ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Robot for Gym Exercise Guidance

Team #34

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1 Introduction

1.1 Problem

In modern society, the significance of physical well-being is progressively increasing. When people engage in gym workouts, it is crucial for them to ensure that their movements are executed in a proper form. Although some trainees opt to hire a personal trainer to maintain correct posture, not everyone can afford this luxury. Consequently, some individuals may fail to achieve desired results when exercising alone, and potentially cause muscle and joint damage due to incorrect movements. According to a study published in the Journal of Strength and Conditioning Research, "improper weightlifting technique is one of the most common causes of injury in eightlifting" [1]. Therefore, it is crucial to maintain proper form while exercising alone. In addition, people sometimes get distracted if they tend to count the number of the movement they do while doing exercise. It will be helpful if there is a robot that can count the number of the movement and give feedback to the user.

1.2 Solution

Inspired by the fact [2], [3] that the role of a personal trainer can also be fulfilled by robotics, our team aim to build an automated system that acts a gym trainer. We plan to achieve our goal from both the hardware and software aspects.

The hardware components of the robot comprise a mobile platform, a control console, a display screen, and a speaker. We also plan to equip our robot with a variety of sensors, including a camera and ultrasonic radars. By utilizing a camera and ultrasonic radars, the robot is capable of determining the user's location and distance. From the software perspective, we plan to adopt algorithms and framework such as Mediapipe to identify human movements when people are moving, compare with the existing action models, and give an performance evaluation and count the number of exercise done. The use of machine learning algorithms will enable the robot to provide more accurate feedback on the user's performance and suggest areas for improvement.

Overall, our solution aims to provide users with a personalized and effective gym training experience, utilizing the latest advancements in robotics and machine learning technologies. By taking a comprehensive approach to implementation, we hope to create a system that is not only effective but also efficient and easy to use.

1.3 Visual Aid

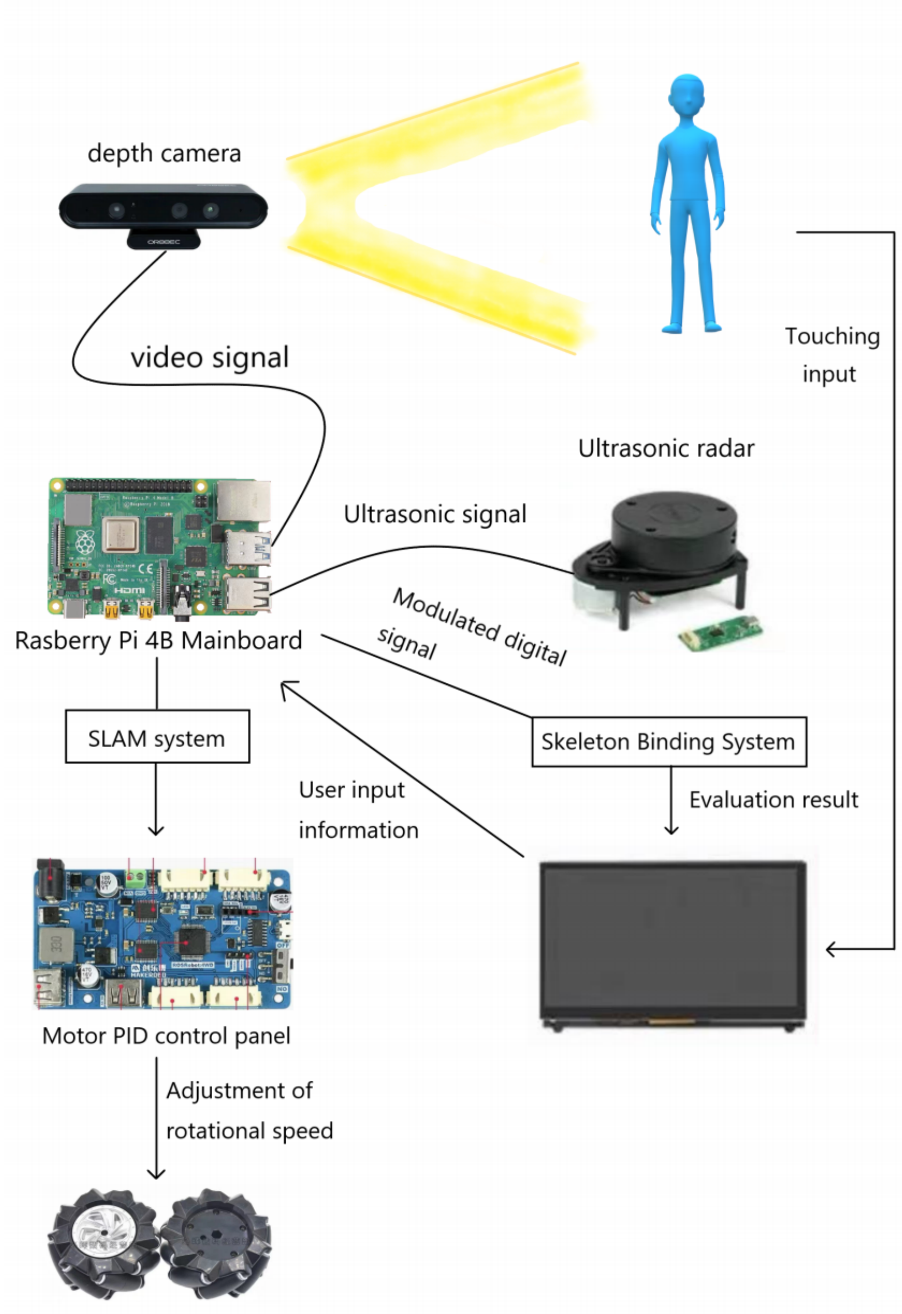

Figure 1: Visual Aid

1.4 High-Level Requirement List

- The robot should be able to use KCF algorithm to track and follow the user's location within a certain distance (2-3 meters) with the distance error smaller than 0.2 meter, using depth camera and ultrasonic radar to get the environment information.

- The robot should be able to recognize body key points and skeleton binding with larger than 0.95 overall high accuracy and speed (fewer than 10 seconds for one minute video), using Mask R-CNN network.
- The robot should be able to count and evaluate the user's performance of two common exercising movements, such as squats and push-up.
- The robot should be able to display the evaluation results on the display screen in a user-friendly manner.

2 Design & Requirements

2.1 Block Diagram

The block diagram is shown in Figure 2.

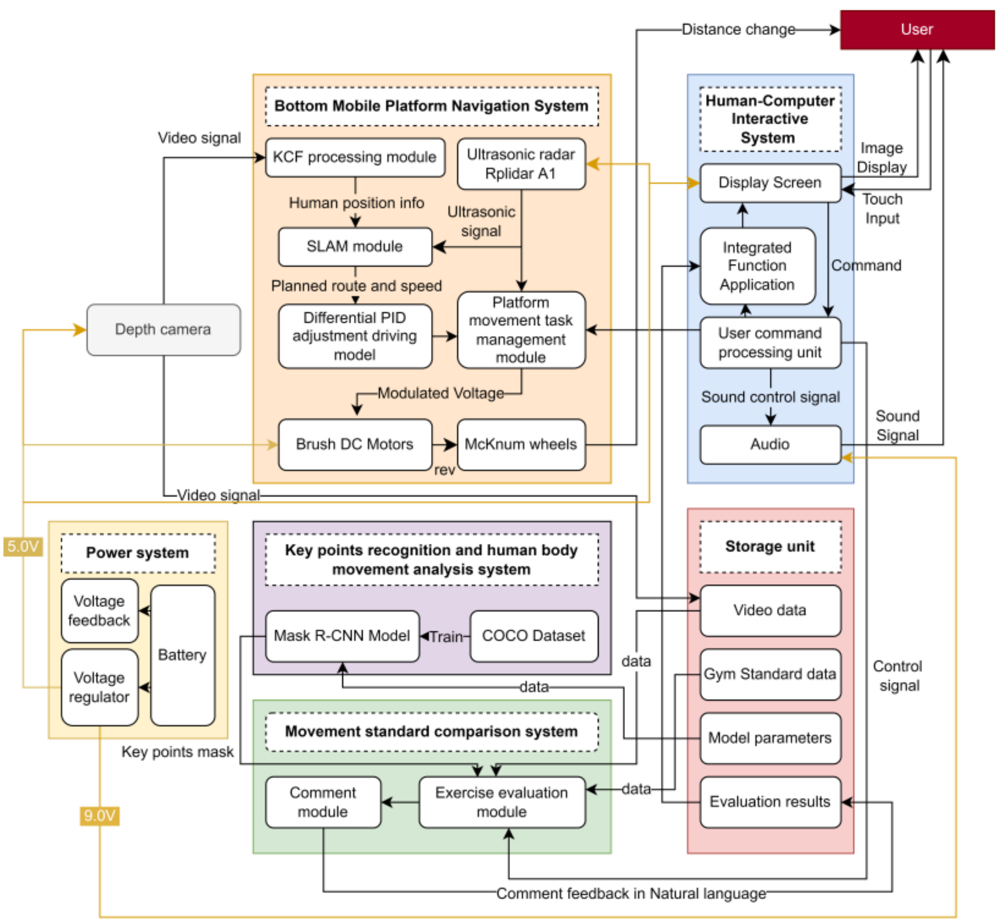

Figure 2: Block diagram

2.2 Subsystem Overview

2.2.1 Bottom mobile platform programming and hardware setting

We plan to take use of the ROS platform as the base movement platform of the robot. This robot platform contains two ultrasonic radars, steering gear and steering gear control system. The control system can be connected to the outer host to program more detailed movement assignments. We will use the camera to capture human's image, and use KCF algorithm to calculate the navigate task information for the steering gear, and then the robot can follow behind the human. We expect that the robot to work on a flat surface, not a rough dirt road. Some obstacles are allowed around the robot, and the robot will avoid them. In addition, other hardware components of our project include the display, the speaker, the control console and the camera.

2.2.2 Key points recognition and movement analysis of the human body

The most important part of this program is that we will use the Mask R-CNN to do the skeletal binding and key points recognition to determine the human's body movement status. When the robot is working, it will first record people's exercise as a video file. Then, it will analyze it to decide how it fits with the standard. In this step, we require the exerciser to do the exercise in the specified orientation. For example, during the squat, we ask the exerciser to face with the robot; during sit-ups, the user should turn the side towards the robot to facilitate movement analysis.

2.2.3 Movement standard algorithms

One important part in this research is that how we decide whether the exercise is "good" or not. For the sports like Chinese middle school broadcast gymnastics, we have a systematic evaluation system, in which we will mark the movement of the user and count the number of the standard movement they make. In such a rhythmic movement, we will use the speaker to play rhythm music or feedback. For such exercises as push-ups, and squats, in addition to detecting whether the corresponding movements are in place, we also need to count the number of a complete round of movements the user has already done.

2.2.4 Man-machine interactive system

All of the above mentioned functions will be integrated into a user-friendly program. In the robot's human-computer interaction platform, we hope that different functions can be freely converted by users, and the output information can also be amateur-friendly.

2.3 Subsystem Requirements

2.3.1 Bottom mobile platform programming and hardware setting

The tracking is required to work with the following rules: 1) When the distance is larger than 3 meters, the robot will start moving; the larger distance is, the higher the motor power is, and with an upper speed limitation. 2) The robot will stop when the distance is smaller than 2 meters. 3) When the user actively approaches the robot, the robot will not go backward. 4) When the robot's tracking program is activated, if no one is in front of the camera, it stays still until someone comes into view; the robot will use the first person it sees as the target to track and movement analyzing, while ignoring other people who come into view later. 5) If there are multiple people in view at startup, it will pick the nearest person as its target. 6) If the target quickly runs out of view, it will stay still until a new target appears.

The hardware utilized on the mobile platform should be assembled and compatible with each other. For one aspect, all hardware devices, including the screen, speaker, camera, etc. should be firmly and aesthetically appropriately installed onto the EAI SMART platform, and in that case, we need to make a steel frame to give the robot a reasonable shape and attach the hardware to the upper frame. For another, the connection and interaction between hardware components have to be smooth and robust, since information from one part need to be spread to the next few parts as "igniter" or "guide".

2.3.2 Key points recognition and movement analysis of the human body

This subsystem will use framework such as Mediapipe to recognize human skeleton and joints. Besides, when the certain movement is given to the robot, it needs to move to an appropriate position for recording videos: having a distance of around 2 meters with the exerciser. Another factor to be taken into consideration is the time of analyzing the recorded video; we require approximate 1 minute or 2 for each individual movement and more for a set of movements.

2.3.3 Movement standard algorithms

We need to design respective algorithms for different movement categories so as to evaluate whether the user is doing the exercise in a standard manner. Considering the push-up, the algorithm should emphasize that the limbs and joints need to be moved to a specified angle and position at a specified point of time. Considering the individual movements, it is necessary for our algorithm to be more flexible in counting the number of movement of the exercisers and whether a period of movement is up to standard.

2.3.4 Man-machine interactive system

We plan to perform the interaction based on a touchpad, and thus the data transfer is required to be quick and lossless. For example, the recording and analyzing of videos need to be able to pulse or cease at arbitrary time. Furthermore, the main information of each interface should be clearly and conspicuously shown to the exerciser, like showing the movement name and time count with large font when recording the exercising videos.

2.4 Subsystem Verifications

2.4.1 Bottom mobile platform programming and hardware setting

To verify the hardware components, we can simply check whether ports can be directly inserted and removed from the data cable without disassembling other hardware components, and whether the frame of the vehicle can move steadily without shake during the driving process.

To verify the tracking functionality of the robot, we can test by guiding the robot to move by ourselves, and measure the distance and speed of the robot as it tracks us. We can check if the robot keeps a distance with the user in a range of 2 to 3 meters, goes backward when the user approaches, and turning left/right if the user does so. With two team members for testing, we can also verify that the robot picks the nearest person as the target at startup, and stays still until a new target appears if the current target runs out of view. If the robot behaves as expected in these testing tasks, we can conclude that the tracking functionality meets the requirements.

2.4.2 Key points recognition and movement analysis of the human body

Verify skeleton and joint recognition accuracy by testing the subsystem on a variety of human movements and measuring its precision, recall, and F1 score.

Verify robot positioning accuracy by testing the subsystem with different movement scenarios and measuring the distance between the robot and exerciser to ensure it's around 2 meters.

Verify video analysis time by testing the subsystem on videos of different lengths and ensuring it can analyze individual movements within 1-2 minutes and longer videos proportionally.

2.4.3 Movement standard algorithms

Verify movement category algorithms by testing their accuracy and robustness on a dataset of videos, measuring precision, recall, and F1 score.

Verify push-up algorithm by testing its accuracy in detecting the correct angles and positions on a dataset of push-up videos, measuring mean absolute error and root mean square error.

Verify individual movement algorithm by testing its flexibility and accuracy in detecting the correct number of movements and evaluating their standards on a dataset of exercise videos, measuring accuracy and F1 score.

2.4.4 Man-machine interactive system

We can verify the quick and lossless data transfer by measuring the transfer speed and checking for lost or corrupted data packets. If the transfer speed is fast and no data is lost or corrupted, conclude that the data transfer meets the requirements. We can verify the ability to pulse or cease video recording and analysis at arbitrary times by performing tests where we manually start and stop the functions. If the functions can be activated and stopped without any issues, conclude that the system meets the requirements. We can verify the clear and conspicuous display of interface information by testing it with exercisers and collecting feedback. If the feedback is positive and the displayed information is clear and conspicuous, conclude that the interface design meets the requirements.

2.5 Tolerance Analysis

Achieving success in our project depends on the continuity of camera-captured photos as the inputs to our model. However, unlike some of the dataset collected by surveillance camera, which is super steady, there might be vibrations in our camera input. Besides, in real-life scenarios, the road may not always be super flat, leading to non-continuous images with significant gaps in a short period. Such unstable images present a challenge when stitching them together to form the whole picture. Misalignment of the same lines in these images can result in distortions, leading to a poorly reconstructed image that is twisted and of low quality.

Another potential problem is how can we deal with the case where there are more than one people in the image. Our model should be able to identify the user we have been tracking and ignore others while not hitting them. Our tracking system should be able to handle those challenges, we will design an algorithm to stabilize the image and provide steady inputs to model, and as for the multiple people case, we think one possible approach is to train our model with test cases with several people. After correctly labeling the people in sight, we could try track our user by putting him in the center of sight.

Besides, During the recognition and analysis of human body movements, occasional errors in key point recognition may occur, potentially affecting the accuracy of movement analysis. In such cases, it is essential that the Mask R-CNN algorithm is robust enough to handle missing or inaccurately detected key points effectively. One possible solution is to incorporate data augmentation techniques during the training of the Mask R-CNN model, such as rotation, scaling, or flipping, to improve its generalization capabilities and tolerance to variations in human body movements. Another possible approach is to leverage ensemble learning techniques, such as stacking multiple models or using model averaging, to improve key point recognition accuracy and robustness.

The tolerance limits we set for the object tracking algorithm is:

1. Mask R-CNN accuracy: Minimum 95% accuracy in key point recognition.
2. Positioning accuracy: ±0.2 meters from the desired 2-meter distance.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Our fixed development costs are estimated to be ¥15/hour, 10 hours/week for everyone.

weekly cost = 15 RMB/hours $\times$ 10 hours/week $\times$ 8 weeks $\times$ 4 = 4800 RMB

3.1.2 Parts

Part	Vendor	Cost (￥)	Qty	Total(￥)
Depth Camera	Taobao	￥980.00	1	￥980.00
Raspberry Pi 4B Main-board	Taobao	￥855.00	1	￥855.00
Rplidar A1 Omnidirectional Ultrasonic Radar	Taobao	￥269.00	1	￥269.00
7 Inch touching display screen	Taobao	￥260.00	1	￥260.00
High-torque motor	Taobao	￥48.25	4	￥193.00
Metal chassis and Mecanum wheel	Taobao	￥98.00	1	￥98.00
Acrylic plate frame	Taobao	￥56.59	1	￥56.59
Differential PID motor speed regulating drive board	Taobao	￥150.00	1	￥150.00
GY-85 Nine-Axis Gyroscope	Taobao	￥70.51	1	￥70.51
Bluetooth speaker	Taobao	￥58.00	1	￥58.00
16G SD card and SD card reader	Taobao	￥34.90	1	￥34.90
12V lithium battery	Taobao	￥3.00	9	￥27.00
Data cables and adapting pieces	Taobao	￥10.00	1	￥10.00
Wired keyboard	Taobao	￥58.00	1	￥58.00
Total				￥3120.00

Table 1: Cost

3.1.3 Total

Total cost estimate: 7920 RMB

3.2 Schedule

Week	Dalei Jiang	Zifei Han	Chang Liu	Kunle Li
3/20/2023	Assemble the robot hardware devices and set up the OS and environment	Documentation reading about ROS and build (later update) lab notebook	Paper reading and environment setup	Environment Setup
3/27/2023	Use the Rviz to set the navigation task management system in ROS	Explore and implement several algorithms on navigation in rospy	Try to launch the detection model on my laptop	Push-up count & motion evaluation
4/03/2023	Based on OpenCV, apply the KCF algorithm on PC, and use the existing video to test	Documentation reading about KCF of recognition of human figure	Write the GUI and complete the related design of the scripts	Integrate the individual methods
4/10/2023	Move the algorithm function to the robot, and connect the camera as input	Deploy the algorithms function onto the platform and debug	Write the GUI and complete the related design of the scripts	Implement the GUI and adjust the adaption of the application
4/17/2023	Set up easy-to-call scripts for target tracking function	Further debug and double check the interaction between software and hardware	Help Kunle combine GUI and Model	Implement the GUI and adjust the adaption of the application
4/24/2023	Help Kunle migrate the system onto robot	Help Kunle migrate the system onto robot	Help Kunle migrate the system onto robot	Migrate the system to the robot
5/01/2023	Test the function and debug	Test in expected usage situations and debug	Test the function and debug	Debug and enhance
5/08/2023	Organize materials and write final report	Test in real applicable situations and debug	Organize materials and write final report	Exhaustive tests to improve stability

Table 2: Calendar

4 Ethics and Safety

4.1 Ethics

Our human identification and tracking system will address ethical concerns related to privacy and information security. The use of camera for user identification presents potential privacy issues since the camera can capture images and other data that can be used to identify individuals. It is therefore essential to ensure that any persons captured are properly anonymized. Furthermore, the storage and transmission of data collected by the camera pose information security concerns. Unsecured data transmission and storage can result in sensitive data being accessed by hackers and sold to malicious organizations, creating significant issues for us and potentially others.

The IEEE and ACM Code of Ethics both emphasize the importance of respecting individuals' privacy and protecting their personal data. According to the IEEE Code of Ethics, engineers must "protect the privacy of others" [4] and use information solely for legitimate purposes. Similarly, the ACM Code of Ethics, Section 1.6 Respect privacy, requires computing professionals to respect others' privacy and protect the confidentiality of accessed data.

To prevent ethical breaches, we will implement appropriate security measures to ensure that the camera's collected data is securely stored and transmitted. These measures will include utilizing an encrypted data transmission protocol, deleting intermediate and temporary data when applicable, and storing reconstruction results in an encrypted folder. We will also seek informed consent from individuals whose data is being collected and ensure their privacy is maintained throughout the project.

4.2 Safety

In our project, safety is our top priority, and we have identified several potential safety issues that need to be addressed. One of the most significant safety concerns is the risk of causing harm to people or property if the robot is not properly controlled, leading to accidents or collisions. Additionally, the battery and power system are crucial components that must be carefully managed to prevent short-circuits or explosions.

To address safety concerns, we will adhere to all relevant government regulations, industry standards, and campus policies related to remote control cars and unmanned vehicles. We will also take appropriate safety measures, including limiting the car's speed and operating it only in controlled environments. Before mounting the power system onto the car, we will perform frequent checks to ensure that it is functioning correctly and is in a normal state. Additionally, we will implement fail-safes to prevent any potential accidents or collisions.

References

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[2] K. Li, K. Zhang, Y. Lv, and X. Wang, "A real-time visual feedback system for squat exercise using kinect and ur3 robot," *Journal of Sports Engineering and Technology*, vol. 233, no. 2, pp. 89–97, 2019.

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[4] IEEE, ""IEEE Code of Ethics"," 2016. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 03/10/2023).