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Preliminary Design: Device to Administer Motor Task Training to Lab Animals

Revisions

Revision	Author	Changes	Date
001	Ang Li Hao Xuan Maocheng Shi Ruichen Chen	First Attempt	2021-02-04
002	Ang Li Hao Xuan Maocheng Shi Ruichen Chen	Addressed the Feedback from Client and Lab TA (Mr. Fan) Initial Release	2021-02-05

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Acronyms

Acronym	Full Description
CBC	Canadian Broadcasting Company
IoT	Internet of Things
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

References

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[6] A. S. App-Generator, "app-generator/flask-dashboard-dattaable," *GitHub, 2020*. [Online]. Available: https://github.com/app-generator/flask-dashboard-dattaable. [Accessed: 04-Feb-2021]

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1 Purpose

This document describes the preliminary design for the Administer Motor Task Training to Lab Animals

2 Concept of Operation

The high-level operation of the Administer Motor Task Training to Lab Animals is illustrated by the following user stories and use cases.

2.1 User Stories

User Story 1:

As a research assistant, I want to train new mice/rats. I attach the whole training system, including the string-pulling device, food dispenser, and web server & hardware controller (i.e., Raspberry Pi), to the training enclosure. Once I turn on the Raspberry Pi, I can access the webpage it hosts through a laptop or tablet computer under the same LAN by entering the specified IP address and port number. Then I post the training preference (e.g., subject ID, required pull force, required pull distance, the maximum allowed time window to complete one task) to the webpage. After receiving the training parameter from the webpage, Raspberry Pi informs the hardware to adjust their setting and meet the requirements.

Raspberry Pi monitors the behavior of the subject through multiple sensors. It interprets the real-time metadata generated by the sensors to the training data (e.g., pull force, pull velocity, and the number of tasks succeeds) and stores them locally. If the subject completes the task, Raspberry Pi will inform the food dispenser to deliver food pellets.

User Story 2

As a research assistant, once I configure the device, I do not have to worry about resetting the string-pulling device or refilling the food tank every time one task is completed (the food dispenser still needs to be refilled weekly, though). Then I can leave the training system and conduct other research. After returning from other works, I want to assess the training data collected. In the webpage, I can view and download the training data (e.g., pull velocity over time, total pull distance, and the number of times the animal completed the task) about one specific subject I am interested in by querying the database.

User Story 3

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As a research assistant, I want to train new mice/rats. I can shift the entire device to a new training enclosure within 15 minutes. However, when we proceed further, it turns out we need a new string to replace the original bitten one. I detach the string-pulling device by simply removing a few pulleys and replace the new string onto it without moving other modules.

User Story 4

As a research assistant, I must provide a valid username and password to login to the webpage. Otherwise, I am forbidden to control Raspberry Pi and access the training data. If I happen to be the system administrator, I can manage the access permission of all accounts that the training system registered after logging in. Also, if there is a new user, I can assign a new account to the user for both username and password.

2.2 Use Cases

Figure 2 illustrates the use cases. The red nodes correspond to user story 1, green nodes correspond to user story 2, grey nodes correspond to user story 3, and blue nodes correspond to user story 4. Notice that user story 1, 2, and 4 needs to access the local data (which consists of training as well as other information, e.g., subject ID).

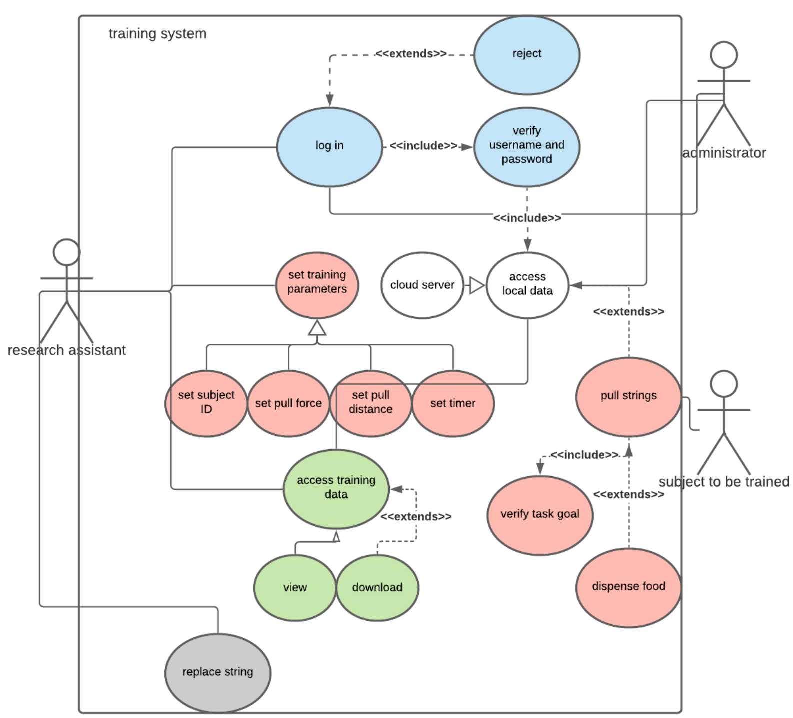

Figure 1: Use Cases

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3 Functional and Performance Requirements

Table 1 Functional Requirements

FR #	Functional Requirement Description
FR-01	The training system shall host the webpage under the LAN, where the user can set training preferences.
FR-02	Once the training preferences are received, the sting-pulling device shall be configured to meet the task requirements (e.g., adjust the force threshold pulling the string).
FR-03	The sensors shall collect the real-time metadata, where the latter is then interpreted as training data.
FR-04	The training data shall be stored at the local database, where the user can query a certain piece of training information from.
FR-05	The food dispenser shall deliver a fixed amount of food pellets when the subject completes one training task.
FR-06	The stored training data shall be transmitted through LAN.
FR-07	The training system shall be easily attached/detached to/from the training enclosure.
FR-08	The training system shall accommodate different sizes of subjects, from mice to rats.
FR-09	The string in the system shall be easily replaced. It shall tolerate edge cases (e.g., animal chewing or biting).
FR-10	The user shall log in to access the training system, while the administrator can manage the access permission of all accounts that the training system registered.

Table 2 Performance Requirements

PR #	Performance Requirement Description	Related FRs
PR-01	The training system shall be set up (i.e., connecting the system to the LAN and running the software) within 5 minutes.	FR-01
PR-02	Once be booted, the training system shall keep functioning for at least one week without any crashing.	FR-01 to FR-06
PR-03	The training system shall respond to incoming user commands (setting training preferences and querying training data) within 30 seconds.	FR-01, FR-04
PR-04	Once the training preferences are received, the sting-pulling device shall be set within 30 seconds.	FR-02
PR-05	The sensors shall collect the real-time metadata of the subject with a satisfying precision and minimum latency (e.g., 0.5 seconds).	FR-03
PR-06	There is no data lost during a sudden outage.	FR-04

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4 System Design

The Device to Administer Motor Task Training to Lab Animals comprises two main subsystems, the client device and web server (which is integrated with hardware manager). Major nodes and components in each subsystem are identified below.

4.1 System Architecture

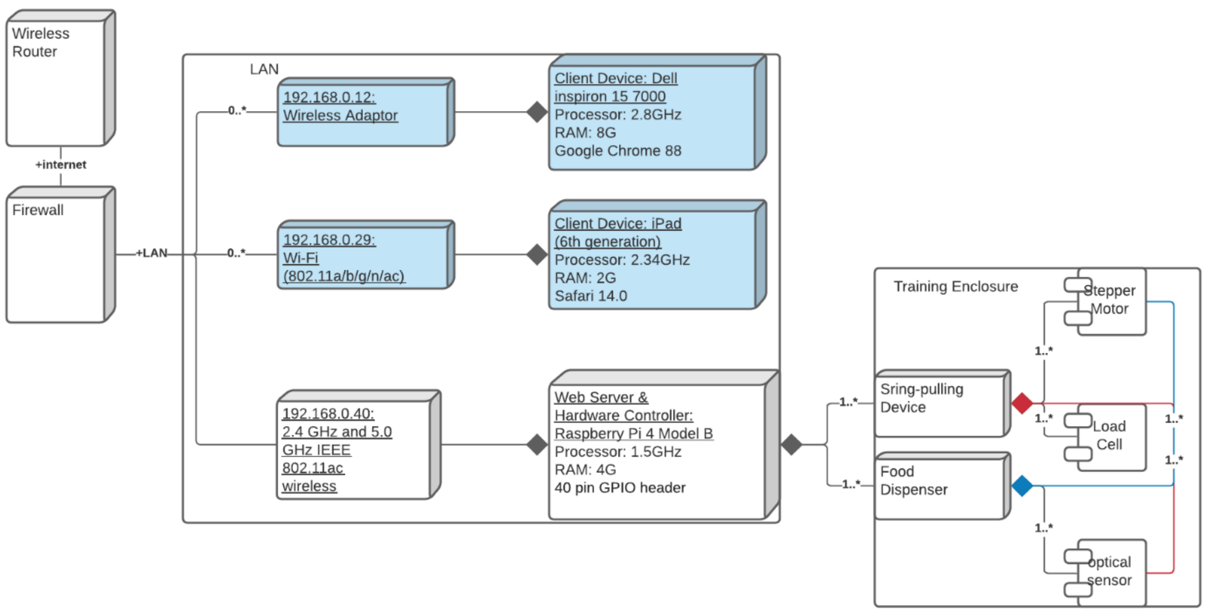

Figure 2: Deployment Diagram

Figure 2 illustrates the deployment diagram of our design. Notice that the string-pulling device contains one stepper motor, one load cell, and one optical sensor, while the food dispenser contains one stepper motor and one optical sensor.

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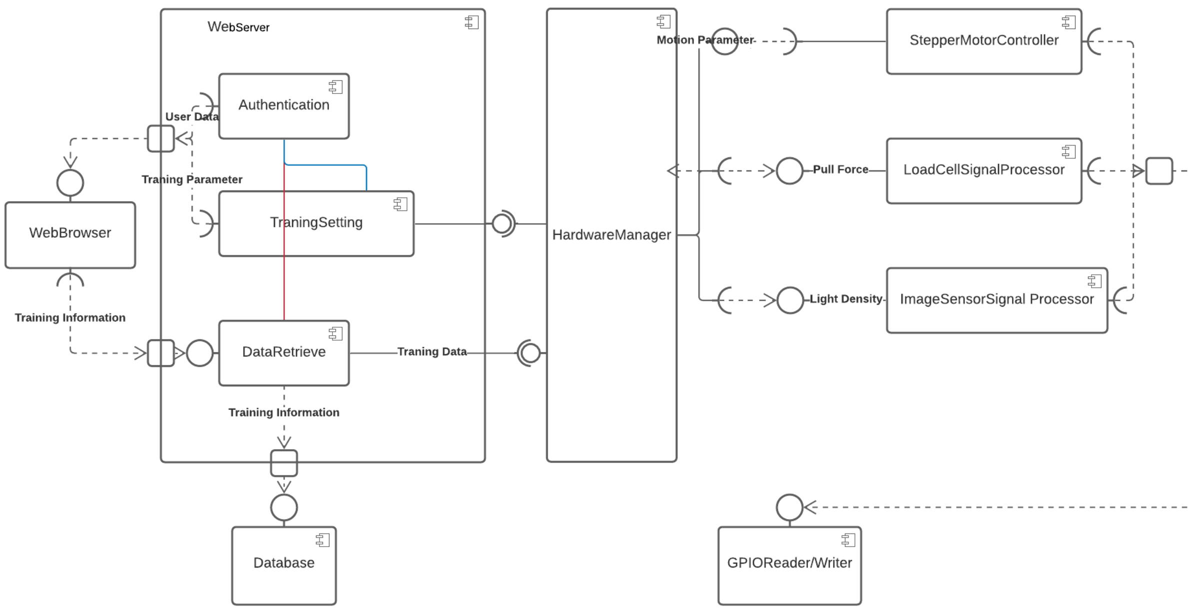

Figure3: Component Diagram

4.1.1 Hardware Components

Table 3 Hardware Components

HC #	Hardware Component Title	Description
HC-01	Raspberry Pi 4 Model B	Executes all software components listed in figure 3 excluding the web browser application.
HC-02	Wireless Adapter: Wi-Fi (802.11a/b/g/n/ac), 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, etc.	Allows the device to access Wi-Fi.
HC-03	String-pulling Device	Consists of the force controller and pulley system. The former (includes the stepper motor and load cell) controls the force threshold pulling the string. The latter (includes load cell) collects the string movement data.
HC-04	Food Dispenser	Dispenses a fixed amount of food pellets to the rats/mice.
HC-05	Stepper Motor	Used on the string-pulling device and food dispenser. On the

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		string-pulling device, it controls the force threshold pulling the string. On the food dispenser, it rotates the floor of dispenser to deliver the food pellets.
HC-06	Load Cell	Measures the pull force on the string.
HC-07	Optical Sensor	Used on the string-pulling device and food dispenser. On the string-puling device, it measures the string velocity. On the food dispenser, it checks whether one food pellet delivery attempt succeeds.
HC-08	Client Device	Accesses the webpage under the LAN through Wi-Fi.
HC-09	Wireless Router	Initializes LAN connection.

4.1.2 Firmware Components

Table 4 Firmware Components

FC #	Firmware Component Title	Description
FC-01	Stepper Motor Controller	Controls the stepper motor.
FC-02	Load Cell Signal Processor	Interprets the analog signal received from the load cell to the digital signal accepted by Raspberry Pi.
FC-03	Image Sensor Signal Processor	Interprets the analog signal received from the image sensor to the digital signal accepted by Raspberry Pi.
FC-04	GPIO Reader/Writer	Provides an interface between software and hardware.
FC-05	Firewall	Protects the web server.

4.1.3 Software Components

Table 5 Software Components

SC #	Software Component Title	Description

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SC-01	Web Server	Hosts a web page allowing the user to customize settings on the string-pulling device.
SC-02	Authentication	Protects the training system.
SC-03	Training Setting	Transfers the custom settings from the web server to the hardware manager.
SC-04	Data Retrieve	Transfers the training data from the hardware manager to the web server and database.
SC-05	Hardware Manager	Controls the hardware.
SC-06	Database	Stores the training data and system information (e.g., user account, subject ID).
SC-07	Web Browser	Accesses the webpage

5 System Requirements

Table 6 System Requirements

SR #	System Requirement Desc	FR#	PR#	Notes
SR-01	Raspberry Pi shall be able to send and receive data through LAN.	FR-01, FR-06	PR-01, PR-03	
SR-02	Raspberry Pi shall be able to R/W signals through its GPIO ports.	FR-02, FR-03	PR-04, PR-05	
SR-03	Raspberry Pi shall have enough GPIO ports connecting the motor/sensors.	FR-02, FR-03		
SR-04	The motor/sensors shall be able to accept/generate the analog signal generated by Raspberry Pi.	FR-02, FR-03		
SR-05	Raspberry Pi shall be able to work long enough without crashing.		PR-02	
SR-06	Raspberry Pi shall be able to store a reasonable amount of training data.	FR-04	PR-06	Through external storage devices, e.g., SD cards.
SR-07	The client device shall be able to send and receive data through LAN.	FR-01, FR-06	PR-01, PR-03	
SR-08	The string-pulling device shall accommodate different sizes of subjects, from mice to rats	FR-08		

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SR-09	The string in the string-pulling device shall be easily replaced.	FR-09		
SR-10	The food dispenser shall be able to function long enough without getting stuck.	FR-05	PR-02	Decreasing the area where food will rub against the structure.

6 Minimum Design

Table 7 Minimum Design

Component	Minimum Feature Requirement
Software Components	
Web server	• Establishes a stable and reliable connection between any devices through LAN. • Allows users to set all training information required by the system. • Stores the training data, which the user can query. • Requires authentication for each user attempting to access the training system.
Hardware Manager	• Interprets the training parameter received from the web server and informs the setting to the corresponding hardware controller. • Interprets the real-time metadata received from the hardware processor into appropriate training data, communicates the data to the web server, and performs further action accordingly.
Stepper Motor Controller	• Administrates the stepper motor.
Load cell signal processor/image sensor signal processor	• Interprets GPIO analog signals from load cell/image sensor into appropriate digital signals.
Hardware Components	
String-pulling Device	• Sets the force threshold pulling the string. • Records the real-time training metadata.
Food Dispenser	• Dispenses a fixed amount of food pellets when the subject completes one task.

The training system will reward the subject when the amount of string pulled meets the distance goal set by user. The optical sensor attached to the pulley system will record the distance pulled and inform the hardware manager that the subject has reached the goal and should be rewarded. Then the food dispenser will be signaled to deliver a fixed amount of food pellets. This functionality can be achieved if the force controller, food dispenser, pulley system and hardware manager are implemented correctly.

Also, the ability to modify training parameters can be achieved if the web server is able to receive the parameter values from users and pass it to the hardware manager. The hardware manager will then use those values to communicate and control the string-pulling system and food dispenser.

7 High-level Hardware Design

Figure 2 illustrates the deployment diagram of our design. We utilize the webpage as one GUI module. The user can review, modify, and retrieve the training setting/data when the client device HC-08 and Raspberry Pi 4 Model B HC-01 are under the same LAN (connected to the same wireless router HC-09).

- This suggests that any client device supporting the web browser SC-07 and has a wireless adapter HC-02 can serve as a front-end (here, we use laptop and iPad as an example).
- Meanwhile, we utilize one Raspberry Pi as the back-end server, which executes all software components listed in figure 3 excluding the web browser application. It can communicate with the webpage user through its built-in wireless adapter, as well as communicate with the string-pulling device HC-03 and food dispenser HC-04 through its built-in GPIO ports.
- The string-pulling device consists of a stepper motor HC-05 to control the required pull force, a load cell HC-06 to measure the current full force, and an image sensor HC-07 to measure the pull velocity. The stepper motor is connected to the output port of the Raspberry Pi GPIO module, while the load cell and optical sensor are connected to the input port in the Raspberry Pi GPIO module.
- The food dispenser consists of a stepper motor to deliver the food pellet and an image sensor to check whether one delivery attempt succeeds. The connection setting of the stepper motor and image sensor is the same as in the string-pulling device.

8 High-level Software/Firmware Design

Figure 3 illustrates the component diagram of our design. We apply Flask Dashboard Datta Able [6] as our back-end server template, which provides fully developer-centric code (Flask python package serves as an engine, while HTML, CSS, JavaScript, SQL are responsible for webpage rendering and data management) for SC-01 to SC-04 and SC-06. For other software/firmware components, they are implemented with python class with support packages (e.g., Node-RED for GPIO W/R).

- LAN network web server SC-01 hosts webpage at the LAN IP address assigned by the router (in the figure, it is 192.168.0.40) with a specified port number (e.g., 5000), where their combination (192.168.0.40:5000) enables the user to access the posted data through their internet browser under the same LAN.
- Authentication SC-02 is the subcomponent of the web server. It provides the interface to register the user, which prevents the potential laboratory data breach. When the product is released, we will provide backdoor administrator accounts for the client to

register other normal users. Those backdoor accounts will be coded in the configure file in the software package, where the client can modify later.

- Training setting SC-03 is the subcomponent of the web server. It communicates the user input training parameter (e.g., required pull force, pull distance, and maximum allowable time window to complete one task) to the hardware manager.
- Data retrieve SC-04 is the subcomponent of the web server. It receives the training data (e.g., pull velocity, number of times the task was completed) from the hardware manager and stores them with other supporting data (e.g., the animal ID) into the database allowing the user to query one specific piece of information.
- Hardware manager SC-05 1) interprets the training parameter received from the web server into an appropriate numerical value (e.g., translate the required pull force into the number of the stepper motor rotations). It then informs the setting to the corresponding hardware controller. 2) interprets the real-time metadata received from the hardware processor into appropriate training data. It then communicates the data to the web server and performs further action accordingly.
- Database SC-06 stores all the collected training data, which is R/W by the data retrieve process, and all the account information. Its data structure is organized in a way that is robust for experimental investigation.
- Web Browser SC-07 provides an interface for the user to access the server. It can be any commercially used application (e.g., Google Chrome, Safari, etc.).
- Stepper motor controllers FC-01 maps digital signals from the hardware manager into appropriate GPIO analog signals to administrate the stepper motors.
- Load cell signal processor FC-02/image sensor signal processor FC-03 maps GPIO analog signals from load cell/optical sensors into appropriate digital signals to the hardware manager for further computation.
- GPIO Reader/Writer FC-04 transmits signals between FC-02/03 and physical GPIO ports in Raspberry Pi.
- Firewall FC-05 is configured to allow the communication between the client device and Raspberry Pie. It is done by editing the router's configuration page.

9 System Budget

Table 8 System Budget (ROM)

Component	Mfr P/N	Mfr	Qty	Unit Price	Extended Price
Stepper Motor 28BYJ-48 [1]	28BYJ-48	Longrunner	5	CDN$ 4.198	CDN$ 20.99
Raspberry Pi 4 Starter Kit (4G RAM) [2]	99467	CanaKit	1	CDN$ 134.99	CDN$ 134.99

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Smooth Belt 1/8" [3]	ROB-2152	Actobotics	5	CDN$ 4.99	CDN$ 4.95
Break Away Headers [4]			3	CDN$ 1.5	CDN$ 4.5
Digital Caliper [5]	B07BC856B5	Diagtee	1	CDN$ 16.68	CDN$ 16.68
3D-printed dispenser			1	CDN$ 50 (estimated)	CDN$ 50 (estimated)
				Total Cost	CDN$ 215.43