ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Bird-Watching Telescope with Real-Time Bird Identification

Team #14

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1 Introduction

1.1 Problem

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. According to Macé, Marc, the average reaction time for birds is around 400ms[1]. Although it is a little slower compared with the animal average, it is not adequate for one to observe thoroughly, making it difficult to determine the species. A smart telescope is needed to greatly assist bird watchers, especially beginners, and provide real-time identification of birds.

In addition, the excellent environment surrounding the campus attracts a wide variety of birds, but many students don't realize that they have such a rich natural resource. According to the German Center for Integrative Biodiversity Research, the diversity of birds bring a sense of satisfaction[2]. 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.

Figure 1: Concept of Bird-Watching Telescope

1.2 Solution

As the name of our project suggests, our solution consists of two parts, a 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. As we expect, 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.

1.3 Visual Aid

Figure 2: Visual Aid

1.4 High-level Requirements List

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.

2 Design

2.1 Block Diagram

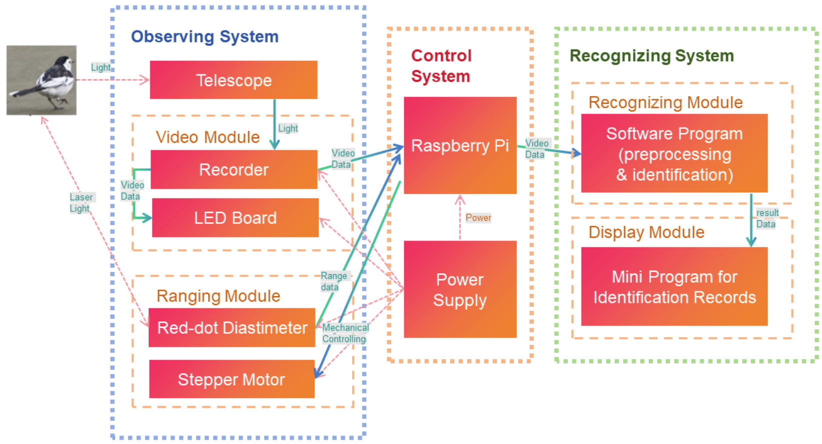

Figure 3: Block Diagram

Our project can be divided into three systems: an observation system, a control system, and an identification system. The control system is the core system, powered by a 5V2A DC power supply connected to a Raspberry Pi. The Raspberry Pi is responsible for controlling the stepper motor and laser range sensor via the GPIO interface, which calculates the distance to the target bird and adjusts the focal length of the telescope (optional design). The LED screen and camera are connected to the Raspberry Pi through DSI and CSI interfaces for data transmission. Additionally, the Raspberry Pi can connect to a cell phone via Bluetooth to communicate with the identification software on the phone.

2.2 Physical Design

To help showcase our design more effectively, we created a physical diagram using CAD modeling software, which is shown in Figure 4. It is important to understand that this diagram is not indicative of the actual form of the finished product. Rather, it represents the relative positions of the various components and the design of the housing that holds them together. The housing itself takes on the shape of a pistol, with a handle that the user can comfortably grip to aim quickly at a target bird. The screen is positioned close to the user's side to provide a clear view of the bird and real-time identification results. The top and left sides of the unit are not fitted with a baffle, which allows for easy installation and commissioning.

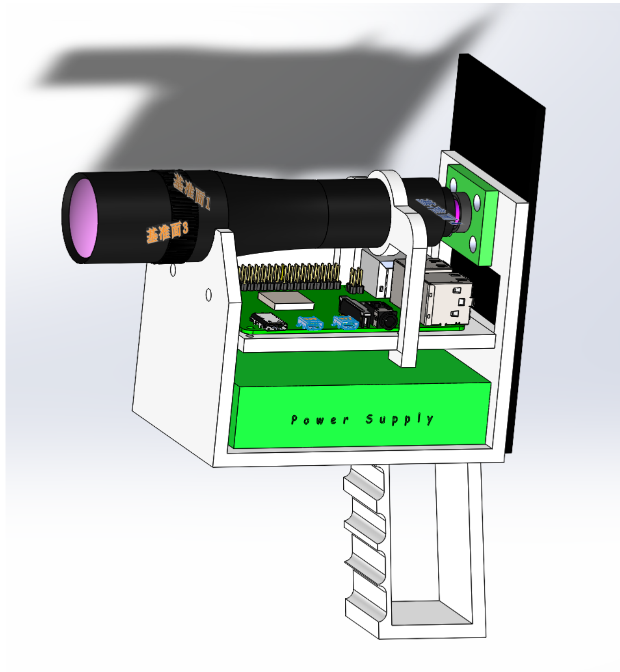

Figure 4: Physical Design of the Telescope

2.3 Observing System

The observing system comprises three parts: a telescope, a video module consisting of a recorder and LED screen board, and a ranging module consisting of a red-dot laser range sensor and a stepper motor.

2.3.1 Telescope

The telescope is capable of magnifying the bird image and projecting it to the camera, while also adjusting focus through the control system. It is recommended that the telescope has at least an 8x magnification rate and can also be adjusted manually. However, since we do not possess the necessary knowledge to design and assemble our own telescope, we will need to purchase one from the market.

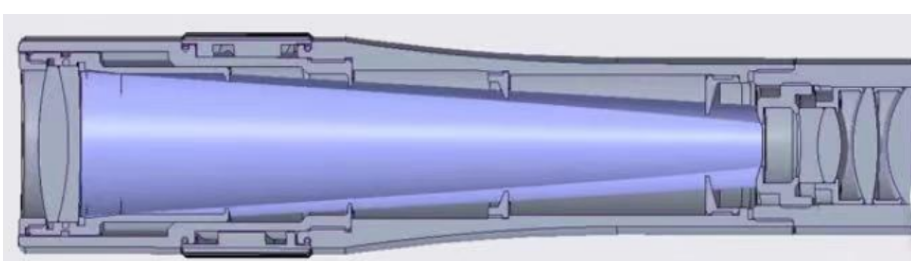

Figure 5: Telescope Inner Diagram

Requirement	**Verification**
1. The telescope has at least an 8x magnification rate. 2. The telescope can be adjusted manually. 3. The telescope is waterproof in light rain.	1. Put the camera at the eyepiece of the telescope and take two pictures of a line drawn on a white with and without the telescope. Then measure the line in two pictures and see if they have a difference of 8 times. 2. Test the telescope's focus function by rotating the knob to see if it works. 3. Use the telescope for 10 minutes in light rain, then check for clarity.

Table 1: R&V Table of Telescope

2.3.2 LED (Screen) Board

The purpose of the LED screen is to display the video captured by the camera and show the result of the identification from the software identification subsystem on the mobile phone. To ensure a comfortable viewing experience, the resolution and refreshing rate should be adequate for the human eye. Additionally, the size of the screen should be proportionate to the overall size of the product.

Requirement	Verification
1. The resolution should be 1080*1920. 2. The refreshing rate should be at least 30Hz 3. The size of the screen should be less than 5.5 inches. 4. The screen should be able to connect to the Raspberry Pi using the DSI interface.	1. Check the LED screen's user manual to confirm the parameters. Compare them with our requirements. 2. Use a ruler to measure the diagonal of the screen. Check if the outcome is less than 5.5 inches.

Table 2: R&V Table of LED Board

2.3.3 Recorder

The recorder should be a portable camera, which would capture the video behind the telescope. It would transmit the video data to the Raspberry Pi with CSI interface, and later transmit to the software identification subsystem for later identification.

Requirement	Verification
1. The recording resolution should be high enough for later identification in the software identification subsystem, in order to make sure of the identification accuracy. The ideal resolution should be more than 2-megapixel. 2. The camera should have basic functions of automatically adjusting the camera to adapt to the environment's luminance, and focus on the frame through the telescope subsystem. 3. The distance between the camera and ocular should be carefully adjusted when designing the spatial arrangement. 4. The camera should be able to connect to the Raspberry Pi with the CSI interface.	1. Read the camera's user manual to confirm the function and resolution. Confirm that they meet the requirements. 2. Use the camera to take a picture and check the resolution of the picture file. 3. Carefully adjust the distance between the camera and telescope, take the picture, and check the clarity.

Table 3: R&V Table of Recorder

2.3.4 Red-dot Laser Diastimeter

The laser diastimeter is used to measure the distance between the telescope and the observed bird, transmitting the data to the Raspberry Pi for automated focusing of the mechanical structure. Note that this function is an alternative feature to implementation. Because this focus technology is the first generation of autofocus functions for cameras and is outdated nowadays.

2.3.5 Stepper Motor

The stepper motor is used to control the focus-adjusting mechanism. It takes inputs generated by the Raspberry Pi and provides torque to rotate the knob on the telescope.

Requirement	Verification
1. The diastimeter should be able to connect to the Raspberry Pi with GPIO 2. The diastimeter should be able to detect objects at least 15 meters away.	1. Check the diastimeter's user manual to confirm the parameters. Compare them with our requirements. 2. Prepare an item in the size of a regular bird and put it 15m away from the diastimeter outdoors on a clear day. Connect the diastimeter and use it to measure the distance to the item. Check if the output distance is around 15m with a 10% error.

Table 4: R&V Table of Red-dot Diastimeter

Requirement	Verification
1. The stepper motor should be able to connect to the Raspberry Pi with GPIO 2. The stepper motor should be able to take at least 0-5V and input. 3. The stepper motor should be able to provide torque that can rotate the telescope's focus-adjusting knob.	1. Check the stepper motor's user manual to confirm the parameters. Compare them with our requirements.

Table 5: R&V Table of Stepper Motor

2.4 Control System

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.

2.4.1 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 6: R&V Table of Power Supply

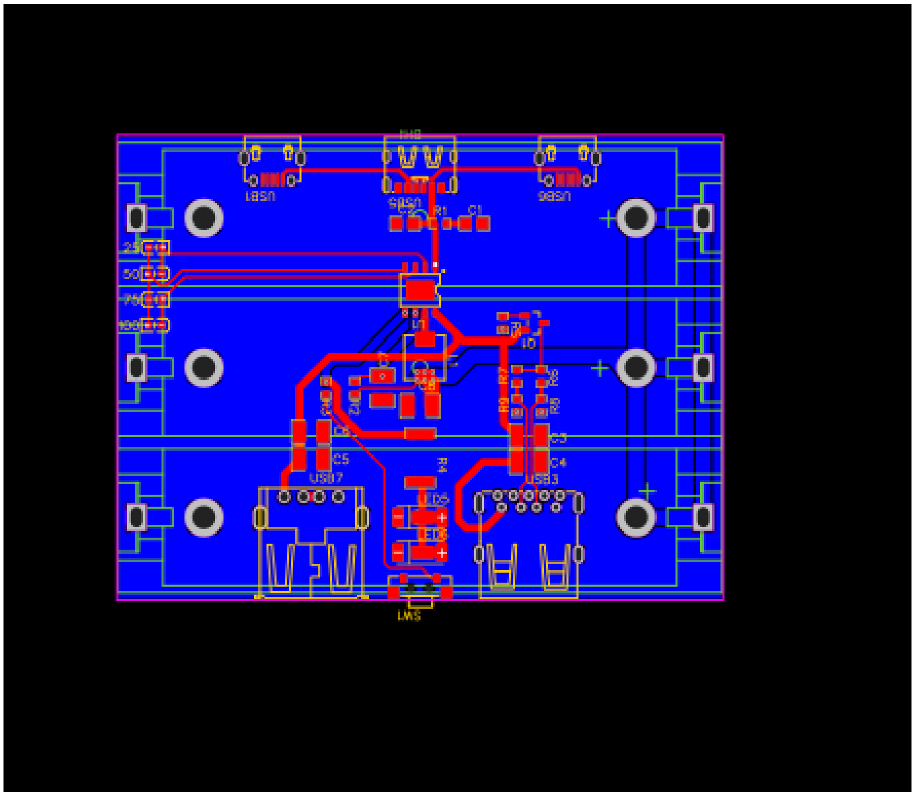

Figure 6: Power Supply PCB Layout

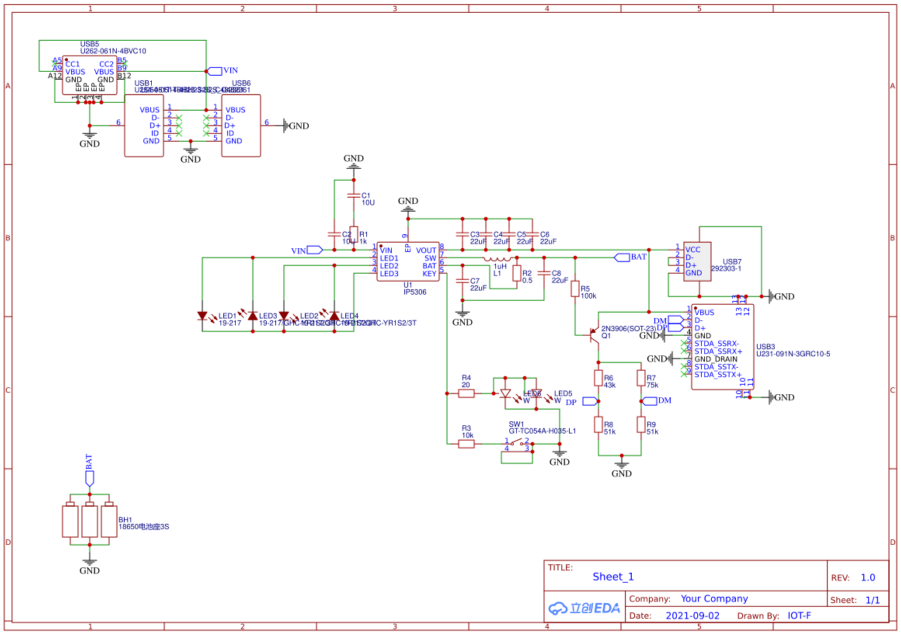

Figure 7: Power Supply Schematic

2.4.2 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.

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 7: R&V Table for Raspberry Pi

2.5 Recognizing System

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 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.

2.5.1 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 8: R&V Table for Recognizing Module

2.5.2 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 9: R&V Table for Display Module

2.6 Tolerance Analysis

2.6.1 LED (Screen) Board

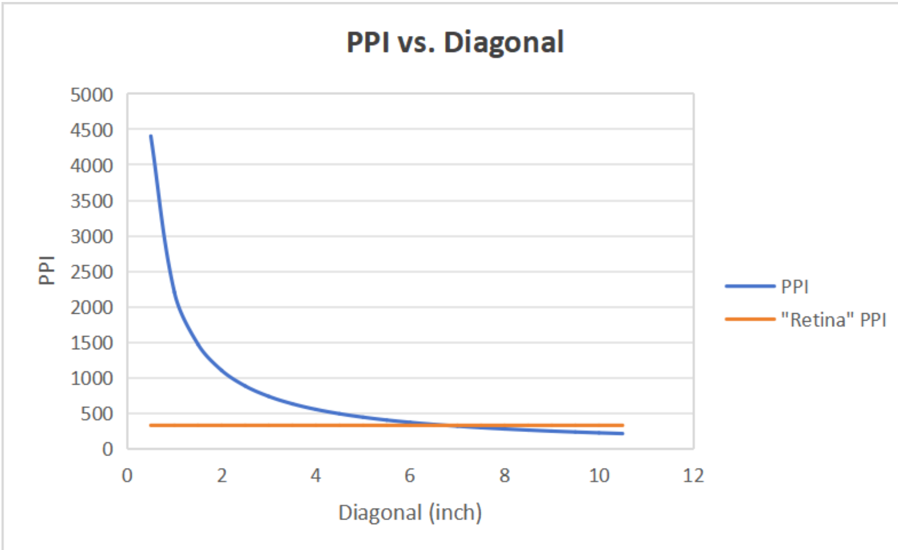

Figure 8: PPI vs. Diagonal for 1080*1920 Resolution

When using a screen, the clarity of the display is determined by PPI (pixels per inch) rather than resolution.

$$PPI = \frac{\sqrt{H^2 + V^2}}{Inch} \tag{1}$$

H is the number of horizontal pixels and V is the number of vertical pixels for a screen. Inch is the diagonal of the screen in inches. According to Steve Jobs, 326 pixels per inch is "Retina" quality[7].

Therefore, according to the PPI vs. Diagonal for 1080*1920 plot, to meet the requirement of "retina" quality, the size of the screen we choose should not be larger than about 7 inches.

2.6.2 Stepper Motor

We want to calculate how much power and torque we need for the stepper motor.

$$Torque = r \cdot F \tag{2}$$

$$Power = T \cdot \omega \tag{3}$$

r is the radius of the telescope's knob. F is the force that is needed to rotate the knob. ω is the angular speed of rotation. For our project, r is 0.032m, F is 1N, and ω is between 0.1

and 1 rad/s. We have the following results.

$$T = 0.032 N \cdot m \tag{4}$$

$$0.0032W \leq Power \leq 0.032W \tag{5}$$

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

- **Yuhao Wang (Mechanical Engineering):**
  - Role: Design and 3D printing of the device casing.
  - Rate: $15/hour
  - Estimated Hours: 120
  - Total: $15/hour × 120 hours = $1800
- **Tiancheng Lv (Mechanical Engineering):**
  - Role: Assist in design and mechanical integration of components.
  - Rate: $15/hour
  - Estimated Hours: 120
  - Total: $15/hour × 120 hours = $1800
- **Haoxuan Du (ECE):**
  - Role: Development of software for image capture and bird identification, electronic integration.
  - Rate: $15/hour
  - Estimated Hours: 120
  - Total: $15/hour × 120 hours = $1800
- **Junhao Zhu (ECE):**
  - Role: Integration of software with hardware and user interface design, electronic circuit design.
  - Rate: $15/hour
  - Estimated Hours: 120
  - Total: $15/hour × 120 hours = $1800

Total Labor Cost: $7200

3.1.2 Total Project Cost

Description	Manufacturer	Part #	Quantity	Cost (CNY)	Cost (USD)
Monocular Telescope	Generic	N/A	1	100	$15
Raspberry Pi 5.0	Raspberry Pi	RPi5	1	700	$105
Lens Module	Compatible with RPi	N/A	1	Included in RPi cost	$0
Power Bank	Generic	N/A	1	100	$15
5.5 inch IPS LCD Screen	Generic	N/A	1	100	$15
Total Parts Cost (USD)					**$150**

Figure 9: Cost of each component

Grand Total: $7200 + $150 = $7350

3.2 Schedule

Week	Task	Responsible Team Member(s)	Details
#1-2	Project Planning & Parts Procurement	All members	Define project goals, select architecture, finalize design strategy, research, and order parts. Arrange initial team meetings to distribute tasks and set milestones.
#3-4	Initial Design & Parts Acquisition	Tiancheng Lv, Yuhao Wang	Start mechanical design of the casing using CAD software. Purchase and verify electronic components like Raspberry Pi, lens module, and other
#5-6	3D Printing & Software Development Start	Tiancheng Lv, Yuhao Wang, Haoxuan Du, Junhao Zhu	Finalize casing design and start 3D printing. Begin basic software development for image capture and test with Raspberry Pi.
#7-8	Assembly & Initial Testing	All members	Assemble electronic components in the casing. Conduct initial tests for mechanical and electronic integration. Troubleshoot any issues found.
#9-10	Advanced Software Development & Integration	Haoxuan Du, Junhao Zhu	Develop and integrate advanced software features, including real-time image processing and bird identification. Ensure software-hardware seamless operation.
#11-12	Prototype Refinement & User Interface Design	All members	Refine prototype based on testing feedback, focusing on ergonomics and user interface. Enhance software for improved user interaction and display.
#13-14	Comprehensive Testing & Debugging	All members	Perform comprehensive system testing for functionality, software stability, and user experience. Identify and resolve bugs or hardware issues.
#15-16	Final Adjustments & Documentation	All members	Make final design and software adjustments. Compile project documentation, including specifications, user manual, and prepare for the final presentation.
#17-18	Final Testing, Presentation & Submission	All members	Conduct final system tests and refinements. Present the completed project, demonstrating features and capabilities. Submit final report and documentation for evaluation.

Figure 10: Schedule and task distribution

4 Ethics and Safety

4.1 Ethics Considerations

In developing a bird-watching telescope capable of recognizing bird species, several ethical concerns arise, primarily related to privacy, environmental impact, and data handling:

- Privacy: The device's ability to capture images could inadvertently invade the privacy of individuals if used in populated areas. To mitigate this, the software will be designed to activate only in recognized natural habitats, minimizing unintended surveillance.
- Environmental Impact: The construction and usage of the device should not disturb the natural behavior of birds or their habitat. The team will ensure that the device operates quietly and blends with the environment to prevent any potential stress or harm to wildlife.
- Data Handling: Any data collected, including images and location data, will be handled responsibly. The team will implement data encryption and secure storage protocols to protect this information from unauthorized access.

4.2 Safety Concerns and Mitigation

- Battery Safety: Since the device uses a portable power bank, there's a risk of battery leakage or explosion. A lab safety document will outline proper handling, storage, and disposal methods for batteries to mitigate this risk.
- Device Handling: The telescope must be ergonomically designed to prevent strain or injury during prolonged use. The design will include a lightweight, balanced structure with grip handles to ensure safe and comfortable operation.
- Electronic Circuit Safety: To prevent electrical hazards, the circuit design will include protective measures such as fuses and circuit breakers. The device will be enclosed in a non-conductive, durable casing to prevent accidental shocks.
- Software Safety: To prevent software malfunctions that could lead to unsafe conditions, the software will undergo rigorous testing, including stress tests and scenario simulations, to ensure its reliability in various environmental conditions.

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