ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Bird-Watching Telescope with Real-Time Bird Identification

Team #14

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Abstract

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 system with a telescope, and camera, controlled by a Raspberry Pi microcontroller. It 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, Raspberry Pi.

Contents

1 Introduction

1.1 Background

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

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. For the two parts to work together, we should implement a set of control units for data communication between them. We will use the camera module with a monocular in front of it to realize the magnification function. At the same time, the focus distance will be controlled by a stepper motor and the corresponding mechanical structure, and a laser ranging module will be set up to 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 ranger by wires to receives and processes the distance data, and controls the stepper motors to adjust the focus. A power supply with batteries will also be included. Once powered on and starting the software, the system will automatically control the camera to record video and transmit the data 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 and display it on the screen.

1.3 Visual Aid

Figure 1: Visual Aid

1.4 High-Level Requirement

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 functional.
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

The project consists of three subsystems: The observing system, the control system, and the recognizing system. The observing system consists of a telescope, a video module and a ranging module. It is used for videotaping, focusing, and displaying the observed birds. The video data will be transmitted to the control subsystem. The control subsystem consists of a Raspberry Pi and a power supply for computing the recognition algorithms, processing the UI, which will be shown on the screen in the recognizing subsystem, and controlling and powering the other components. The identification subsystem is used to recognize the category of the bird and display it to the user.

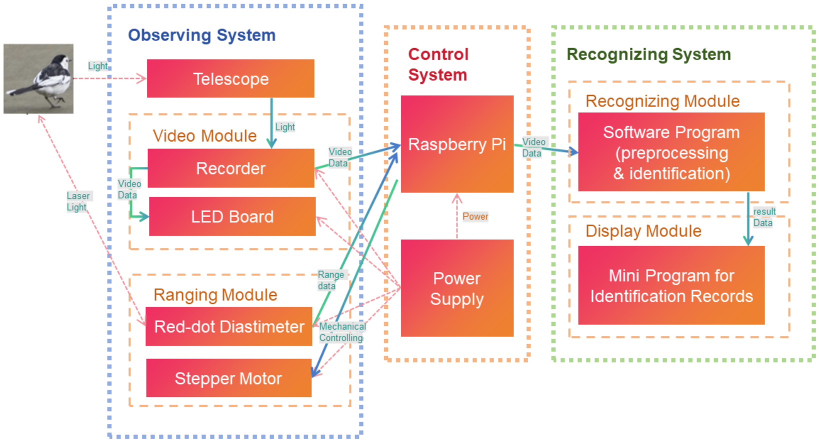

Figure 2: Subsystem Block Diagram

2 Design

2.1 Housing

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 3.

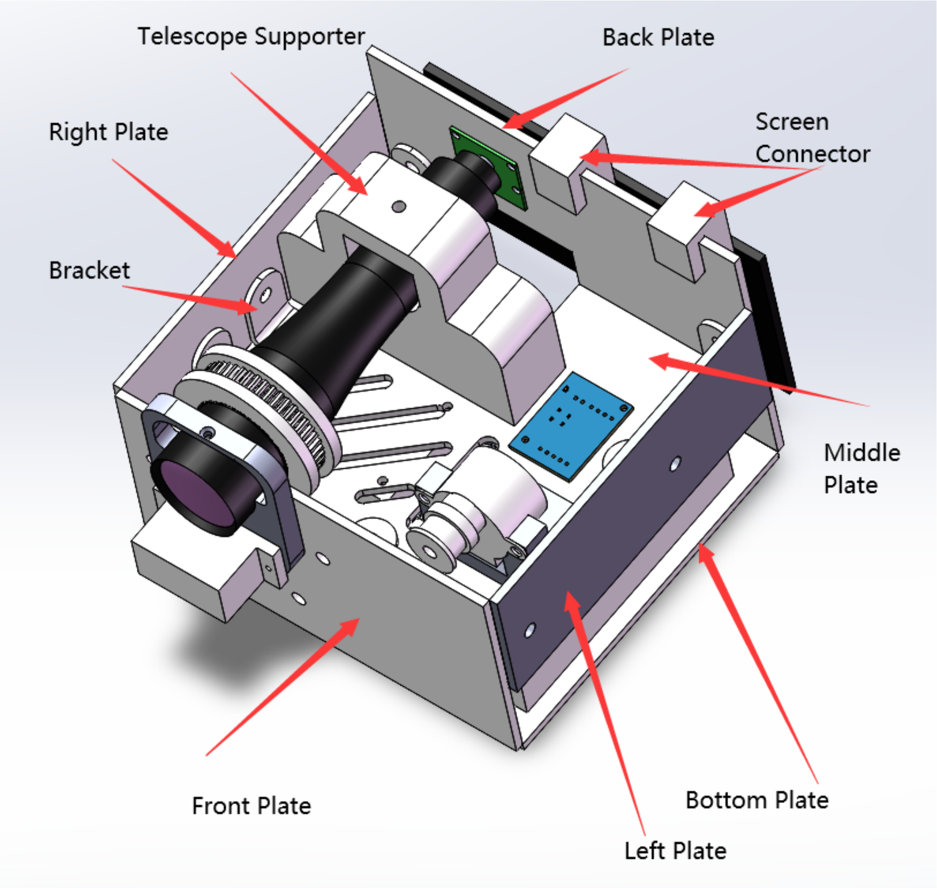

Figure 3: Housing Introduction

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.

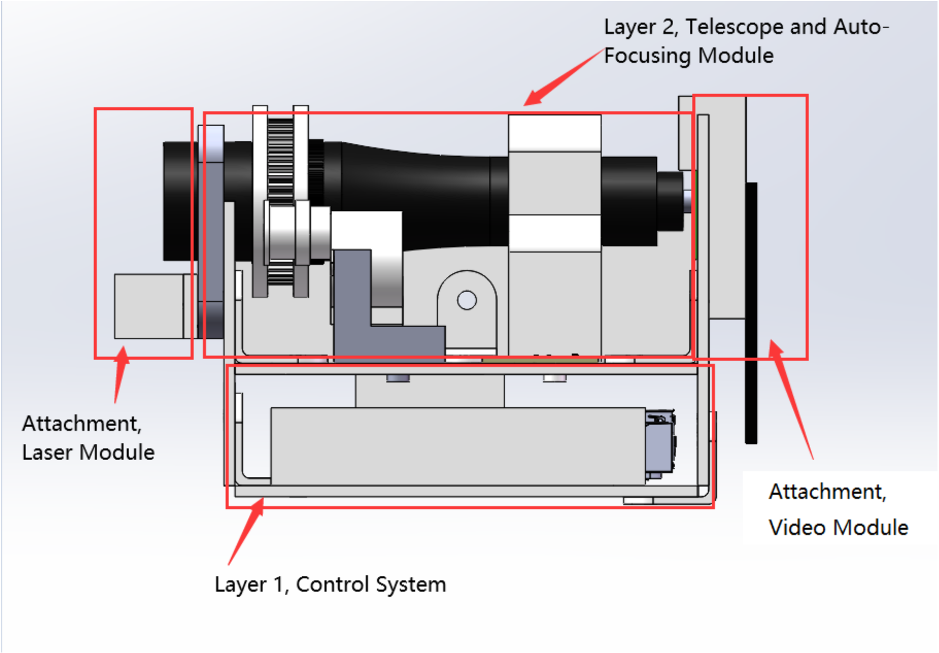

Figure 4: Module Arrangement

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.

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 3 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.

2.2 Telescope and Auto Ranging System

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 5. The software includes an auto-focusing algorithm.

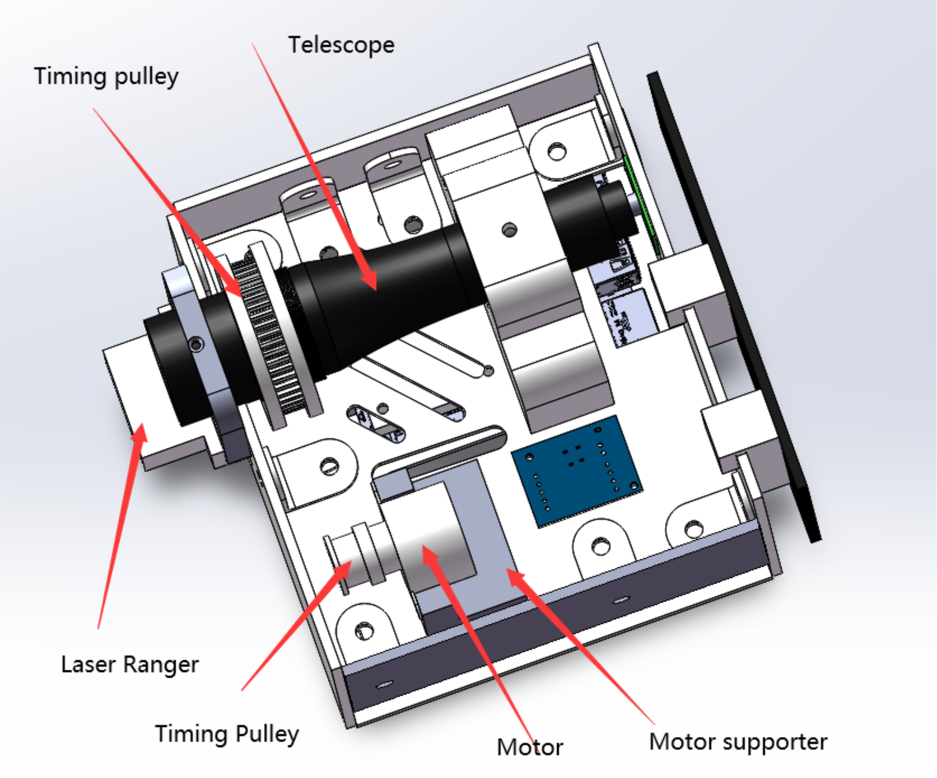

Figure 5: Auto Focusing System Logic

Figure 6 shows the logic of the overall system.

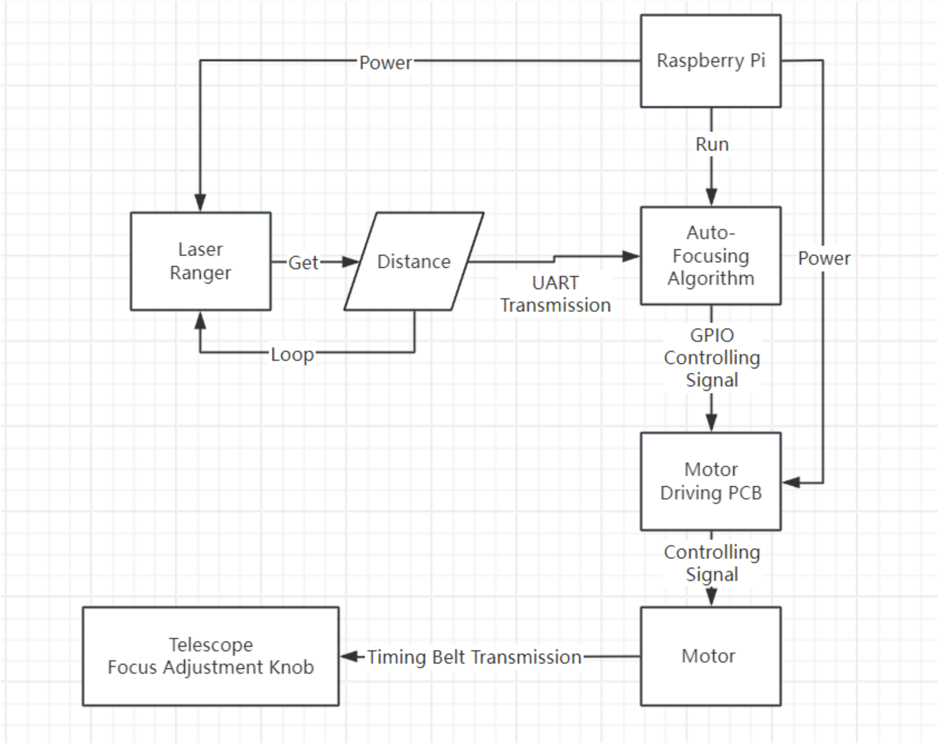

Figure 6: Auto Focusing System Logic

2.2.2 Mechanical Design

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

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 5 V output pins. Therefore, the motors need to be able to utilize 5 V 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.

The telescope focus knob is 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=0.13 N. We also measure the radius of the telescope's objective, which is 0.016 m. Then, we can calculate the torque needed for the motor by torque equation [3].

$$Torque(\tau) \quad = Distance(d) \times Force(F) \tag{1}$$

$$\tau \quad = \quad 0.13\ N \times 0.16\ m \tag{2}$$

$$Torque(\tau) \quad = \quad 0.0208\ N \cdot m \tag{3}$$

The stepper motor we use is 28BYJ-48, which will provide $0.0343\ N \cdot m$ torque [4], which is larger than the torque we need. The teeth number of the driver and the driven pulley are designed to be 15 and 48 respectively. The teeth type is S3M. We only design the driven pulley because it is not purchasable. To design the driven pulley, we need to determine the pitch diameter and the outer diameter, which are 45.84 mm and 45.07 mm [5]. The length of the timing belt is measured to be 32 cm using SolidWorks. All timing pulleys are connected with set screws.

2.2.3 Electrical system

28BYJ-48 stepper motor needs at least 5 V to function, but the output pins of the Raspberry Pi 5 is 3.3 V. A dedicated circuit is required to drive the motor. ULN2003A is a chip consisting of Darlington transistor arrays [6], which function as switches to control each coil in the motor. Darlington transistor is basically two transistors that work together to provide a larger current for the motor. The designed PCB circuit is shown in figure 7.

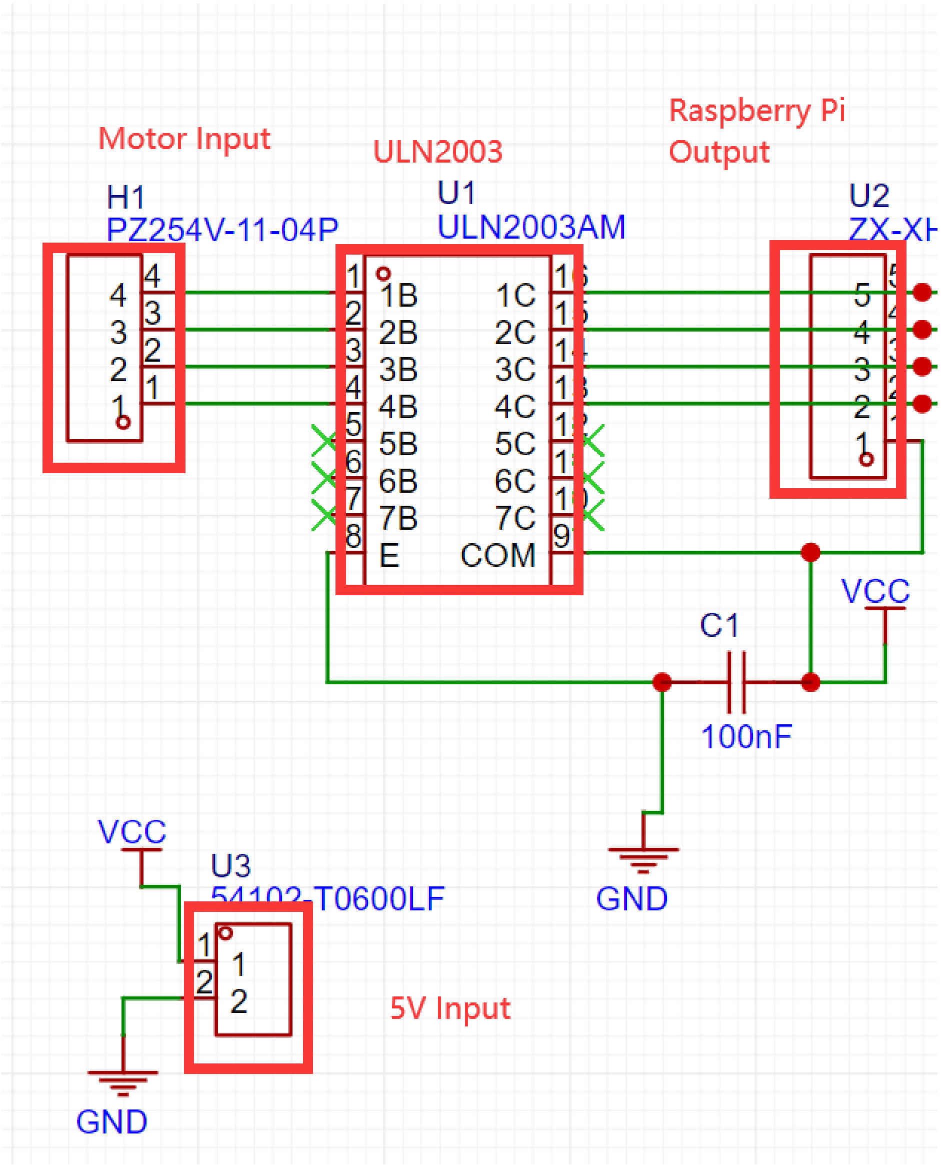

Figure 7: Motor Driver PCB Design

The function of the circuit is to convert the 3.3 V of Raspberry Pi output to 5 V and provide it to the motor.

The laser ranger we use is SDM15 provided by Ydlidar, which is controlled by the serial communication port on the Raspberry Pi.

2.2.4 Controlling Algorithm

Stepper motors have 4 control pins, which control the motor's rotation angle and direction by sending pulses. For the 28BYJ-48 we are using, each pulse will rotate the motor by $5.625°/64$. Therefore, by controlling the number and sequence of pulses, we can keep track of the motor's rotation angle and direction. We use an eight-step motor drive mode, which offers several advantages such as smoother operation, higher torque at lower speeds, and reduced resonance compared to simpler drive methods like four-step modes.

To implement the auto-focus function, we need to first rotate the telescope's focusing knob all the way to the left, which corresponds to the closest focus. At this position, we need to measure the relationship between the angle at which the stepper motor rotates to the right and the focusing distance. Since the maximum range of the laser rangefinder is 15 m and the minimum focal length of the telescope is 1.5 m, we have taken measurements at 14 distances within the range of 1.5 m to 15 m, obtained the corresponding angles at which the motor rotates to the right, and performed fitting to ultimately derive the functional relationship between the rotation angle and the focusing distance as $\theta(L)$.

$$\theta(L) = 7.02 \times 10^{-18}L^5 - 3.60 \times 10^{-13}L^4 + 7.17 \times 10^{-9}L^3 - 6.98 \times 10^{-15}L^2 + 3.4 \times 10^{-1}L - 377.4 \tag{4}$$

Using the Raspberry Pi, we obtain the distance transmitted by the laser rangefinder and input it into $\theta(L)$ to calculate the target angle the motor needs to rotate to. By subtracting the motor's current angle from this target angle, we can determine the angle the motor needs to rotate. Thereby, we can send the corresponding number of pulses to the motor to rotate it to the target angle, achieving the function of autofocus. At the same time, we update the current angle with each pulse sent.

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 module we purchased has a battery pack consisting of three 18650 lithium-ion batteries, each with a capacity of 3400 mAh, culminating in a total capacity of approximately 10,000 mAh. This substantial capacity is essential to accommodate the energy demands of the device's sophisticated hardware components. Additionally, this power supply can provide a voltage of 5V and a high current of 5A to power the Raspberry Pi. It also supports the function of charging while in use.

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[7]. 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[8]. 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 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

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 1: R&V Table for Raspberry Pi

v2[9], 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.

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.

3 Cost and Schedule

3.1 Schedule

Week	Task	Responsible Team Member(s)	Details
3/15/2024	Project Planning & Parts Procurement	All members	Define specific project objectives, select system architecture, finalize design strategy, research suppliers, and order components. Schedule and conduct initial team meetings to allocate tasks and establish project milestones.
4/3/2024	Initial Design & Parts Acquisition	Tiancheng Lv, Yuhao Wang	Design the mechanical casing using CAD software. Verify dimensions and compatibility. Order and confirm delivery of electronic components such as the Raspberry Pi and lens module. Conduct initial quality checks on received parts.
4/10/2024	3D Printing & Software Development Start	Tiancheng Lv, Yuhao Wang, Haoxuan Du, Junhao Zhu	Finalize design and initiate 3D printing of the casing. Begin development of basic software for image capture. Test initial software functions with Raspberry Pi to ensure compatibility.
4/17/2024	Assembly & Initial Testing	All members	Assemble the electronic components within the casing. Execute initial integration tests for mechanical and electronic components. Identify and troubleshoot any integration issues.
4/24/2024	Advanced Software Development & Integration	Haoxuan Du, Junhao Zhu	Develop advanced software features, including real-time image processing and specific object (e.g., bird) identification algorithms. Test and ensure seamless software-hardware integration.
5/1/2024	Prototype Refinement & User Interface Design	All members	Refine the prototype based on initial user and technical feedback, focusing on improving ergonomics and the user interface. Update software to enhance interaction and display quality.
5/8/2024	Comprehensive Testing & Debugging	All members	Conduct comprehensive testing of the system for functionality, software stability, and overall user experience. Document and resolve any software or hardware issues identified.
5/15/2024	Final Adjustments & Documentation	All members	Make final design and software adjustments based on testing feedback. Compile comprehensive project documentation, including technical specifications, a user manual, and prepare for the final presentation.
5/22/2024	Final Testing, Presentation & Submission	All members	Conduct final system tests and make necessary refinements. Present the completed project to stakeholders, demonstrating its features and capabilities. Submit the final report and all project documentation for formal evaluation.

Figure 8: Schedule

3.2 Costs

3.2.1 Labor Cost

In the realm of senior design projects, labor cost holds significant weight. Our estimations peg the expense at 30 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 24000 Yuan.

3.2.2 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 9: BOM Table
The total cost includes 24000 Yuan of labor cost and 1720 Yuan of material cost, a total of 25720 Yuan

4 Conclusion

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 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. 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. 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. 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 sunlight, the performance of the AF system can sometimes be seriously affected. The condition may cause the ranging accuracy of the infrared ranging module to decline, 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 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.

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 the application, and address existing technical limitations:

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.

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

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 behavior 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.

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.

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Appendix A Verifications (Unfinished)

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 2: R&V Table of Housing

Housing requirement verification status: Passed.

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 3: R&V Control System

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

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