ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Bird-Watching Telescope with Real-Time Bird Identification

Team #14

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Abstract (AI generated, need polishment)

This paper introduces a smart telescope system designed to assist birdwatchers, particularly beginners and students, in identifying bird species in real-time. The system includes an autofocus telescope, camera, and laser rangefinder, controlled by a Raspberry Pi microcontroller. It connects to a smartphone for remote operation and uses AI software to analyze video footage and identify bird species. The solution aims to enhance the birdwatching experience and promote appreciation of campus biodiversity.

Keywords: Smart Telescope, Bird Identification, Real-Time, AI, Biodiversity, Raspberry Pi.

Contents

1 Introduction

1.1 Background (Finished)

When observing wild birds at a distance with a handheld telescope, due to the agility of the birds, before one can carefully identify or record the characteristics of the birds (appearance and call), they often fly away quickly. The average reaction of birds is reported to be around 400 ms[1].

Although the reaction time of birds is longer than the animal average, it is still not sufficient for a person to observe fully to be able to determine the species. Therefore, a smart telescope that can provide real-time identification of birds is greatly demanded to assist bird watchers, especially beginners.

In addition, a smart telescope can make students of our campus aware of the rich natural resources and get relax by using the birdwatching scope to observe birds. According to the German Center for Integrative Biodiversity Research, the diversity of birds brings a sense of satisfaction**bio**. Therefore, students on our campus need a novice-friendly birdwatching scope to identify and view the different birds on campus, so they can take advantage of the diversity of birds on campus to help them relax outside of their school workload

1.2 Solution (Need change)

As the name of our project suggests, our solution consists of two parts, an automatically focused telescope and camera to observe and record birds, and software to recognize bird species. In order for the two parts to work together, we need to implement a set of control units for data communication between them. We will use the camera module with a set of lenses in front of it, similar in structure to a monocular, to realize the magnification function. At the same time, the distance between certain lenses will be controlled by a stepper motor as well as the corresponding mechanical structure, and the side of the telescope will pretend a laser ranging module and measure the distance between the telescope and the observed bird. The control unit is a microcontroller computer (Raspberry Pi) with remote communication capabilities, connected to a monitor. It is connected to the stepper motors and the laser ranging module by wires and receives and processes the distance data, and controls the stepper motors to adjust the lens to focus. In addition, it is remotely connected to a cell phone, and once connected, the built-in software will automatically control the camera to record video and transmit the footage to the software in the cell phone that identifies the bird species. The software will use an artificial intelligence model to recognize the species of bird present in the video transmit it to the control unit and display it on the screen.

Figure 1: Concept of Bird-Watching Telescope (AI Generated)

1.3 Visual Aid (Need description)

Figure 2: Visual Aid

1.4 High-Level Requirement (Need change)

1. The data flow should be constructed properly, which means the camera and LED screen should be able to connect to the Raspberry Pi and the data transferred between them should be alright, and the communication between Raspberry Pi and mobile phone should be realized.

2. The bird identification software should have at least an 80% successful rate.

3. The power supply should be able to provide 5V to the Raspberry Pi and the Telescope should have an 8x magnification rate.

1.5 Subsystems (Need description)

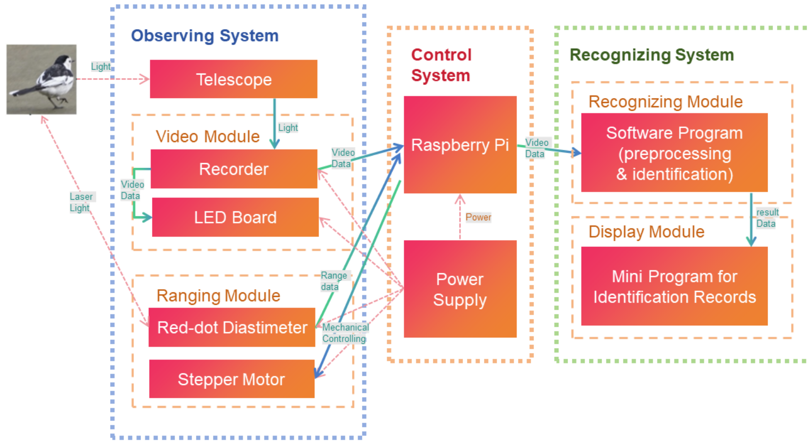

Figure 3: Subsystem Block Diagram

2 Design

2.1 Housing (Finished)

The housing serves as the foundation for our project, housing all the component parts and also serving as a testing platform. Therefore, the design of the housing is of paramount importance. The design must meet the following criteria:

1. The housing must facilitate the mounting of all functional parts in a manner that avoids physical interference.

2. The housing must be easy to manufacture.

3. The housing must optimize space utilization and facilitate assembly and disassembly.

Prior to examining the design specifics of the housing, it is beneficial to review the simplified model of our design and familiarize with the nomenclature of its constituent parts. The details can refer to figure 4.

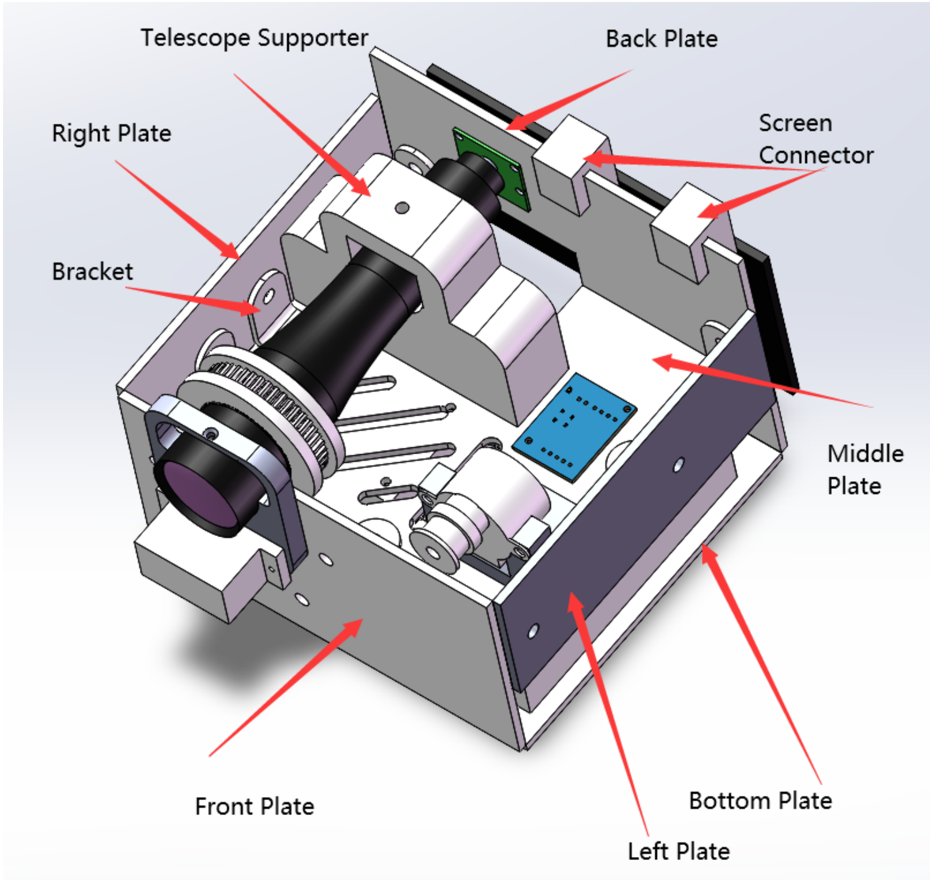

Figure 4: Housing Introduction

2.1.1 Manufacturing Consideration

In response to potential changes in our project design and the need for module testing, it is probable that housing design changes will be made. Furthermore, our project's requirement of not taking up too much space leads to frequent fine-tuning of the housing size. Therefore, the production of the housing must be fast and the assembly must be simple. For this reason, we have used laser-cut acrylic panels for the panels on each side of the unit. Concurrently, readily available plastic brackets, bolts, and nuts were utilized as connectors between the individual panels to minimize processing time and reduce overall weight. It is crucial to acknowledge that the lower elastic modulus of plastic in comparison to steel allows for greater deformation of the plastic bolts and nuts when attached to the brackets. This phenomenon is analogous to the addition of a spring washer, which enables the connection to resist stronger vibrations. This fortuitous discovery also resolved the issue of the device frequently disintegrating after assembly.

Laser cutting acrylic panels does not resolve all issues. Our design necessitated the use of non-standard components, including screen connectors and telescope supporters, rendering 3D printing a viable manufacturing way. PLA has a melting point of 180 to 190 °C [2]. since our equipment is incapable of operating at temperatures exceeding 100 °C, 3D printing can be safely used. The utilization of 3D printing enables the expeditious fabrication of non-standard components, thereby facilitating the expeditious iteration of designs.

2.1.2 Double Layers Design

In order to optimise the utilisation of space and facilitate the logical arrangement of components, a double-layer plus attachment design has been implemented. This approach ensures that the requisite space is allocated for each system and module, thus facilitating the logical arrangement of components. Furthermore, there is a considerable amount of space remaining on the surface between the two layers, which can be utilized for wiring and heat dissipation.

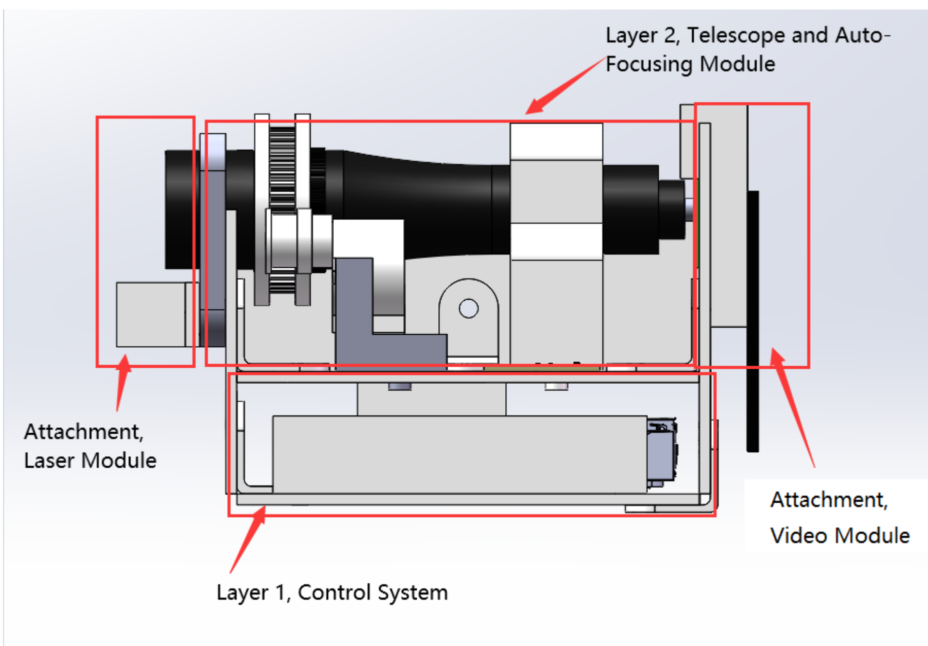

Figure 5: Module Arrangement

2.1.3 Non-standard Components

Screen Connector Due to the bolts on the back plate, the screen cannot be attached directly to the back plate and needs to be spaced a certain distance from it to prevent interference. We designed the screen connector to be connected to the back plate by hanging, and its outer part has a certain thickness and extends downward to provide more area for attaching to the screen. Since the screen is a whole, and considering the size, direct adhesion is the best choice.

Telescope Supporter Used to support the eyepiece end of the telescope. The lower end of its center opening is shaped to fit perfectly with the telescope to restrict up and down movement of the telescope. The upper opening goes right through the top and is used to drive in setscrews to hold the telescope in place. The component is connected to the middle plate by a self-tapping screw. When we are assembling the telescope supporter, we find that it is hard to keep the component at expected position. So we design the protrusions at the bottom, which are used to insert into the corresponding holes in the middle plate to limit the position and prevent the parts from sliding when the screws are tapped in.

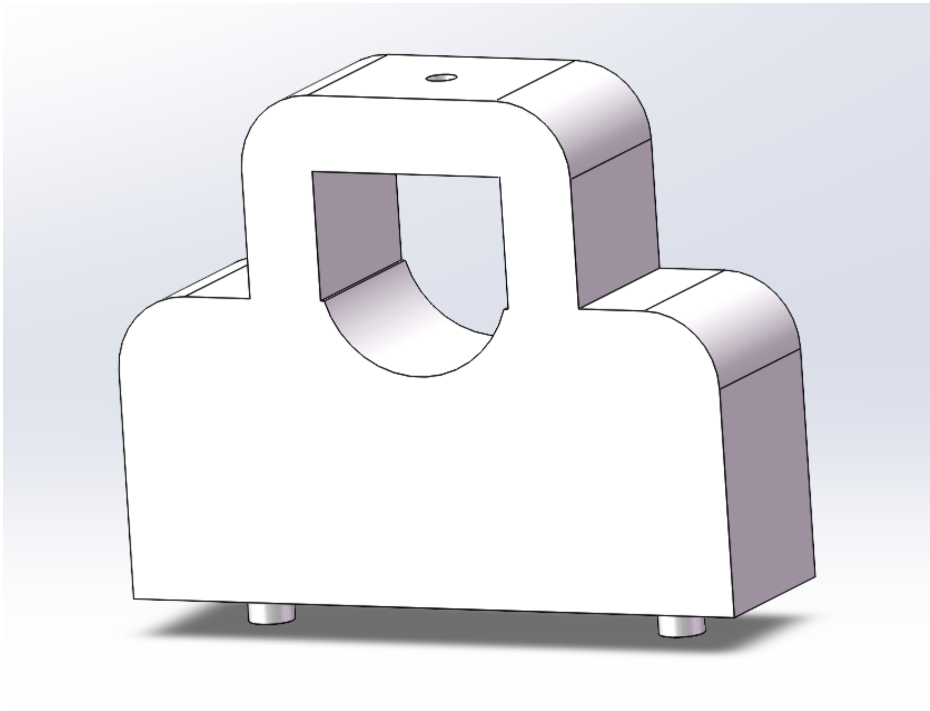

Figure 6: Telescope Supporter

2.1.4 Justification

The justification of the housing is performed by assembling every necessary part together in Solidworks. Then the interference check is performed to ensure no interference. Figure 4 shows the assembly after the interference check. The laser cutter and the 3D printer have a 2% error, so every hole and enclosure are enlarged by 2 % to eliminate the error.

2.1.5 Requirement and Verification

Requirement	**Verification**
1. The housing must facilitate the mounting of all functional parts in a manner that avoids physical interference. 2. The housing must be easy to manufacture. 3. The housing must optimize space utilization and facilitate assembly and disassembly.	1. The verification of the housing is performed alongside the manufacturing and assembling procedure. Every part can be successfully manufactured and assembled together, and systematic testing procedures can be performed easily, which means the housing design is verified without problems.

Table 1: R&V Table of Housing

2.2 Telescope and Auto Ranging System (Unfinished)

2.2.1 System Overview

Auto Ranging System consists of hardware and software. Hardware includes a telescope, laser ranger, a stepper motor and its controlling PCB, and timing pulleys, which are shown in figure 7. The software includes an auto-focusing algorithm.

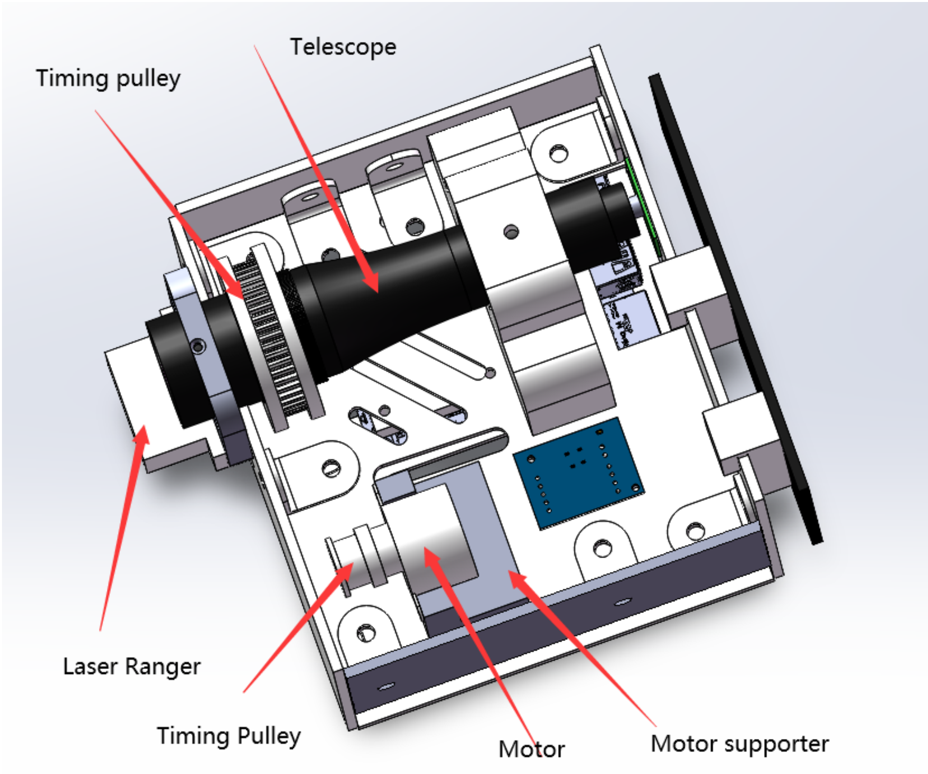

Figure 7: Auto Focusing System Logic

Figure 8 shows the logic of the overall system.

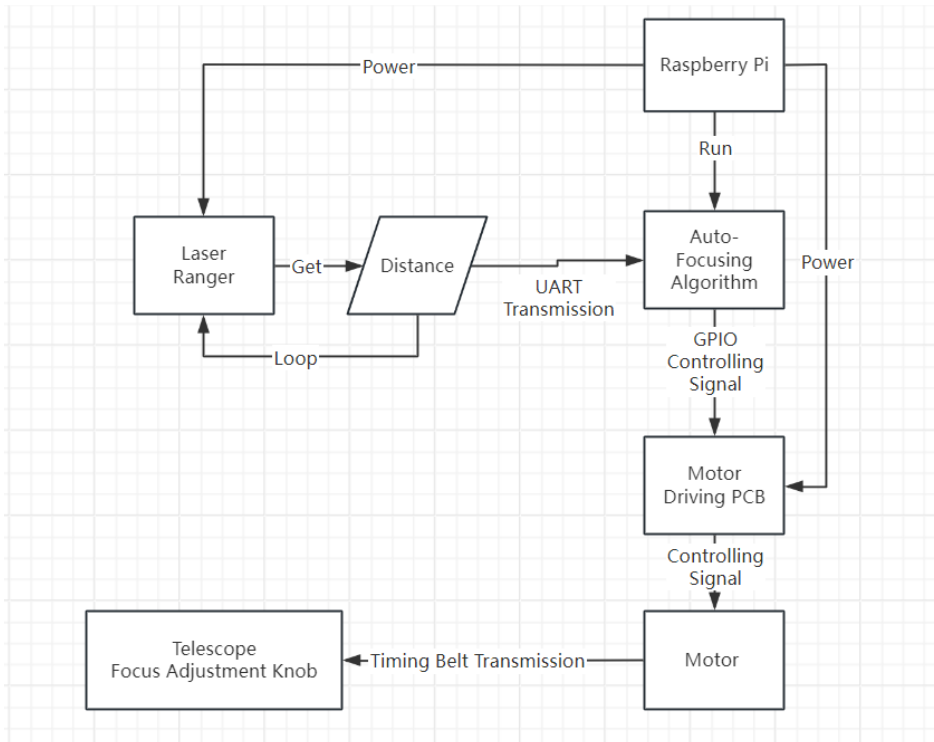

Figure 8: Auto Focusing System Logic

2.2.2 Mechanical Design

The auto-focusing system is a combination of mechanical and electrical designs. This part focuses on mechanical design.

Motor The motor is used to provide rotational torque and power that are transmitted through the transmission system to the focusing knob on the telescope. There are many factors to consider when selecting a motor. First, the Raspberry Pi has two 5V voltage output pins. Therefore, the motors need to be able to utilize 5V power supply. Second, the motor needs to be small enough to take up less space. Finally, we must be able to accurately control the angle of rotation of the motor in order to accurately control the focusing distance.

It's worth noting that when we tested the telescope focus knob we found it to be damped. The faster it rotates, the greater the force needs. Therefore, we decided to measure the force required to rotate the knob at a speed similar to that required to rotate the knob by hand. The measurement $F = 0.13N$. We also measure the radius r of the telescope's objective, which is $0.016m$.

2.3 Control System(Unfinished)

The control system includes a Raspberry Pi, which would provide power and act as the controller for some simple processing, with a Bluetooth USB transmitter connected. The control subsystem will transmit the video data to the mobile phone, and get the identification result back with annotations for bird species and accuracy. Then the subsystem should convey the data to the LED for display. Also, for the automatic focusing, the control system will help process the distance range and send commands to stepper motors to adjust the focus onto the bird.

2.3.1 Power Supply

The power supply has batteries and provides electrical power to the Raspberry Pi. Due to our lack of electrical engineers, we are not capable of designing power supply circuits on our own. Therefore, we will use open-source power supply circuits[3] and modify them to fit our project.

Requirement	Verification
1. The power supply should be able to provide 5V 2A to the Raspberry Pi. 2. The power supply should be able to connect to the Raspberry Pi by TYPE-C interface and be charged with a USB port. 3. The power supply should provide power for the device for at least 30 minutes.	1. Use a power meter to test the power supply's maximum power 2. Use a multimeter to test its voltage and current. Compare with our requirement. 3. Connect it to the Raspberry Pi and run benchmark software to test how long the battery can last.

Table 2: R&V Table of Power Supply

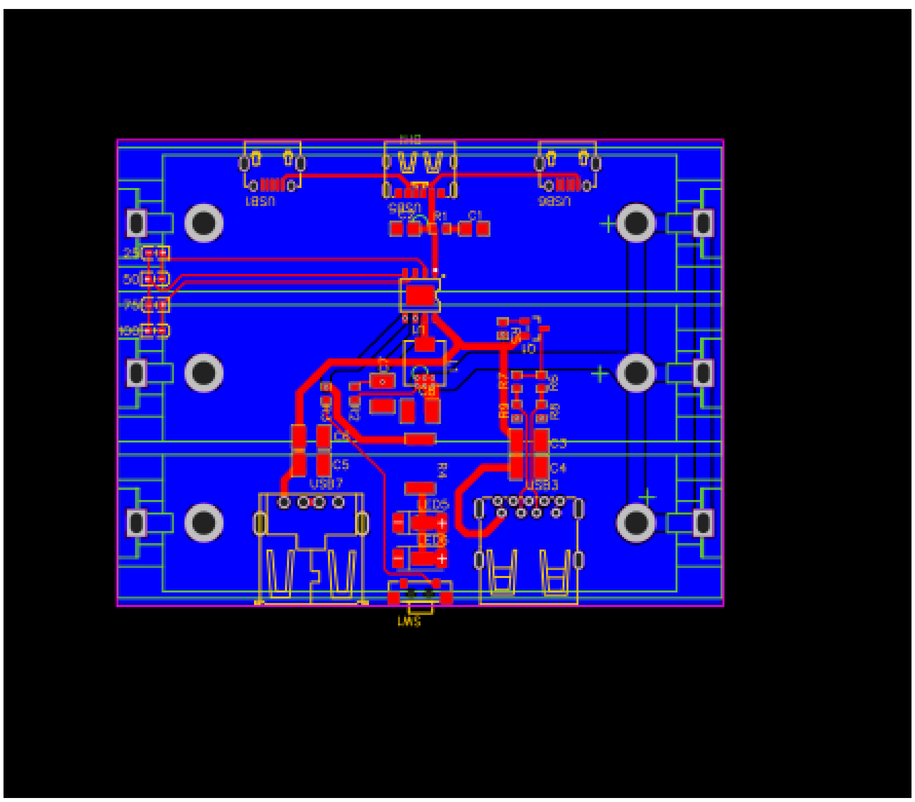

Figure 9: Power Supply PCB Layout

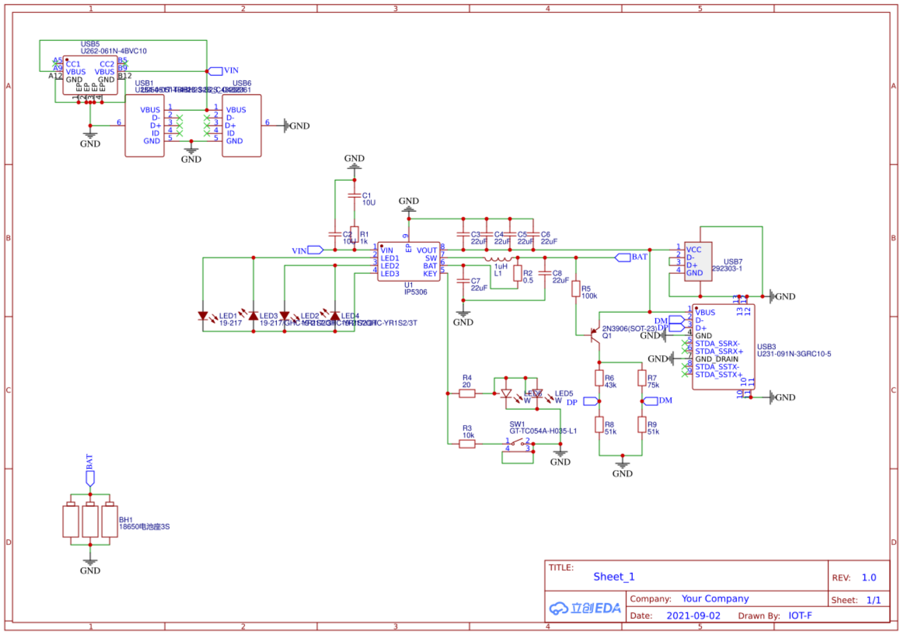

Figure 10: Power Supply Schematic

2.3.2 Raspberry Pi

Raspberry Pi Fifth Flagship Development Computer is assembled with a powerful 2.4GHz 64-bit quad-core Arm processor and an 800MHz Video Core VII GPU for impressive graphics. It offers advanced camera support, versatile connectivity, and enhanced peripherals, perfect for multimedia, gaming, and industrial tasks[4]. And the Bluetooth USB transmitter should accept at least Bluetooth Core v5.0, since new Bluetooth protocol would serve a better speed and bandwidth. Here lossless audio source transmission at 24bit/192KHz is supported[5]. And most products on markets are using Bluetooth Core v5.0. This would mostly satisfy our needs.

2.4 Recognizing System (Unfinished)

The recognizing system is responsible for analyzing video data from the Raspberry Pi to identify and classify bird species present in the field of view. It utilizes advanced computer vision and machine learning techniques to extract relevant features from the images and make accurate predictions regarding the identity of observed birds. The module typically consists of several components, including preprocessing, feature extraction, and

Requirements	Verification
1. The Raspberry Pi should facilitate seamless and reliable transmission of video data.	1. Test the control module's data transmission capabilities by measuring data transfer rates between the recorder and identification software. Verify that data is transmitted reliably without loss or corruption.
2. The Raspberry Pi should be capable of processing ranging data and adjust the telescope in real-time.	2. Validate the control module's real-time control capabilities by conducting tests with the red-dot diastimeter. Measure the latency between ranging data acquisition and telescope adjustment to ensure timely response.

Table 3: R&V Table for Raspberry Pi

machine learning model, working together to process raw image data and produce identification results. We have chosen to refine a bird identification model, denoted as bird v2[6], utilizing a dataset comprising bird species frequently encountered on our campus. This endeavor aims to enhance the effectiveness of the identification system by tailoring the model to recognize avian species prevalent within our campus environment.

2.4.1 Recognizing module

The recognizing module in a bird identification telescope is the central component responsible for processing video data from Raspberry Pi and accurately identifying bird species observed through the telescope. By combining advanced computer vision and machine learning techniques, this module preprocesses the incoming video streams, extracts relevant features, and conducts precise identifications. This acts as a backend of our software part.

Requirements	Verification
1. Capable of processing incoming video data in real-time.	1. Measure processing time for each frame and ensure it does not exceed the maximum latency of 100 milliseconds per frame.
2. Produce reliable results about the bird identification.	2. Evaluate the performance of the system using public and self-produced datasets to verify that the accuracy exceeds 90%.
3. Demonstrate robust performance under diverse environmental conditions.	3. Subject the recognizing system to diverse environmental conditions, including changes in lighting, weather, and background clutter. Evaluate system performance under these conditions and verify that it maintains accurate identification results with minimal degradation in accuracy or speed.

Table 4: R&V Table for Recognizing Module

2.4.2 Display module

The display module serves as a critical interface for showcasing the identification results to users through a mini-program accessible on mobile phones. This module acts as a conduit between the backend recognition system and the end-user, providing an intuitive and visually engaging platform for presenting the identified bird species.

Requirements	Verification
1. Must showcase identification results in real-time on the mobile phone's mini-program interface.	1. Test the display module with live identification results and measure the time taken to update the mini-program interface to ensure that identification outcomes are displayed within the specified time frame for real-time access.
2. Must have user-friendly interface that is intuitive and easy to navigate.	2. Conduct usability testing with a diverse group of users to evaluate the interface's ease of use and intuitiveness. Gather feedback on navigation, layout, and accessibility features to ensure a positive user experience.
3. Must visualize the identification results effectively and clearly.	3. Assess the visualization of identification results on the mini-program interface, ensuring that bird species names, images, and additional information are presented clearly and attractively. Gather user feedback to refine visualization techniques.

Table 5: R&V Table for Display Module

3 Cost and Schedule(Unfinished)

3.1 Schedule

3.2 Costs (Unfinished)

3.2.1 Labor cost

In the realm of senior design projects, labor cost holds significant weight. Our estimations peg the expense at 100 Yuan per hour per person, which aligns with the standard salary for undergraduates at Zhejiang University. Considering a weekly workload of 20 hours per person, we anticipate this commitment throughout the 10-week project duration. Crunching the numbers reveals a total labor cost of 80,000 Yuan, derived from the formula: 4 x 100 Yuan per hour x 20 hours per week x 10 weeks.

3.3 Material cost

Part	MFT	Desc	Module	Price	Qty	Total
Raspberry Pi 5 with IMX219 camera module	Yabo	Memory 4.0G	Control System	769	1	769
M2x16 stainless steel round head Phillips screw	Easter		Mechanical	5.7	1	5.7
Wire holder FC-1	Beretta		Mechanical	3.26	1	3.26
Nylon square bearing seat with bearing	Shenma		Mechanical	15.2	1	15.2
Tuba hot melt injection copper nut	Bizhou		Mechanical	2.41	1	2.41
Nylon outer hexagon screw nut	Jingchao		Mechanical	5.13	1	5.13
Synchronous wheel drive belt	Jianggong		Mechanical	4.1	5	20.5
USB to TTL-CH340 module	Risym		Control System	6.26	1	6.26
M2x14 Stainless steel screws and nuts	Chuwei		Mechanical	2.17	1	2.17
Laser ranging module	YAHBOOM		Control System	128	1	128
M4x8 PP outer hexagonal screws	Jingxuan		Mechanical	3.93	2	7.86
x20 Plastic corner code	Lidiya		Mechanical	13.8	1	13.8
500x500mm acrylic plate	Clomon		Mechanical	23	2	46
x10 Stainless steel angle code	Shouli		Mechanical	0.48	10	4.8
5.5-inch display	Amelin	1080*1920 TFT IPS		130	1	310
Lithium battery charging stand	Frshion		Power Supply	24.5	1	24.5
x4 18650 rechargeable lithium battery	Panasonic	3400mAh 3.7V	Power Supply	25.9	1	25.9
28BYJ48 stepper motor	Xinlong	5V 0.3A 15-20rpm 34.3mN*m		10	1	10
motor driver board	Xinlong		Control System	20	1	20
single-tube telescope	Curb		Control System	300	1	300

Figure 11: BOM Table

3.3.1 Justification

4 Conclusion (Unfinished)

4.1 Accomplishments

The core achievement of the project was the successful combination of advanced birding technology with a user-friendly interface to create an autofocus birding telescope. In particular, this device includes the following innovations and implementations:

Autofocus system: The system uses infrared ranging module and stepper motor to precisely adjust the focal length of the telescope so that clear images can be obtained quickly at different observation distances.

Mature bird recognition algorithm: We did not develop our own recognition algorithm, but effectively integrated the existing mature bird recognition technology in the market, and realized efficient bird detection and recognition function through Raspberry PI 5.0 and camera module.

Power management and structural design: A power supply system composed of rechargeable batteries and battery holders is designed to ensure the long-term operation of the equipment. The housing is made of 3D printed materials and acrylic panels, ensuring that the device is lightweight and strong enough for field use.

User interface: Through a small screen to display real-time bird identification results and related information, greatly enhance the user's bird watching experience.

4.2 Uncertainties

During the implementation of this project, we encountered a number of technical and environmental uncertainties that challenged the performance and reliability of the equipment:

The adaptability of autofocus system:

In extreme climatic conditions, such as strong winds, high humidity, or extreme temperatures, the performance of the AF system can sometimes be seriously affected. These environmental conditions may cause the ranging accuracy of the infrared ranging module to decline, and the response speed of the stepper motor to slow down, thus affecting the overall focusing speed and accuracy.

In addition, the focusing system may experience performance degradation after continuous operation for a long time due to mechanical wear or insufficient thermal compensation.

Limitations of mature bird recognition algorithms:

Despite the use of well-established bird recognition algorithms on the market, the algorithm's accuracy and robustness in certain environments, such as dim light and complex backgrounds, are limited. Algorithms may have difficulty distinguishing between certain bird species that are similar in appearance or size, especially if the birds are moving rapidly or partially shielded. The algorithm has limited ability to identify new or rare bird species, which can lead to identification errors and affect the data quality of research and observation.

Hardware compatibility and durability:

When designing and integrating a power supply system, changes in battery charge cycles and discharge efficiency can affect the overall uptime and performance stability of the device. In addition, the battery may not perform as expected under extreme temperature conditions, affecting the usability of the device.

While the 3D printing materials used have advantages in weight and cost, their long-term durability and structural integrity in sun and wet environments is a major challenge. Materials may age, deform or crack, requiring regular inspection and replacement, increasing maintenance costs and complexity.

4.3 Future Work

In response to the results of the current project and its shortcomings, we have planned a series of improvements and development directions to improve the performance of the equipment, expand the scope of application, and address existing technical limitations:

Technology optimization and iteration:

Improved autofocus system: The introduction of higher precision ranging sensors and faster response stepper motors is planned to improve the accuracy and reliability of the focusing system in a variety of climatic and lighting conditions.

Algorithm upgrade: Although we currently use mature bird recognition algorithms, in the future we plan to work with professional organizations to develop more efficient and accurate custom algorithms, especially to improve the identification of rare and endemic bird species.

Hardware upgrade:

Power system improvements: In order to meet the needs of long-term field observation, longer-lasting battery technology and solar-assisted charging systems will be developed to provide more stable and environmentally friendly power solutions.

Camera and display technology upgrades: Consider higher resolution and low light sensitivity cameras to improve image quality in low light conditions. At the same time, the display is updated to provide clearer images and a richer user interface.

Function extension:

GPS and geotagging function: Integrated GPS module can not only record the observation site in real time, but also provide relevant bird species information according to geographical location data, enhancing education and scientific research value.

Mobile device and cloud platform connectivity: Develop wireless connectivity with a smartphone or tablet, allowing users to remotely control the telescope, receive and share observation data in real time. In addition, through cloud platform integration, users can store, analyze and compare long-term observation data.

Market and application expansion:

Education and research cooperation: In cooperation with schools and research institutions, the birding telescope is promoted as a teaching and research tool, especially in the field of biodiversity monitoring and environmental science education.

Product diversification: The development of multiple models of telescopes to meet the needs of different user groups, such as the design of easier to operate models for beginners, to provide higher performance equipment for professional bird watchers.

4.4 Ethical Considerations

In designing and implementing this bird-watching telescope project, we faced a number of ethical and social responsibility issues that we had to ensure were fully considered and addressed in the research and development process:

Minimal disturbance to wildlife:

Equipment must be used to ensure minimal disturbance to wild birds and their habitats. This includes adopting a silent or low voice mode when operating the equipment, and avoiding the use of high frequency or bright light equipment during the breeding season so as not to interfere with the birds' natural behaviour and breeding cycle.

We also need to ensure that the physical setup of the equipment does not damage the bird's habitat, such as avoiding installation of equipment or wiring in sensitive areas.

Data Privacy and Information Security:

Although mature bird recognition algorithms are used, data protection laws and ethical standards must be observed when processing and storing image data captured by the device. This includes anonymising captured images to ensure that the data is not misused or made public without permission. Strict data access and processing protocols need to be established to ensure that only authorized personnel have access to sensitive data, and that all data processing should be transparent to enhance public trust in the project.

Environmental Impact and Sustainability:

Environmentally friendly materials and methods should be used in the design and manufacture of the equipment. For example, choose 3D printed materials that are recyclable or biodegradable to reduce the negative impact on the environment.

Consider the energy efficiency and overall carbon footprint of the equipment and optimize the power management system to reduce energy consumption and extend the service life of the equipment, thereby reducing the environmental impact of the entire project.

Compliance and Liability:

Ensure that all research and development activities comply with national and international laws and regulations, in particular those relating to wildlife conservation and environmental protection.

The project team should continue to be sensitive and responsive to social and environmental responsibilities, be open to the public, and regularly publish project progress and impact reports for public scrutiny.

References

[1] M. J.-M. Macé, O. R. Joubert, J.-L. Nespoulous, and M. Fabre-Thorpe, "The time-course of visual categorizations: You spot the animal faster than the bird," *PloS one*, vol. 4, no. 6, e5927, 2009.

[2] makershop.co. "What temperature can pla withstand(+ how to strengthen)." (Dec. 14, 2021), [Online]. Available: https://makershop.co/what-temperature-can-pla-withstand/#google_vignette.

[3] W. R. Q. Tu. "Ip5306 double usb port charger." Accessed: 2024-03-11. (2021), [Online]. Available: https://oshwhub.com/EDAF/ip5306-shuang-lu-chong-dian.

[4] R. P. Foundation. "Rasberry pi 5." Accessed: 2024-03-11. (2024), [Online]. Available: https://www.raspberrypi.com/products/raspberry-pi-5/.

[5] M. Woolley. "Bluetooth core specification version 5.0 feature enhancements." Accessed: 2024-03-11. (2021), [Online]. Available: https://www.bluetooth.com/wp-content/uploads/2019/03/Bluetooth5-FINAL.pdf.

[6] LeeM, *Bird v2 dataset*, https://universe.roboflow.com/leem-pf8fb/bird-v2, Open Source Dataset, visited on 2024-03-27, Feb. 2023. [Online]. Available: https://universe.roboflow.com/leem-pf8fb/bird-v2.

Appendix A Example Appendix

An appendix can go here! Make sure you use the `\label{appendix:a}` above so that you can reference this section in your document.