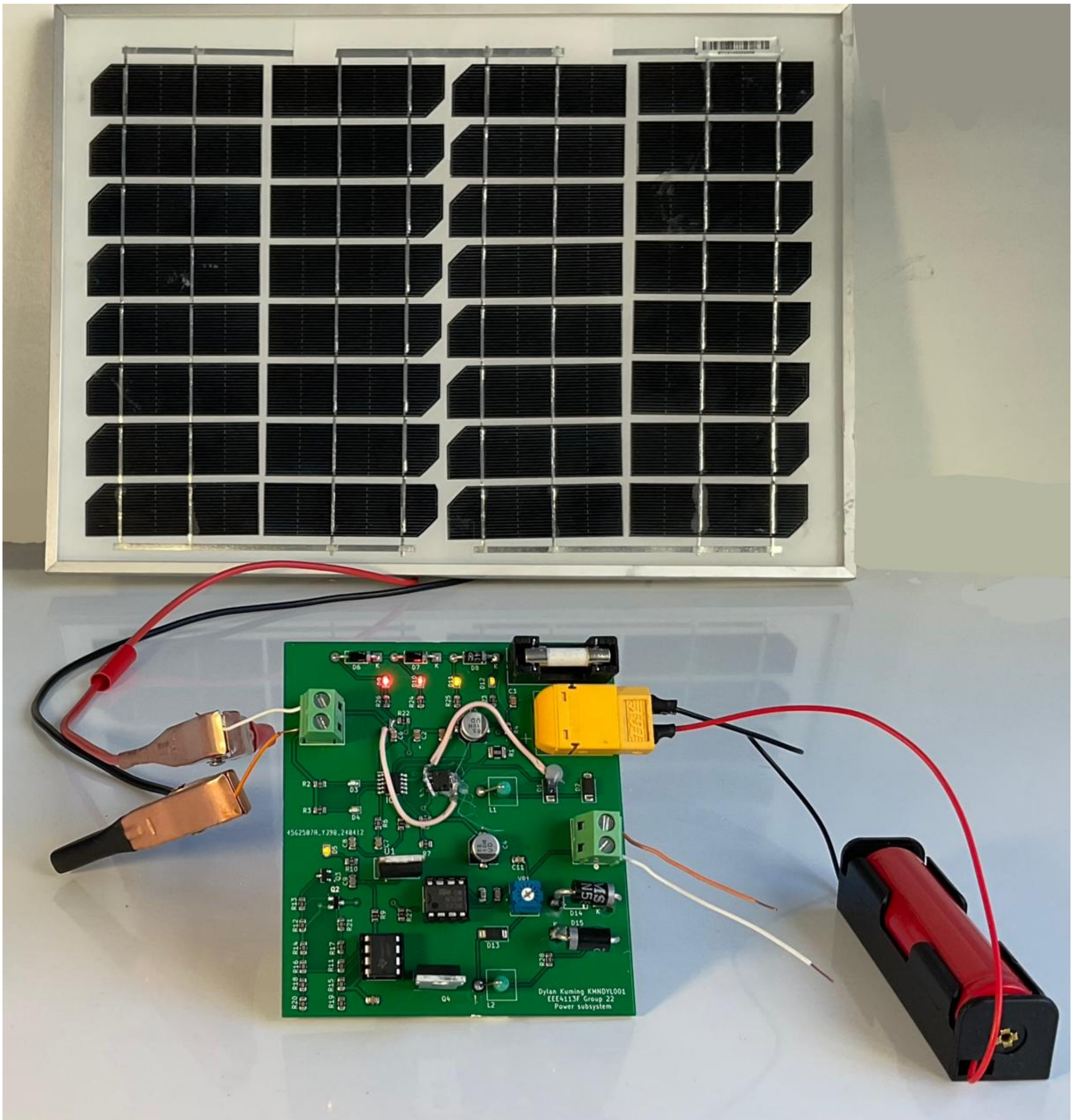

Figure A.3: Setup of the Power Module

Appendix B

Bill of Material

Table B.1: Bill of Materials (BOM)

Item	**Subsystem**	**Cost (R)**
Camera	Camera and Sensing	399.90
SBC (Not purchased)	Camera and Sensing	278.33
Light Sensor	Camera and Sensing	102.35
Pi Zero Camera Cable	Camera and Sensing	49.90
Subtotal	Camera and Sensing	**830.48**
Solar Panel	Power	295.00
PCB	Power	766.00
Battery	Power	75.00
Subtotal	Power	**1136.00**
Wood	Housing	40.00
3D Printing	Housing	15.00
Paint	Housing	25.00
Screws + Hinges	Housing	29.99
Glue	Housing	20.00
Subtotal	Housing	**129.99**

Appendix C

Graduate Attributes

Table C.1: Graduate Attributes met by Dylan Kuming (KMNDYL001)

GA	Description	Where met
3	Engineering Design	Designed the Power module for the system (Chapter 3).
7	Sustainability and Impact of Engineering Activity	D-school (Chapter 1, Section 1.6). The designed system aids in Wildlife conservation
8	Individual, Team and Multidisciplinary Working	See teams group for meeting minutes
10	Engineering Professionalism	All submission activities met including final report and presentation.

Table C.2: BRYLIA002 Graduate Attributes Met

GA	Description	Where met
3	Engineering Design	Design of the Mechanical Housing to enclose and protect the electrical components as well as hold the solar panel. Refer to Chapter 5
7	Sustainability and Impact of Engineering Activity	D-school, (Chapter 1, Section1.6)The designed system aids in Wildlife conservation
8	Individual, Team and Multidisciplinary Working	See teams group for meeting minutes
10	Engineering Professionalism	All submission activities met including final report and presentation. All communication is conducted on Microsoft Teams

Table C.3: TMBTIN004 Graduate Attributes Met

GA	Description	Where met
3	Engineering Design	Designed a Graphical User Interface. Refer to Chapter 6,
7	Sustainability and Impact of Engineering Activity	D-school, (Chapter 1, Section1.6)The designed system aids in Wildlife conservation
8	Individual, Team and Multidisciplinary Working	See teams group for meeting minutes
10	Engineering Professionalism	All submission activities met including final report and presentation.

Table C.4: LNKMAL001 Graduate Attributes Met

GA	Description	Where met
3	Engineering Design	Designed a image processing based camera trigger system. Refer to Chapter 4
7	Sustainability and Impact of Engineering Activity	D-school, (Chapter 1, Section1.6)The designed system aids in Wildlife conservation
8	Individual, Team and Multidisciplinary Working	See teams group for meeting minutes and attended every group's online meeting.
10	Engineering Professionalism	All submission activities met including final report and presentation, communicated all group issues via teams

Appendix D

Git Repository

This is a link to Group 22's github repository: https://github.com/Tinashe-Timba/EEE4113F_GROUP_22.git