Final Project
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Table 1: Content Breakdown

Student No.	GA3 - Individual	GA3 - Team	GA7 - Individual	GA8 - Team	GA8 - Individual
MMBLON001	Sections 4, .3	Section 1, 2, 3 & 7	Section .2.3,4	See teams group	See teams group
LNDCAI001	Section 5	Section 1, 2, 3 & 7	Section .2.2	See teams group	See teams group
NSXSIV001	Section 6	Section 1, 2, 3 & 7	Section .2.1	See teams group	See teams group

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Chapter 1

Introduction

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

The Southern yellow-billed hornbills of the Kalahari have been suffering an extreme decline in successful breeding attempts and this is largely due to the rising temperatures in the Kalahari. In order to improve their chances of successful breeding it is important scrutinize the environment in which it happens particularly their nests.

Southern yellow-billed hornbills' nests are typically made in the hollows of trees, in which the females and the young are sealed in their nests until the young are old enough to leave the nest i.e. the nest becomes too small. In an attempt to aid their breeding artificial nests have been introduced with the intention of them being cooler than the natural nests that the hornbills would occupy. However, these nests still leave much room for improvement since they do not collect any data about the conditions of the birds or the nest, which would be vital for finding ways to improve their conditions. There is a need for a nest that can collect data on the birds and their environmental conditions, while keeping itself cool enough for the birds and also blends into their natural environment so that it is non-invasive and does not scare them away from the observational environment.

Chapter 2

Problem Analysis (D-School)

2.1 Initial Problem Statement

Sally who is a UCT researcher studying the UCT starlings needs a way to ensure that data collected on the birds is assigned to each bird because she needs accurate and up to date data on each bird in different conditions

2.2 Design Choices

Figure 2.1: Idea Matrix

2.3 Unpacking Stakeholders

Figure 2.2: Unpacking

2.4 Initial System Prototype

In Figure 2.3 below is the prototype our group made in order to meet Sally's user requirements. Our

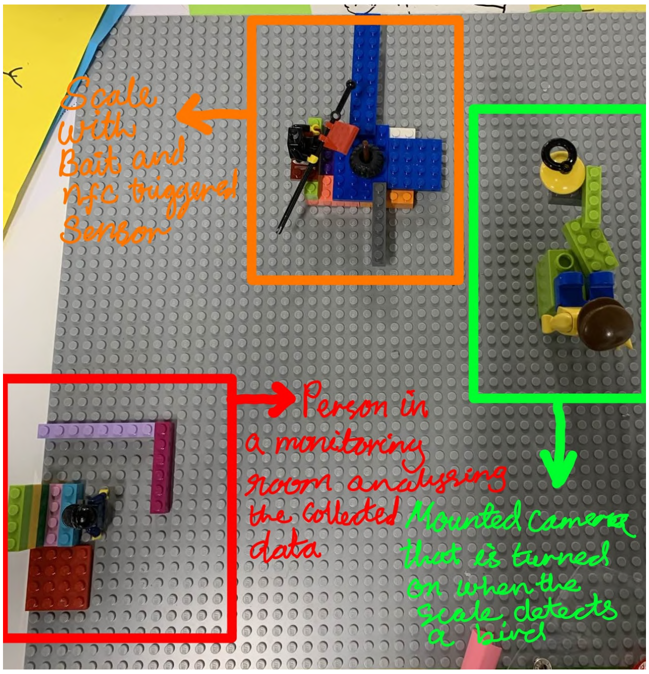


Figure 2.3: Initial Design Prototype

initial client, Sally, demonstrated unreliability in communication with the team, whereas Ben responded promptly. Recognizing the potential challenges posed by this communication disparity, the team collectively decided to address it. After reviewing the skill sets of the group members and reassessing their individual interests, we concluded that the project most suited to the group was Ben's proposal for the nest cooling system for the Southern Yellow-billed Horn-bills. As a result of this reassessment, the final problem statement differed from the one presented during D-school.

2.5 Final Problem Statement

Ben, who is a PhD student studying the southern yellow-billed hornbill has taken notice to their failed breeding attempts due to the rising temperatures in the Kalahari and as such needs an effective cooling system that is able to cool down the nest environments of the southern yellow-billed horn-bill to a temperature in which they can successfully breed. This section also covers the design of an electronics housing.

2.6 Subsystems Description

2.6.1 Electronics Subsystems

The electronics subsystem encompasses sensing, software, user interface, and data transmission components, working together to monitor nest temperature and humidity, record time-labeled data, facilitate viewing of current conditions, transmit logged data, and control a cooling apparatus based on temperature thresholds

2.6.2 Cooling and Nest Design

The cooling and nest design subsystem aims to provide a cost-effective solution for maintaining a relatively cool interior temperature within the artificial nests, using active cooling methods like Peltier coolers and heat sinks, while ensuring minimal disturbance to the birds and considering factors such as noise levels, non-toxic materials, and weather resistance.

2.6.3 Power Subsystem

The power subsystem aims to provide a reliable and independent power supply for the artificial nests, ensuring uninterrupted operation and monitoring of the battery level for timely maintenance.

Chapter 3

Literature Review

If you wish to make an apple pie from scratch, you must first invent the universe.

—*Carl Sagan*

3.1 Optimal Breeding Conditions for Southern Yellow-billed Hornbills

This section explores the ideal conditions necessary for successful breeding and egg incubation among Southern Yellow-billed Hornbills.

Maintaining optimal breeding temperatures is crucial for the reproductive success of Southern Yellow-billed Hornbills. Research indicates that these birds prefer breeding temperatures below 35.7°C (5). "Out of the 118 breeding attempts the team monitored over the decade period, not a single attempt succeeded where the average air temperature during the attempt was equal to or greater than 35.7°C' (5). This highlights the critical importance of maintaining nest temperatures below this threshold, regardless of external conditions.

Variations in nest temperature significantly impact breeding success among Southern Yellow-billed Hornbills. In a study by T. Van De Ven et al. (6), successful nesting attempts were characterized by a mean maximum temperature around 34.4°C (±1.3°C). Conversely, failed nests experienced notably higher average maximum temperatures, reaching approximately 36.9°C (±1.7°C). This disparity underscores the direct correlation between temperature and avian nesting success.

Furthermore, the convergence of similar results from these independent studies bolsters their credibility, enhancing the validity of their findings and emphasizing the importance of temperature management in avian parental care and nesting success.

3.2 Exploring Alternative Nesting Materials for Temperature Regulation

This section aims to investigate alternative materials for nest construction, with a focus on reducing nest temperatures without relying on complex cooling techniques like active cooling.

Research conducted by M. Johns et al. (7) highlights the effectiveness of ceramic nest modules in maintaining nest chambers approximately 1.2°C cooler than wooden boxes during extreme heat events in warmer, drier southern island locations. This finding suggests that ceramic materials offer a promising solution for addressing overheating concerns in bird nests.

In a separate study (8), double-layered ceramic artificial nests demonstrated their ability to reduce heat stress in African Penguins by maintaining cool temperatures and high humidity, thus reducing the risk of hyperthermia. These results emphasize the importance of selecting appropriate materials to create thermally comfortable nesting environments for birds.

Furthermore, there is growing interest in a potential alternative material known as Starlite, despite its limited coverage in academic research. Starlite boasts exceptional thermal insulation properties, with a low thermal conductivity (K-Value) of 0.039 W/m.K (9). Compared to air (0.027 W/m.K) and plywood (0.15 ± 0.01 W/m.K) (10), Starlite serves as a medium between air and wood. This suggests that Starlite could serve as a viable option for nest construction, offering improved thermal regulation compared to traditional materials.

Ben Cusick's comprehensive YouTube series provides insights into creating Starlite at home, utilizing basic non-toxic ingredients such as Flour, Corn Starch, Sugar, Baking Soda, and Water (11). By showcasing the material's resilience under extreme conditions, Cusick demonstrates its potential usefulness in various applications, including artificial nest creation. However, further research is needed to fully understand the practical implications of using Starlite in bird nest construction.

Overall, the exploration of alternative nesting materials presented in this section contributes to a deeper understanding of how to mitigate overheating in bird nests, ultimately promoting the well-being and reproductive success of avian populations.

3.3 Various Passive Cooling Techniques and How They May be Adapted to birds nests

This section explores various passive cooling techniques observed in nature and architecture, examining their potential adaptation for bird nests. By implementing these strategies, birds could potentially create more thermally comfortable environments for their chicks.

3.3.1 Learning from Vernacular Wisdom: Windcatchers and Shading

Our exploration begins with vernacular passive cooling techniques. One promising approach is the windcatcher, a traditional element in Middle Eastern architecture (12). Windcatchers are essentially towers that channel prevailing winds into buildings, promoting natural ventilation and cooling. This concept could be adapted by incorporating strategically placed openings within the nest structure to facilitate airflow.

Another valuable vernacular technique is the use of shading elements (12). Birds often construct their nests in the protective cover of trees or foliage, instinctively utilizing shade to minimize solar heat gain. We can learn from this behavior by encouraging the incorporation of natural or artificial shading elements near nesting sites.

3.3.2 Stack Ventilation and Biomimicry: Inspiration from Nature

Stack ventilation, a method that utilizes natural pressure differences to induce air movement, offers another potential cooling strategy (12). Similar to a chimney, a vertical temperature gradient within the nest could drive warm air upwards, drawing cooler air in from below. As shown by Nchiye: The efficiency of stack ventilation is closely tied to the building's height, as taller structures enhance ventilation by expanding the vertical displacement between the intake and outflow apertures. This means that as the 'chimney' gets taller so does the effectiveness of this technique.

Biomimicry, the practice of imitating nature's designs, provides further inspiration. The article further explores passive cooling by delving into biomimicry and it's role in architecture. Namely it speaks about the East Gate building in Harare, Zimbabwe which was largely designed based off of the African termite mound. These mound serves as a remarkable example of self-regulating temperature control (12). These structures employ a combination of ventilation and material properties to maintain stable internal temperatures. Depending on the specific design, termite mounds utilize either a "thermosiphon' effect or a "stack effect' for cooling. The thermosiphon effect relies on warm air rising and cooler air sinking within the mound's structure, while the stack effect creates a one-directional airflow similar to a chimney. The termite mound's unique design enables it to draw in cool air through small holes on it's edges while allowing heated air to rise and escape through the top, creating a natural cooling system that helps regulate the internal temperature of the mound effectively (12). Studying these principles could inform the design of passive cooling features within bird nests.

3.3.3 Beyond Cacti: Exploring Surface Properties for Thermal Regulation

The prickly exterior of cacti offers another interesting consideration – it discourages predators while also influencing thermal properties (12). The spines of cacti absorb heat efficiently during the day but excel at radiating heat away at night. Whereas smooth surfaces are good at absorbing heat as well as poor emitters of heat into space at night (12).

While directly replicating cactus spines might not be feasible, understanding how surface properties affect heat absorption and emission could inform the selection of nesting materials that promote nighttime cooling.

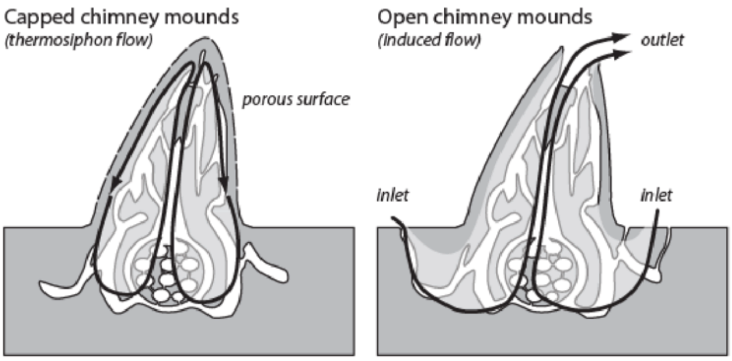


Figure 3.1: Two versions of termite mounds and their airflow. Source: (1)

3.4 Temperature Monitoring

Temperature is a fundamental parameter in the welfare of any living creature, therefore accurately measuring temperature and being able to quickly analyze this data is vital for understanding the types of conditions the birds are in and how best they can be improved. In this section the different aspects of an effective temperature monitoring system will be investigated.

3.4.1 Principles of Temperature Sensing

Temperature sensors work by converting thermal energy into electrical signals that can then be interpreted by the processor of the system. Temperature sensors fall under two main categories namely, contact temperature sensors and non-contact temperature sensors (13). Contact temperature sensors read the temperature of an object or environment by being placed in direct contact with the object or in the environment in which the temperature is being measured (13). Non-contact temperature sensors do not go in direct contact with the object whose temperature they are measuring, rather they measure temperature by means of the radiation given off by heat sources (13). With an understanding of how the different types of temperature sensors work, it is now possible to look at what temperature sensors may be selected, and how it can be implemented into the system.

3.4.2 Selecting Temperature Sensors for the Nest

Temperature monitoring is an essential part of trying to improve the success rate in the breeding of the southern yellow-billed hornbills. However, with that in mind it is also necessary to find the appropriate type of temperature sensor for monitoring the nest.

Sensor Type	Thermistor	RTD	Thermocouple
Temperature Range(typical)	-100 to 325°C	-200 to 650°C	200 to 1750°C
Accuracy	0,05 to 1.5° C	0.1 to 1°C	0.5 to 5°C
Long-Term Stability @100C	0.2°C /year	0.05°C	Variable
Linearity	Exponential	Fairly linear	Non linear
Power required	Constant voltage or current	Constant voltage or current	Self-powered
Response time	Fast 0.1 to 10 sec	Generally slow 1 to 50 sec	Fast 0.10 to 10 sec
Susceptibility to Electrical noise	Rarely susceptible High resistance only	Rarely susceptible	Susceptible/ Cold junction Compensation
Cost	Low to Moderate	High	Low

Figure 3.2: Comparison of Various Temeperature Sensors (**?**)

The table 3.2 above provides ample information for a decision to be made on which temperature sensor from these common ones would be most suited for the purpose of monitoring the nest of the birds. By virtue of its fast response time, low susceptibility to noise, high accuracy, temperature range and low cost the thermistor is an obvious choice for this type of system.

3.4.3 Data Transmission and Viewing Methods for data collected from the Nest

According to Das et al (14) internet of things (IoT) allows the different systems to connect to each other and exchange data. They then propose a system that consists of sensors, microcontroller, and a web server to store the data. Deekshath et al. (15) proposes a similar real-time system and both use Thingspeak to store and fetch data using http (Hypertext Transfer Protocol) over the internet. George et al (2).

Figure 3.3: Block diagram plan for monitoring temperature and humidity in an enclosure (2)

The diagram 3.3 provided by George et al (2) breaks down their temperature and humidity monitoring system into its core parts and they use a raspberry pi connected to the internet that uploads the information from the sensors to ThingSpeak which further show just how solid of a solution ThingSpeak is for monitoring the system.

While uploading the data to an online cloud server via the internet is shown to be a popular option for data transmission and viewing, it does however come with the caveat of always needing a constant stable internet connection. To deal with the issue of not being able to send data without internet, other methods must be explored. A system such as the one presented by C. Butkowski et al (16) is useful in this system they set up a local network using long-range wide-area networks (LoRaWAN) that would allow the sensors to connect to a local cloud network and to each other without the need for the internet. This technology further solidifies itself as a good choice for remote areas because they are low energy and do not require a direct connection to the internet thus sensor data could just be sent and stored locally until an internet connection is available for the data to be uploaded for further processing and use. Shinde et al (**?**) strongly recommends the use of the Node MCU since it can be used to process and transfer information hence one can be used at the sending and receiving end of this system. Upon determining what methods of data transmission and viewing may be used, it is essential to now find a suitable processor (controller) that is compatible with these selected technologies.

3.4.4 Selection of a Controller for the Nest and its Implementation

Temperature monitoring is the recording of the temperature over a set period, this data is recorded and uploaded to then allow for further processing (usually to implement control of the temperature in said environment) (13). Temperature control is usually the intent behind temperature monitoring and as such, collection of this data is only the starting point of this process.

Data collected from the sensors is processed locally by a programmed controller. Shinde et al. (**?**) proposes the use of the Node MCU, Arduino Uno and Raspberry pi to be used to actively control apparatus intended to maintain the temperature in the environment ultimately agreeing to use the Node MCU due to its low cost and inbuilt Wi-Fi that will allow data transmission at no additional cost. Shinde et al .(**?**) then describes a system in which after the temperature is measured and the signal is processed, the control is done automatically by the chosen microcontroller therefore allowing control with a feedback loop which means the system can continuously adjust itself according to the criteria set, which contrasts with the method of manual control via an android application sending commands to the on-site controller that was presented by Ega et al (17). With these methods of control outlined an informed decision can now be made on the best way to implement the control based on the circumstances of the project.

3.4.5 Methods of Storing Data Collected from the Nest

Since the system is meant to monitor an environment, it is only natural that it would need a way to store the data collected. Al-Bhadili and Drewll (18) suggest the use of a secure digital (SD) card, as modules are readily available for them that allow information to be written to or read off of the SD cards. While this is a feasible idea it does however mean that for data to be retrieved there might be a need for other systems to allow it to be retrieved remotely otherwise it would need someone to physically go to retrieve it. In light of the drawback of SD cards another solution that is proposed George et al. (2) could overcome this, by opting for a IoT based system in which the data is sent to the cloud for processing and viewing as soon as it is collected thereby also allowing for the data to be accessed from anywhere in the world and in real-time as long as an internet connection is present. This is further cemented as a viable option by Ega et al (17). who goes on to also describe using an android application to access data stored online. Evidently, cloud storage offers a well rounded and convenient solution for temperature monitoring. However, factors such as ongoing internet connectivity need further consideration when implementing such a system.

3.5 Thermal Management Techniques in Environment Cooling and Solar Power Integration

Thermal management is important in various domains, including outdoor environments and animal housing, to ensure required conditions for the occupants. Cooling mechanisms explored in this paper play a significant role in maintaining thermal comfort, particularly in places like the Kalahari where the southern yellow-hornbill is known to exist. This study's primary objective is to develop a precise temperature control system that maintains temperatures below 35.7°C, thereby supporting successful breeding in southern yellow-hornbills.

3.5.1 Cooling Mechanisms and Strategies in Bird Nests or Similar Environments

Investigating various methods birds use to cool down, such as evaporative cooling systems (EC), in environments like poultry birds' nests can provide valuable insights that could aid in supporting the well-being of yellow-hornbills. Raza et al. (19) examined different evaporative cooling methods for poultry birds in Pakistan, which include Direct Evaporative Cooling (DEC), Indirect Evaporative Cooling (IEC), and Maisotsenko-cycle evaporative cooling (MEC). DEC system involves direct contact between air and water to reduce temperature, as noted by Xuan et al. (**?**) and Mehere et al. (20). In IEC, heat and mass transfer occur without moisture addition, utilizing sensible cooling (21). The MEC system combines evaporative cooling and heat transfer processes, offering cost-effective and environmentally-friendly solutions (21). The EC systems show their ability to provide cost-effective and an enevironmentally-friendly solution.

3.5.2 Peltier Cooling Technology and Solar Power Integration

This section focuses on integrating Peltier Cooling Technology, also referred to as Thermoelectric Cooling, with solar power to efficiently regulate nest environment temperatures. Peltier devices, commonly known as Thermoelectric Cooler Peltier Plates or Peltier modules, play a pivotal role in this regard by harnessing the Peltier effect, which refers to the phenomenon where heat is absorbed or emitted at junctions between different conductive materials when an electric current flows through them, it is fundamental to the operation of Peltier cooling technology (3). This semiconductor-based technology generates a cooling effect when an electric current is passed through them, making them indispensable for precise temperature control in various environmental settings. Other key advantages of the Peltier module, is that they offer maintenance-free usage, compact size, and the ability to cool below ambient temperatures. Furthermore, they allow for closed-loop control, making them suitable for diverse applications (3). The figure 3.4 below shows the Peltier Module, it may not be directly clear that it is small but its dimensions are 40x40x40mm.

Figure 3.4: Peltier Module (3).

A notable advantage of the Peltier module is its dual functionality, capable of providing both cooling and heating effects. For instance, in a project described by Attavane et al. (22), the extraction of heat results in cooling, while the absorbed heat is utilized for heating purposes. This feature is realized with a prototype consisting of four structures, each cubical in shape, with Peltier modules embedded on perpendicularly placed walls (22). The prototype utilizes foldable solar panels to harvest the required power, charging a Lithium Polymer (LiPo) battery capable of discharging high current with minimal size (22). The battery is connected to a buck converter, controlling the input voltage to the Peltier modules and thereby regulating their temperature. The duty cycle of the buck converter is controlled by a mobile app through a microcontroller via Bluetooth communication (22). Furthermore, an inbuilt temperature display on the prototype shows the current temperature of the gel packs, providing real-time monitoring of the system (22).

The Application of Peltier Devices for Temperature Regulation

Various studies have demonstrated the versatility and effectiveness of Peltier devices in maintaining temperature control across different applications. Zakari et al. (23) introduced a cooler box utilizing thermoelectric cooler Peltier Plates for outdoor activities, along with heat sinks to dissipate generated heat. This cooler box is mainly powered by a rechargeable battery that uses Solar Panels. Additionally, Remeli et al. (24) fabricated a mini Peltier Cooler using thermoelectric Peltier cells coupled with fan-cooled heat sinks. These studies showcase the versatility and effectiveness of Peltier devices in maintaining temperature control in various outdoor environments.

The potential of Peltier elements extends beyond conventional cooling applications. Studies like the one conducted by Slanina et al. (25) highlight the versatile application of Peltier elements in cooling devices designed for medical purposes. In medical practice, the treatment of swelling or inflammation with a cold wrapper is a known method for reducing pain and swelling (25). There are various techniques used in such cases but often result to higher demand of storage capacity, and as directly said by Slanina et al., "The disadvantage of these methods is the need to have a pre-prepared substance. This results in the demand for storage capacity and, in particular, the energy required to keep a large quantity of matter at a constant temperature' (25). The various techniques often use a compressor system, and therefore have a high energy consumption and are large in size (25). The study then proposes a cooling system that uses the Peltier device as a source of coldness.

In electronic cooling applications, Thermoelectric Coolers (TE) are utilized to transport heat away from devices like polycarbazole processors, known for generating excessive heat during operation (26). As previously mentioned by Khode et al. (3), the Peltier element is compact in size and therefore allows for use in electronic cooling applications where space is an issue (26).

The Solar Power Unit

Given the high temperatures currently experienced in the Kalahari, using solar power presents an ideal solution for powering the cooling system. The sunny areas in the Kalahari produce tremendous amounts of energy which is known as solar energy. Solar energy, being renewable and readily available, aligns with the remote nature of the project location (27). The solar power unit will comprise solar panels to capture sunlight and convert it into electrical energy, providing the necessary power to drive the Peltier element and other system components. An example of technology in which heat is converted is PV technology, which converts the sun's radiation into electrical energy (28). Solar PV systems are further divided into 2 subsystems namely grid-connected and stand-alone systems (28). Our focus is mainly on the stand-alone system, due to the remote nature of our system.

Solar Energy (Electricity) Production in off-grid environments

Stand-alone solar-PV systems are generally used to supply power to distant areas, with just a combination of a battery and solar panels (29). The system can be designed as shown in the Figure 3.5. In this system, the PV module harvests energy, and the battery is the storage facility. A DC/AC converter is also depicted on the image for AC loads (4).

The key qualities for a storage system for stand-alone solar-PV applications are low cost, high energy efficiency, longer lifetime, low maintenance, self-discharging and simple operation , so the paper by Akikur et al. (29) argues that the battery storage systems require high initial investment but are generally the best. Also a paper by Jossen et al. (30) mentions that some Stand-alone PV systems use lead-acid batteries because of their cost-effectiveness and longer lifetime, and thus addressing the issue of investment. Generally, the battery size depends on the load consumption and required backup

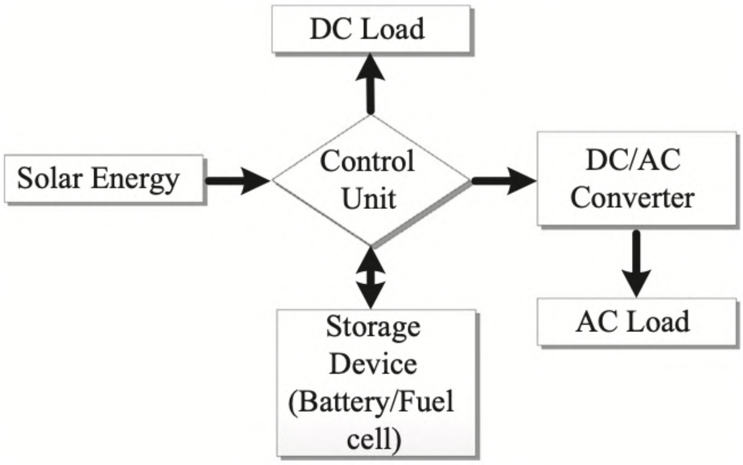


Figure 3.5: Solar Energy General Architecture (4)

period.

Peltier-Solar Integration (Solar Thermoelectric Cooling System)

The integration of Peltier cooling with solar power, offers numerous advantages. Thermoelectric cooling systems (Peltier), allow for direct current, eliminating the need for an AC-DC inverter, thus reducing costs (26). Moreover, the power produced directly from solar panels can be seamlessly supplied to the Peltier cooling system, enhancing overall energy efficiency (26). Successful integration projects like the portable Peltier-based solar-powered unit proposed by Arjun et al. (31) and the cooler box proposed by Zakaria et al. (23) demonstrate the feasibility and effectiveness of this approach. Additionally, the dual functionality of Peltier modules, providing both cooling and heating effects, enhances the versatility and applicability of such integrated systems (22).

In conclusion, the potential of Peltier-Solar technology for achieving precise temperature control in remote environments makes it a valuable solution for various applications.

3.6 Conclusion

In conclusion, this literature review delves into the pressing issue of declining breeding success among Southern Yellow-billed Hornbills in the Kalahari region, attributed to rising temperatures. A thorough examination of the factors influencing breeding conditions has prompted an investigation into optimal temperature ranges, alternative nesting materials, passive cooling techniques, temperature monitoring systems, and the integration of Peltier cooling technology with solar power, the review offers a comprehensive overview of potential solutions that could aid the Southern Yellow-billed Hornbills' breeding attempts. By incorporating findings from a range of sources, the review highlights the importance of interdisciplinary approaches and innovative technologies in addressing environmental challenges. Furthermore, the review highlights the urgency of conservation efforts to mitigate the impacts of climate change on vulnerable species.

Overall, this literature review contributes valuable insights to the field, paving the way for further research and practical interventions aimed at supporting the successful breeding of Southern Yellow-billed Hornbills and safeguarding their habitats.

Chapter 4

Electronics Subsystem

This section was authored by Longa Maimbo (MMBLON001)

4.1 Introduction

This section pertains to the sensing, software, user interface and the transmission data in the system. It will discuss how the hardware works together to make one fully functional system. The final system should be able to monitor the temperature and humidity of the Southern yellow billed hornbills' nests and record time labelled values of the of temperature and humidity to a storage device to allow for analysis of long-term temperature conditions within the nest. The system should also act as an access point to allow the viewing of the current conditions within the nest and should further facilitate the transmission of logged data to a client device.

4.2 Electronic Subsystem Requirements

Prior to any design taking place it is important to take note of what is required of the system by the intended user, it is from these requirements that specific solutions (design specifications) on how to solve this problem may be derived. Upon deciding on the specifications of the solution, a set of tests(Acceptance Test Procedures or ATPs for short) are developed to ensure the quality of the solution in reference to the user requirements.

4.2.1 Non-Functional Requirements

User Requirement	Specification Description	Acceptance Criteria
Must be able to store data recorded over a long period of time	SD card should have enough space to store the logged data over long periods of time	The system is able to store a large amounts of data before it runs out of space
Must be able to access data quickly	web page must load hastily	The web page must load within 5 seconds
Long battery life	System should be able to save power	Must be able to lower processing power during periods of idling

Table 4.1: Electronics non-functional specifications

4.2.2 Functional Requirements

User Requirement	Specification Description	Acceptance Criteria
Must be able to read the data collected	The sensor data should be stored on the SD card as a csv file	The system stores the sensor readings on an SD card and they are accessible to the user
Data should be accessible without tampering with the nest	Should be able to access the data without disturbing the nest	Live and past data must be accessible wirelessly
Needs to know when data was collected	The data collected should have accurate time information	Data collected must have the accurate time and date information tied to each reading
Needs physical copy of data	In case of failure there should still be accessible data	Final data stored should be physically accessible if the system fails
Quality of data should match current solution	The data collected should match or be better than the current solution	The data should be as accurate or more accurate than the current solution
Intuitive user Interface	The user interface must have all graphs and buttons clearly labelled	User interface must be easily navigable and must show all data clearly

Table 4.2: Electronics functional specifications

4.3 Hardware Design Choices

This section will detail the various considerations that the subsystem went through and the how each major aspect of the hardware system was decided and finalized for the system.

4.3.1 Choice of Data Transmission

There are several methods over which the data that is collected from the sensors may be transmitted however given Ben's requirement to be able to receive the data without the nest being disturbed it is apparent that the method used would have to be wireless. Looking at some of the available options for data transmission the overall list was narrowed down to two choices LoRa and Wi-Fi. while LoRa definitely has the advantage of its long range communication capabilities there are certain drawbacks that disqualified it as an option for the system.

LoRa modules require a microcontroller at the transmitting and receiving end of the communication system and this is not ideal given the budget constraints of the project, while Wi-Fi transmission would only require either a microcontroller that is capable of hosting a Wi-Fi server and a client device which could be any modern computer or smartphone which are devices that people would typically already have hence there is no additional cost for receiving the data. LoRa modules are more prone to interference and skewed data than Wi-Fi and finally LoRa modules also provide much slower data transfer speeds than Wi-Fi, therefore Wi-Fi is the preferred method of data transmission.

4.3.2 Choice of Microcontroller

Arguably the most important decision for this section as since it is the basis of the entire subsection, as it will determine the performance of the subsection. The main contenders for the choice of microcontroller for this section were the ATmega328P, the arduino nano 33 IOT and the ESP32 Dev kit. Considering what is required of the microcontroller, they need to be compared to determine which one would be best suited for this system.

Feature	Arduino nano 33 IOT	ATmega328P	ESP32 DevKit
Processor Speed	20MHz	20MHz	160MHz
RAM	512kB	2kB	32kB
Cost	R516.04	R120.06	R159.00
Connectivity	Wi-Fi, BLE 4.2	N/A	Wi-Fi, BLE 4.2

Table 4.3: Microcontroller Feature Table

By considering all the features of the above microcontrollers, a decision of which is the most suitable for this project may be made. Looking at the processing speeds of each microcontroller it is immediately obvious that while the Atmega328P and the Arduino nano 33 IOT match each others processing speeds they are significantly slower when compared to the ESP32 DevKit as such the ESP is the obvious choice for any computationally heavy tasks.

The Random Access Memory (RAM) of these microcontrollers is the next aspect to consider. The ATmega328P has significantly less ram than the other microcontrollers, and while the ESP32 DevKit has more RAM than the ATmega328P it still has significantly less RAM than the Arduino nano 33 IOT, which has much more RAM than the other options. RAM and processor speed work together to determine the performance of a system as such both must be taken into account when making a meaning that considering the processor speed of the ESP32 DevKit it still makes a decent comparison in this aspect when compared to the Arduino.

Considering the limited budget of this project the cost of the microcontroller being used in the system must be weighed against the benefits of the microcontroller. The ATmega328P is the cheapest of the three, the ESP32 DevKit is not much more expensive than the ATmega328P but the Arduino nano 33 IOT is the most expensive of the three choices which makes it a tough choice for the microcontroller of the system.

Finally the connectivity of the three should be taken into account while the Arduino nano 33 IOT and the ESP32 DevKit both have bluetooth and are Wi-Fi capable the ATmega328 P does not and considering the aforementioned requirement of being able to receive data from the microcontroller without making physical contact with it, the ATmega328P would simply not be a viable choice on its own and it would need to be purchased with modules to accommodate for its shortcomings.

Taking all these factors into account a definitive decision on the best microcontroller for this system can be made. The ESP32 DevKit is taken as the obvious choice given the analysis above it has the best balance of speed, ram and price from the three options.

4.3.3 System Timing

Any monitoring/data logging system would need to be able to accurately log the time that each of the readings was taken. There is the option of using the internal timer of the selected microcontroller unit, however this is not the most suitable option as microcontroller clocks are notorious for losing accuracy fairly quickly which is less than ideal for this type of system. Having discussed the issues with the internal clock of the microcontroller it is necessary to explore the alternative options that could remedy the problem, which would naturally lead to discussion of the real-time clock module. Real-time clock modules are quite abundant as such it is important to pick the best one for this system. The final decision on the real-time clock module would come down to two choices the DS3231 and the DS1302.

Feature	**DS3231**	**DS1302**
Accuracy	accurate to 2ppm (loses accuracy by about 2 minutes per year)	loses accuracy by about 2 minutes a year
Interface	Communicates via I2C which makes it easier to integrate with a microcontroller	Communicates over a 3-wire interface which may be beneficial in simpler projects
Cost	R60.00	R20.00

Table 4.4: Real-time clock feature comparison

Considering the nature of the use of the system being designed and the minimal interaction it will receive for maintenance it is important to ensure that it stays as accurate as possible for as long as possible to maintain the integrity of the data collected, this is why the DS3231 is the obvious choice in terms of accuracy for the system.

The interface used for the real-time clock, while not being of particular importance to the core functionality of the system could however open up a myriad of different use cases for the clock in this system. An example of a possible additional feature is the integration of an alarm that wakes the ESP32 and allows it to compute on a schedule thereby reserving resources and making for an overall more efficient system. This would make the DS3231 a better contender for the real-time clock of the system.

The cost of the DS3231 is 3 times more than the DS1302 however despite this they are both still relatively low cost components for the system meaning that cost is not as weighty of a factor for the selection of the real-time clock as it may be for other components, as such either component could be selected based on this criterion.

Having compared the two real-time clocks the clear choice for the real-time clock of the system is the DS3231 primarily based on its superior accuracy which is an absolutely integral part of the performance of the system, moreover it expands the possible functionality of the clock which may allow for more improvements to be made to the system in the future.

4.3.4 Data Storage

The objective of this system is monitor the nest of the Southern yellow-billed hornbill. Since it is being monitored it means that there is a long term aspect to the system therefore it is not enough to simply view the most recent data of the nest, but rather all data over a long period of time must be available to the user of the system.

Given the need for the ability to access long-term data for this system an appropriate method of data storage and an appropriate format for the data to be manipulated is also necessary. The possibilities for data storage are limited to storing the data locally on an SD card or storing the data on the cloud, however due to the nature of the environment (a remote area within the Kalahari) in which the system is to be deployed, cloud storage is not a feasible option as there is no infrastructure to facilitate a stable and reliable supply of internet, which means that the storage would have to be done locally. The obvious solution to local data storage is the use of an SD card hence an SD card module is integrated into the system. Another important aspect of data storage is the format of data files, for the purposes of this project the format of the data recorded, will be csv due to how well organised the data can be and the ease in which the collected data may be shown in different forms such as graphs. This is in contrast to text files which would need further processing or transferring to new apps before it can be utilised properly.

4.3.5 Temperature Sensing

The temperature Sensor choice was guided by the by the specifications of the hardware that Ben currently uses to monitor temperature as the system is aiming only to maintain or improve upon the quality of the data that he collects.

Feature	**DS1922L-F5#**	**DHT22**
Accuracy	Accurate to 0.5°C	Accurate to 0.5°C
Temperature Range	-40°C to +85°C	: -40°C to +80°C
Sensing Period	1 second	2 seconds
Cost	R1,931.69	R104.35

Table 4.5: Temperature Sensor Comparison

The accuracy of DHT22 and the DS1922L-F5H(from here on referred to as the iButton) is the same hence there is no loss of accuracy when switching from the iButton to the DHT22, thus making the DHT22 suitable in regards to its accuracy.

The temperature range of the iButton is greater than the temperature range of the DHT22 however this is of no detriment to the DHT22, due to the fact that the temperature sensor is only required to measure the temperature of the nest in the kalahari. In the kalahari even on the hottest of summer days the temperature stays below 50°C and during the coldest of nights it would be higher than -15°C therefore the DHT22 will be able to record all expected data in the environment it will be deployed in.

The iButton is able to at its max log temperatures twice as fast as the DHT22 however temperature is not an erratically changing variable that needs to be measured frequently the system only needs to be able to measure the temperature in intervals of several minutes hence the DHT22 is able to carry out this task just as well as the iButton.

Finally the cost of the iButton is vastly greater than the cost of the DHT22. While the DHT22 may not perform to the level of the iButton in certain aspects, it is perfectly capable of being a replacement to the iButton for the monitoring system and it does this at a fraction of the cost.

4.4 Software Design Choices

This Section will detail the the logic behind the software decisions that led to the final system. The key aspects of the software design are the Data format, Platform, Framework and User interface.

4.4.1 Facilitating Data Transmission

In the hardware design decisions it was decided that Wi-Fi would be used to transmit the data. In this section the details of how the data transmission will be facilitated over Wi-Fi. The data in this system is of two types the logged data that is stored on the SD card and the live data that will be viewable by means of a web page. Therefore a web page will be used to facilitate the downloading of data from the SD card directly onto the client device being used to view the web page. The choice of a web page for the purpose of facilitating the viewing and access of data is due to the complexity and functionality that a web page is capable of, thus making it a prime candidate for this system that is highly dependent on dynamic and static information.

4.4.2 Framework

The frameworks being used on this system are JavaScript, HTML and CSS they were prime candidates for this system due to their ease of use and their capability to produce a well designed and highly functional web page using minimal amounts of data which is ideal for the system as it will result in minimal resources being used to access the pages created using these frameworks. Taking all these factors into account makes them a better choice than more demanding frameworks such as Django and Ruby that are much more resource intensive on the system due to their server-side processing nature as compared to JavaScript, HTML and CSS's client-side processing.

4.4.3 Server Type

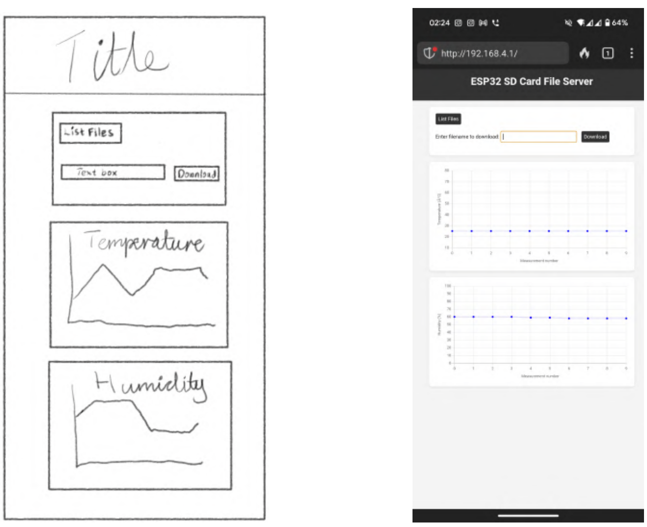
When choosing the server type i.e. asynchronous server or synchronous server. The guiding factor in this choice is the what information needs to be relayed via the web page, in this case the information is the live graphs of the temperature and humidity in the nest. Due to the highly dynamic nature of these graphs they would need an asynchronous server which in turn would imply the necessity for them to have asynchronous communication protocols, in this case web sockets were used due to how well documented they are for use in microcontrollers (particularly arduino's and by extension ESPs) thus making them an obvious choice.

4.4.4 Software Storage

There are two possible options for how to store the software(web page) on this system with it could be served from the SD card or it could be saved on the flash memory that is on the ESP32. While the SD card has much more storage at 8GB compared to the ESP32's 4MB, it would be better to store the web page code on the ESP since if it is stored on the SD card whenever the SD card is removed the web page would not be accessible and if the SD card needed to be replaced the new one would have to be configured to display the web data as such it is stored on the ESP32 using SPIFFS (Serial Peripheral Interface Flash File System) to allow for minimum maintenance/configuration of the web server.

4.4.5 User Interface

The Overall functionality of the web page determined the design of the web page. The web page would need to show real-time graphs of the temperature and humidity, showing the data collected over the past 10 seconds. There must be buttons to allow the user to view the files available on the SD card and a text box with a button to allow the user to download a specified file. Following these criteria the following design was curated.



(a) Initial sketch of web page (b) Final web page

Figure 4.1: Iterations of the user interface

4.5 Final Design

Having Decided on the parts that make up the hardware and the software of the system, a block diagram describing the interaction of all the components of the sub-module with each other to make one fully functional system is shown below.

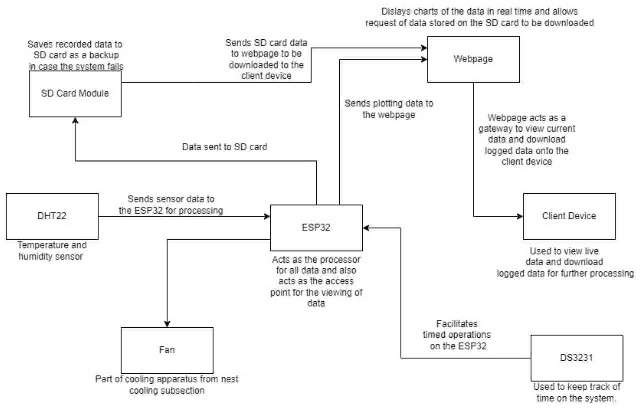


Figure 4.2: Block diagram of the entire Electronics Sub-module

4.5.1 Hardware Implementation

Based on the discussion above the ESP32, DHT22, DS3231 and an SD card reader were chosen to complete the physical aspect of the design. The flowchart below shows how all of the hardware interacts with each other.

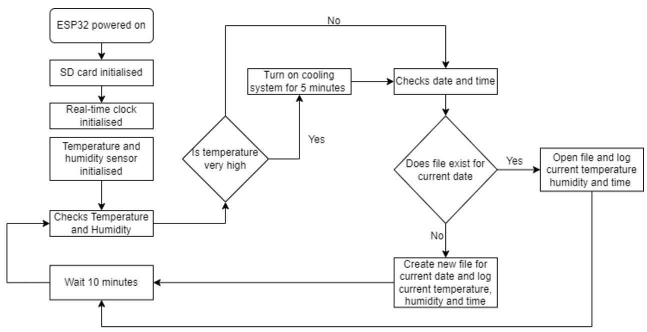


Figure 4.3: Flowchart detailing the hardware operation

4.5.2 web server Implementation

Having explained the choices made to decide on the final features of the web server. The exact working of the server is elaborated on in the flowchart shown below (all code for the web server can be found in appendix c):

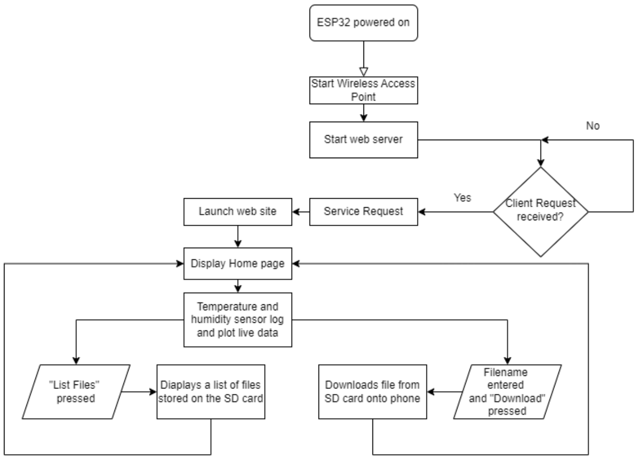


Figure 4.4: Flow chart detailing the web server operation

4.6 Testing and results

Having built the final system it is important to check that the system is able to carry out the functions that it was built for and it must be able to do this to a clearly defined level. Each acceptance test procedure will be investigated:

No.	User Requirement	Specification Description	Acceptance Test Procedure	ATP Status
1	Must be able to store data recorded over a long period of time	SD card should have enough space to store the logged data over long periods of time	The system is able to store a large amounts of data before it runs out of space	Pass
2	Must be able to access data quickly	web page must load hastily	The web page must load within 5 seconds	Pass
3	Long battery life	System should be able to save power	Must be able to lower processing power during periods of idling	Fail
4	Must be able to read the data collected	The sensor data should be stored on the SD card as a csv file	The system stores the sensor readings on an SD card and they are accessible to the user	Pass
5	Data should be accessible without tampering with the nest	Should be able to access the data without disturbing the nest	Live and past data must be accessible wirelessly	Pass
6	Needs to know when data was collected	The data collected should have accurate time information	Data collected must have the accurate time and date information tied to each reading	Pass
7	Needs physical copy of data	In case of failure there should still be accessible data	Final data stored should be physically accessible if the system fails	Pass
8	Quality of data should match current solution	The data collected should match or be better than the current solution	The data should be as accurate or more accurate than the current solution	Fail to test
9	Intuitive user Interface	The user interface must have all graphs and buttons clearly labelled	User interface must be easily navigable and must show all data clearly	Pass

Table 4.6: List of Acceptance test procedures to be passed

4.6.1 ATP1

To meet this ATP we consider the size of the files and determine how much space is needed the system uses an 8GB SD card to store csv files, considering we are planning on taking a reading every 10 minutes there would be a total of 144 readings taken daily. A csv file consisting of 60 data points uses about 2kB of space thus a data file with 144 data points would take 2.4 times more space thus the system would use 4.8kB per day thus it would be able to store data for 1666666.7 days thus it passes.

2024-5-4.csv	Microsoft Excel Co...	2 KB
2024-5-5.csv	Microsoft Excel Co...	2 KB
2024-5-6.csv	Microsoft Excel Co...	2 KB
2024-5-7.csv	Microsoft Excel Co...	2 KB
2024-5-8.csv	Microsoft Excel Co...	2 KB

Figure 4.5: List of test files saved on SD card and their sizes

4.6.2 ATP2

To meet this ATP the server was loaded ten times using DuckDuckGo browser and the browser data and cache were cleared after each test. Each test was screen recorded and taken to a video editor to capture the exact moment the enter key is pressed to the moment the web page displayed, this takes an average 3.24s thus it passes.

4.6.3 ATP3

This particular ATP failed due to a lack of time to properly find a way to implement this feature while also being able to use the server any time the user wants. A suggested solution to this problem would be to add a receiver that allow the server to be turned on using a remote.

4.6.4 ATP4

The microcontroller saves the the data directly to the SD card and using the server this data can be downloaded off of the web server for viewing by the user at any time. Therefore it passes.

Time	Temperature	Humidity
23:04:01	26.7	56.4
23:04:02	26.7	56.4
23:04:03	26.7	56.2
23:04:04	26.7	56.2
23:04:05	26.7	56.1
23:04:06	26.7	56.1
23:04:07	26.8	56.3

Figure 4.6: Format of data stored in CSV file

4.6.5 ATP5

The data that is collected in the past can be downloaded via the web page as seen in the in the user interface section of the paper. The live data is also viewable as shown in the final web page image, the system therefore passes.

4.6.6 ATP 6

As seen in the image below the data collected has the accurate time attached to it by means of the real-time clock module that keeps time for the system thus it passes the ATP.(time in the corner matches time according to DS3231)

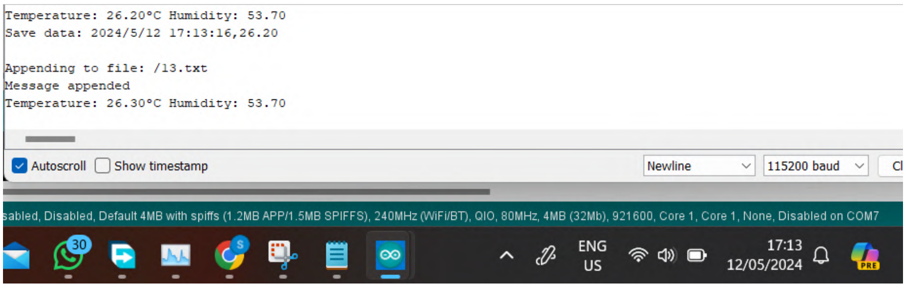


Figure 4.7: Proof of accurate time on being recorded into csv file

4.6.7 ATP 7

While the data is accessible via the web server it is all physically stored on an SD card that facilitates all storage of data as such it passes this test.

4.6.8 ATP 8

This particular ATP was a fail to test due to a lack equipment to test the DHT22's accuracy to 0.1°C, however to the nearest 1°C it passed every test. The test performed is shown below:

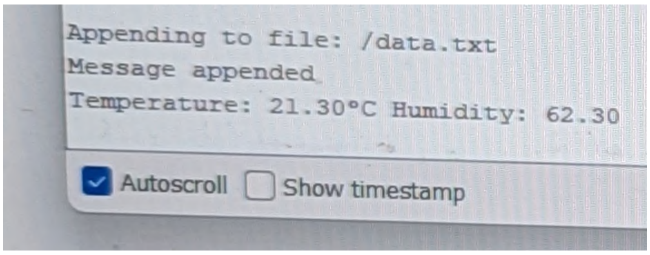


Figure 4.8: DHT22 temperature reading

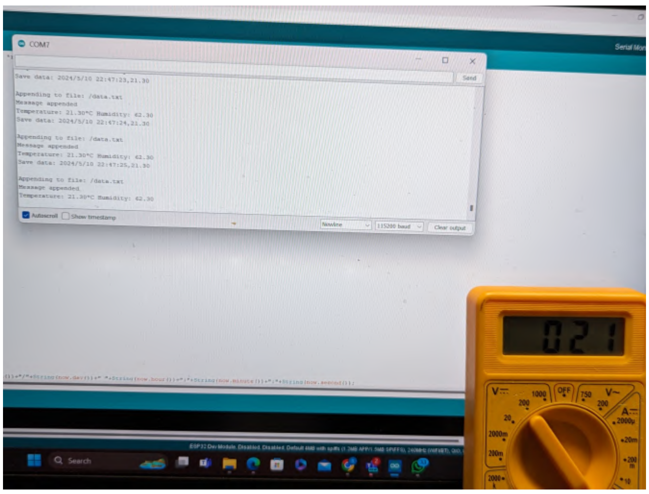


Figure 4.9: Multimeter Temperature reading

4.6.9 ATP 9

The data collected stored on the SD card is stored according to and named according to the date it was collected making it well organised and data on the web server is shown on clearly marked graphs that can be easily read.Moreover The web page as shown in 4.1b is simple but has all elements clearly labelled thus making the web page intuitive which is an earmark of any good web design. Therefore it passes the test

4.7 Conclusion

The electronics subsystem developed for monitoring the nests of Southern yellow-billed hornbills meets most of the key functional and non-functional requirements set out initially. The system achieves wireless data transmission and remote accessibility through a Wi-Fi web server, allowing users to view both live and past temperature and humidity data without disturbing the nests. Data is accurately timestamped using a real-time clock module (DS3231) and stored locally on an SD card, which provides a physical record even if the system fails.

The user interface offers a web page to visualize real-time graphs of sensor data and allows the user to download logged data files from the SD card. All this was achieved by means of careful component selection, to find a balance between cost and performance to meet the project's goals within the constraints of the project.

While the system passed most of the defined acceptance test procedures, two areas fell short - achieving use of a low power mode to enhance battery life, and ensuring the accuracy of the DHT22 matched the accuracy of current temperature monitoring solution used. Potential improvements would explore power saving techniques and compare sensor accuracy more rigorously against the existing approach.

Overall, the developed electronics subsystem successfully implements the core requirements for remotely monitoring hornbill nest conditions over long periods through wireless data access and local storage capabilities. With some further refinements, it can provide a relatively cheap and convenient monitoring solution to support research on this bird.

Chapter 5

Cooling and Nest Design

This section was authored by Caide Lander (LNDCAI001)

5.1 Introduction

The design of an effective cooling system for the nest boxes is a crucial aspect of ensuring the well-being of the Yellow-Billed Horn-bills in the Kalahari region. With the potential for extreme temperatures in this arid environment, it is important to maintain a suitable internal temperature within the nests to protect the birds and their offspring. This chapter presents a comprehensive analysis of the cooling and nest design requirements, followed by a detailed exploration of the design choices and evaluation processes undertaken to develop an optimal solution. The chapter begins by outlining the user requirements, functional requirements, and design specifications derived from the project's objectives and constraints. These requirements serve as the foundation for the subsequent design process, ensuring that the proposed solution addresses key factors such as cost-effectiveness, temperature regulation, noise control, material selection, and space considerations.

5.2 Requirements Analysis

5.2.1 User Requirements

UR1	**Cost Effectiveness**
Requirement	The solution must be cost effective.
Refined by	FR1:DS1
Verification	ATP1

UR2	**Interior Temperature Control**
Requirement	The interior of the nest must be relatively cool and cooler than the external temperature.
Refined by	FR2:DS3
Verification	ATP2

UR3	**Component Disturbance**
Requirement	Components must not disturb the birds.
Refined by	FR3:DS3
Verification	ATP3

UR4	**Non-Toxic Materials**
Requirement	Materials used must be non-toxic.
Refined by	DS2
Verification	ATP4

UR5	Space Availability
Requirement	Birds must have enough space.
Refined by	FR4:DS5
Verification	ATP5

UR6	Weather Resistance
Requirement	Electronics housing should be weather resistant.
Refined by	FR5:DS6
Verification	ATP6

5.2.2 Functional Requirements

UR1:FR1	Cost-effective Components and Materials
Requirement	The solution must use relatively low-cost components and materials.
Refines	UR1
Refined by	DS1
Verification	ATP1

UR2:FR2	Temperature Control Limits
Requirement	The interior of the nest should not exceed 50°C while the external air temperature is 35°C.
Refines	UR2
Refined by	DS3
Verification	ATP2

UR3:FR3	Noise Control
Requirement	Noise levels produced should be reasonable; noise produced by components should not exceed 45dB.
Refines	UR3
Refined by	DS4
Verification	ATP3

UR5:FR4	Nest Volume Preservation
Requirement	Nest solution should not reduce the volume of the inner chamber of the nest; internal dimensions of the nest should not be less than 170x210x500mm (L×W×H).
Refines	UR5
Refined by	DS5
Verification	ATP5

UR6:FR5	Housing Rating
Requirement	Electronics housing should be IP52 rated.
Refines	UR6
Refined by	DS6
Verification	ATP6

FR6	Housing Storage Capacity
Requirement	Electronics housing holds all the necessary sub-modules
Refines	NA
Refined by	DS7
Verification	ATP7

5.2.3 Design Specifications

DS1	**Cooling Mechanism**
Requirement	Peltier coolers should be used; as they are the cheapest way to actively cool. A CPU heat-sink should be used for price to performance ratio.
Refines	UR1:FR1
Verification	ATP1

DS2	**Material Selection**
Requirement	Wood should be used as the main material as it is cheap and non-toxic.
Refines	UR1:FR1, UR4
Verification	ATP1, ATP4

DS3	**Cooling Efficiency**
Requirement	Peltier coolers with a potential temperature difference of at least 15°C should be used to ensure effective cooling.
Refines	UR2:FR2
Verification	ATP2

DS4	**Noise Control Mechanism**
Requirement	Either no moving parts must be used or in case of the need of a fan to be used in conjunction with a heat-sink - a fan optimized for low noise must be used.
Refines	UR3:FR3
Verification	ATP3

DS5	**Space Considerations**
Requirement	Peltiers connected to the floor would not change the volume of the inner chamber, ensuring that the birds have sufficient space.
Refines	UR5:FR4
Verification	ATP5

DS6	**Housing Sealing**
Requirement	Electronics housing can use a rubber seal to ensure a tight seal against dust and water.
Refines	UR6:FR6
Verification	ATP6

DS7	**Housing Storage Capacity**
Requirement	Electronics housing can have the same length and width as the nest box.
Refines	FR7
Verification	ATP7

5.3 Design Choices

5.3.1 Evaluation of Cooling Strategies

Option 1: Passive cooling; Nest design (Initial choice)

Considering a largely passive approach to nest design, biomimicry could be employed by shaping the nest akin to a termite mound, enhancing surface area by covering it with simulated cactus thorns. Vents positioned atop the nest could regulate internal temperature by closing to retain heat or opening to vent excess heat. Additionally, applying a non-toxic thermally resistant paint with UV protection may further enhance thermal management. The outer wooden wall could be replaced with ceramic, as ceramic nests have been shown to maintain cooler temperatures compared to wooden boxes during extreme heat conditions. The potential of these strategies is supported by literature review which explored alternative nesting materials and passive cooling techniques. Passive cooling techniques would be preferable as they do not require power to work and are thus innately sustainable. However after consulting the client (Ben) about this option it was mentioned that the nest shape should not change substantially and the birds would seal any vents or holes within the nest, rendering most passive options unfeasible. Due to the lack of expertise in CFD simulations and lack of hardware testing capabilities, the options involving simulated cactus thorns and applying a thermally resistant paint with UV protection were omitted from implementation.

Option 2: Active cooling; Nest design (Final choice)
The initial plan for active cooling was to use peltiers to create an air conditioning system, but it was later realized that the airflow would disturb the birds, leading to a change in approach. Instead, the focus shifted to cooling the nest floor, inspired by the sealed termite mound concept discussed in the literature review. By leveraging convection, hot air rises to the top of the box while cooler air remains at the bottom where the birds reside. To achieve this, the nest floor would consist of a material with reasonable thermal conductivity, such as wood veneer on an aluminum plate, to avoid disturbing the birds. Two peltiers would be utilized, each positioned at the center of one half of the nest floor. An aluminum linking plate would connect the hot sides of the peltiers to conduct heat away, and a heat sink connected to the linking plate would dissipate heat. Non-toxic thermal paste or adhesive would ensure efficient heat transfer between materials.

In selecting the two components for this design, thorough research was crucial to ensure the best options were chosen, given their substantial individual impact.

5.3.2 Heat-sink Selection and Evaluation

The choice of heat sinks is crucial for effective thermal management in the cooling system. This subsection presents an evaluation of different heat sinks based on key parameters such as size, cooling potential, maximum noise level, and price. The analysis aims to identify the most suitable heat sink for the application, considering factors such as cooling performance, noise levels, and budget constraints.

Typically, heat sinks utilize aluminum blocks milled to create fins, enhancing surface area. While reliable due to simplicity, they often exhibit limited thermal performance relative to cost, primarily due to the absence of heat pipes. For instance, the FHS-A7015B62 from Digikey, priced at R329.97, provides a maximum cooling capacity of 100W. To address this, CPU coolers or repurposed GPU heat sinks were considered. Opting for readily available CPU heat-sinks ensures repeatability. Notably, the cooling capacity assumes maximum fan RPM, with potential noise implications as shown below:

Table 5.1: Comparison of Heat-sinks

Heat-sink Name	**Size (mm) (L×W×H)**	**Cooling potential (W)**	**Max noise (dB)**	**Price**
ID-Cooling SE-214-XT Pro	124×72×151	180	28.9	R339.00
ID-Cooling SE-224-XTS	120×75×151	180	28.9	R429.00
ID-Cooling FROZN A410	120×73×152	220	29.85	R479.00
ID-Cooling FROZN A400	93×78×123	180	25.8	R379.00

All of the above heat-sinks use four 6mm heat-pipes. Heat-sinks with heat pipes were chosen because they offer superior cooling performance. Heat pipes efficiently transfer heat away from the CPU through a phase change process, distributing heat evenly across the heat sink and enabling faster dissipation.

When considering which option to choose, it was decided to purposefully get an overkill heat-sink in terms of thermal capability for testing purposes and to see if it would be possible to avoid the use of the fan - due to the cooling overhead. Therefore the FROZN A410 form ID-COOLING was chosen, as it has the highest cooling potential albeit the highest price. In adherence to Ben's requirement for low bird disturbance, it was necessary to create a proper functional requirement. Research revealed that noise levels surpassing 45 dBA could detrimentally impact sound reproduction and elevate cortisol levels, a stress hormone in the Yellow-Billed Horn-bills. Consequently, our objective was to maintain noise levels well below this threshold. The fan selected for use alongside the heat-sink boasts a maximum noise output of 29.85dB, thus falling comfortably within the acceptable range deemed by Ben and aligning with our commitment to meeting stringent noise level criteria. The FROZN A400 would be the next preferred choice because of its compact size, affordability, and remarkable cooling efficiency, all achieved without sacrificing noise levels despite its smaller dimensions. However this cooling potential may not translate as well without a fan as the ID-Cooling SE-214-XT Pro for example, due to its comparatively smaller volume. It is also important to note that the max RPM of the fans in the SE series is 1500, whereas the FROZN series have a 2000 RPM max. This is likely the reason why the cooling potential on the FROZN series is higher. Therefore the next best choice for use without a fan would be the ID-Cooling SE-214-XT Pro due to it's low price point. Whereas if a fan was to be used the FROZN A400 would be second choice.

The theorised design entails connecting 2-3 Peltier modules to a single heatsink through an aluminum linking plate. With a maximum cooling capacity of 220W, the FROZN A410 accommodates the heat generated by the Peltiers, which can produce up to 60W each. Even with three Peltiers operating at full capacity, totaling 180W of heat output, there remains a margin to accommodate the theoretical maximum heat output of the Peltiers. This consideration is particularly significant in environments with elevated ambient temperatures, such as the Kalahari region. However, to prioritize minimizing potential noise generated by the fan attached to the heatsink, the decision was made to utilize only two Peltiers.

5.3.3 Peltier Module Selection and Evaluation

The selection of suitable Peltier modules is critical for the effectiveness of the cooling system. This subsection presents an evaluation of different Peltier modules based on key specifications such as voltage, current, maximum cooling capacity, temperature differential, size, and price. The analysis aims to identify the most suitable Peltier module for the intended application, considering factors such as performance, cost-effectiveness, and size constraints. Table 5.2 bellow summarises this data:

Two datasheets were discovered for the TEC1-12706 Peltier module, each offering differing specifications, prompting the inclusion of both datasets for comprehensive evaluation. Despite the inconsistencies, the TEC1-12706 emerged as the preferred choice due to its notably lower cost (ATP1), while still delivering competitive thermal performance at modest current levels.

Table 5.2: Comparison of Peltier Modules

Peltier Module	Voltage (V)	Current (A)	Qmax @ Th (W)	ΔTmax @ Th (°C)	Size (mm) (L×W×H)	Price (R)
TEC1-12706	14.4; 17.2	6.1	92.4; 66.7	66; 79	40x40x4	85.00
ADV-127-140170-S	15.4	5	42.8	65	40x40x3.9	176.09
ETH-049-10-15-S-H1	6.2	3.2	11.5	72	18x18x3.40	127.66
TEC1-12715	15.4	15.0	136	70	40x40x3.6	189.95

Additionally, the ETH-049-10-15-S-H1 presents an appealing option with its lower voltage and current requirements. However, the smaller size of the ETH-049-10-15-S-H1 Peltier module may result in inferior cooling performance compared to larger modules due to reduced surface area for cold transfer. This limitation also affects its ability to dissipate heat efficiently, potentially leading to higher temperatures on the hot side of the module. As a result, the smaller module may exhibit reduced cooling capacity and effectiveness, particularly when subjected to high heat loads. Hence, at R127.66, the ETH-049-10-15-S-H1 was deemed unsuitable. However, if facing stringent power constraints alongside a more flexible budget, this Peltier could warrant consideration.

5.3.4 Material Selection for Nest Floor

In considering materials for the nest floor, several options were explored, including wood vinyl over an aluminum plate, ceramic tile, and conductive wood. However, each option presented specific challenges.

Wood vinyl, which was found to need to be between 13°C and 38°C, was deemed unsuitable due to concerns about toxicity from the adhesive used in its application. Furthermore, the narrow temperature range rendered it inadequate for our requirements.

Although ceramic tiles boasted superior thermal conductivity compared to wood, the potential discomfort and injury risk to the birds, especially during adolescence when their claws are prone to breakage upon impact with hard surfaces, led to their exclusion from consideration.

Ultimately, wood emerged as the preferred choice, given its compatibility with the birds' natural habitat and existing nest materials. However, the poor thermal conductivity of wood necessitated a compromise solution. An aluminum plate was selected as the foundation, leveraging its exceptional thermal conductivity, with wood veneer secured to it using non-toxic thermal adhesive to provide the desired aesthetic and comfort for the avian occupants.

Following discussions with the power lab, three readily available wood types were identified, prioritizing accessibility and affordability to ensure the scalability and cost-effectiveness of the design. Namely: MDF, MDF hardwood and Plywood. Various other materials were also used for testing purposes.

To facilitate material testing, an aluminum linking plate was fabricated to connect two Peltier modules to a single heatsink. Aluminum was chosen for its minimal thermal resistance and high thermal conductivity, crucial for efficient heat transfer within the nest box floor.

The subsequent assessment aimed to determine the suitability of various wood types and alternative materials for optimal performance and durability in the nest floor design.

It's worth noting a potential solution that couldn't be implemented in this design involved carbonizing wood. This process significantly enhanced thermal conductivity, with promising results in both cross-plane and parallel directions. The compound, achieved by impregnating polyamide-imide (PAI) into the wood, offered improved mechanical performance as well.

5.4 Housing Design

When designing the housing, reference to figure 5.1 ensured compatibility with the nest. It was crafted to match the dimensions of the existing nest, facilitating seamless integration underneath, directly connecting to it. Therefore the external dimensions of the housing (L x W) matched that of the nest.

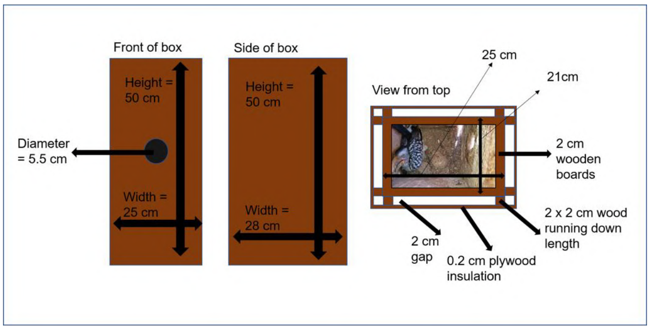


Figure 5.1: Existing Nest Box

It became imperative to confirm that all components would fit within the designated housing. Table 5.3 outlines the required dimensions for clarity.

Component	Length (mm)	Width (mm)	Height (mm)
Electronics Sub-module	100	140	70
Power Sub-module electronics	100	100	20
Battery enclosure	75	80	20

Table 5.3: Dimensions of all internal electronics

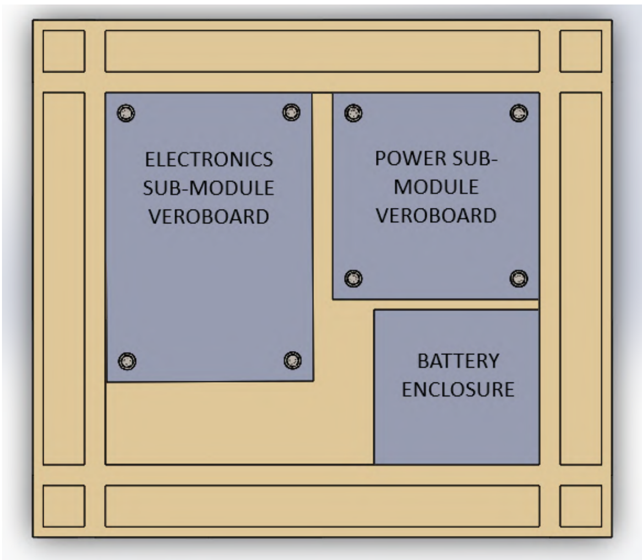


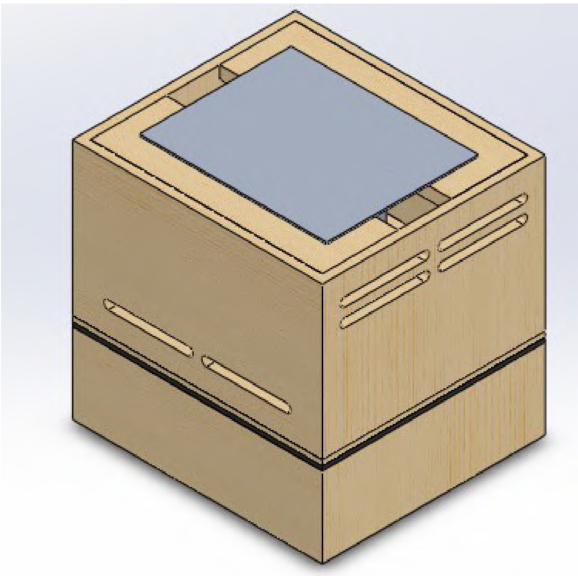
Figure 5.2: Lower Enclosure Floor

As shown in figure 5.2 all the electronics fit within the housing (passing ATP7). The screws selected are standard M3 PCB screws, chosen to maintain compatibility with PCB circuits once the design transitions from the testing phase - using veroboard circuits - to utilizing a printed PCB.

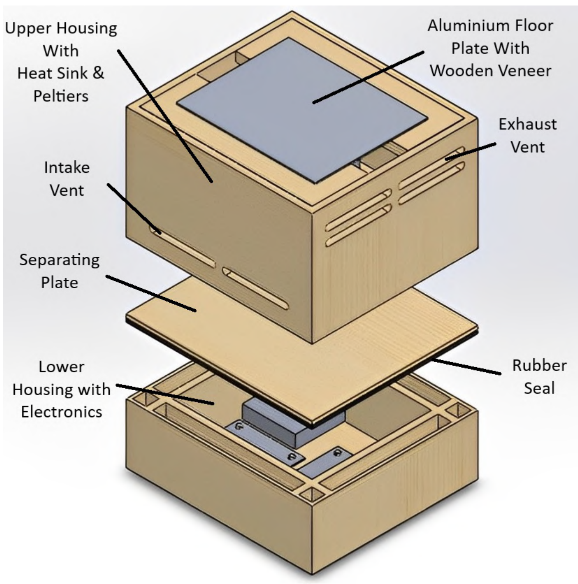
Following DS2, wood was selected as the housing material due to its non-toxic nature (ATP4), abundant availability, sustainability, renew-ability, cost-effectiveness (ATP1), and biodegradable properties, aligning with environmental considerations. Plastic alternatives, including most 3D printed plastics, were deemed unsuitable due to their toxicity and non-biodegradability. Notably, prolonged exposure to UV radiation can lead to photo-degradation in plastics, resulting in reduced strength and potential ecological harm if ingested by wildlife, such as the Yellow-Billed Horn-bills in the Kalahari ecosystem.

The housing design was segmented into two parts: The upper section accommodated the heat-sink, peltiers, and the nest floor (maintaining its original size to preserve nest volume, Passing ATP5). Whilst lower section housed the remaining electronics. While the top section required airflow for cooling, water and dust resistance were not a priority however, a woven wire mesh can be utilized in the vents to obstruct insects and large debris. In contrast, the bottom section was designed to meet IP52 standards, ensuring protection against dust ingress and vertically dripping water at a 15° tilt angle. This was done by utilising a neoprene rubber seal given its UV resistant and non-toxic nature (ATP4) as well as relatively low cost (ATP1). Additionally, an air-gap of 2 cm, similar to that of the artificial nest, was incorporated into the bottom section to mitigate heat buildup from ambient temperatures and safeguard the electronic components. It was not a requirement to make the housing thermally insulative, however after discussion amongst our group it was determined to be best engineering practice to do so.

For the upper housing, intake vents were positioned at the bottom, while exhaust vents were placed at the top, facilitating convection. Cold air enters through the intake vents, warms up as it passes over the heat-sink, and exits through the exhaust vents.

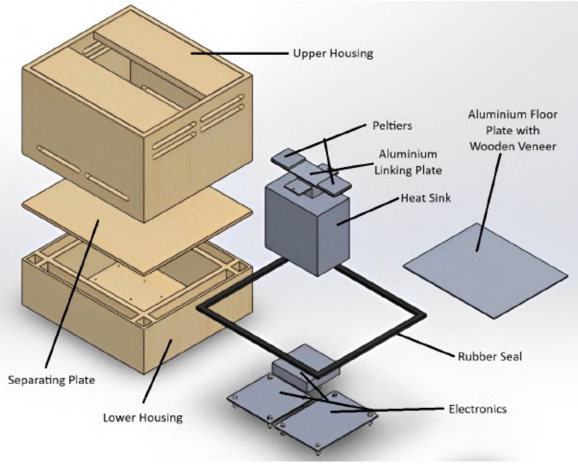


(a) Fully Assembled Final Design

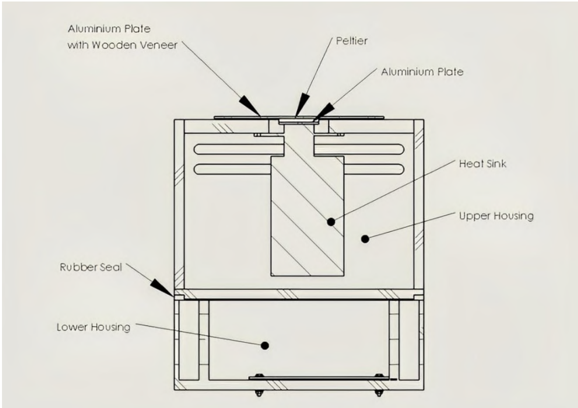


(b) Opened Housing

Figure 5.3: Fully Assembled Final Design and Opened Housing



(a) Exploded Housing



(b) Cross Section

Figure 5.4: Exploded Housing and Cross Section

5.5 Testing

During testing, all materials were cut to uniform dimensions of 170 x 110 mm, representing half the total area of the current nest floor. This decision capitalized on the symmetry achieved by centrally positioning two peltiers with the heat sink. Connecting these peltiers with an aluminum linking plate, as depicted in the exploded housing above. The plate was crafted to match the width of the peltiers, minimizing unnecessary heat dispersion. Thus, results obtained from testing with one peltier on one half could be readily extrapolated to simulate the performance of two peltiers covering the entire floor. See Figure 5.5 for reference.

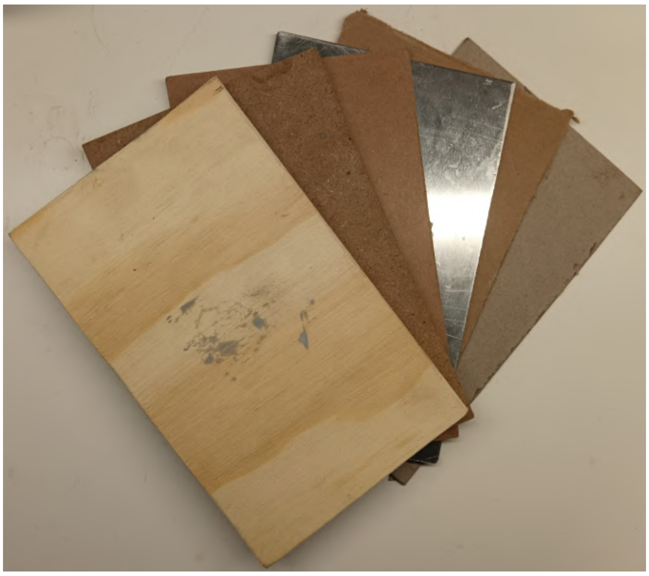


Figure 5.5: Various materials that were tested

It was assumed that a single Peltier module would not provide sufficient cooling for the entire nest floor. Initially, the plan involved determining the required wattage for each material to achieve the desired temperature differential (ΔT) of -15°C. However, due to time and power constraints, a constant wattage approach was adopted instead.

Maysan Soltanian, our Chief Technical Officer, identified the thin wires on the Peltiers (0.4mm diameter) and recommended driving the Peltiers with a maximum potential of 3A per module instead of their potential max amperage of 6.1A. Consequently, employing multiple Peltiers wired in parallel became the logical choice. However, during testing with the provided power supply, it was observed that the maximum output was limited to 6V at 3A, rather than the anticipated 6A. Recognizing this constraint, it was decided to conduct the majority of testing using a single Peltier module instead of the originally planned two. This adjustment was made to align with the available power supply capabilities while still ensuring meaningful experimental results.

Thermal paste was applied between all surfaces in contact with the Peltier or aluminum plate to ensure optimal heat transfer. To promote proper thermal contact, the materials were weighed down onto the heat-sink and Peltier with a 1kg weight (although in the pictures provided a lesser weight is shown). The temperature sensor was securely taped to the center of the material's surface directly above the Peltier. Temperature readings were taken only after the temperature had stabilized, ensuring accurate data collection.

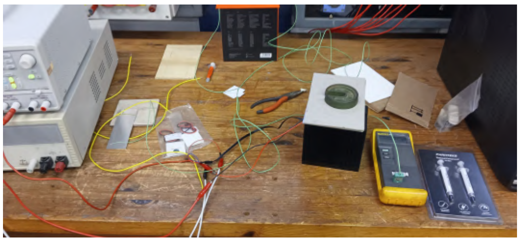


Figure 5.6: Testing set-up

For all materials below the starting temperature was fixed at 21.2°C and the current was fixed at 3A:

Table 5.4: Thermal Performance of Different Materials

Material	**Thickness (mm)**	**End Temp (°C)**	**ΔT (°C)**	**Voltage (V)**
MDF Hardwood	3	9	-12.2	10
MDF Hardwood on Aluminium	4.6	14.2	-7	10
Plywood	9	10.5 (Centre)	-10.7	10
		20.8 (Edge)	-0.4	
Plywood on Aluminium	10.6	17.2	-4	10
MDF	6	8.5 (Centre)	-12.7	10
		20.1 (Edge)	-1.1	
MDF on Aluminuim	7.6	14.9	-6.3	10
Aluminium	1.6	10.2	-11	5
Aluminium	1.6	4.2	-17	10
Direct Peltier	0	-0.5	-21.7	5
Direct Peltier	0	-8.5	-29.7	10
Compressed cardboard on Aluminium	2.6	14.5	-6.7	10
Heat-sink no fan	NA	41.1	19.9	10
Wood Veneer on Aluminium	2.1	5	-16.2	10
Aluminium with two peltiers	1.6	14.2 (Centre)	-7	6
		15.5 (Edge)	-5.7	

An attempt to normalise the temperature difference based on temperature was made however it was later realised that all of the calculations were incorrect and due to time constraints they could not be redone.

The heat-sink effectively maintained temperatures below the Peltier's 70°C limit even without a fan, demonstrating the feasibility of fanless operation. However, to enhance longevity and mitigate potential failures, a fan running at 5V and 0.1A (0.5W) was utilized, spinning at 500 RPM silently. Given its minimal power consumption and negligible noise output, incorporating the fan into the final design was deemed sensible to optimize the Peltier's performance and ensure longevity, by keeping the peltier cooler. All without disturbing the environment or wildlife. In testing the fan's noise output in the quietest available room with a noise floor of 30dB, it proved quieter than 30dB even at max RPM, as confirmed by the decibel meter (Passing ATP3).

MDF demonstrated exceptional performance, notable for its substantial thickness and achieving the highest ΔT among the pure wood materials. Conversely, wood veneer on aluminum showcased the most effective performance, blending superior thermal characteristics with an aesthetic resembling a wooden floor, thus minimizing disruption to the birds. Wood veneer also showed a ΔT of more that -15°C (Passing ATP2).

Focusing solely on the temperature directly above the Peltier may have been an oversight. It would have been more informative to take readings at both the center and the edge of the material to illustrate how the cold spreads. However, readings at the edge were not taken due to not realizing the need for them in time and subsequently not having enough time to redo all the readings. The powerful performance of the Peltiers caused significant temperature drops directly above them. This difference in temperature distribution is evident in the tests conducted on Plywood, MDF, and Aluminium with two Peltiers. Given that aluminium with two peltiers showed such impressive edge vs centre temperatures especially in comparisson to the woods, it can be assumed that veneer on aluminium would show similar improvements. And thus continues to be the superior material choice.

Throughout the design process ATP1 and ATP4 were carefully considered, all components and materials used were both cost-effective and non-toxic. Therefore both these tests were passed.

The components housing was never physically built and therefore could not be tested for its IP rating.

Table 5.5: Summary of Acceptance Test Procedures (ATPs) and their results

Code	Name	Refines	Requirement	Pass/Fail
ATP1	Cost-effectiveness Evaluation	UR1:FR1:(DS1, DS2)	Assess solution's cost-effectiveness based on components and materials.	Pass
ATP2	Temperature Regulation	UR2:FR2:DS3	Ensure a ΔT of -15°C of the floor materials when connected to peltier.	Pass
ATP3	Noise Level Testing	UR3:FR3:DS4	Confirm noise produced by components does not exceed 45dB.	Pass
ATP4	Material Toxicity Testing	UR4:DS2	Confirm materials used are non-toxic.	Pass
ATP5	Space Adequacy	UR5:FR4:DS5	Verify internal dimensions meet minimum requirements of 170x210x500mm (L×W×H)	Pass
ATP6	IP Rating	UR6:FR6:DS6	Ensure housing meets IP52 rating for dust and water protection.	NA
ATP7	Housing Storage Capacity	FR7:DS7	Ensure housing can hold all sub-modules.	Pass

5.6 Conclusion

The cooling and nest design process presented in this chapter represents a thorough and methodical approach to addressing the challenges posed by the extreme environmental conditions in the Kalahari region. By employing a rigorous evaluation of user requirements, functional requirements, and design specifications, the proposed solution offers an effective and cost-efficient method for maintaining suitable thermal conditions within the nest boxes. The selection of appropriate materials, such as wood veneer on aluminum for the nest floor, and the incorporation of Peltier modules and a high-performance heat sink, ensures optimal temperature regulation while minimizing disturbance to the birds. The housing design, with its weather-resistant enclosure and convection-based cooling system, further contributes to the overall effectiveness and durability of the solution. Throughout the design process, careful consideration was given to factors such as noise levels, material toxicity, and space availability, ensuring a harmonious integration with the natural habitat and the well-being of the Yellow-Billed Horn-bills. The extensive testing and evaluation process provided valuable insights and validation for the chosen design components and materials. This chapter serves as a comprehensive documentation of the design process, highlighting the critical decisions, trade-offs, and evaluations that shaped the final solution. The proposed cooling and nest design not only addresses the immediate needs of the project but also lays the foundation for potential future enhancements and adaptations to meet evolving requirements or environmental conditions.

Chapter 6

Sivuyile Nose: Power Subsystem

6.1 Introduction

The objective of the power subsystem is to provide a reliable, efficient, and independent power supply for the artificial nests introduced to aid the hornbills' breeding. Additionally, it aims to facilitate the monitoring of the battery level, ensuring uninterrupted operation and timely maintenance.

6.2 Context and Analysis

The power subsystem is an integral part of a larger system aimed at collecting environmental data, regulating the nest's temperature, and blending seamlessly into the hornbills' natural habitat without causing disturbance. The remote location of the artificial nests necessitates an independent power supply that can operate without reliance on the main grid. A reliable and efficient power subsystem is crucial for the success of this project and the conservation efforts for the Southern yellow-billed hornbills.

6.3 Requirements Analysis

6.3.1 User Requirements

UR1	**Reliability**
Requirement	Ben requires a reliable power supply.
Rationale	Since all other subsystems depend greatly on the power supply, a need for a reliable power supply is needed as it needs to be operational and long-lasting to ensure continuous system operation.
Refined by	UR1:FR1, UR1:FR2, UR1:FR3, UR1:FR4
Verification	ATP1

UR2	**Efficient**
Requirement	Ben requires that the power supply is not dependent on the main grid supply.
Rationale	Due to the system's remote nature, utilizing available solar power is essential.
Refined by	UR2:FR5
Verification	ATP6

UR3	**Battery Level Monitoring**
Requirement	Ben requires a way to easily monitor the battery level of the power supply.
Rationale	Monitoring the battery level is crucial for ensuring the system's continuous operation and timely replacement or recharging of the battery.
Refined by	UR3:FR6
Verification	ATP7

6.3.2 Functional Requirements

UR1:FR1	**Protection Circuitry**
Requirement	Protection circuitry to ensure minimal or no damage to hardware.
Refines	UR1
Refined by	UR1:FR1:DS1, UR1:FR1:DS2
Verification	ATP1, ATP2

UR1:FR2	**Rechargeable Battery**
Requirement	System battery needs to support recharging through various forms of energy (e.g., solar).
Refines	UR1
Refined by	UR1:FR2:DS3
Verification	ATP3

UR1:FR3	**Power Regulation**
Requirement	System needs to supply correct voltages to other subsystems.
Refines	UR1
Refined by	UR1:FR3:DS4
Verification	ATP4

UR1:FR4	**Removable Power Supply**
Requirement	Power supply should support isolation and substitution from other subsystems.
Refines	UR1
Refined by	UR1:FR4:DS5
Verification	ATP5

UR2:FR5	**Solar Power**
Requirement	Given the remote nature of the system, utilizing available solar power is crucial.
Refines	UR2
Refined by	UR2:FR5:DS6
Verification	ATP6

UR3:FR6	**Battery Level Indicator**
Requirement	The power supply should include a battery level indicator to display the remaining charge level.
Refines	UR3
Refined by	UR3:FR6:DS7
Verification	ATP7

UR1:FR7	**Rapid Battery Recharging**
Requirement	The power supply should include a battery level indicator to display the remaining charge level.
Refines	UR1
Refined by	UR1:FR7:DS8
Verification	ATP8

UR1:FR8	**Extended Battery Runtime**
Requirement	The battery pack should be able to power the system continuously for at least 8 hours before requiring recharging.
Refines	UR1 (Reliability)
Refined by	UR1:FR8:DS9
Verification	ATP9

6.4 Design Specifications

UR1:FR1:DS1	**Reverse Polarity Protection**
Requirement	An N-channel MOSFET with a continuous drain current rating of at least 5A and a drain-source voltage rating higher than the maximum battery pack voltage should be used for reverse polarity protection.
Refines	UR1:FR1
Verification	ATP1

UR1:FR1:DS2	**Over-charge and Over-discharge Protection**
Requirement	The protection circuit should prevent over-charging and over-discharging of the battery pack, with the following specifications: - Over-charge detection voltage: 16.8V (4.2V x 4 series) - Over-discharge detection voltage: 8V (2V x 4 series)
Refines	UR1:FR1
Verification	ATP2

UR1:FR2:DS3	**Battery Charging Circuit**
Requirement	The charging circuit should charge the 4 x 18650 Li-ion battery pack (4S configuration) with the following specifications: - Input voltage: 20V (from solar panel) - Charging voltage: 14.8V (3.7V x 4 series) - Maximum charging current: 2A
Refines	UR1:FR2
Verification	ATP3

UR1:FR3:DS4	**Voltage Regulator Specifications**
Requirement	The voltage regulator should meet the following specifications: - Output 1: 5V $\pm$ 5% at 80mA for the ESP Dev Board (TMU) - Output 2: 3.3V $\pm$ 5% at 10mA for the Temperature and Humidity Sensor (TMU) - Output 3: 6V $\pm$ 5% at 2A for the Peltier Module (CU) - Output 4: 12V $\pm$ 5% at 0.25A for the Heatsink/DC fan Module (CU)
Refines	UR1:FR3
Verification	ATP4

UR1:FR4:DS5	**Battery Enclosure**
Requirement	An enclosure that will allow for easy exchange of specific-sized batteries is required.
Refines	UR1:FR4
Verification	ATP5

UR2:FR5:DS6	**Solar PV Panels**
Requirement	Solar panels able to provide a minimum specified voltage
Refines	UR2:FR5
Verification	ATP6

UR3:FR6:DS7	**Battery Level Display**
Requirement	A visual battery level display, such as a digital display, should be implemented to indicate the remaining battery charge level.
Refines	UR3:FR6
Verification	ATP7

UR1:FR7:DS8	**Solar Charging Rate**
Requirement	The solar charging circuit should be designed to provide a charging current that enables the battery pack to recharge fully in less than 8 hours under optimal solar conditions.
Refines	UR1:FR7
Verification	ATP8

UR1:FR8:DS9	**Battery Capacity Specification**
Requirement	The battery pack should have a minimum capacity of 8.39 Ah to provide at least 8 hours of continuous runtime while powering all subsystems under typical load conditions.
Refines	UR1:FR8
Verification	ATP9

6.5 Acceptance Test Procedures

Code	Refines	Description
ATP1	UR1:FR1:DS1	Test reverse polarity protection by reversing polarity and verifying circuit protection.
ATP2	UR1:FR1:DS2	Overcharge/overdischarge battery pack and verify protection activation at specified voltages.
ATP3	UR1:FR2:DS3	Fully discharge battery pack, then recharge using different energy sources and verify specified charge rates.
ATP4	UR1:FR3:DS4	Verify voltage regulator outputs meet specified voltage
ATP5	UR1:FR4:DS5	Verify battery enclosure accommodates specified battery sizes, allows easy replacement, and provides protection and ventilation.
ATP6	UR1:FR5:DS6	Verify solar panels provide minimum specified voltage for charging under varying sunlight conditions and specified current rate.
ATP7	UR3:FR6:DS7	Verify battery level indicator accurately displays charge level at different states(fully charged, half-charged, low battery)
ATP8	UR1:FR7:DS8	Fully discharge battery pack, then monitor charging time under optimal solar conditions and verify full recharge in less than 8 hours.
ATP9	UR1:FR8:DS9	Fully discharge battery pack, then monitor runtime under typical load conditions and verify minimum 8-hour operation before depletion.

6.6 Design Choices

Before beginning with the design process, the table below gives a summary of the Power Requirements of other submodules.

Table 6.1: Power Consumption Summary

Subsystem	Component	Voltage [V]	Current [A]	Power [W]
Temperature Monitoring	ESP DevBoard	5	0.08	0.4
	Temp. & Humidity Sensor	3.3	0.01	0.033
	SD Card Module	5	0.01	0.05
	High Precision Clock Module	3.3	0.01	0.033
Cooling	Peltier Device	6	2	12
	Heatsink/Fan	12	0.25	3
Total Power Consumption	-	-	-	15.516

6.6.1 Solar Charge Controller

Table 6.2: Comparison of Solar Charge Controller Designs

Feature	MPPT Charge Controller	PWM Charge Controller	My Proposed Design
Charging Efficiency	High	Moderate	Moderate
Maximum Power Extraction	Yes (Advanced Algorithms)	No	No
Complexity	High	Moderate	Low
Cost	High	Moderate	Low
Overcharge Protection	Yes	Yes	Yes
Battery Type Compatibility	High	Moderate	Moderate
Additional Components	Yes (MPPT Circuitry)	Minimal	Minimal

Justification:

For this project's moderate power requirements and cost considerations, my proposed design offers a simple and affordable solution. While it lacks advanced features like MPPT, it provides basic charge control, overcharge protection, and compatibility with commonly used battery types. The use of readily available components (LM317, transistor, Zener diode) further contributes to the cost-effectiveness of this design. Although not the most efficient option, it strikes a balance between functionality and simplicity, making it a suitable choice for our application.

6.6.2 Voltage Regulator

Providing the required voltage as per table 6.1 to other subsystems is an important aspect of the Power Supply Subsystem, therefore a need for a DC-DC converter is required. The table below gives a comparison of the technical data of some of the options available for stepping down voltage.

Table 6.3: Comparison of buck converters

	First Principles Design	**MD0209 DC-DC step down**	**LM2575**
Input Voltages [V]	14.8	3-40	12-25
Output Voltage [V]	3.3-12	1.25-30	3.3-12
Max Ouput Current [A]	Dependant	3	1
Cost [Rands]	18.82	50.7	26.45
Additional Reqs	PWM	none	none
Ripple	Dependant	-	0.1

Option 1: First Principles Design
Designing a buck converter from first principles involves selecting and sizing individual components, such as inductors, capacitors, and switching elements, to meet the desired performance specifications. While this approach offers flexibility and potential cost savings, it requires extensive design calculations and careful component selection to achieve the required output voltages, current ratings, and ripple specifications. Additionally, generating the necessary pulse-width modulated (PWM) signal can add complexity to the design.

Option 2: MD0209 DC-DC Step-down Module
The MD0209 is a ready-made DC-DC step-down module that offers a wide input voltage range (3-40V) and adjustable output voltage (1.25-30V), making it suitable for our application. It can provide a maximum output current of 3A, which meets the current requirements outlined in Table 6.1. However, it comes at a higher cost compared to designing from first principles.

Option 3: LM2575 DC-DC Buck Converter IC
The LM2575 is an integrated circuit designed specifically for implementing buck converters. It has an input voltage range of 12-25V and can provide output voltages between 3.3V and 12V. While it meets the voltage requirements, its maximum output current is limited to 1A, which may not be sufficient for our application, particularly for the Peltier module requiring 2A.

After considering the pros and cons of each option, the decision was made to design the buck converter from first principles. While this approach involves additional complexity and design effort, it allows for greater flexibility in meeting the desired performance characteristics, such as output voltages, current ratings, and ripple specifications. Additionally, it provides a valuable learning experience as an aspiring engineer, enabling a deeper understanding of the design process and component selection.

6.6.3 Battery

The total power consumption of all the subsystems is given in table 6.1 as 15.516 W. The desired battery runtime is 8 hours. and we plan to use a 4-cell (4S) battery pack with a nominal voltage of 14.8 V

The calculation is as follows:

$$\begin{aligned}\text{Total energy required} &= \text{Total power consumption} \times \text{Desired run time}\\ &= 15.516\,\text{W} \times 8\,\text{hours}\\ &= 124.128\,\text{Wh}\end{aligned}$$

$$\begin{aligned}\text{Battery capacity (in Ah)} &= \frac{\text{Total energy required}}{\text{Battery voltage}}\\ &= \frac{124.128\,\text{Wh}}{14.8\,\text{V}}\\ &= 8.39\,\text{Ah}\end{aligned}$$

$$\text{Battery capacity needed factoring in the safety margin of } 20\% = 1.2 \times 8.39\,\text{Ah} = 10.068\,\text{Ah}$$

The table 6.4 below gives a comparison of some of the available battery options.

Table 6.4: Comparison of Relevant Battery Specifications

	18650 Li-ion	**NiMH D Battery**	**VRLA AGM Battery**
Chemistry	Li-ion	NiMH	VRLA
Rated Voltage (V)	3.7	1.2	6
Rated Capacity (mAh)	8800	10000	10000
Dimensions	18x650 (mm)	33x61.5 (mm)	151×50×94 (mm)
Price (R)	120 (Pack of 4)	478 each	248.40 each

Option 2: NiMH D Cell
Higher capacity but lower 1.2V voltage for each cell and higher cost make it unsuitable.

Option 3: VRLA AGM Battery
Matches capacity requirement but lower 6V voltage and higher cost than Li-ion.

Option 1: 18650 Li-ion Battery Pack
Rated 8.8Ah capacity is sufficient for lower cooling demands during nigh-time without solar supply, therefore a battery capacity of less than the actual needed capacity(10Ah considering additional factors) calculated before but not lower than battery capacity assuming 100% efficiency (8.39Ah) would still work. Comes as a pack of 4 3.7V cells, which allows us to connect in 4S configuration thus achieving 14.8V at a lower cost. Li-ion batteries can also handles high charge/discharge rates. Therefore choosing the 18650 Li-ion battery pack for this application is the best solution.

6.7 Final Power Subsystem Design

6.7.1 Functional Block Diagram

Illustration of the overall architecture and power flow

Figure 6.1: Power Subsystem Block Diagram

6.7.2 Solar Battery Charger and Protection Circuit Design

In the figure 6.2 below, The solar battery charger circuit utilizes an LM317 regulator to provide a constant 15.8V output from the solar panels. Two LEDs, one red and one green, indicate the charging status. The red LED turns on when solar power is available, while the green LED illuminates when the battery is charging. To prevent overcharging, a 15V Zener diode and a 1N4148 diode are used. When the battery is fully charged, the reverse voltage from the Zener diode turns on a BD139 transistor, effectively stopping the charging process. In the figure 6.3, the reverse polarity protection circuit

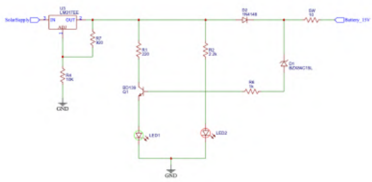


Figure 6.2: Battery Charger Circuit

employs a P-channel MOSFET. When the battery is connected correctly, the MOSFET remains on, allowing current flow to the load. However, if the polarity is reversed, the MOSFET turns off, preventing current flow and protecting the circuit from damage. The simulations in figures 6.3a and 6.3b showcase both scenarios.

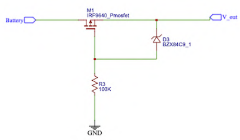
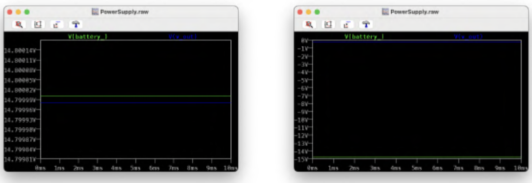


Figure 6.3: Reverse Polarity Protection Circuit



(a) Normal Polarity (b) Reversed Polarity

Figure 6.4: Reverse Polarity Protection Circuit Simulation

Battery Level Indicator

On the figure 6.5 below, the battery level indicator circuit uses Zener diodes to display the battery charge level at 25%, 50%, 75%, and 100%.

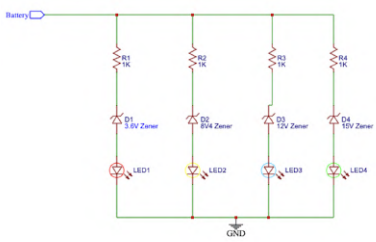


Figure 6.5: Battery Level Indicator

6.7.3 Buck Converter Design(Voltage regulation)

Buck Converter Design

Input Voltage (V_{in}) = 14.8V
Output Voltage (V_o) = 3.3V
Ripple (Δv) = 0.005V For continuous inductor current

Duty Cycle:

$$D = \frac{V_o}{V_{\text{in}}} = \frac{3.3}{14.8} = 0.223$$

Switching Frequency (f_{sw}):
To avoid audible noise but minimize switching losses, choose $f_{\text{sw}} = 40\text{kHz}$

Inductor Value:

$$\begin{aligned} L_{\min} &= \frac{(1-D)R}{2f} = \frac{(1-0.223)(10)}{2(40000)} \\ &= \frac{0.777 \times 10}{80000} = \frac{7.77}{80000} \approx 97.128\mu H \end{aligned}$$

Design Factor (df) = 1.25
Choose $L = 1.25 \times L_{\min} = 1.25 \times 97.128\mu H \approx 121\mu H$
Output Capacitor:

$$
\begin{aligned}
C &= \frac{(1-D)}{8L(\frac{\Delta V_o}{V_o})f^2} \\
&= \frac{(1-0.223)}{8\times 121\mu(\frac{0.005V_o}{V_o})\times(40000)^2} \\
&\approx 100\mu F
\end{aligned}
$$

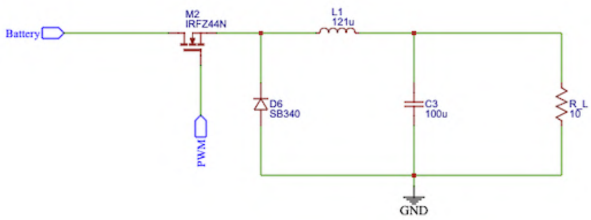


Figure 6.6: Final Buck Converter Circuit Diagram

Pulse Width Modulated Signal Generation

Using a 555 timer in astable mode for PWM generation.

$$t_{\text{on}} = D \times T = 0.223 \times (1/40000) = 5.575\mu\text{s}$$

For the 555 timer:

$$
\begin{aligned}
t_{\text{on}} &= 0.693 \times (R_1 + R_2) \times C \\
t_{\text{off}} &= 0.693 \times R_3 \times C
\end{aligned}
$$

Choose $R_1 = 500\Omega$ and $C = 10\text{nF}$

Then, $R_2 = \left(\frac{t_{\text{on}}}{0.693\times C}\right) - R_1 = \left(\frac{5.575\mu s}{0.693\times 100\text{nF}}\right) - 500 = 304\Omega$

$R_3 = \left(\frac{t_{\text{on}}}{0.693\times C}\right) = 2800\Omega$

The PWM signal generated by the 555 timer will have a duty cycle of 0.223 and a frequency of 40kHz, which will be used to drive the switching element (MOSFET) in the buck converter circuit. To achieve

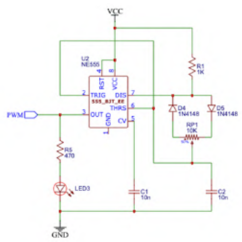


Figure 6.7: PWM Circuit Diagram with adjustable duty cycle

the desired output voltages of 3.3V, 5V, 6V, and 12V from the buck converter, the duty cycle of the pulse-width modulated (PWM) signal was adjusted accordingly and the output of the used buck converters is shown below in figure 6.8.

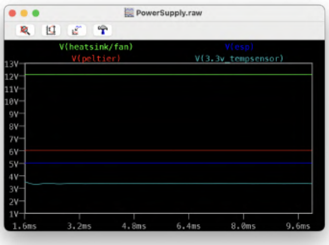


Figure 6.8: Buck Converters Simulation Outputs

6.7.4 Final Design Implementation

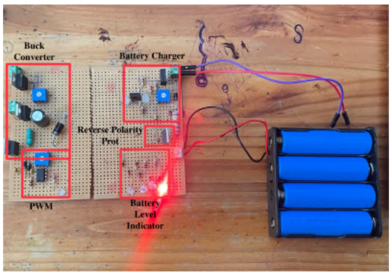


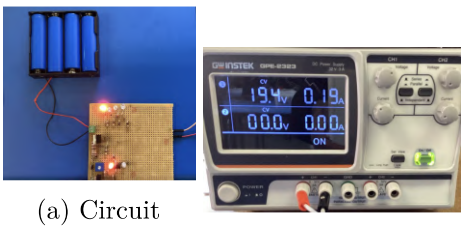
Figure 6.9: Hardware Implementation of The Power Subsystem

6.8 Testing and Validation

6.8.1 Test Protocols

Battery charger and Battery Level indicator testing:

Battery was drained to 8V, as shown by one LED ON(indicating battery level less than 9V) in figure 6.10a, and the battery charger circuit was connected to the power supply, as shown by the bottom LED in 6.10a, and its performance was observed. In the figure 6.10b, battery charging current observed is 0.2A.



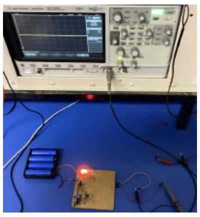
(a) Circuit connected to supply

(b) Multimeter Reading

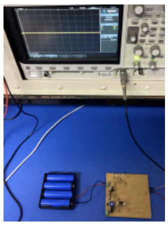
Figure 6.10: Battery Charging Set up

Protection circuit testing:

Figures 6.11 illustrate the testing of the reverse polarity protection circuit. Figure 6.11a shows the output when the battery polarity is connected correctly, demonstrating proper operation. Figure 6.11b shows the output when the battery polarity is reversed, verifying that the protection circuit effectively prevents current flow, protecting the circuit from damage caused by reverse polarity.



(a) Normal Polarity Output



(b) Reversed Polarity Output

Figure 6.11: Reverse Polarity Testing

Buck converter testing:

Figures 6.12 and 6.13 demonstrate the testing of the buck converter circuit. Figure 6.12 shows the initial testing setup on a veroboard. Figures 6.13a, 6.13b and 6.13c display the output voltage measurements of 3.3V, 5V, and 6V, respectively, confirming that the buck converter meets the specified voltage requirements for various subsystems. Figure 6.13d shows the simultaneous output of 12V and 5V, with the complete setup.

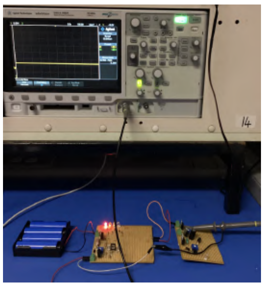
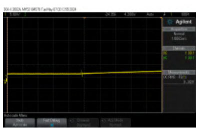
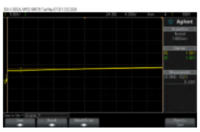


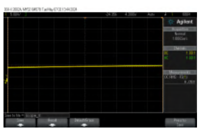
Figure 6.12: Testing of the Power Subsystem on a veroboard



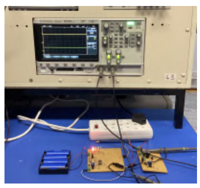
(a) 3.3V



(b) 5V



(c) 6V



(d) 12V and 5V output

Figure 6.13: Power Supply Voltage Output Measurements

6.8.2 Consolidation of ATPs

Table 6.5 consolidates the results of the acceptance test procedures (ATPs). It indicates whether each ATP passed or failed, with brief explanations provided for any failed ATPs.

Table 6.5: Acceptance Test Procedures Consolidation

Code	Description	Pass/Fail
ATP1	Test reverse polarity protection by reversing polarity and verifying circuit protection.	Pass
ATP2	Overcharge/overdischarge battery pack and verify protection activation at specified voltages.	Pass & Fail
ATP3	Fully discharge battery pack, then recharge using different energy sources and verify specified charge rates.	Pass
ATP4	Verify voltage regulator outputs meet specified voltage and current tolerances.	Pass
ATP5	Verify battery enclosure accommodates specified battery sizes, allows easy replacement, and provides protection.	Pass
ATP6	Verify solar panels provide minimum specified voltage for charging under varying sunlight conditions and specified current rate.	N/A
ATP7	Verify battery level indicator accurately displays charge level at different states.	Pass
ATP8	Fully discharge battery pack, then monitor charging time under optimal solar conditions and verify full recharge in less than 8 hours.	Fail
ATP9	Fully discharge battery pack, then monitor runtime under typical load conditions and verify minimum 8-hour operation before depletion.	Fail

ATPs not met explaination:

ATP2: The overcharge protection worked as intended, but the overdischarge protection failed as the battery voltage dropped below the specified 8V.
ATP6: Not Applicable because solar panels were not available for testing due to budget constraints.
ATP8: failed because the observed charging current was not sufficient to ensure a full recharge within 8 hours.
ATP9: The power consumption of the Peltier modules was underestimated, leading to the failure to meet the 8-hour runtime requirement before depletion.

6.9 Suggestions for Improvements

To address ATP2 (overcharge/overdischarge protection), improve the current battery charger circuit by including a separate overdischarge protection circuit. To meet ATP6, it is recommended to acquire solar panels within the allocated budget and conduct thorough testing under varying sunlight conditions to verify the charging capabilities and ensure compliance with the specified requirements. To address the issue with ATP8, the rectifier diode in the charging circuit should be re-evaluated and potentially replaced with a diode that can handle higher current ratings. Alternatively, the charging circuit design could be modified to accommodate higher charging currents, thereby reducing the recharge time and meeting the specified requirement. For ATP9 (extended battery runtime), revisit the power consumption estimates for the Peltier modules and other subsystems, ensuring accurate calculations based on real-world measurements or manufacturer specifications. Consider using more energy-efficient components or implementing power-saving strategies to reduce overall power consumption. If necessary, explore the possibility of using a larger battery pack or incorporating additional battery packs in parallel to increase the overall capacity and runtime.

Chapter 7

Conclusions

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

The multidisciplinary project aimed at designing an artificial nest solution for the Yellow-Billed Hornbills in the Kalahari region has successfully addressed various aspects, including nest design and cooling, power supply, and electronic monitoring systems. However, several future plans and improvements have been identified to further enhance the overall effectiveness and reliability of the proposed solution.

For the nest design and cooling section, the immediate focus will be on constructing the actual enclosure based on the proposed design to verify its practicality and feasibility. Subsequently, passive cooling techniques, such as simulating cactus thorns and applying non-toxic, thermally resistant paint with UV protection, will be implemented. Once these passive cooling methods are integrated, comprehensive testing will be conducted through simulations or physical prototypes in the Kalahari region itself. If the prototypes demonstrate promising results, discussions with the client, Ben, will take place to explore the possibility of producing the nest design and deploying it for use with the actual Yellow-Billed Horn-bills.

Regarding the power section, the development of an overdischarge protection circuit is a priority to address the issue identified during testing. Additionally, solar panels will be acquired and thoroughly tested to verify their charging capabilities and ensure compliance with the specified requirements. The power consumption estimates for the Peltier modules and other subsystems will be revisited, and options for extending battery runtime, such as using larger batteries or more energy-efficient components, will be explored. Furthermore, transitioning to a printed circuit board (PCB) design is highly recommended for improved reliability and better integration of the power subsystem components. Regular progress reviews and collaboration will be conducted to ensure the continuous improvement and robustness of the power supply for the artificial hornbill nests project.

For the electronics section, future plans include implementing a power-saving mode to address the failure of ATP3 (long battery life). Acquiring the necessary equipment or setting up a controlled environment is crucial to thoroughly test the accuracy of the temperature and humidity sensor against the current solution, addressing the failure of ATP8 (data quality). Developing a mobile application or improving the user interface will provide a more user-friendly experience for accessing and analysing the collected data. Furthermore, implementing a remote control or wake-up mechanism will enable the server to be turned on or off remotely, addressing the lack of power-saving capabilities. A timeline will be established for the implementation of these additional features and improvements, taking into consideration the available resources and prioritising the most critical aspects.

By addressing these future plans and continuously improving the system, the nest design, power supply, and electronics subsystems can be optimized to meet the project's objectives and provide a reliable and efficient solution for monitoring the Yellow-Billed Horn-bills in the Kalahari region.

Mock Timeline:

Year 1: - Construct the actual enclosure design (3 months) - Implement passive cooling techniques (simulated cactus thorns, thermally resistant paint) (2 months) - Develop overdischarge protection circuit for power subsystem (1 month) - Acquire and test solar panels for charging capabilities (2 months)

Year 2: - Conduct comprehensive testing of nest solution through simulations or physical prototypes in the Kalahari region (6 months) - Revisit power consumption estimates and explore options for extended battery runtime (2 months) - Transition to printed circuit board (PCB) design for power subsystem (3 months) - Implement power-saving mode or sleep mode functionality for electronics subsystem (2 months) - Acquire necessary equipment or set up controlled environment for sensor accuracy testing (2 months)

Year 3: - Discuss potential production and deployment of nest design with client (Ben) based on testing results (2 months) - Integrate additional sensors (light, motion) to expand monitoring capabilities (3 months) - Develop mobile application or improve user interface for data access and analysis (4 months) - Implement remote control or wake-up mechanism for server power management (2 months) - Continuous progress reviews and collaboration for overall system optimization (ongoing)

This timeline is a tentative outline and may be subject to adjustments based on resource availability, project priorities, and any unforeseen challenges that may arise during the implementation phase.

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.1 Appendix A: Miscellaneous Design Documents

.1.1 Bill of Materials

Manufacturer	Component	Price incl. VAT	Quantity	Total Price
Communica	HKD I2C REAL TIME CLOCK- DS3231	60.00 ZAR	1	60.00 ZAR
Communica	HKD ESP-32 WIFI B/T DEV BOARD	159.00 ZAR	1	159.00 ZAR
Communica	micro SD breakout module	23.00 ZAR	1	23.00 ZAR
Communica	HKD TEMP+HUM SNSR DHT22 ON PCB	120.00 ZAR	1	120.00 ZAR
Communica	HKV HS-TFC1-64GB+ADPT	82.50 ZAR	1	82.50 ZAR

Table 1: Electronics Bill of Materials

Supplier	**Component**	**Price (Rands)**
	Buck Converter	
Mantech	MF50-100K-F T/B *DBK*	R0,25
Communica	BZX83C9V1	R0,58
Mantech	IRFZ44NPBF	R10,62
Communica	NE555	R2,52
Mantech	EC0410-121K	R2,04
	Reverse Polarity	
Mantech	MF50-100K-F T/B *DBK*	R0,25
Communica	BZX83C9V1	R0,58
Mantech	IRF9540NPBF	R20,61
	Battery Level Indicator	
Communica	BZX83C2V4	R0,58
Communica	BZX83C4V7	R0,58
Communica	BZX83C9V1	R0,58
Communica	BZX83C11V	R0,58
Communica	MFR25F-100R	R0,40
Communica	MFR25F-150R	R0,40
Communica	MFR25F-180R	R0,40
Communica	MFR25F-220R	R0,40
	Solar Charger	
Communica	LM317T	R9,95
Communica	1N4007F	R0,44
Communica	BZX85C12V	R1,32
Communica	BZX83C12V	R0,58
Communica	LED5140GR	R1,09
Communica	HKD 100X5MM ASSTD LEDS-5 COLORS	R50,00
Communica	CFR25J-220R	R0,16
Communica	CF 1/4W 5% 2K	R0,07
Communica	KNP5WS 10R 5%	R2,59
Communica	HKD S/S PROTOBOARD 8X12CM	R17,00
Communica	CT6P10K	R10,81
	Total (Rands)	119,37

Table 2: Bill of Materials of the Power Subsystems

Name	**Individual Price (R)**	**Quantity**	**Total Price (R)**
TEC1-12706 Peltier	85	2	170
FROZN A410 Heat-sink	479	1	479
Aluminium Scrap (Estimate)	10	1	10
Wood (Estimate)	70	1	70

Table 3: Nest Design and Cooling BOM

.1.2 N-Channel MOSFET used

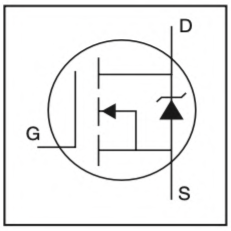
International
IOR Rectifier

PD - 94787

IRFZ44NPbF

HEXFET® Power MOSFET

- Advanced Process Technology
- Ultra Low On-Resistance
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated
- Lead-Free



V_{DSS} = 55V

$R_{DS(on)}$ = 17.5mΩ

I_D = 49A

Description

Advanced HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.

TO-220AB

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	49	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	35	
I_{DM}	Pulsed Drain Current ①	160	
P_D @T_C = 25°C	Power Dissipation	94	W
	Linear Derating Factor	0.63	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
I_{AR}	Avalanche Current①	25	A
E_{AR}	Repetitive Avalanche Energy①	9.4	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	——	1.5	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	——	
$R_{\theta JA}$	Junction-to-Ambient	——	62	

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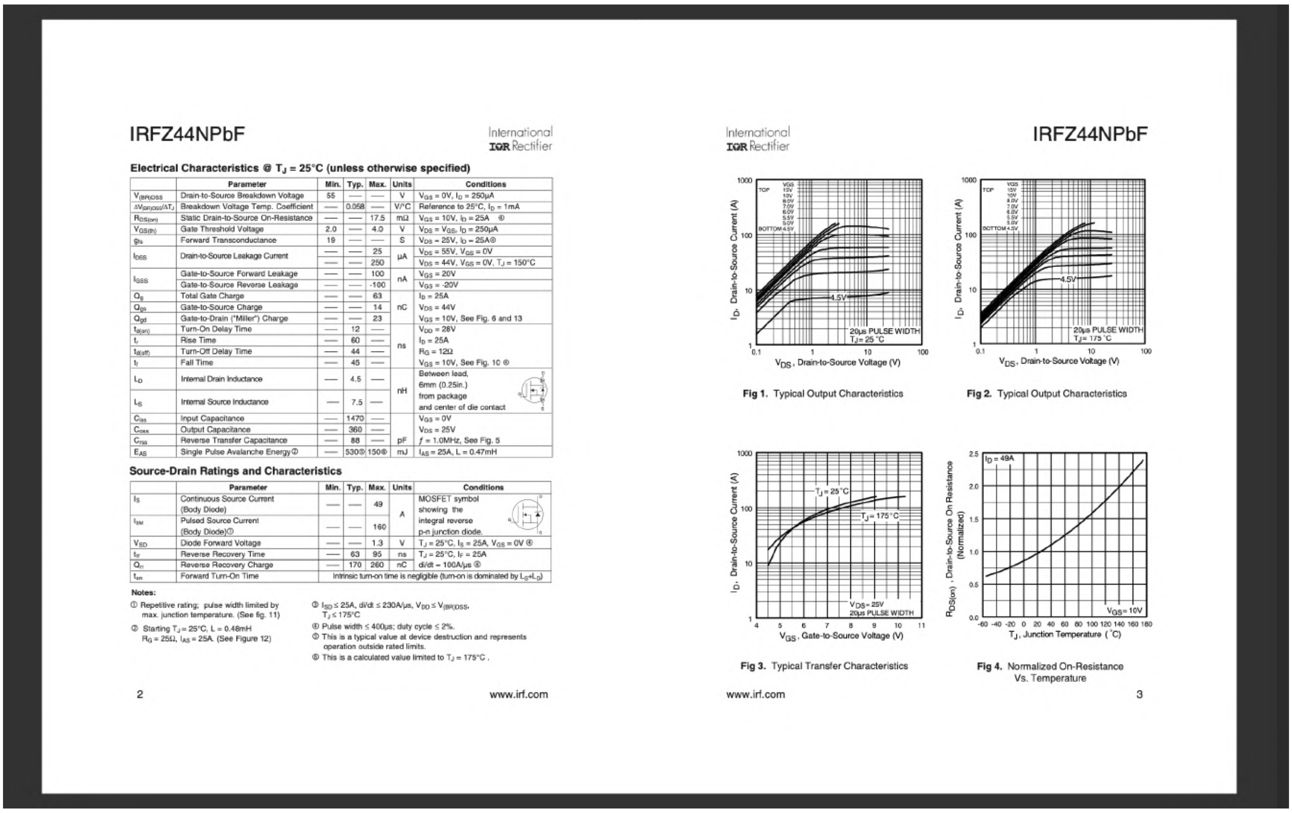
10/31/03

Figure 1: IRFZ44N



IRFZ44NPbF

International IOR Rectifier

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	55	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.058	—	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	17.5	mΩ	V_{GS} = 10V, I_D = 25A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250μA
g_{fs}	Forward Transconductance	19	—	—	S	V_{DS} = 25V, I_D = 25A④
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	μA	V_{DS} = 55V, V_{GS} = 0V
		—	—	250		V_{DS} = 44V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	63	nC	I_D = 25A
Q_{gs}	Gate-to-Source Charge	—	—	14		V_{DS} = 44V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	23		V_{GS} = 10V, See Fig. 6 and 13
$t_{d(on)}$	Turn-On Delay Time	—	12	—	ns	V_{DD} = 28V
t_r	Rise Time	—	60	—		I_D = 25A
$t_{d(off)}$	Turn-Off Delay Time	—	44	—		R_G = 12Ω
t_f	Fall Time	—	45	—		V_{GS} = 10V, See Fig. 10 ④
L_D	Internal Drain Inductance	—	4.5	—	nH	Between lead, 6mm (0.25in.)
L_S	Internal Source Inductance	—	7.5	—		from package and center of die contact
C_{iss}	Input Capacitance	—	1470	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	360	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	88	—		f = 1.0MHz, See Fig. 5
E_{AS}	Single Pulse Avalanche Energy②	—	530⑤	150⑥	mJ	I_{AS} = 25A, L = 0.47mH

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	49	A	MOSFET symbol showing the
I_{SM}	Pulsed Source Current (Body Diode)①	—	—	160		integral reverse p-n junction diode.
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S = 25A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	63	95	ns	T_J = 25°C, I_F = 25A
Q_{rr}	Reverse Recovery Charge	—	170	260	nC	di/dt = 100A/μs ④
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② Starting T_J = 25°C, L = 0.48mH R_G = 25Ω, I_{AS} = 25A. (See Figure 12)

③ $I_{SD} \le$ 25A, di/dt $\le$ 230A/μs, $V_{DD} \le V_{(BR)DSS}$, $T_J \le$ 175°C

④ Pulse width $\le$ 400μs; duty cycle $\le$ 2%.

⑤ This is a typical value at device destruction and represents operation outside rated limits.

⑥ This is a calculated value limited to T_J = 175°C .

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International IOR Rectifier

IRFZ44NPbF

Fig 1. Typical Output Characteristics

Fig 2. Typical Output Characteristics

Fig 3. Typical Transfer Characteristics

Fig 4. Normalized On-Resistance Vs. Temperature

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Figure 2: IRFZ44N1

.1.3 Voltage Regulator Used

TEXAS INSTRUMENTS

LM317

www.ti.com SLVS044Y – SEPTEMBER 1997 – REVISED APRIL 2020

7 Specifications

7.1 Absolute Maximum Ratings

over virtual junction temperature range (unless otherwise noted)[1]

		MIN	MAX	UNIT
$V_I - V_O$	Input-to-output differential voltage		40	V
T_J	Operating virtual junction temperature		150	°C
	Lead temperature 1.6 mm (1/16 in) from case for 10 s		260	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

7.2 ESD Ratings

			MAX	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	2500	V
		Charged device model (CDM), per JEDEC specification JESD22-C101[2]	1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

		MIN	MAX	UNIT
V_O	Output voltage	1.25	37	V
$V_I - V_O$	Input-to-output differential voltage	3	40	V
I_O	Output current	0.01	1.5	A
T_J	Operating virtual junction temperature	0	125	°C

7.4 Thermal Information

THERMAL METRIC[1]		LM317				UNIT
		DCY (SOT-223)	KCS (TO-220)	KCT (TO-220)	KTT (TO-263)	
		4 PINS	3 PINS	3 PINS	3 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	66.8	23.5	37.9	38.0	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	43.2	15.9	51.1	36.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	16.9	7.9	23.2	18.9	°C/W
ψ_{JT}	Junction-to-top characterization parameter	3.6	3.0	13.0	6.9	°C/W
ψ_{JB}	Junction-to-board characterization parameter	16.8	7.8	22.8	17.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	NA	0.1	4.2	1.1	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC package thermal metrics* application report.

Figure 3: Voltage Regulator Used 1

TEXAS INSTRUMENTS

LM317

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7.5 Electrical Characteristics

over recommended ranges of operating virtual junction temperature (unless otherwise noted)

PARAMETER	TEST CONDITIONS(1)			MIN	TYP	MAX	UNIT
Line regulation(2)	$V_I - V_O$ = 3 V to 40 V		T_J = 25°C		0.01	0.04	%/V
			T_J = 0°C to 125°C		0.02	0.07	
Load regulation	I_O = 10 mA to 1500 mA	C_{ADJ}(3) = 10 μF, T_J = 25°C	$V_O \le 5$ V			25	mV
			$V_O \ge 5$ V		0.1	0.5	%V_O
		T_J = 0°C to 125°C	$V_O \le 5$ V		20	70	mV
			$V_O \ge 5$ V		0.3	1.5	%V_O
Thermal regulation	20-ms pulse,	T_J = 25°C			0.03	0.07	%V_O/W
ADJUST terminal current					50	100	μA
Change in ADJUST terminal current	$V_I - V_O$ = 2.5 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA				0.2	5	μA
Reference voltage	$V_I - V_O$ = 3 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA			1.2	1.25	1.3	V
Output-voltage temperature stability	T_J = 0°C to 125°C				0.7		%V_O
Minimum load current to maintain regulation	$V_I - V_O$ = 40 V				3.5	10	mA
Maximum output current	$V_I - V_O \le 15$ V,	$P_D < P_{MAX}$(4)		1.5	2.2		A
	$V_I - V_O \le 40$ V,	$P_D < P_{MAX}$(4),	T_J = 25°C	0.15	0.4		
RMS output noise voltage (% of V_O)	f = 10 Hz to 10 kHz,	T_J = 25°C			0.003		%V_O
Ripple rejection	V_O = 10 V,	f = 120 Hz	C_{ADJ} = 0 μF(3)		57		dB
			C_{ADJ} = 10 μF(3)	62	64		
Long-term stability	T_J = 25°C				0.3	1	%/1k hr

(1) Unless otherwise noted, the following test conditions apply: $|V_I - V_O|$ = 5 V and I_{OMAX} = 1.5 A, T_J = 0°C to 125°C. Pulse testing techniques are used to maintain the junction temperature as close to the ambient temperature as possible.
(2) Line regulation is expressed here as the percentage change in output voltage per 1-V change at the input.
(3) C_{ADJ} is connected between the ADJUST terminal and GND.
(4) Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A) / \theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

Figure 4: Voltage Regulator Used 2

.2 Appendix B: Sustainability and Impact of Engineering Activity Essays

.2.1 Analysis: Sivuyile Nose (NSXSIV001)

In the design phase of the artificial nest project aimed at supporting the breeding of Southern yellow-billed hornbills, I exhibited a critical awareness of the sustainability and impact of my engineering activities on the social, industrial, and physical environment.

Tackling the Circular Economy in the African Context

I recognized the importance of aligning my solution with sustainable development goals and promoting circular economy principles within the African context. Through extensive discussions, I explored strategies to design a self-sustaining and environmentally friendly power subsystem that minimizes waste and maximizes resource efficiency.

In selecting the Lithium-Ion (Li-Ion) battery for the power supply subsystem, I considered its environmental impact and disposal implications. While Li-Ion batteries are generally considered more environmentally friendly than some alternatives, proper disposal and recycling are still crucial to mitigate environmental harm. Fortunately, organizations like Virgin Earth in South Africa specialize in recycling electronic waste, contributing to sustainability efforts.

Design Thinking Methodologies and Sustainable Solutions

Employing design thinking methodologies, I meticulously brainstormed and evaluated various power subsystem configurations, prioritizing efficiency, reliability, and environmental sustainability. Worksheets, simulations, and analyses were conducted to compare different battery chemistries, solar charge controllers, and voltage regulation techniques. The final design incorporates a solar-powered battery charging system with overcharge protection, ensuring efficient energy utilization and extended battery life. The use of readily available and recyclable components further promotes a circular economy approach, minimizing waste generation.

Impact Assessment and Mitigation Strategies

While the operational phase of the power subsystem minimizes environmental impact, I acknowledged the potential negative effects during the manufacturing and disposal phases of the electronic components. To mitigate these concerns, I proposed investigating recycling and proper disposal methods for the materials used in the project, demonstrating a commitment to responsible resource management throughout the product lifecycle.

Sustainability and Impact on User

User requirements dictated that the power supply subsystem be reliable and easy to maintain. Multiple forms of protection circuitry were incorporated to ensure system robustness. Additionally, Li-Ion batteries were chosen for their reliability, long cycle life, and safety compared to other battery types like Nickel Metal Hydride (NiMH) or Lithium Polymer (LiPo).

While the inclusion of rechargeable batteries may increase initial costs, the long-term benefits justify the investment. Proper user adherence to charging and storage procedures ensures optimal battery performance, contributing to the overall sustainability of the project.

Through my collective efforts, I demonstrated a comprehensive understanding of the sustainability and impact of my engineering activities, seamlessly integrating principles of circular economy, community engagement, and environmental stewardship into the design and development process of the power subsystem.

.2.2 Nest design and cooling (Caide Lander - LNDCAI001)

The cooling and nest design solution presented in this report aligns with the principles of sustainability and recognizes the impact of engineering activities on the social, industrial, and physical environment. The design process was guided by a critical awareness of these factors, and conscious efforts were made to address them effectively.
Social Impact: The solution prioritizes the well-being of the Yellow-Billed Horn-bills, a species native to the Kalahari region. By maintaining suitable thermal conditions within the nest boxes, the design aims to provide a comfortable and safe environment for the birds and their offspring. This consideration extends beyond mere technical specifications and reflects a commitment to preserving the natural ecosystem and biodiversity of the region.
Industrial Impact: The design emphasizes cost-effectiveness and the use of readily available, locally sourced materials. This approach not only reduces the overall environmental footprint but also promotes the local economy and supports sustainable industrial practices. The selection of wood, a renewable and biodegradable material, further contributes to the circular economy model and minimizes waste generation. Physical Environment: The design incorporates passive cooling strategies inspired by biomimicry and the principles of thermal management observed in nature. The exploration of techniques such as simulated cactus thorns and thermally resistant paints demonstrates a deep appreciation for the physical environment and the potential for engineering solutions to coexist harmoniously with natural systems. Throughout the design process, community engagement played a crucial role. Discussions with local experts, such as the power lab, ensured that the proposed solution was tailored to the specific needs and constraints of the Kalahari region. This Afro-centric focus enabled a deeper understanding of the cultural and environmental context, leading to informed decision-making and a solution that resonates with the local communities.
The design thinking methodologies employed, including rigorous testing, evaluation, and iterative refinement, exemplify the critical consideration given to sustainable practices. The extensive documentation and evidence presented in the report, including photographs and videos, provide a comprehensive account of the design journey and the measures taken to address sustainability and environmental impact.
In conclusion, the cooling and nest design solution showcases a holistic approach to engineering,

where technical excellence is harmonized with social responsibility, environmental care, and a deep appreciation for the local context. By aligning with the principles of sustainability and recognizing the impact of engineering activities, this project demonstrates a commitment to creating positive change and contributing to the achievement of the Sustainable Development Goals.

.2.3 Electronics (Longa Maimbo - MMBLON001)

Tackling the Circular Economy in the African Context

The circular economy in Africa is focused on the principles of regenerating nature, circulating products and eliminating waste. Trying to adhere to these principles and taking notes from discussions with my team members some major focuses of my when design was ensuring longevity and repairability and upgradeability and resource efficiency and local supply.

The system uses strictly tried and tested components that are capable of surviving the environment that they are to be deployed (They can operate normally in the harsh conditions of the Kalahari). Due to the modular nature of the temperature monitoring sub-system and the use of only open-source software in the creation of the system repairing and upgrading the system can be easily done therefore extending the products life cycle. The system is also low power and a proposed addition to the system was an efficiency mode to further lower power consumption thus reserving resources. Finally all components for this sub-module were sourced locally thus aiding the local economy(It should be noted they were not locally manufactured however).

Design Thinking Methodologies

Having engaged with the stakeholder (Ben) and reading through his responses in the stakeholders chat a set of requirements for this system were recognised and based on these requirements a set of well thought out specifications for the that met all the recognised requirements. Having defined the specifications of this system the process of ideation then begins, in which several components and software implementations were scrutinised to come determine the best hardware and software choices given the environment and budget constraints. When all components arrived the prototyping stage began in which while the hardware was fully compatible, the software that had been developed prior to the component arrival was not, thus the system had to go through several software iterations before the deployable system was ready. This system was then tested using the accepted test procedures to ensure quality work had be done.

Impact Assessment

Monitoring the temperature and humidity conditions within the nests can provide valuable data for understanding the impact of environmental changes on the Southern yellow-billed hornbill population. The data collected can aid conservation efforts and habitat management strategies for this species, contributing to its preservation. The wireless data transmission and access capabilities of the system minimises the need for physical disturbance of the nests, thereby reducing the potential impact on the birds and their environment. The use of electronic components and the eventual disposal of the system may have some environmental impact, but the overall benefits of the data collected for conservation purposes could potentially outweigh these impacts.

.3 Appendix C: Electronics Documentation and Git Repo

https://github.com/NANO-ARTRICAN/EEE4113F-GROUP-14-2024

.3.1 ESP32 Temperature monitoring and webserver code

```
#include "DHT.h"
#define DHT11PIN 16
#define DHTTYPE DHT22
#include <Wire.h>
#include "RTClib.h"
#include <Arduino.h>
#include <SPIFFS.h>
#include <ESPAsyncWebServer.h>
#include <WebSocketsServer.h>                    // needed for instant communication between client and server through Websock
#include <ArduinoJson.h>                         // needed for JSON encapsulation (send multiple variables with one string)
#include <WiFi.h>                                // needed to connect to WiFi
RTC_DS3231 rtc;


// Define CS pin for the SD card module
#define SD_CS 5

RTC_DATA_ATTR int readingID = 0;
DHT dht(DHT11PIN, DHTTYPE);

String dataMessage;
int setter = 0;
// Libraries for SD card
#include "FS.h"
#include "SD.h"
#include <SPI.h>


// Replace with your network credentials
const char* ssid     = "LONGA'S ESP32-Access-Points";
const char* password = "tigeruppercut6";

// global variables of the LED selected and the intensity of that LED
int random_intensity = 5;

const int ARRAY_LENGTH = 10;
int sens_vals[ARRAY_LENGTH];
int humi_vals[ARRAY_LENGTH];
// We want to periodically send values to the clients, so we need to define an "interval" and remember the last time we sent data t
int interval = 1000;                             // send data to the client every 1000ms -> 1s
unsigned long previousMillis = 0;                // we use the "millis()" command for time reference and this will output an u

// Initialization of webserver and websocket
AsyncWebServer server(80);                       // the server uses port 80 (standard port for websites
WebSocketsServer webSocket = WebSocketsServer(81);    // the websocket uses port 81 (standard port for websockets
// Set web server port number to 80

// Variable to store the HTTP request
String header;

// Auxiliar variables to store the current output state
String output26State = "off";
String output27State = "off";

// Assign output variables to GPIO pins
const int output26 = 26;
const int output27 = 27;
String currentfile = "/data.txt";

void setup()
{
  Serial.begin(115200);
  Wire.begin();
/* Start the DHT11 Sensor */
  dht.begin();

  WiFi.softAP(ssid, password);

  IPAddress IP = WiFi.softAPIP();
  Serial.print("AP IP address: ");
  Serial.println(IP);


 // Initialize SPIFFS
  if(!SPIFFS.begin(true)){
    Serial.println("An Error has occurred while mounting SPIFFS");
    return;
  }

  server.serveStatic("/", SPIFFS, "/");

  webSocket.begin();                             // start websocket
  webSocket.onEvent(webSocketEvent);             // define a callback function -> what does the ESP32 need to do when an event
```

Figure 5: ESP32 Temperature monitoring and webserver code

```
 // Initialize SD card
SD.begin(SD_CS);
if(!SD.begin(SD_CS)) {
  Serial.println("Card Mount Failed");
  return;
}
uint8_t cardType = SD.cardType();
if(cardType == CARD_NONE) {
  Serial.println("No SD card attached");
  return;
}
Serial.println("Initializing SD card...");
if (!SD.begin(SD_CS)) {
  Serial.println("ERROR - SD card initialization failed!");
  return;    // init failed
}

// If the data.txt file doesn't exist
// Create a file on the SD card and write the data labels
File file = SD.open("/data.txt");
if(!file) {
  Serial.println("File doens't exist");
  Serial.println("Creating file...");
  writeFile(SD, "data.txt", "Reading ID, Date, Hour, Temperature \r\n");
}
else {
  Serial.println("File already exists");
}
file.close();

  // Route for root / webpage
server.on("/", HTTP_GET, [](AsyncWebServerRequest *request){
  request->send(SPIFFS, "/index.html", String(), false);
});
  // Route to list files on SD card
server.on("/list", HTTP_GET, [](AsyncWebServerRequest *request){
  String output = "<h1>Files on SD Card:</h1><ul>";
  File root = SD.open("/");
  while(File file = root.openNextFile()){
    output += "<li>" + String(file.name()) + " - " + String(file.size()) + " bytes</li>";
    file.close();
  }
  output += "</ul>";
  request->send(200, "text/html", output);
});

// Route to download a file from SD card
server.on("/download", HTTP_GET, [](AsyncWebServerRequest *request){
  if(request->hasParam("file")){
    String filename = request->getParam("file")->value();
    File file = SD.open("/"+filename);
    if(file){
      request->send(SD, "/"+filename, String(), false);
      file.close();
      return;
    }
  }
  request->send(404, "text/plain", "File Not Found");
});
if (!rtc.begin()) {
  Serial.println("Couldn't find RTC");
  while (1);
}
rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));

server.begin();
}

void loop(){
 webSocket.loop();
 DateTime now = rtc.now();
 //Creates new file everyday
 if (now.hour() == 00 and now.day() != currentday){
   currentday = now.day()
   currentfile = "/"+String(now.year())+"-"+String(now.month())+"-"+String(now.minute())+".csv";
   File file = SD.open(currentfile);
   if(!file) {
   Serial.println("File doens't exist");
   Serial.println("Creating file...");
   appendFile(SD, currentfile.c_str(), "Time, Temperature, Humidity \r\n");
   writeFile(SD, "data.txt", "Reading ID, Date, Hour, Temperature \r\n");
 }
   }
 logSDCard();
 }
```

Figure 6: ESP32 Temperature monitoring and webserver code

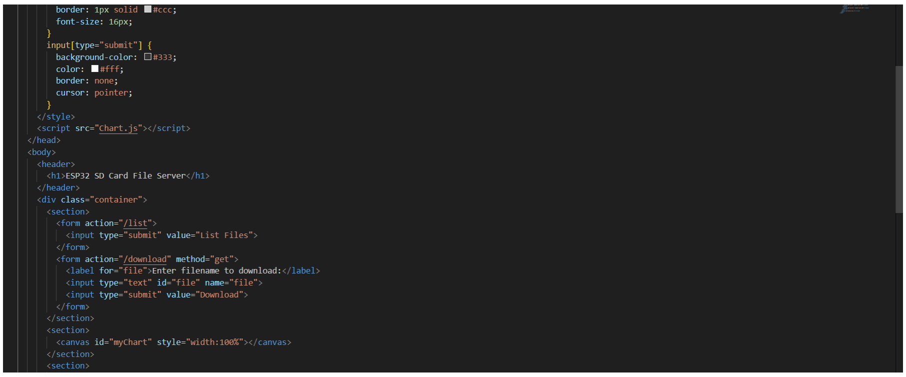
```
// Write the sensor readings on the SD card and update data on live graphs
void logSDCard() {
  float humi = dht.readHumidity();
  float temp = dht.readTemperature();
  Serial.print("Temperature: ");
  Serial.print(temp);
  Serial.print("°C ");
  Serial.print("Humidity: ");
  Serial.println(humi);
  delay(1000);
  DateTime now = rtc.now();
  String times = String(now.hour())+":"+String(now.minute())+":"+String(now.second());
  String dataMessage = String(times) +","+ String(temp) +","+ String(humi) + "\r\n";
  Serial.print("Save data: ");
  Serial.println(dataMessage);
  for(int i=0; i< ARRAY_LENGTH - 1; i++){
    sens_vals[i] =sens_vals[i+1];
    humi_vals[i] =humi_vals[i+1];
    }
  sens_vals[ARRAY_LENGTH - 1] = round(10*temp);
  humi_vals[ARRAY_LENGTH - 1] = round(humi);
  sendJsonArray("graph_update", sens_vals);
  sendJsonArray("humi_update", humi_vals);
  appendFile(SD, currentfile.c_str(), dataMessage.c_str());
}

// Write to the SD card
void writeFile(fs::FS &fs, const char * path, const char * message) {
  Serial.printf("Writing file: %s\n", path);

  File file = fs.open(path, FILE_WRITE);
  if(!file) {
    Serial.println("Failed to open file for writing");
    return;
  }
  if(file.print(message)) {
    Serial.println("File written");
  } else {
    Serial.println("Write failed");
  }
  file.close();
}

// Append data to the SD card
void appendFile(fs::FS &fs, const char * path, const char * message) {
  Serial.printf("Appending to file: %s\n", path);

  File file = fs.open(path, FILE_APPEND);
  if(!file) {
    Serial.println("Failed to open file for appending");
    return;
  }
  if(file.print(message)) {
    Serial.println("Message appended");
  } else {
    Serial.println("Append failed");
  }
  file.close();
}
```

Figure 7: ESP32 Temperature monitoring and webserver code

.3.2 HTML code

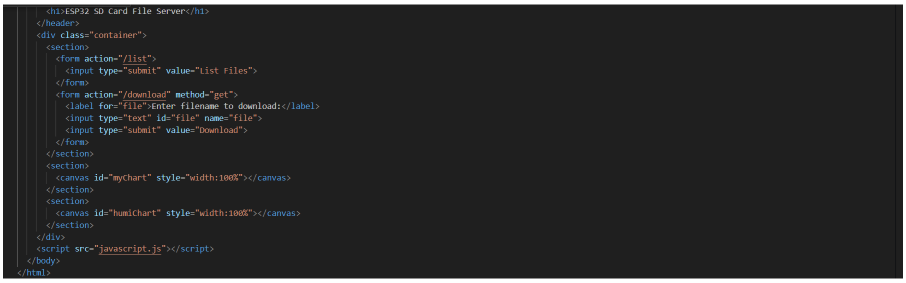
```
<!DOCTYPE html>
<html>
  <head>
    <title>Merged Title</title>
    <link rel="icon" type="image/png" href="favicon.png">
    <style>
      body {
        font-family: Arial, sans-serif;
        margin: 0;
        padding: 0;
        background-color: #f4f4f4;
      }
      header {
        background-color: #333;
        color: #fff;
        padding: 20px;
        text-align: center;
      }
      h1 {
        margin-top: 0;
      }
      section {
        margin: 20px auto;
        max-width: 600px;
        background-color: #fff;
        border-radius: 8px;
        padding: 20px;
        box-shadow: 0 2px 4px rgba(0,0,0,0.1);
      }
      form {
        margin-bottom: 20px;
      }
      input[type="text"],
      input[type="submit"] {
        padding: 8px;
        margin-right: 10px;
        border-radius: 4px;
```

Figure 8: HTML/CSS code for the User Interface



```
        border: 1px solid #ccc;
        font-size: 16px;
      }
      input[type="submit"] {
        background-color: #333;
        color: #fff;
        border: none;
        cursor: pointer;
      }
    </style>
    <script src="Chart.js"></script>
  </head>
  <body>
    <header>
      <h1>ESP32 SD Card File Server</h1>
    </header>
    <div class="container">
      <section>
        <form action="/list">
          <input type="submit" value="List Files">
        </form>
        <form action="/download" method="get">
          <label for="file">Enter filename to download:</label>
          <input type="text" id="file" name="file">
          <input type="submit" value="Download">
        </form>
      </section>
      <section>
        <canvas id="myChart" style="width:100%"></canvas>
      </section>
      <section>
```

Figure 9: HTML/CSS code for the User Interface



```
      <h1>ESP32 SD Card File Server</h1>
    </header>
    <div class="container">
      <section>
        <form action="/list">
          <input type="submit" value="List Files">
        </form>
        <form action="/download" method="get">
          <label for="file">Enter filename to download:</label>
          <input type="text" id="file" name="file">
          <input type="submit" value="Download">
        </form>
      </section>
      <section>
        <canvas id="myChart" style="width:100%"></canvas>
      </section>
      <section>
        <canvas id="humiChart" style="width:100%"></canvas>
      </section>
    </div>
    <script src="javascript.js"></script>
  </body>
</html>
```

Figure 10: HTML/CSS code for the User Interface

.3.3 Javascript data transfer and plotting code

.3.4 Final Board

```javascript
var array_length = 10;
var xValues = [];
for (let i = 0; i < array_length; i++) {
  xValues[i] = i;
}

var yValues = [];
var humiValues =[];

const myChart = new Chart("myChart", {
  type: "line",
  data: {
    labels: xValues,
    datasets: [{
      fill: false,
      lineTension: 0,
      backgroundColor: "rgba(0,0,255,1.0)",
      borderColor: "rgba(0,0,255,0.1)",
      data: yValues
    }]
  },
  options: {
    legend: {display: false},
    scales: {
      yAxes: [{
        scaleLabel: {
            display: true,
            labelString: 'Temperature (°C)'
        },
        ticks: {min: 10, max:80}}],
      xAxes: [{
            display: false
        },
        {
            scaleLabel: {
                display: true,
                labelString: 'Measurement number'
```

Figure 11: Javascript data transfer and plotting code

```javascript
            }
        }]

    }
  }
});

const humiChart = new Chart("humiChart", {
  type: "line",
  data: {
    labels: xValues,
    datasets: [{
      fill: false,
      lineTension: 0,
      backgroundColor: "rgba(0,0,255,1.0)",
      borderColor: "rgba(0,0,255,0.1)",
      data: humiValues
    }]
  },
  options: {
    legend: {display: false},
    scales: {
      yAxes: [{
        scaleLabel: {
            display: true,
            labelString: 'Humidity (%)'
        },
        ticks: {min: 0, max:100}}],
      xAxes: [{
            display: false
        },
```

Figure 12: Javascript data transfer and plotting code

```javascript
        {
            scaleLabel: {
                display: true,
                labelString: 'Measurement number'
            }
        }]

    }
  }
});

var output = document.getElementById('ID_RANDOM_INTENSITY_VALUE');

var Socket;

function init() {
  Socket = new WebSocket('ws://' + window.location.hostname + ':81/');
  Socket.onmessage = function(event) {
    processCommand(event);
  };
}

function processCommand(event) {
  var obj = JSON.parse(event.data);
  var type = obj.type;
  if (type.localeCompare("graph_update") == 0) {
    console.log(obj.value);
    var temp_values = obj.value;
    for(var i=0, length = temp_values.length; i < length; i++) {
      temp_values[i] = temp_values[i] / 10;
    }
    myChart.data.datasets[0].data = temp_values;
    myChart.update();
```

Figure 13: Javascript data transfer and plotting code

```javascript
  }

  if (type.localeCompare("humi_update") == 0) {
    console.log(obj.value);
    var humi_values = obj.value;
    for(var i=0, length = humi_values.length; i < length; i++) {
      humi_values[i] = humi_values[i];
    }
    humiChart.data.datasets[0].data = humi_values;
    humiChart.update();
  }
}
window.onload = function(event) {
  init();
}
```

Figure 14: Javascript data transfer and plotting code

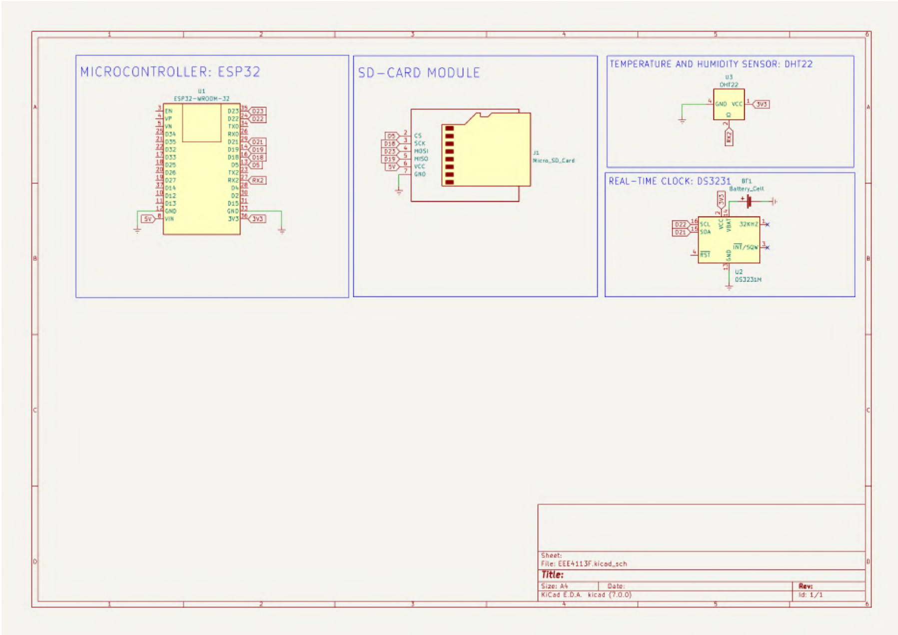


Figure 15: Schematic of final Electronics sub-module

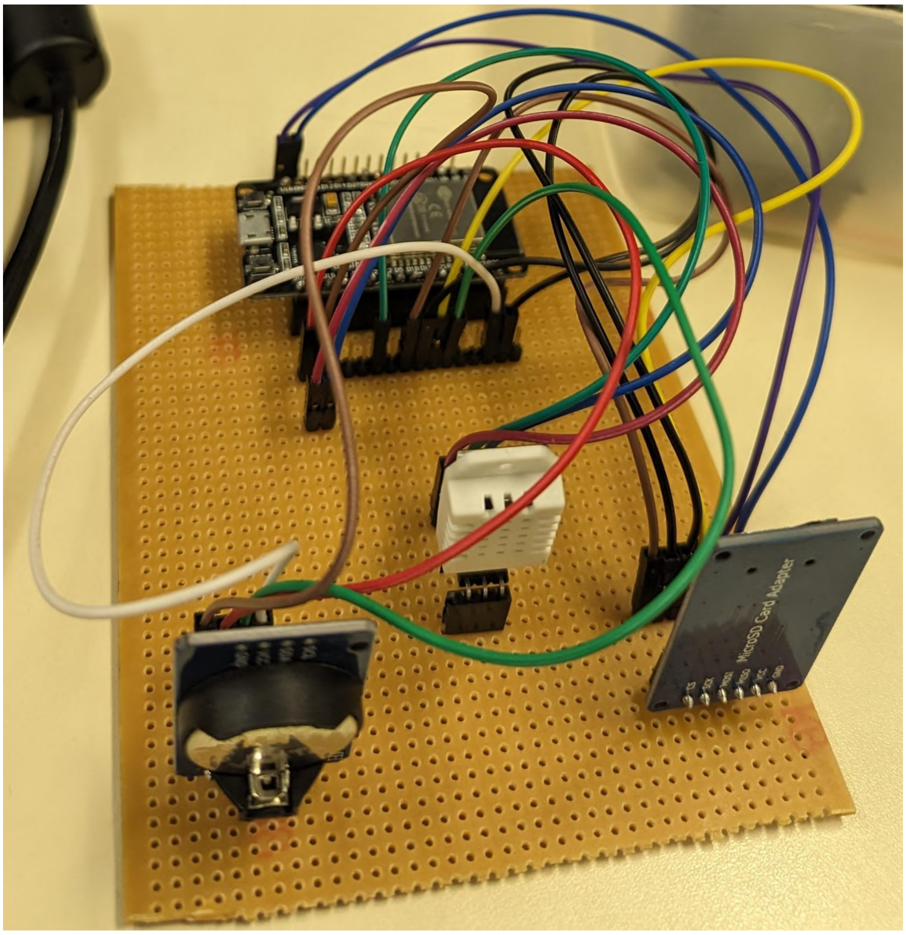


Figure 16: Soldered Electronics sub-module