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Final Report: <Project or system name>

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Acronyms

Acronym	Full Description
AMTTLA	Administer Motor Task Training to Lab Animals
CSS	Cascading Style Sheets
GPIO	General Purpose Input/Output
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
ID	Identify Document
IP	Internet Protocol
LAN	Local Area Network
R/W	Read/Write
SQL	Structured Query Language
PDD	Preliminary Design Document
SDD	System Design Document

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1 Purpose

This document is the final report for the Administer Motor Task Training to Lab Animals design project. It is based on the System Design [3], which references the Preliminary Design [2] and Proposal Response [1], and the results of prototype development up to this time.

2 Introduction

Rehabilitation training is a practical treatment strategy for most types of nervous system injury and disease. Despite its universal application in the clinic and the recognition that it contributes to the beneficial effect of drag promoting nervous system recovery, the effect of rehabilitation training is rarely investigated in pre-clinical biomedical testing due to its time-consuming and costly nature. To overcome those barriers, we present the AMTTLA, which automates the rehabilitation training and evaluation for lab animals in skilled movement tasks.

The string-pulling task is one of the bimanual skilled tasks recently developed in the laboratory to assess bimanual forelimb function in rats/mice. The main process of the task is to motivate the animals to pull strings, which is usually done by tying food rewards to the string ends. However, the original setting requires tedious preparation, as it involves over one thousand repetitions of the string tying operation per week. Looking for a commercial solution is impracticable, as those devices are either expensive or incapable of meeting the customized requirements.

The design we proposed consists of a string-pulling device, a food dispenser, with an integrated control/storage module. The fundamental functionalities of the design include automated control of the training parameters, food pellet dispensing, as well as performance data recording. The training system shall be easily and reliably connected/detached from the training enclosure.

3 System Design Overview

The AMTTLA comprises two main subsystems, the client device and web server (which is integrated with the hardware manager). The system design realizes the One Goal by using the Raspberry Pi to host a webpage where users can set all the training parameters and use the Pi to control a food dispenser and the pulling system. In the webpage, the users can set the required pulling distance, the minimum force required to pull the string, and the time window to complete the task. All the data collected by the sensors are stored in the database connected to the webserver and can be retrieved at any time. To maintain data confidentiality, only authenticated users can log in to the webpage and access the data. The pulling system has a load cell in it, the load cell measures the force pulling on the string and the Pi reads the real-time data from the load cell through GPIOs. The string is driven by a stepper motor

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controlled by the Pi and its speed varies when the force applied to the string changes. When the training animal completes a task, the food dispenser will drop food pallets for the animal. The component diagram and deployment diagram can be seen in System Design Document [3].

Our team had encountered multiple challenges in the development of AMTTLA. In the early stage of developing the pulling system, our team conceived to use an electromagnet to provide friction on the string. We could adjust the friction accurately by changing the current going through the electromagnet. However, we could not find the digital potentiometer that works in 12V. In the end, we came up with a more elegant solution, which used a single stepper motor to control the required pull force. It was also challenging to develop a program that controlled the stepper motor smoothly and sent real-time data to the webserver.

4 Prototype Implementation

The deployment diagram and block diagram updated from the System Design Document [3] are shown below.

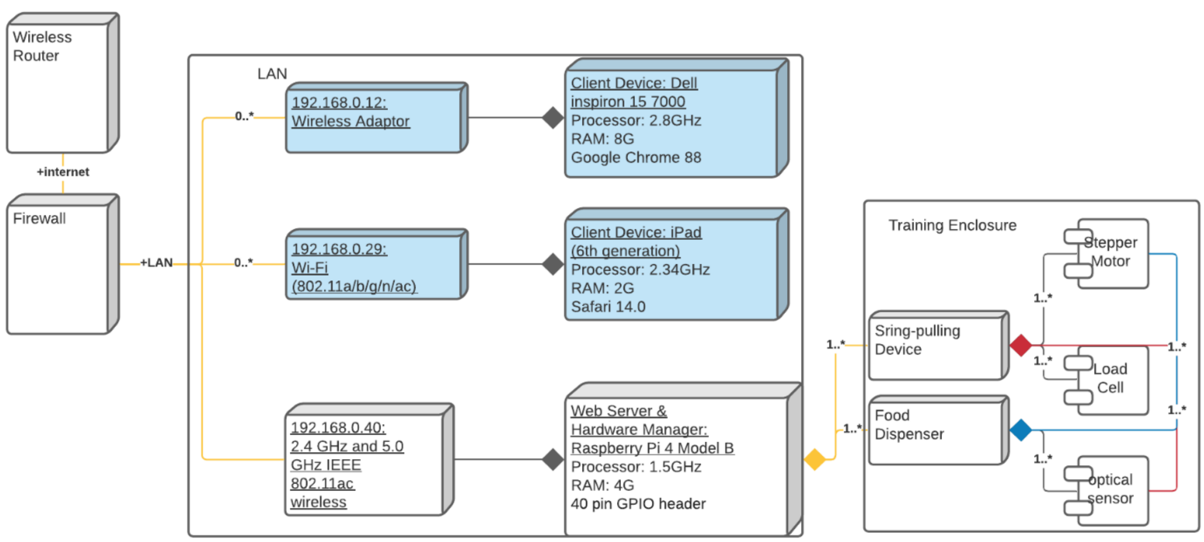

Figure 1: Deployment Diagram

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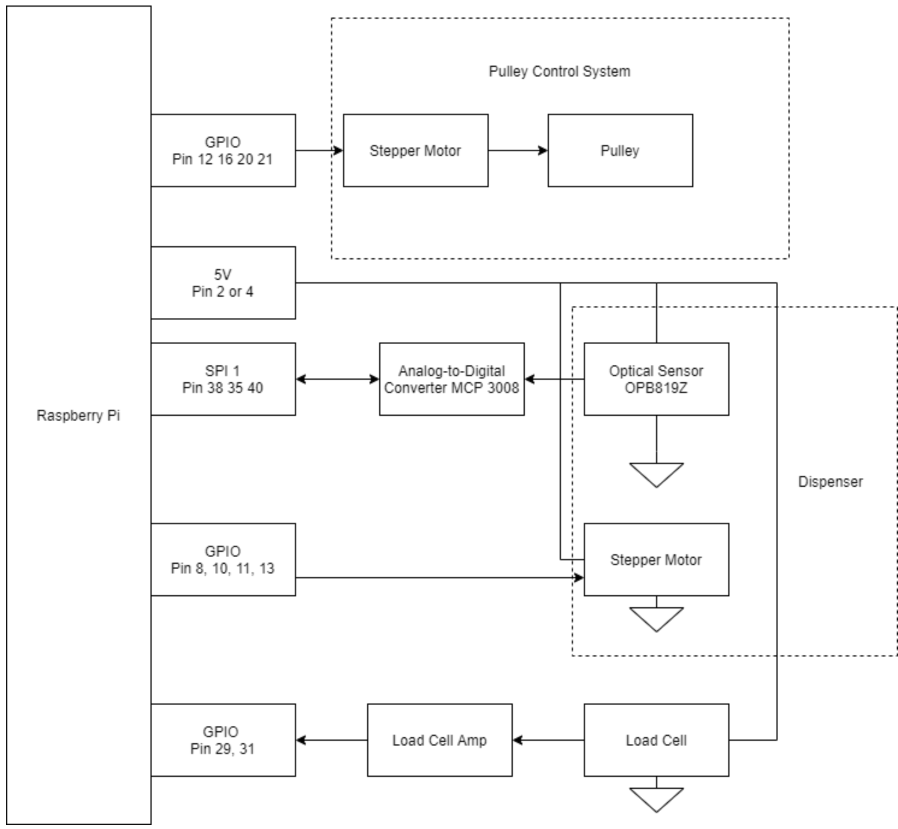

Figure 2: Block diagram

Notice that compared with System Design Document [3], the deployment diagram and block diagram have a major modification: a single stepper motor replaces the electromagnet and potentiometer. We find that using a single stepper motor is sufficient to control the required pull force instead of relying on the sophisticated electromagnet controller mechanism.

The deployment diagram illustrates the interaction between the web server and the training enclosure. The web server hosts a web page allowing the user to customize configurations on the string-pulling device and retrieve training information. The hardware manager controls the hardware and records the real time training data.

The block diagram illustrates the main hardware components of the prototype: the pulley control system and the food dispenser:

- The pulley control system: our prototype applies the stepper motor to control the pulley. The original idea is using electromagnet to apply different force on the pulley to generate different levels of static friction, which correspond to the threshold values that the pull force could rotate the pulley. The new idea is using a stepper motor to drive the pulley. The pull force applied on the string would be measured by the load cell. When the obtained value is

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lower than the required force, the stepper motor would hold its current position. Otherwise, the stepper motor would accelerate, keep with a constant velocity, or decelerate depends on the pull force variation. We use the RpiMotorLib [4] to drive the stepper motor.

- The food dispenser: The food dispenser uses a stepper motor to pass the food pellet from the floating floor to the dropping position. An optical sensor is used to determine whether one food pellet is successfully dispensed. An Analog-to-Digital converter is used to interpret the analog signal generated by the optical sensor.

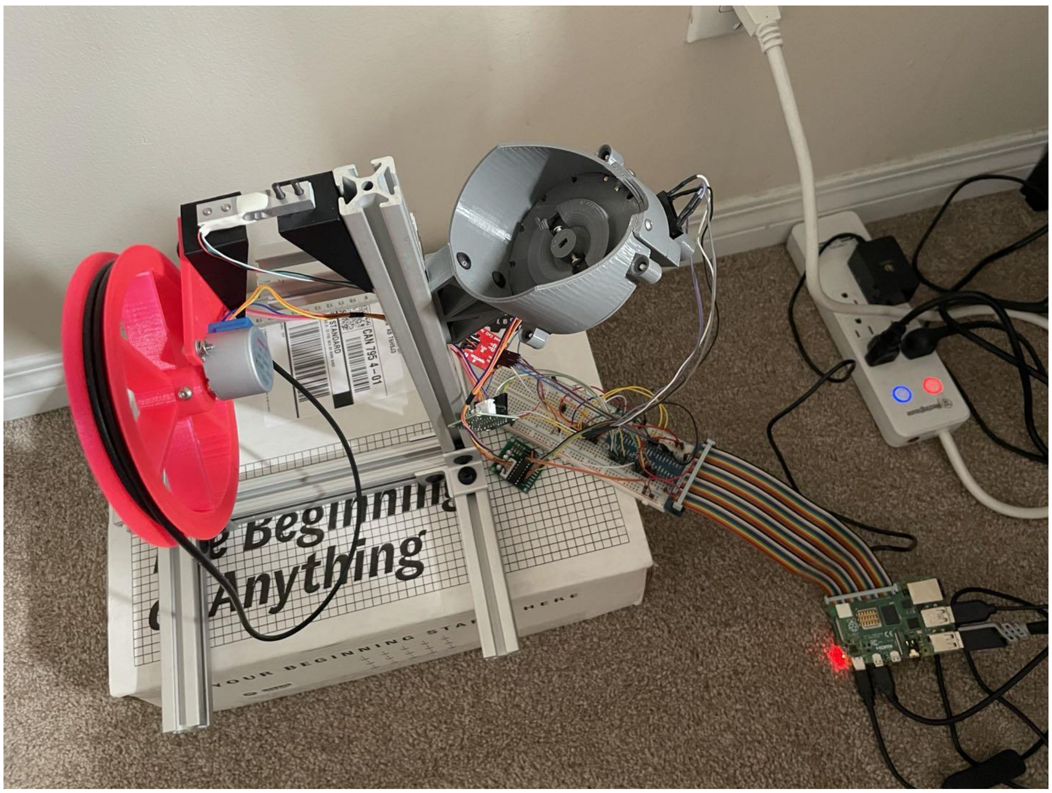

Figure 3: The prototype, hardware components from left to right are the pulley control system, load cell, food dispenser, and Raspberry Pi.

Our testing plan is first validating by parts, then validating the whole system. Our testing results of each components can be summarized as:

- The pulley control system: the pulley system could accelerate or decelerate the motor smoothly. But the string will start slipping on the pulley once the force exceeds the upper limit.
- The dispenser: The dispenser could dispense a precise number of food pellets. However, some pellets might get stuck between the floating floor and the outer floor, which would affect the dispenser's performance.
- The load cell: It has an error around ±3 grams.

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- The web server: It could correctly configure the training setting, monitor the real time data, and store the data into the database.
- The hardware manager: It is tested together with the hardware components. It is responsible to run the hardware and retrieve the data from the hardware. Since the hardware works, the hardware manager also works.

Having those partial testing results, the whole prototype shall work. It meets all fundamental requirements as we demonstrated at the final presentation.

5 Prototype Discussion

The whole design process for the prototype was full of challenges. When designing the force control of the system, we wanted to make the structure simple and strong while being able to provide linear resistance to the pulley. At first, we decided to implement a structure similar to the wheel brake as listed in the System Design Document [3]. By using one or two brake pads to apply force to the pulley, it should provide controllable resistance. However, when designing the mechanism, we found that in order to make the resisting force have a wider range, the structure needed to be relatively complicated. In this way, the installation process needed to take a relatively long time, and maintaining the system became quite difficult. Also, we originally planned to use an electromagnet [5] and a metal block as a braking system. By changing the current applied to the electromagnet, we could have a different amount of force theoretically. However, when we actually got our hand on the electromagnet, we found it was extremely difficult to get linear control of the force since it was designed to perform binarily, on or off.

Facing such difficulty, we decided to communicate with our client Dr. Fenrich and then came out with another brand-new solution to the design that inspired him. Instead of letting the pulley rotating freely and then applying resistance to it, we decided to use the stepper motor [6] to control the pulley to rotate. Since the pulley system was attached to a load cell [7] which measured the weight of the structure, it could also be used to measure the pulling force on the string. Therefore, we wrote a program that allowed the stepper motor to rotate with the pulley at a certain speed when the load cell detected a minimum amount of pulling force and accelerated when the force increases. This implementation required a minimum amount of hardware design and was easy to maintain the string when needed. After series of testing and adjustments, we were finally able to make the system operate nicely and correctly.

Moreover, when the hardware manager part was developed, we encountered some problems with the stepper motor [6] and the load cell [7]. We wanted the stepper to have a near-linear acceleration according to the readings from the load cell. However, the load cell provided us with a noisy reading which would constantly change even without touching it and drift away from the initial calibration. After searching for help from all the resources, we found that it was a relatively common problem for the load

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cell and decided to use a better library [8] to read from the load cell. This solved the drift problem, but the reading was still noisy. After trying a lot of different things, we decided to compromise and made the load cell reading accurate to 3g. In this way, the reading from the load cell became quite consistent and accurate while not losing force control.

6 Future Work

6.1 Hardware Design

6.1.1 String-Pulling Device

- In the prototype, we utilize the load cell to measure the pull force, where the observational error is below 3 grams. This conclusion holds when the pull force is applied vertically below the pulley. However, the training subjects might pull the string at different angles during the experiment, which causes the reading to be less accurate. Therefore, our system should be tested thoroughly under the training enclosure and see if the undesirable torque could be filtered by 1) fine-tuning the load cell driver settings 2) finalizing the mechanical design. The testing and revision are estimated to be done within two weeks.
- Ideally, the stepper motor should keep the pulley at a fixed position. Once the pull force is applied, the load cell would tell the hardware manager the measured value, where the latter administrates the stepper motor whether to rotate the pulley. For example, if the force threshold is 0.2 newton, then any pull force below the specified value would not make the motor step (i.e., the pulley would not rotate).
  The stepper motor model 28BYJ-48 [6] used for the prototype is not powerful enough against the pull force. That is, the pulley slips as we pull the string mildly. Therefore, we recommend using a more robust stepper motor with the same ULN2003APG driver [9] to rotate the pulley in the final product. The motor might require an additional 12V power supply instead of the 5V Raspberry Pi GPIO output. The replacement is estimated to be done within three days.

6.1.2 Food Dispenser

- Since the food dispenser is 3D printed device, its manufacturing accuracy might not meet the design requirements. During the testing, we find that the food pellet (which is around 3 diameters) occasionally falls into the gap between the floating floor and the bottom of the dispenser, which causes the whole device to be trapped. To fix the issue, we must disassemble the dispenser and clean its interior. Therefore, we recommend designing an extra mechanism to avoid the pellet being stuck in the final product. The dispenser refinement and manufacturing are estimated to be done within one month.

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6.1.3 Electrical Circuit

- In the prototype, we use the breadboard to accommodate processor chips and jumper wires. The whole electrical circuit is sophisticated and fragile. During the testing, the system occasionally stops functioning due to the loose circuit connection. Therefore, we recommend integrating all electrical components hooked in the breadboard into one PCB board in the final product. The PCB board should provide the interface for the Raspberry Pi. The PCB design and manufacturing are estimated to be done within one month.

6.2 Firmware and Software Design

6.2.1 Stepper Motor Driver

- We used the stepper motor rotating the pulley to give the training subject the feedback as the string is being pulled. The stepper motor would accelerate, keep with a constant velocity, or decelerate according to the pull force variation. The stepper motor acceleration and deceleration simulate the momentum when the string is being pulled. However, detail setting (e.g., the exact acceleration and deceleration rate) should be further investigated and fine-tuned under the training enclosure to avoid scenarios such as the pulley keeps rotating when the training subject stops pulling. We hardcode the acceleration and deceleration rate in our hardware manager class, which is easy to modify. The stepper motor driver code revision is estimated to be done within one week.

6.2.2 Code Revision and Documentation

- We use the multi-processing architecture to ensure the load cell and stepper motor responding one event in time. The corresponded code is tedious and lacks explanation. For example, we currently allocate several variables carrying the status information for different processes, which might confuse the user. One potential elegant solution is using the queue structure instead.
  On the other hand, as the hardware used for the prototype might be replaced with robust ones, it is essential to make our code portable (i.e., easier to adopt different hardware types). Our code should achieve high modularity as well as provide an interface for different hardware types.
  We will revise our code and document it in the following weeks. The goal is to make the code understandable and easier to be used. We would also write a fully detailed user guide.

6.2.3 Deployment and Testing

- Due to the COVID -19 quarantine policy, we could not deploy and test our system in the laboratory environment. However, it is critical to integrate the string-pulling device into the

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training enclosure and let it operate for several hours to days to evaluate its reliability while recovering the potential flaws.

7 Conclusions

This project is an administer motor task training to lab animals with a user-friendly interface. Users can use it to automize the procedure of training animals and customize many training parameters including the required pulling force, required pulling distance, and time window. The training parameters and the data collected by the users are stored in the database and can be retrieved easily. It has met the one goal specified in PDD [2] but still needs further improvement to be practicable for use in the Labs.

For future development, it is recommended to replace the 28BYJ48 stepper motor with more powerful models, so that the motor will not slip when stronger torque is applied to it. It is also necessary to make modifications to the food dispenser, so the food pallets shall not fall between the rotating floor and bottom of the food dispenser and stuck the dispenser. The program that controls the stepper motor can be improved to make the acceleration and deceleration of the string smoother.

It is too bad about the file name oversight. I took away only half the marks I said I would for that error because the project was well done and it seemed a pity that something so simple would have such a large impact (almost 10%).

As I have said, this was a challenging project and you as a team did very well under difficult circumstances.