ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

RASPBERRY PET PAL

Team #31

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1 Introduction

1.1 Problem and Solution Overview

In today's fast-paced and high-pressure world, young people are experiencing both loneliness and poverty. They long for social engagement and relationships, but most social activities are costly and pose a risk of infection during the pandemic. As a result, many young people turn to pets for companionship. However, owning a pet can financially burden those struggling to make ends meet. Furthermore, cute pets can sometimes create chaos in their owners' homes. Thus, an affordable and functional electronic pet seems like a necessary solution. Unfortunately, the current products are either too expensive or fail to match a real pet's abilities, such as voice and behavior interaction. Therefore, lonely and financially strapped young people require an affordable and functional electronic pet.

The electronic pet should be able to perform all the desired functions reliably and accurately. It should be able to follow objects, display a range of emotions on its screen, recognize and respond to voice commands, carry and weigh objects, count steps, avoid obstacles, and interact with limbs using infrared detection. It will be equipped with cutting-edge technology and advanced features for an interactive and engaging experience. It can follow its owner's movements through target detection technology while displaying a range of expressions through a high-quality display screen. With its voice recognition and corresponding audio output, this pet can communicate with its owner and respond to commands. Additionally, it can assist in carrying objects through a built-in weighing system, track physical activity through its motion detection capabilities, and navigate its surroundings using obstacle avoidance technology. Furthermore, the pet's limbs are designed for interactive play and detection through infrared technology. With its advanced features, this electronic pet offers unparalleled interactivity and companionship for pet lovers of all ages.

1.2 Visual Aid

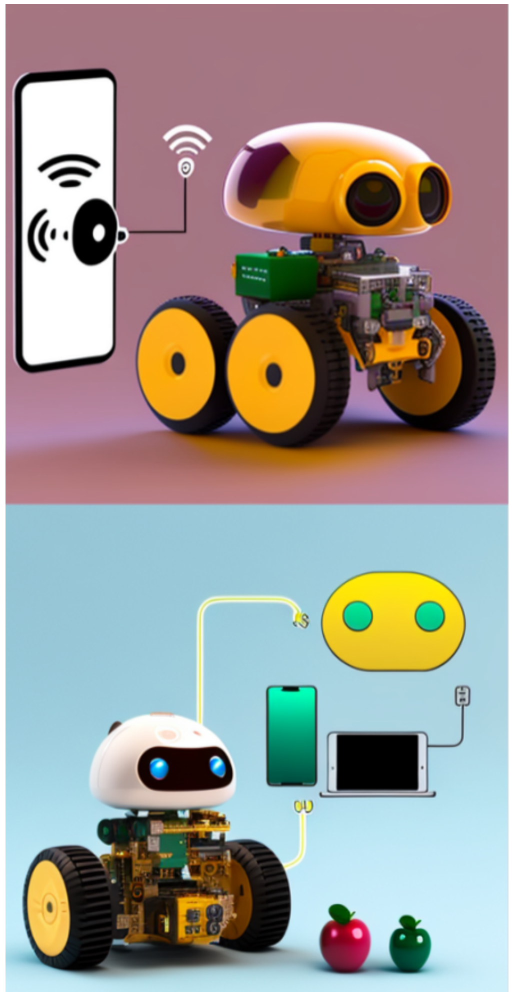

Figure 1: Visual Aid

1.3 High-Level Requirements List

- Functionality: The electronic pet should be able to perform all the desired functions reliably and accurately. It should be able to follow objects, display a range of emotions on its screen, recognize and respond to voice commands, carry and weigh objects, count steps, avoid obstacles, and interact with limbs using infrared detection.

- User experience: The electronic pet should be easy to use and interact with. Users should be able to easily control and communicate with the pet through its display screen and voice recognition system. The pet should also respond to user interactions fun and engagingly.

- Durability and stability: The electronic pet should be built using durable and stable components to ensure that it can withstand regular use without breaking down. The car should be stable enough to navigate different terrains and avoid obstacles without getting stuck or tipping over.

- Battery life: The electronic pet should have a long-lasting battery life to ensure that it can be used for extended periods without recharging. This is particularly important if the pet is intended for use by children or in educational settings where it may be used for extended periods.

2 Design

2.1 Block Diagram

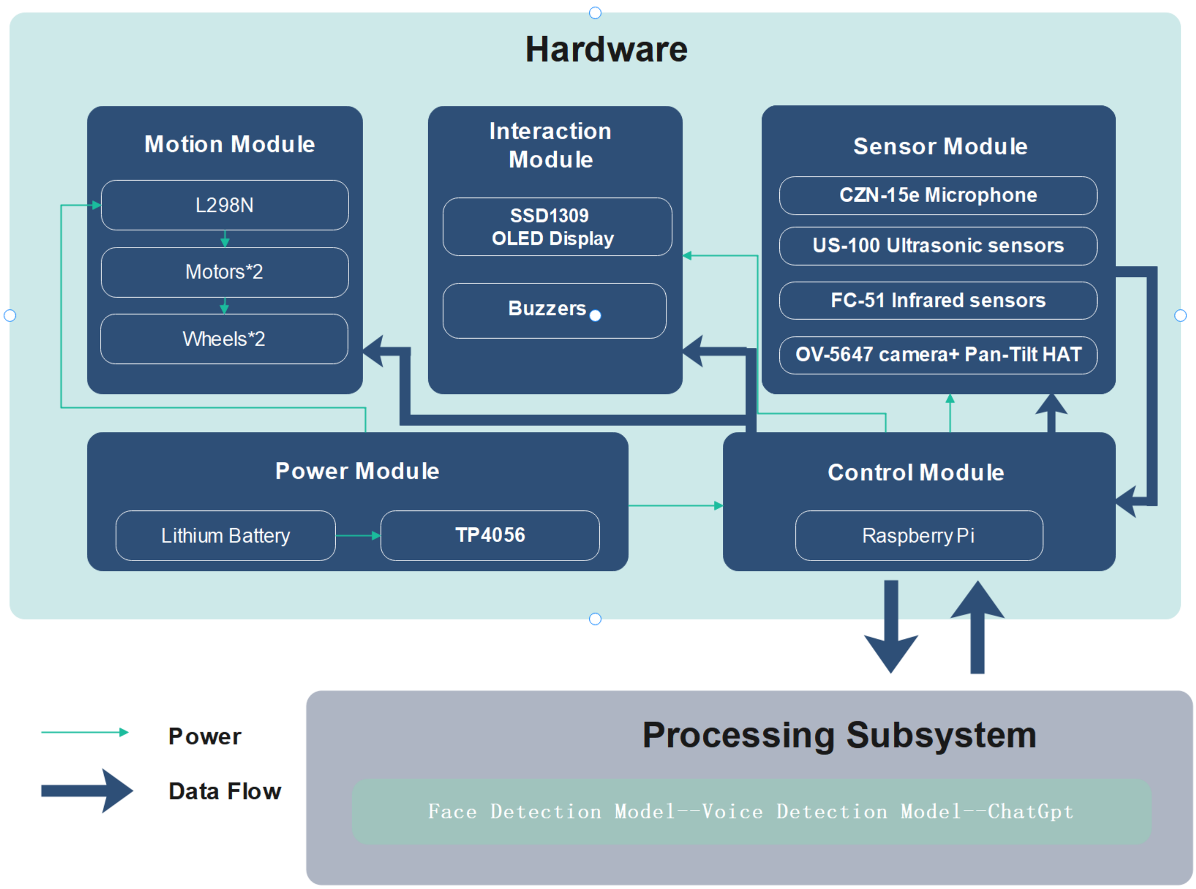

Figure 2: Block Diagram

Our system consists of software and hardware components. In terms of hardware, we have five modules: control, motion, interaction, sensor, and power. The control module is implemented by Raspberry Pi, which serves as the hub connecting our software and hardware. The software controls the hardware through the Raspberry Pi. The power module relies on lithium batteries for power supply and uses a protection circuit to prevent damage to the Raspberry Pi and sensors. The motion module relies on L298N to control two motors to achieve pet movement. The interaction module includes voice interaction and display interaction. The sensor module captures external information through ultrasonic sensors, infrared sensors, cameras, microphones, etc.

2.2 Physical Structure

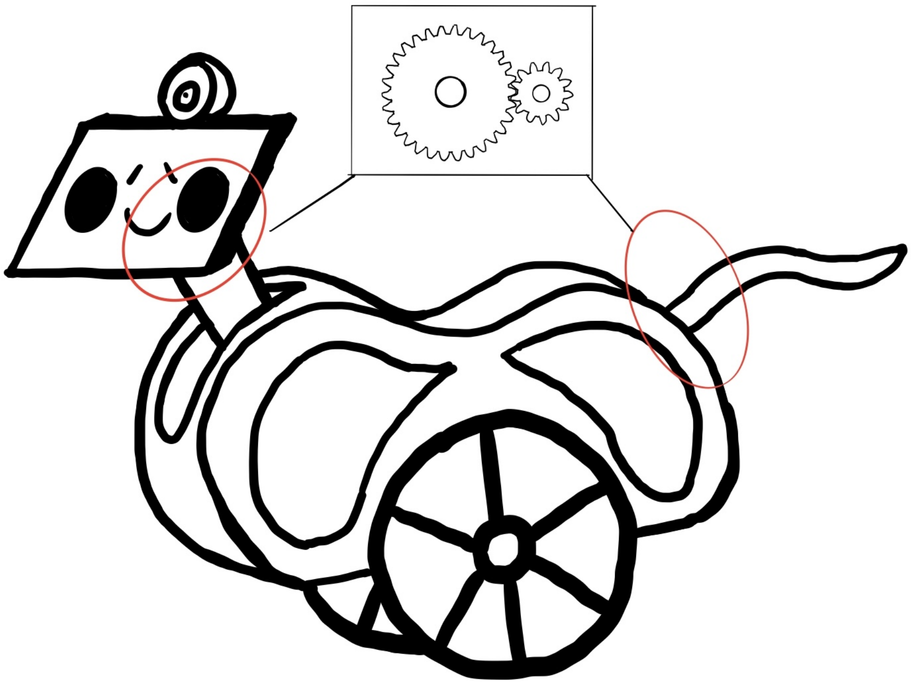

Figure 3: Original Design Sketch

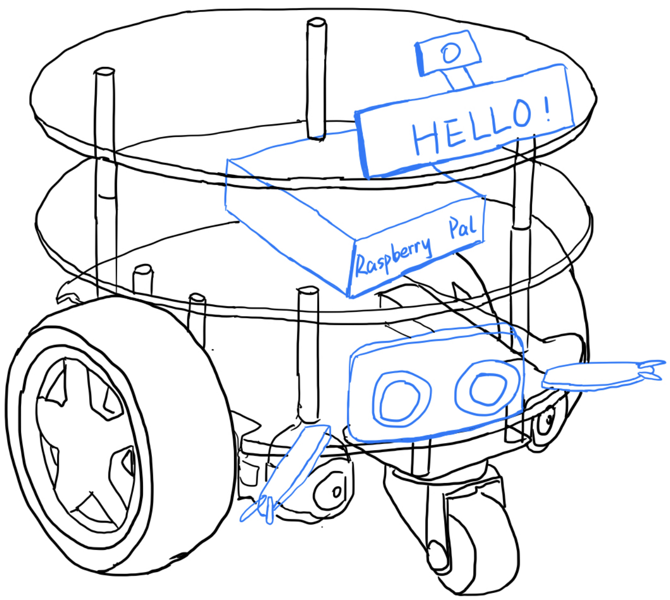

Figure 4: Recent Design Sketch

The physical structure is a three-layer car. The base layer is the bottommost layer of the car, which acts as the foundation for the other layers. It is usually a flat and rigid board that holds the motors, wheels, battery, and other components like ultrasonic sensors, and infrared sensors. The base layer may also have mounting holes for attaching the other layers. The control layer is the middle layer of the car, which houses the Raspberry Pi board and other control electronics. The control layer is responsible for processing the sensor data and sending commands to the motors. The interactive layer is the topmost layer of the car, which is designed to hold the pan-tilt camera and LED screen. The whole appearance will be designed to be very cute.

2.3 Functional Overview and Block Requirements

The electronic pet module consists of four main components: the control module, the motion module, the sensor module, and the power module.

2.3.1 Power Module

The power system provides power to the device. It consists of a 18650 lithium-ion battery pack (5V 6000mAh) and a protection circuit. The protection circuit is designed to ensure the safe charging and discharging of the battery pack as well as make sure the current supply to the rpi won't be too large to damage it. It supports charging the lithium-ion battery pack through a type-C interface and can provide a maximum output current of 3A.

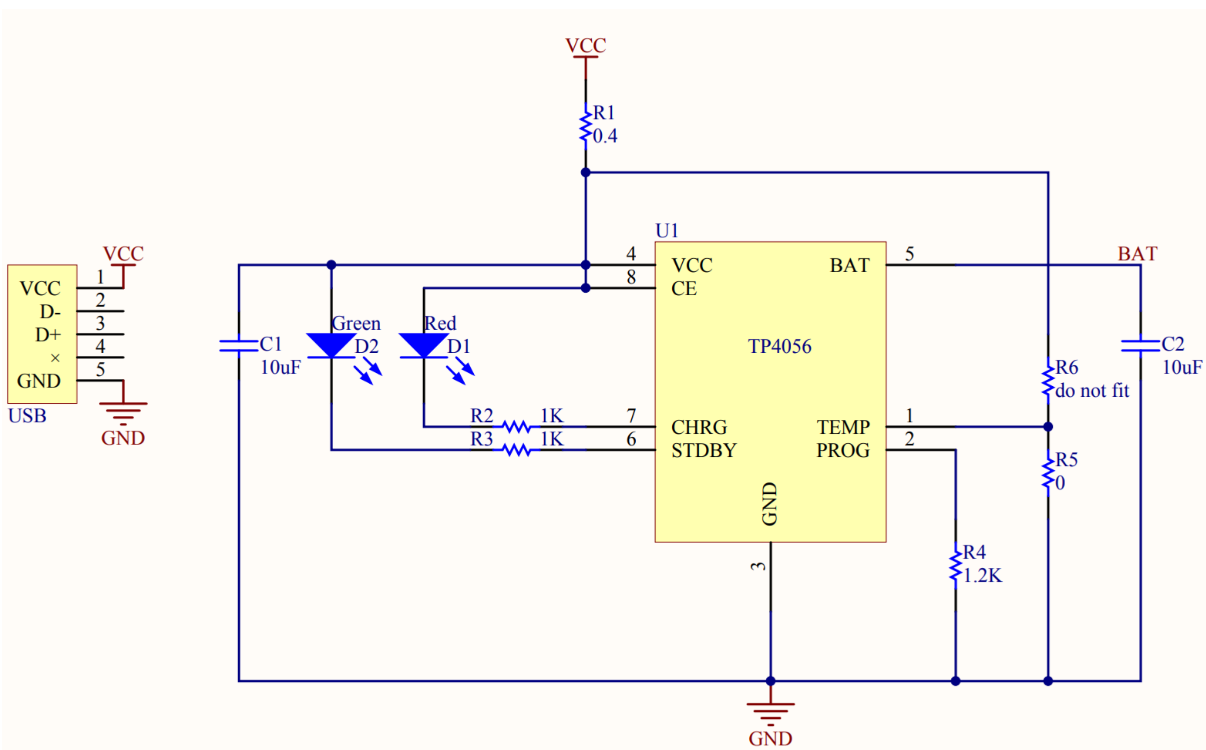

Figure 5: Diagram of the protection circuit.

Table 1: Requirements and Verification for Power System

Requirements	Verification Steps
The power module shall have nominal voltage of 5V	Measure the voltage of the power module
The power module shall have nominal current of 3A	Measure the current of the power module
The protection circuit shall support safe charging and discharging of the battery pack	Test the protection circuit with a charging and discharging cycle
The protection circuit shall support charging through a type-C interface	Connect the protection circuit to a type-C charger and verify charging

2.3.2 Control Module

The control system manages the operation of the device. It consists of a Raspberry Pi board and a software program written in Python. The Raspberry Pi board provides a platform for running the software program and communicating with the hardware. The software program is written in Python and utilizes the GPIO Zero library to interface with the hardware. The GPIO Zero library provides a convenient interface for controlling the Raspberry Pi's GPIO pins.

First, we wrote the raspbain operating system into the rpi. After that, we connect the rpi and PC to the same Wifi spot. Then we can ssh PC to rpi using putty. In this way, we now know the IP address of the rpi. The next step is to settle the IP address of the rpi into a certain value. Then we change the pip source from the original one to the ones provided inside of China. After this, we finish the preparation work. We now can use vscode to write python code to control the whole system.

Table 2: Requirements and Verification for Control System

Requirements	Verification Steps
rpi with correct os	Check if rpi can be started correctly
rpi connect to the same wifi as PC	Check it on PC cmd using ”ping -4 raspberrypi.local”
rpi with fixed ip	Use ”ipconfig” on to see ip and restart to see if if the same
control rpi using python	Test GPIO port on vscode using motor

2.3.3 Motion Module

The **motion module** consists of the motor driver board, motors, and wheels. The motor module is connected to the Raspberry Pi through GPIO pins, and the Python-written method is used to control the motor speed and achieve differential drive control of the two wheels. The primary function of this module is to move the pet robot.

Table 3: Requirements and Verification for Motion System

Requirement	Verification
The GPIO pins do PWM functionality	Changing PWM can change the speed of the motors
L298N works	The speed of the two motors can be varied
Robot can go straight and turn successfully	Observe the robot'path

2.3.4 Sensor Module

The **sensor module** includes the OV-5647 camera module, a pan-tilt module, the US-100 ultrasonic sensor, and the FC-51 infrared sensor. The Raspberry Pi is used to control the GPIO pins and communicate with other hardware through the GPIO Zero library. This module is responsible for sensing the environment and detecting obstacles.

Table 4: CZN-15e Microphone

Requirement	Verification
Voltage range: 1.5V-10V	Measure the voltage of the pin use the oscilloscope
Current consumption: Max.0.5mA	Measure the current of the pin
Standard operation voltage:4.5V	Check if the raspberry pi receive the voice file correctly

Table 5: US-100 Ultrasonic sensor

Requirement	Verification
Power and Logic Voltage: DC 2.4V 5.5V	Measure the voltage of the pin use the oscilloscope
Current: 2mA	Measure the current of the pin
Detection Distance: 2cm – 450 cm	Move an object in front of the sensor and check if the raspberry pi receive the correct distance

Overall, these four modules work together to create a functional electronic pet that can be controlled remotely and move around while sensing the environment.

Table 6: FC-51 Infrared sensor

Requirement	Verification
Operating Voltage: 3.0V – 6.0V	Measure the voltage of the pin use the oscilloscope
Detection range: 2cm – 30cm	Move the sensor around a sign and check if the raspberry pi receive the right signal and if the IR receiver light is correct

Table 7: OV-5647 camera

Requirement	Verification
voltage: 3.3V/5V	Measure the voltage using the oscilloscope and check if it is around 5V
interface: I2C	Check if the raspberry pi receive the correct video

2.4 Tolerance Analysis

Motor driver board compatibility issues: If the motor driver board is not compatible with the motors or the Raspberry Pi, it may not function properly or could potentially damage the components. This could be mitigated by carefully selecting a motor driver board that is rated for the appropriate voltage and current and has the necessary features to support the required number of motors. This interface is responsible for translating the commands received by the Raspberry Pi into the necessary signals to drive the motors. Any variation or error in this interface can lead to erratic behavior or complete failure of the car.

To analyze this interface mathematically, we can consider the specifications of the motor controller board and the requirements of the Raspberry Pi. Let us assume that the motor controller board can receive commands from the Raspberry Pi with a voltage range of 3.3V to 5V, and can drive the motors with a current range of 0A to 5A. The Raspberry Pi sends commands to the motor controller board through a GPIO (General Purpose Input/Output) pin.

To ensure that the Raspberry Pi car operates correctly, we need to ensure that the voltage and current levels at the interface between the Raspberry Pi and the motor controller board are within acceptable tolerances. Let us assume that the allowable voltage tolerance is +/- 0.1V and the allowable current tolerance is +/- 0.1A.

If we consider a worst-case scenario where the Raspberry Pi sends a command with a voltage of 3.3V and the motor controller board outputs a current of 5A, we can calculate the maximum voltage drop and current rise that would still be within tolerances. The maximum allowable voltage drop would be 0.1V, which means that the voltage at the interface could drop to 3.2V and still be within tolerance. The maximum allowable current rise would be 0.1A, which means that the current at the interface could rise to 5.1A and still be within tolerance.

To implement this interface with the required tolerances, we can use a voltage regulator and a current limiter circuit at the output of the Raspberry Pi's GPIO pin. The voltage regulator would ensure that the voltage at the interface is always within the allowable tolerance range, while the current limiter would ensure that the current at the interface is always within the allowable tolerance range. These circuits can be designed and implemented using off-the-shelf components such as voltage regulators and current limiters, and can be tested and validated to ensure that they meet the required specifications.

Power supply issues: If the lithium battery voltage drops too low or the Raspberry Pi and motor driver board are not properly protected, it could result in damage to the components or loss of power. This could be mitigated by selecting a lithium battery with the appropriate voltage and capacity for the project, using a charging and protection circuit to ensure safe operation, and monitoring the battery levels to prevent over-discharging. To analyze the tolerance requirements of the power supply, we can use statistical methods such as Monte Carlo simulation to determine the effects of manufacturing variations on the power supply voltage. We can model the power supply voltage as a normal distribution with a mean voltage value and a standard deviation that represents the manufacturing tolerance.

Assume that the required voltage for the Raspberry Pi car is 5V, and the manufacturing tolerance for the power supply is +/- 0.1V. We can model the power supply voltage as a normal distribution with a mean value of 5V and a standard deviation of 0.1V. Using Monte Carlo simulation, we can generate a large number of random samples from this distribution and calculate the percentage of samples that fall within the acceptable voltage range.

Suppose we require the power supply voltage to be within +/- 0.2V of the target voltage. In that case, we can calculate the percentage of samples that fall within this range using the cumulative distribution function of the normal distribution. If this percentage is high enough to meet our requirements, then we can conclude that the power supply tolerance is feasible and can be implemented.

Suppose the calculated percentage is not high enough to meet our requirements. In that case, we may need to adjust the power supply design or specifications to increase the tolerance or reduce the manufacturing variations to ensure that the power supply can provide a stable and consistent voltage to the Raspberry Pi car.

AI model size: Considering the computational power of raspberry Pi, we should choose the lite weight AI model for inference. we can use the following formula to estimate the memory required for a neural network:

Memory (MB) = (Number of Parameters x Precision) / (8 x 1024 x 1024)

Where:

- Number of Parameters: The number of parameters in the neural network
- Precision: The precision of the data (e.g. 32-bit, 16-bit, etc.)

- 8 x 1024 x 1024: Conversion factor to convert bytes to megabytes

Assuming a neural network with 100 million parameters and a precision of 16 bits, the memory required would be:

Memory (MB) = (100,000,000 x 16) / (8 x 1024 x 1024) = 190.73 MB

This calculation shows that a neural network with 100 million parameters and a precision of 16 bits would require approximately 190 MB of memory. This can be a challenging requirement for the Raspberry Pi Car, which has limited memory resources.

Physical Structure Simulation The physical structure of the car is likely to be its stability and balance, as this affects its ability to navigate and maneuver. To analyze the tolerance of the physical structure of the Raspberry Pi car, we need to consider the critical dimensions that affect its stability and balance. These dimensions might include the distance between the wheels, the height of the car, the weight distribution of the components, and the alignment of the motors and sensors. Here, we do force simulation on the bottommost layer, assume the weight above is 1100g and the material of layer is Acrylic.

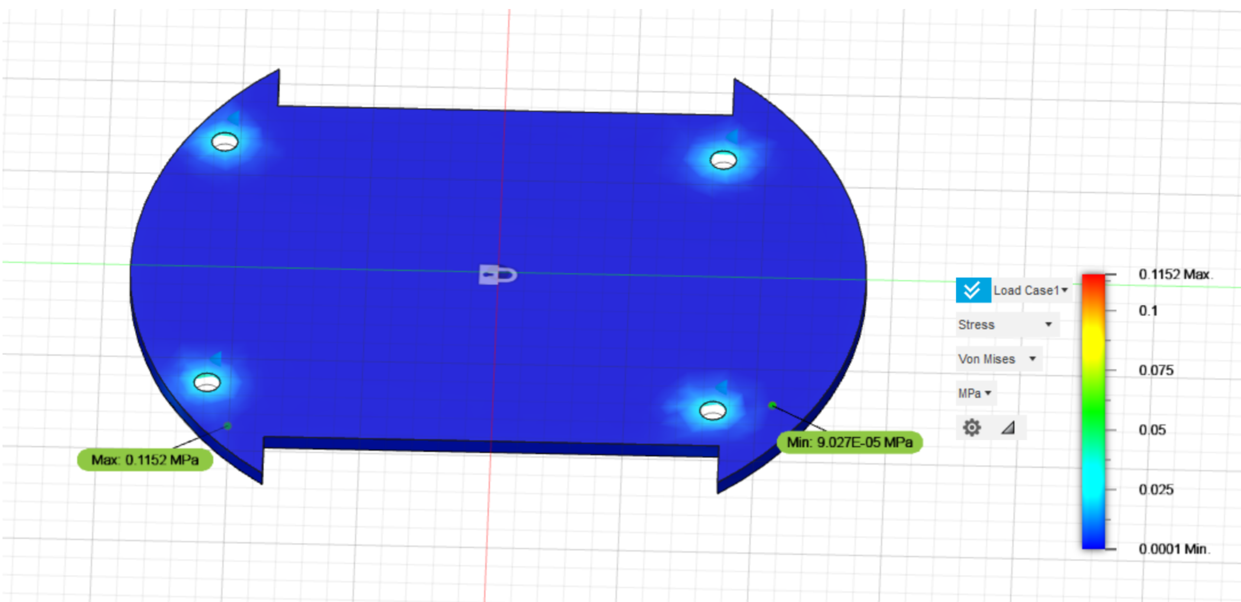

Figure 6: Simulation of Stress

And Acrylic's ultimate stress is 78.9Mpa. This layer plate will not be broken. After we determine final positions of all components, we will do simulation first to see the weight distribution and balance.

3 Cost and Schedule

3.1 Cost Analysis

The labor cost for our project is estimated as follows. The estimated salary is ¥60 per hour per person, following the salary standard for Zhejiang University undergraduates. We expect 20 hours of contribution from each team member each week, due to the complexity of our design. This project is expected to be completed in 16 weeks. With the assumptions given above, the calculation of labor cost is as follows.

$60/hr \times 2.5 \times 15hr/week \times 16week \times 4people = 144000$

Table 8: Cost Analysis of Components

Description	Mft	Part #	Qty	Cost	Total
3.7V 6000mAh lithium battery	Delipow	18650	2	26.9	45.4
4GB Raspberry Pi	Raspberry Ri Foundation	4B	1	998	998
2WD trolley with 3-6V motors	Jiaxingwei	JXINW	1	15.8	15.8
3.3/5V Pan-Tilt Hat	Shenzhen Continental Electronics	PCA9685 & TSL2581	1	97	97
32G 120mb/s tf card	SanDisk	ZN6MA	1	28.8	28.8
1A battery protect	TELESKY	534316461	1	3.59	3.59
500w pixels camera	Dalysheng	Raspberry Pi Camera	1	19.8	19.8
3.3-5V infrared sensor	Risym	E18D80NK	2	3.72	7.44
1.4-5.5V 2mA ultrasonic module	Risym	US-100	1	16.4	16.4
Motor drive module	Risym	L298N	1	9.8	9.8
					1242.03

3.2 Schedule

Include a time-table showing when each step in the expected sequence of design and construction work will be completed (general, by week), and how the tasks will be shared between the team members. (i.e. Select architecture, Design this, Design that, Buy parts, Assemble this, Assemble that, Prepare mock-up, Integrate prototype, Refine prototype, Test integrated system).

	Xiaoshan Wu	Xiaomin Qiu	Yirou Jin	Shuhan Guo
3/18	deploy existing models locally	Set up local environment	Purchase components	Design model of the robot
3/25	Configuring environment on Raspberry Pi	Implement face detection model locally	Assemble the robot and test the function of the components	Implement motion module and make unit test, check if the power module work correctly
4/1	Integrate voice detection algorithm into Raspberry Pi and deal with the signal transmission problem	Debug the face detection model and debug the video signal transmission between raspberry pi and PC	Evaluate the robot's basic performance and the sensors' function	Evaluate the motion module performance and make the robot's shell
4/8	Optimize the algorithm and integrate ChatGpt into the algorithm	Deploy face detection module and optimize signal transmission problems	Make integrate test and use the robot to perform Track finding and obstacle avoidance functions	Optimization of issues such as robot shape and steering sensitivity
4/15	Performance evaluation and Debug	Performance evaluation and Debug	Performance evaluation and Debug	Performance evaluation and Debug
4/22	Optimize the control module performance	Optimize the control module performance	Optimize the sensor module performance	Optimize the motion module performance
4/29	Fix bugs and make integration testing	Fix bugs and make integration testing	Fix bugs and make integration testing	Fix bugs and make integration testing
5/8	Prepare the demo and Presentation	Prepare the demo and Presentation	Prepare the demo and Presentation	Prepare the demo and Presentation
5/22	Finish the final report	Finish the final report	Finish the final report	Finish the final report

4 Ethics and Safety

4.1 Ethics

Data privacy: The electronic pet module may collect and store personal data, such as images and audio recordings, as well as potentially sensitive data such as school network information. It is important to ensure that this data is collected and stored securely and that it is not used for any unauthorized purposes.

Accessibility: The electronic pet module should be designed to be accessible to a wide range of users, including those with disabilities. This may include features such as audio or haptic feedback, as well as support for assistive technologies.

Security: The electronic pet module should be designed to be secure against potential attacks, such as hacking or malware. This may include features such as encryption, firewalls, and user authentication.

4.2 Safety

Electrical Safety: The electronic pet may pose a risk of electric shock or overheating if not designed and constructed properly. Electrical safety features, such as grounding and insulation, must be incorporated into the design and manufacturing process to mitigate this risk.

Mechanical Safety: The electronic pet's moving components, such as its limbs, may pose a risk of injury if not designed and manufactured with safety in mind. It is important to ensure that the pet's moving parts are not sharp, can't pinch or crush, and are not likely to break off during use.

Teammember Safety: Working alone in the lab is strictly prohibited. A minimum of two individuals must be present in the lab at all times. Prior to being granted lab access, completion of mandatory online safety training is mandatory.

5 Citation

References

[1] ACM Code of Ethics and Professional Conduct, web page. Available at: https://www.acm.org/codeof-ethics. [Accessed March 2023].

[2] European Union, ”General Data Protection Regulation (GDPR)”, Official Journal of the European Union, vol. 59, no. 1, pp. 1-88,2016.

[3] IEEE Code of Ethics, web page. Available at: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed March 2023].