ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Robot for Gym Exercise Guidance

Team #19

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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 weightlifting" [1]. Therefore, it is crucial to maintain proper form while exercising.

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 such as Mask R-CNN to identify human movements when people are moving, compare with the existing action models, and give an performance evaluation. 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: Human tracking

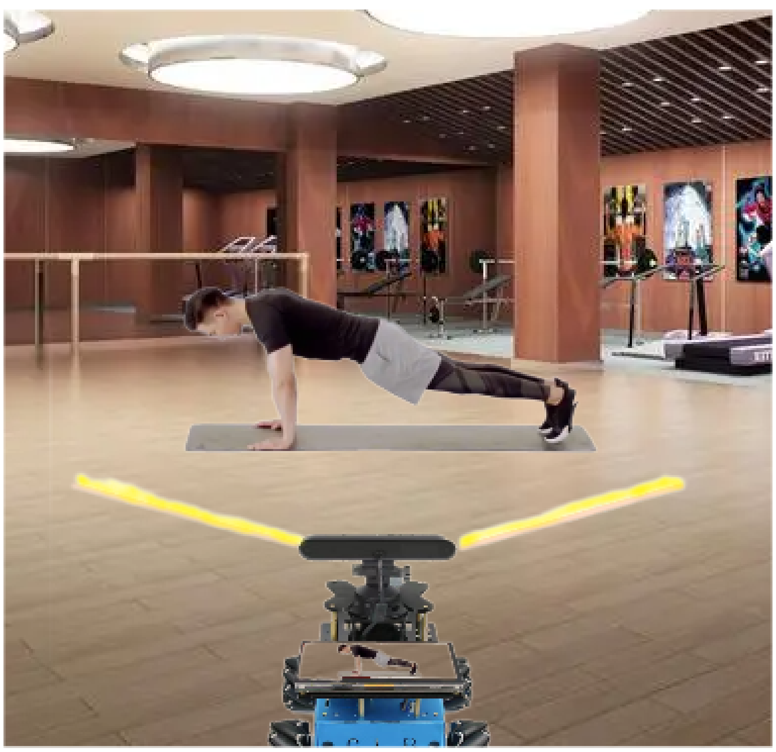

Figure 2: Position analyzing

1.4 High-Level Requirement List

- The robot can automatically track the user based on the user's location within a certain distance range (2-3 meters).
- The robot can successfully recognize body key points and skeleton binding in an acceptable time.
- The robot can adopt a reasonable algorithm to evaluate the user's doing common exercising movements, such as jumping rope and squats.

2 Design

2.1 Block Diagram

The block diagram is shown in figure 3.

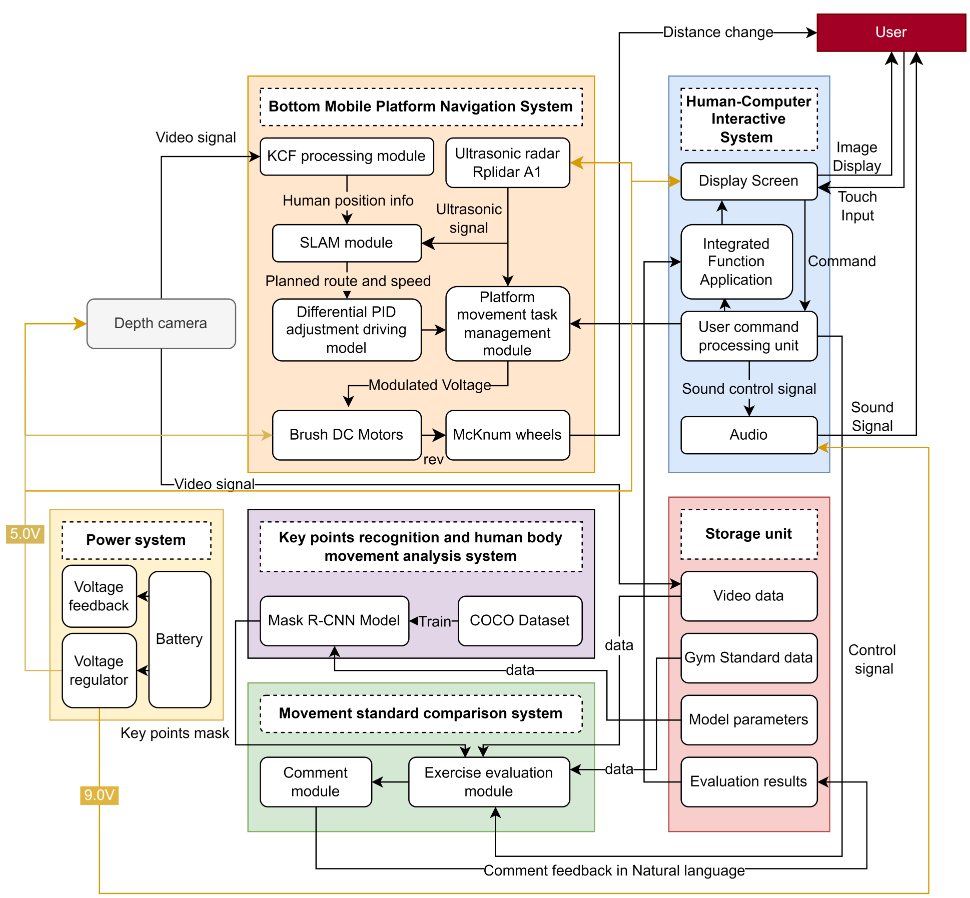

Figure 3: Block diagram

2.2 Subsystem Overview

2.2.1 Bottom mobile platform navigation system

We plan to take use of the ROS mobile platform as the base movement platform of the robot. This robot platform contains two ultrasonic radars, Differential PID adjustment driving system, DC motors and McKnum wheels. The Differential PID adjustment driving 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 knocking them. In addition, other hardware components of our project include the display screen, the speaker, the control host and the camera.

2.2.2 Key points recognition and human body movement analysis system

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 comparison system

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 compare the exerciser's body position at a given time, compare it with the standard, and calculate the deviation value of the position. In such a rhythmic movement, we will use the speaker to play rhythm music. For such exercises as push-ups, sit-ups and skipping rope, in addition to detecting whether the corresponding movements are in place, we also need to consider the "frequency", rather than intercept a specific point in time to evaluate. The greater frequency of movement proves the athleticism of the exerciser, and that will result in a higher grade.

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 navigation system

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 ROS mobile 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 human body movement analysis system

This subsystem requires datasets to train the Mask R-CNN, and we plan to take use of the training data-set on COCO to train an efficient model to help us realize fast analysis. 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 comparison system

We need to design respective algorithms for different movement categories so as to evaluate the deviation values between exerciser's performance and the standard under different circumstances. Considering the broadcast gymnastics, the algorithm should emphasize that the limbs and joints need to be moved to a specified height and position at a specified point of time. Considering the individual movements, it is necessary for our algorithm to be more flexible in identifying the frequency 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 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.

3 Ethics and Safety

3.1 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.

3.2 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).