EZ MOVE COMPANY

March 16, 2022

Dr. Mike Hegedus
School of Engineering Science
Simon Fraser University
8888 University Dr.
Burnaby, BC

RE: ENSC 405W/440 Design Specification for EZ Table

Dear Dr. Hegedus,

The following document was prepared by the EZ Move Company for ENSC 405W: Capstone A, and details the Design Specifications for our product, the EZ Table. The primary goal of our company is to create a remote controlled motorized table, capable of carrying everyday necessities for people who may have mobility impairments. EZ Table is focused towards supporting individuals who will use the device on a daily basis in a home environment.

EZ Table will be equipped with a vertical height adjustable tabletop, which is meant to increase the reachability of the tabletop and further reduce the stress on back and hips of the user. Video feed from the camera will be relayed back to the user on a web based application and an additional storage space is available on the table, for storing day-to-day items.

This document will list both hardware and software design specifications that will fulfill the requirements set out for our project. Justification for the parts chosen and the supporting calculations are listed, along with an appendix describing the alternate design options that are considered during planning of EZ Table. At the near end, a supporting test plan is provided which is meant to test the listed design requirements before production.

Thank you for your time in reviewing our design specification for the EZ Table. For any further questions or concerns, please contact our designated Chief Communications Officer, Sachin at smomuli@sfu.ca.

Sincerely,

David Song
CEO
EZ Move Company

EZ MOVE COMPANY

Design Specification

EZ Table

Team

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Submitted To:

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Submission Date:

Mar 16th 2022

Abstract

The purpose of this document from the EZ Move Company is to detail the design specifications for the EZ Table. The document will detail the preliminary design specifications for the components which make up the EZ Table. The aim of this document is to provide the reader with reasons for the chosen design specifications which the EZ Move Company has made.

The EZ Table can be categorized into three major sections which are the software design specifications, hardware design specifications, and mechanical design specifications. The document's software design specifications will detail how the EZ Table is designed to be controlled through a web based application through a Wi-fi capable smart device. The document's hardware design specifications will look into the choice of electronic components such as microcontrollers, motors, circuits, batteries, and choice of material with which the EZ Table is planned to be built with. The mechanical design specifications will look into our choice of materials in constructing the EZ Table, and the shape of design for the whole system.

The document will mostly focus on the technical aspects of the design specification requirements. This includes both the software specification, hardware specifications and the mechanical specification, which will be detailed with justification. This document will also detail several design alternatives and test plans in an appendix section near the end of the document. The document will conclude with detailing our final proof of concept test plan, which our device will be showcased on April 12th, 2022.

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Revision History

Date	**Version**	**Description**
Mar 16th, 2022	1.0	Final Draft (Submission)

Ⅰ. List of Figures

Ⅱ. List of Tables

1. Introduction

The EZ Move Company plans to develop a product which aids users such as elderly and low - mid mobility individuals. There are also certain situations where the EZ Table will significantly ease the mobility of senior adults that have recently been hospitalized. A study in 2009 by Cynthia J Brown et al highlighted that on average, 83% of the measured hospitality stay was spent lying in bed, despite an ability to walk independently[1]. Consumers may choose to reduce their time spent walking and carrying items around the house, thus the need for the EZ Table becomes apparent.

To solve this problem, EZ Move company proposes EZ Table, which can be navigated throughout the household via application and has ample storage for daily necessities to be moved around. This device should be easily accessible for users with low technical ability and is designed to be robust and convenient to be used reliably around the house.

1.1 Background

A recent census done in the past decade by the government of Canada, shows that the majority of persons aged 65 and over, are living alone with a percentage of 83.9%[2]. It is important to note that the number of injuries will increase as people age as well [3]. Another important statistic also done by the government of Canada shows that one in five of the Canadian population or 6.2million individuals had a disability or some sort [4]. This means that many individuals might have trouble with some daily things such as carrying things, or moving from one point of their house to another.

Our company, the EZ Move Company's goal is to provide a product which can assist people having trouble moving within their own house. The EZ Table will be a remote controlled product which can help move things around the individual's house through the use of their smart device when connected to the EZ Table.

1.2 Scope

This document will list out various design specifications that need to be achieved, which are referenced to respective requirement specification ID. These design requirements are separated into developmental stages for proof-of-concept, prototype, and consumer final product. The document will consider the software, hardware and mechanical design specifications that are required to meet EZ Move Co.'s objectives for the successful introduction of the EZ Table to the consumer market. The document will also provide alternate design choices considered and supporting test cases.

1.4 Design Specification Classification

This section will list the labeling convention used for the various design requirements that should be met during the design and development of the EZ Table.

The labeling schema is similar to what was used for the requirement specification which is as shown below.

[Des X.Y.Z-Phase]

X - Section
Y - Subsection
Z - Specification Number
The encoding for *'Phase'* is as shown in *Table 1.1* below

Encoding	Development stage
A	Alpha (Proof-of-Concept)
B	Beta (Engineering Prototype)
C	Production Version

Table 1.1 *Development Stage encoding*

2. System Overview

The EZ Table is a motorized table which can be remote controlled by a user over WiFi. It is designed to help people at home who might have mobility issues, to move things around. The user could be someone who wants to move objects within a household from point A to point B. Users can place an object on the tabletop, then direct the device to destination via browser application. It is designed to be capable of carrying lightweight, everyday items. The EZ Table is designed for use with a smart device. When paired successfully, a camera, which broadcasts a live feed of its current surroundings and controls will be displayed on a web application. The user interface is designed to be intuitive, since careful consideration of users without much technical expertise is taken into account as seen in *Figure 2.2*. The system proposed uses a main base, which houses most of the hardware components with an adjustable tabletop which can be lowered to lower the center of mass of the system when in motion. The visual representation of the EZ Table is shown in *Figure 2.1* below.

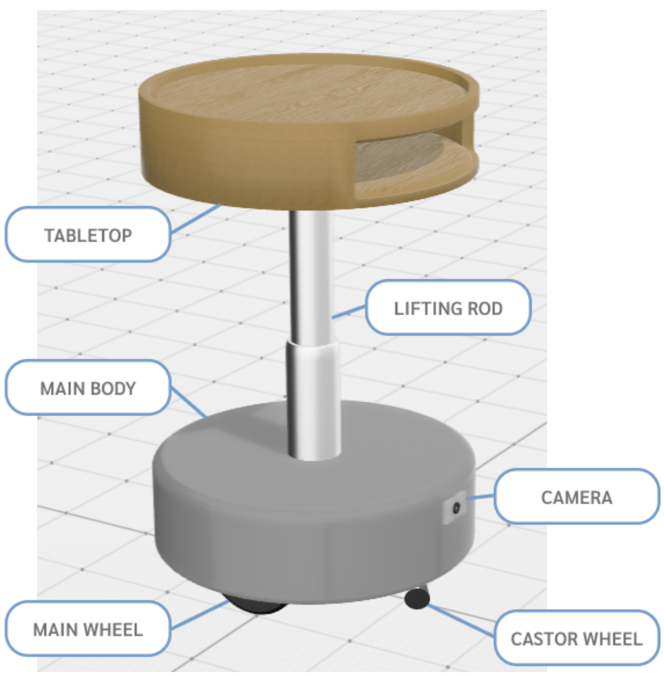

Figure 2.1: *3D Model of the EZ Table*

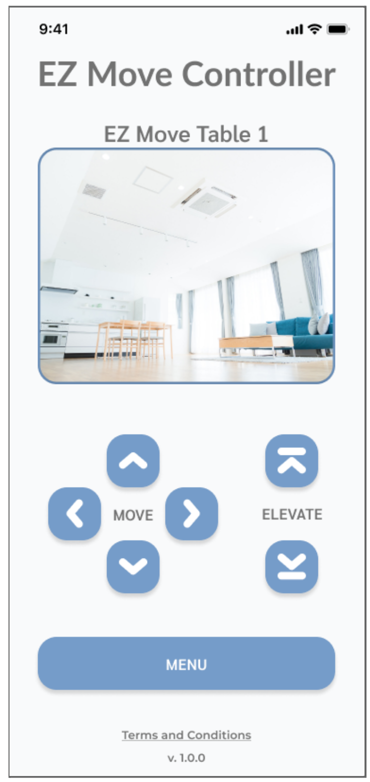

Figure 2.2: *Web browser UI*

The system of the main body can be seen as the EZ Table's main control center which houses all the electrical hardware and software. The diagram in *Figure 2.3* shows the system block diagram for the EZ Table. The controller of choice is the Raspberry Pi 400, which has increased processing power over other microcontrollers as well as reliable WiFi functionality. Two DC motor driver circuits are used to move the robot and a camera which provides the user a live video feed. The system is powered through a 12V battery system. The tabletops height will be adjusted using a linear actuator which is also powered by the battery system.The system will be controlled by the user through a web-interface accessible through the local WiFi network hosted on the Raspberry Pi. This connectivity is demonstrated in *Figure 2.4.*

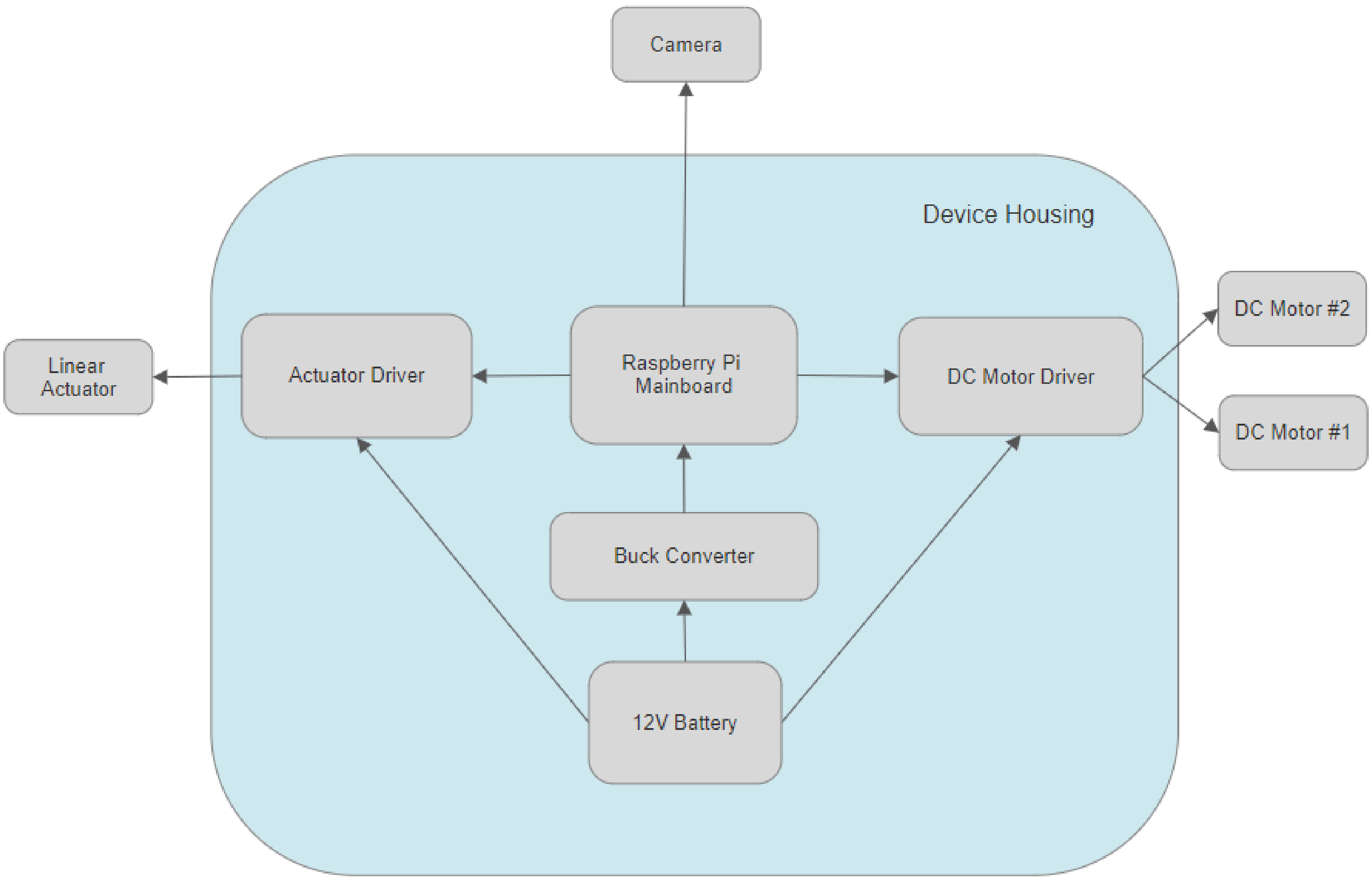

Figure 2.3 *System Overview of the EZ Table*

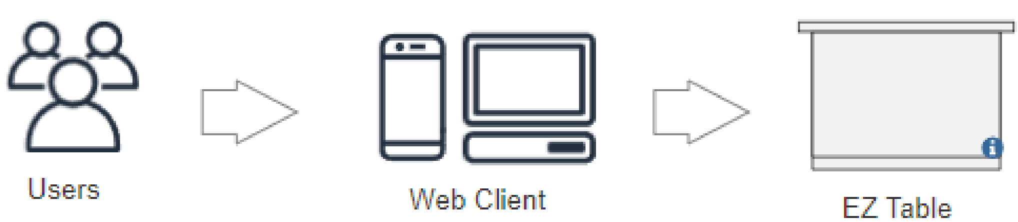

Figure 2.4 *Software Connectivity*

Since the EZ Table system is designed to be mobile and thus battery powered, the system's design specification must meet certain requirements. The main specifications which the EZ Table must meet are size, weight, battery life, and safety. The block diagram of the EZ Table system seen in *Figure 2.3* will allow for the design requirements to be met as detailed below. List of design requirements that need to be met, for EZ Table as a whole is shown in *Table 2.1*

Design ID	**Design Specification Requirements**	**Corresponding Requirement ID**
Des 2.1.1-A	The device will have a rechargeable battery system.	**[Req 3.1.1-A], [Req 3.1.6-B], [Req 3.1.7-B]**
Des 2.1.2-C	The device will have a battery life of 8 hours while in standby.	**[Req 3.1.7-B]**
Des 2.1.3-B	The device will be able to navigate and fit within a typical living space when the tabletop is retracted.	**[Req 3.1.2-A], [Req 3.2.1-C]**
Des 2.1.4-C	The device system as whole will not weigh more than 30 pounds.	**[Req 3.3.1-B]**
Des 2.1.5-C	The device will cost under 800$.	**[Req 3.1.5-C]**

Table 2.1: *List of Design Specification Requirements*

3. Software Design

3.1 Software Design Specifications

The Software design for the EZ Table is mostly all done on the Raspberry Pi 400. With the Raspberry Pi's built-in Wi-fi capability, the Pi is connected to a network through a router. Once connected, using any smart device with a web browser application and entering the correct web address, the user is then able to connect directly to the EZ Table through the Pi, and viewing its user interface. The details of software design specifications are detailed below in *Table 3.1*.

Design ID	Design Description	Corresponding Requirement ID
Des 3.1.1-A	User interface web page will be hosted on the device's onboard Raspberry Pi computer.	**[Req 3.2.1]**
Des 3.1.2-A	The Raspberry Pi computer shall be connected to a wifi network when the device is in use.	**[Req 3.4.2]**
Des 3.1.3-A	The user interface web page will be available to any commonly used web browser that is connected to the same network.	**[Req 3.4.5]**
Des 3.1.4-A	When movement or elevation controls are activated in the web interface, signals will be sent to the correct GPIO pins on the Raspberry Pi computer.	**[Req 3.2.1]**
Des 3.1.5-B	Motors will react within three seconds when movement or elevation controls on the web interface are pressed.	**[Req 3.4.3]**
Des 3.1.6-C	User Interface shall display only necessary elements and use larger font size and bright colors	**[Req 3.4.1]**

Table 3.1: *List of Software Design Specifications*

3.2 Software User Interface Design Specifications

The user interface design specifications for the EZ Table is also all programmed onto the Raspberry Pi 400. The user-interface of the web-application has a live video feed with low latency feedback, so that remote control of the EZ Table is easy, and done without much of a delay. The controls provide clear visual feedback, and are also labeled clearly. Details of the software user interface design specifications are detailed below in *Table 3.2*.

Design ID	**Design Description**	**Corresponding Requirement ID**
Des 3.2.1-A	User interface will display a live feed of the device's camera view.	**[Req 3.2.1], [Req 3.2.4]**
Des 3.2.2-A	User interface will display buttons for the control of the wheel motors for movement.	**[Req 3.4.6]**
Des 3.2.3-A	User interface will display buttons for the control of the linear actuator for elevation of the tabletop.	**[Req 3.4.1], [Req 4.0.3]**
Des 3.2.4-A	Feedback delay of the camera feed will be less than 100 ms.	**[Req 3.2.4], [Req 3.4.3]**
Des 3.2.5-B	User interface will display an error message if the move controls are pressed when the tabletop is at its max height.	**[Req 3.4.4], [Req 4.0.4]**
Des 3.2.6-B	User interface will display an error message if any robot controls are pressed while the battery is charging.	**[Req 3.4.4], [Req 4.0.3]**
Des 3.2.7-A	Main user interface page will immediately appear when the user connects to the valid address of the device when it is connected to the network.	**[Req 3.4.3]**

Table 3.2: *List of User Software User Interface Design Specifications*

4. Hardware Design

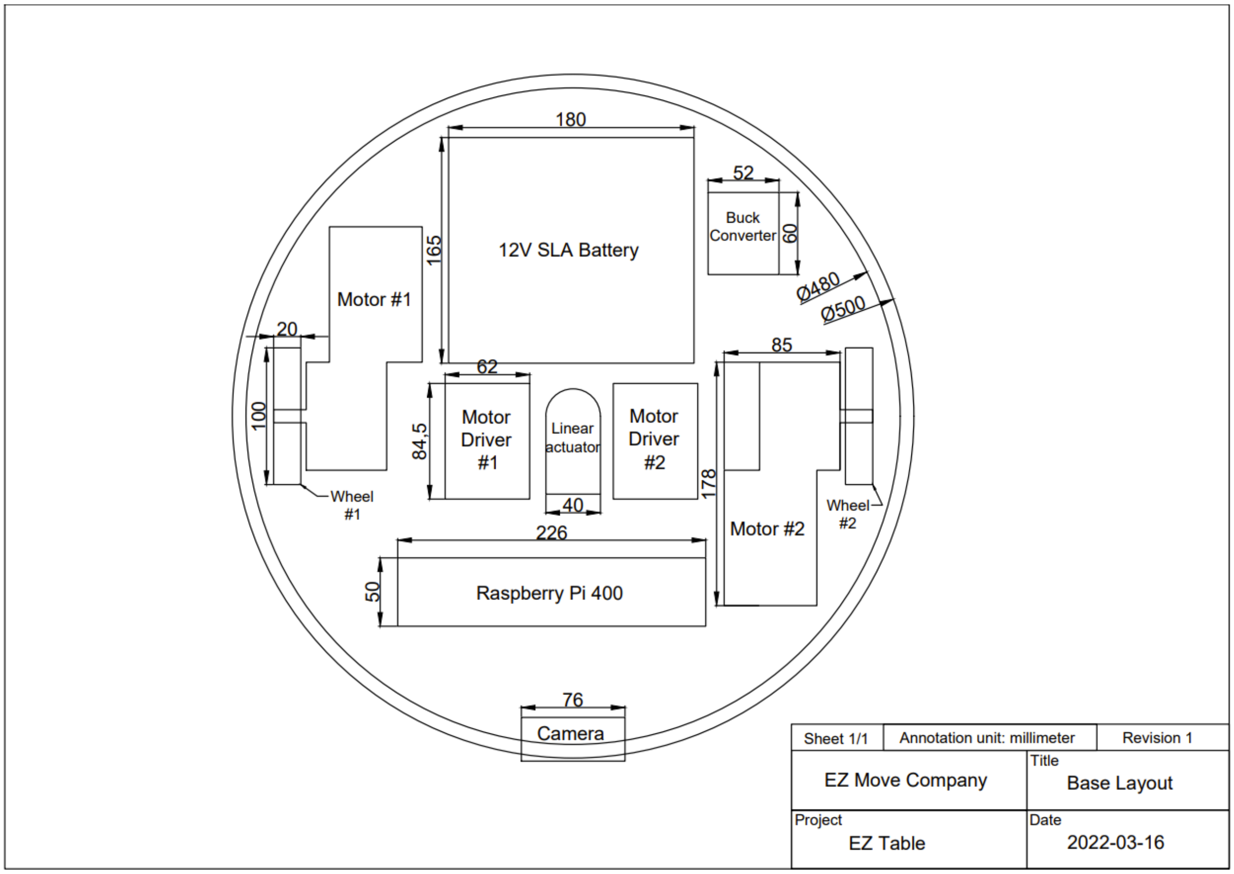

Figure 4.1: *Layout of components in main housing*

EZ Table is a system consisting of a microcontroller, motors, motor drivers, battery, camera and linear actuator. All these components are integrated together to work as one system, as shown in the *Figure 4.1* above. In this section, we will specify the design specifications of each of the hardware components that are used in developing EZ Table.

4.1 Microcontroller

The Microcontroller used in EZ Table must support hosting an interactive web server with live video feed, wireless connectivity and have the ability to output signals for motor driver logic. For our use case, we have decided to go with a Raspberry Pi 400 due to current parts availability, its superiority in computing power compared to other controllers, familiarity with the operating system, as well as its robust documentation and community support.

The Raspberry Pi 400 is equipped with a Broadcom BCM2711 quad-core processor, built-in WiFi connectivity, and a flexible 40-pin general purpose input/output header. This GPIO header, as shown in *Figure 4.3* is capable of outputting 3.3V high signals, which will be necessary for the motor drivers specified in an upcoming section. More technical specifications are listed in *Table 4.1*

Figure 4.2: *Raspberry Pi 400*

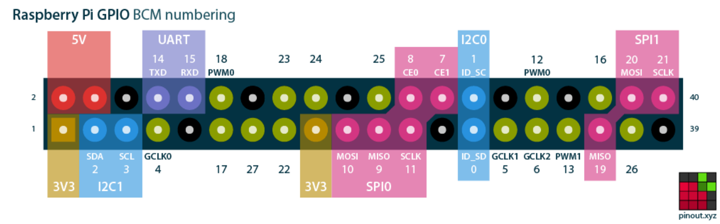

Figure 4.3: *Raspberry Pi GPIO Pinout*

Technical Specifications
• Broadcom BCM2711 quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz • 4GB LPDDR4-3200 • Dual-band (2.4GHz and 5.0GHz) IEEE 802.11b/g/n/ac wireless LAN • Bluetooth 5.0, BLE • Gigabit Ethernet • 2 × USB 3.0 and 1 × USB 2.0 ports • Horizontal 40-pin GPIO header

Table 4.1: *Technical Specifications of Raspberry pi 400[16]*

Design ID	**Design Description**	**Corresponding Requirement ID**
Des 4.1.1-A	The microcontroller will run an interactive web server.	**[Req 3.2.4-A]**
Des 4.1.2-A	The microcontroller will support live video streaming with low latency.	**[Req 3.4.3-B]**
Des 4.1.3-A	The microcontroller will support 2.4GHz WiFi.	**CSA ISO/IEC/IEEE 8802-11:19**
Des 4.1.4-A	The microcontroller will have pinouts capable of driving motor driver logic.	**[Req 3.1.1-A]**

Table 4.2 *List of Microcontroller Design Specifications*

4.2 Motor Circuit Design

The motor circuit in the EZ Table will be powered by a single 12V sealed lead-acid battery. This battery will connect directly to the power inputs of each motor driver to provide power to the motors. The motor drivers themselves will receive 3.3V logic from the Raspberry Pi GPIO through pairs of pins to control the speed and direction of each motor.

Item	PWM Pin	Direction Pin
Wheel Motor 1	12	11
Wheel Motor 2	16	15
Linear Actuator	32	31

Table 4.3: *GPIO Pin Assignment for EZ Table*

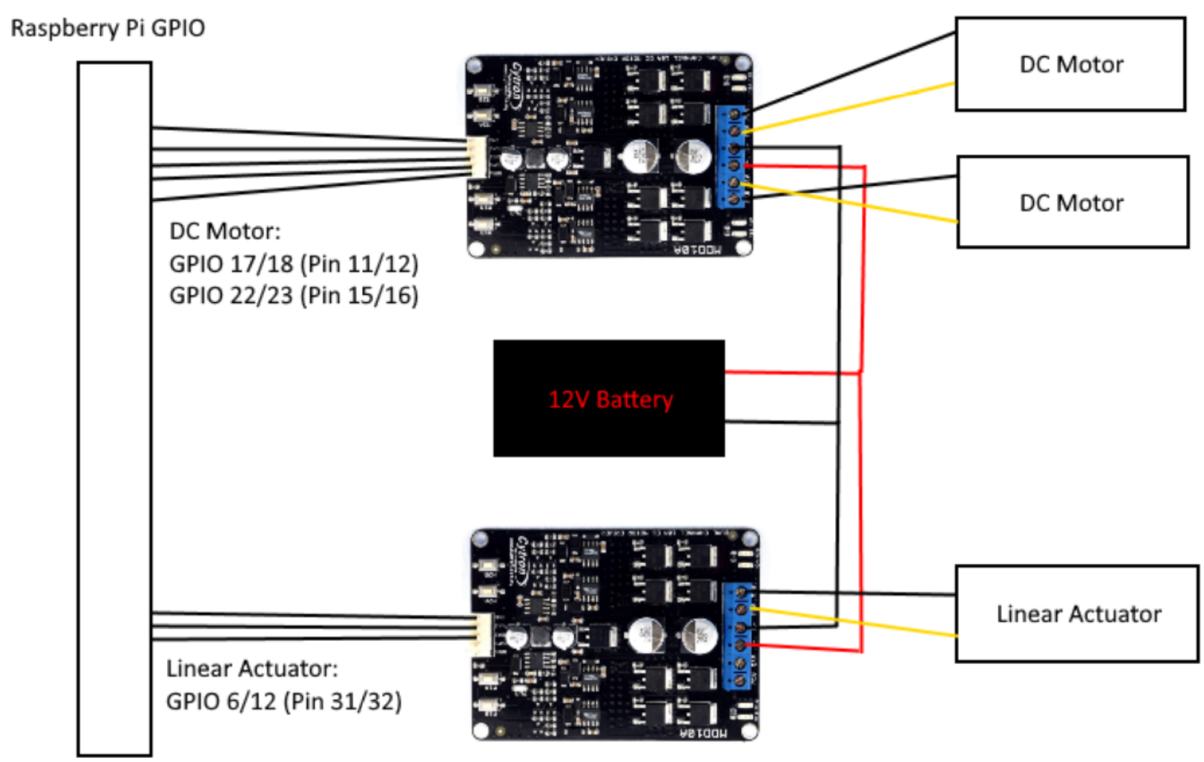

Figure 4.4: *Circuit Design for EZ Table*

4.3 Wheels and Motors

For our project, we are using two Makermotor branded 12V DC motors for our wheels. These motors have a power rating of 60W each and list 6 N.m of torque at 50 RPM. Since our requirements specifications document, we have decided that the decrease in speed from using these low power motors is worth the tradeoff for increased runtime and safety of the device while in operation. Technical specifications of the motor are as shown in *Table 4.4* below.

Technical Specifications
• Item Weight = 1.18 Kg • Maximum Rotational Speed = 50 RPM • Rated Torque = 6 N-m (4.4 ft-lb) • Rated Load: 60 Watts • Rated Voltage: 13.5 VDC

Table 4.4: *Technical Specifications for MakerMotor (PN01007-38) [18]*

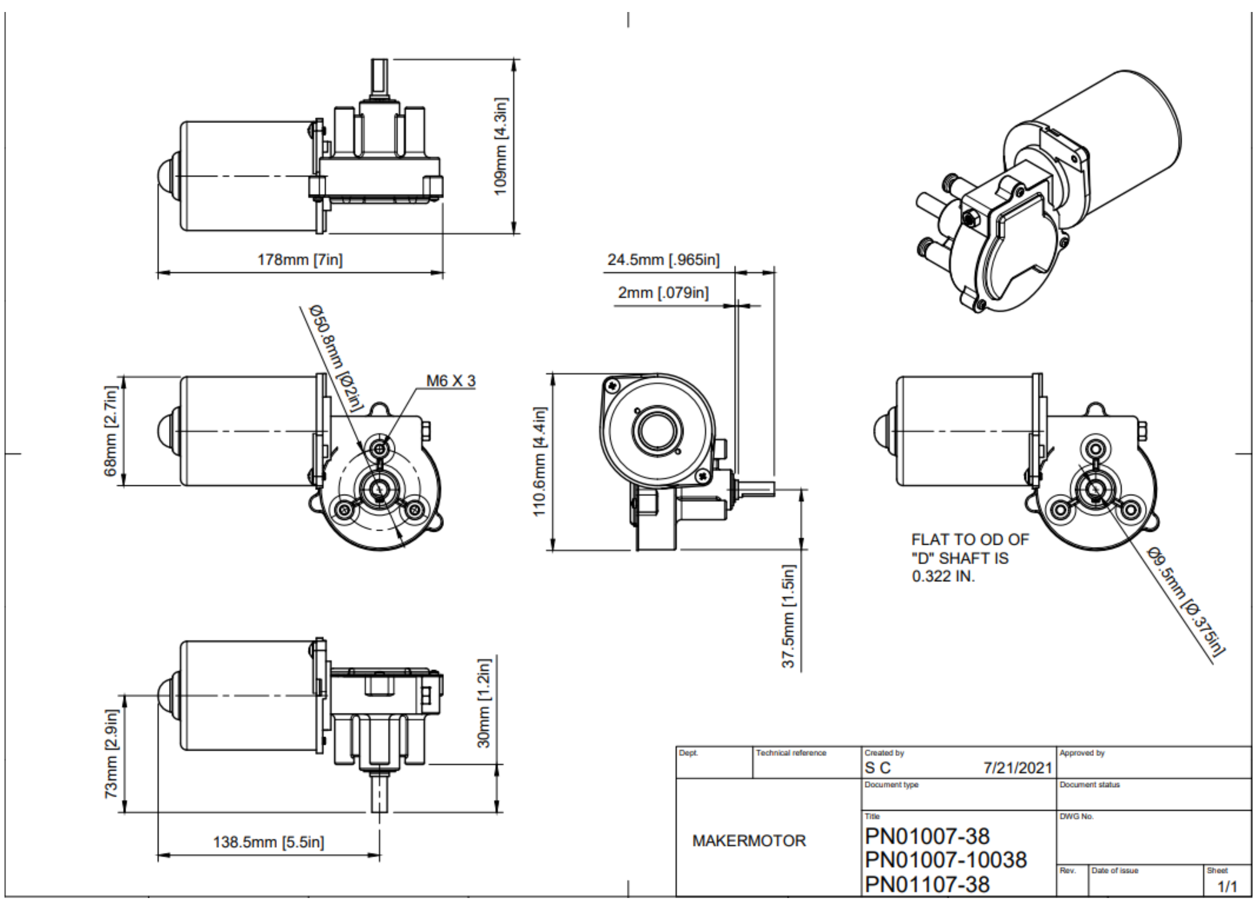

Figure 4.5: *Schematic for PN01007-38 [24]*

Design ID	Design Description	Corresponding Requirement ID
Des 4.3.1-B	Motors will move a combined weight up to 50lbs.	**[Req 3.3.1-B]**
Des 4.3.2-A	Motors will have a 100% duty cycle.	-
Des 4.3.3-B	Motors will consume 37W each.	**[Req 3.3.4-A]**
Des 4.3.4-B	Wheels will support the weight of the entire system.	**[Req 3.1.9-A]**
Des 4.3.5-B	Wheels will be made of material suitable for home terrain.	**[Req 3.3.3-A]**
Des 4.3.6-B	Motors and wheels will move the robot at 0.25 m/s (modified) without tipping	**[Req 3.1.10-A]**
Des 4.3.7-B	Device will be able to turn with a zero turning radius	**[Req 3.1.11-A]**

Table 4.5: *Motor and Wheel Design Specification*

4.3.1 Supporting Calculations

$Power\ required\ to\ move\ 30kg\ object\ at\ 0.25m/s$

$P\ =\ (30kg)\ *\ (9.8m/s^2)\ *\ (0.25m/s)$

$P\ =\ 73.5kgm^2/s^3\ or\ 73.5\ W$

$Torque\ required\ to\ hold\ 30kg\ at\ 0.05m\ away\ from\ motor\ axis$

$T\ =\ (30kg)\ *\ (9.8m/s^2)\ *\ (0.05m)$

$T\ =\ 14.7kgm^2/s^2\ or\ 14.7\ Nm$

$With\ 2\ motors,\ this\ load\ is\ equally\ distributed\ so\ specs\ for\ single\ motor\ are$
$P\ =\ 36.75\ W$
$T\ =\ 7.35\ Nm$

$Wheel\ RPM\ for\ system\ that\ moves\ 0.25m/s$
$Circumference\ of\ the\ wheel\ is\ (2\ *\ \pi\ *\ 0.05)m$
$RPM\ =\ (15m)/(2\ *\ \pi\ *\ 0.05m)\ =\ 48\ RPM$

4.4 Linear Actuator

Thanks to the SFU Capstone Parts Library, EZ Move Company was able to procure a linear actuator by Artilife. This actuator has a stroke length of 400mm and can support a load weight of 900N. While the stroke length is lower than specified in the requirements specification, as a company we have agreed that 1ft is suitable to accommodate for safety and stability concerns. Technical Specifications for chosen linear actuator is as shown in *Table 4.6* below.

Technical Specifications	
● Material: Aluminum Alloy ● Standard stroke: S=16"/400mm, ● Minimum mounting size L=S+105mm(19.9"/505mm), ● Extended Length=35.6"/905mm,	● Speed:10mm/s ● Rating voltage:12v DC ● Linear Actuator Load Capacity:900N ● Duty Cycle:25%

Table 4.6: *Technical Specifications for Artilife Linear Actuator[19]*

Design ID	**Design Description**	**Corresponding Requirement ID**
Des 4.4.1-A	The linear actuator will rise at least 1ft from the resting position.	**[Req 3.1.4-B]**
Des 4.4.2-B	The linear actuator will support the weight of the table and user accessories.	**[Req 3.3.1-B]**

Table 4.7: *Linear Actuator Design Specification*

4.5 Motor Drivers

The motor drivers we have selected for this project are two of Cytron Technologies, MDD10A dual channel DC motor drivers. This motor driver supports supply voltages ranging from 5V to 25V and 10A of continuous current through each channel which fit our hardware specifications. Control is done through 3.3V logic pins on the board, which match the output capabilities of the Raspberry Pi 400. Two drivers were purchased, one for the wheels and the other for the linear actuator.

Technical Specifications
● Motor Channels = 2 ● Operating Voltage(VDC) = 5 - 25 ● Peak Current (A) = 30 (10 seconds) ● Continuous Current(A) = 10

Table 4.8: *Technical Specifications for MDD10A*

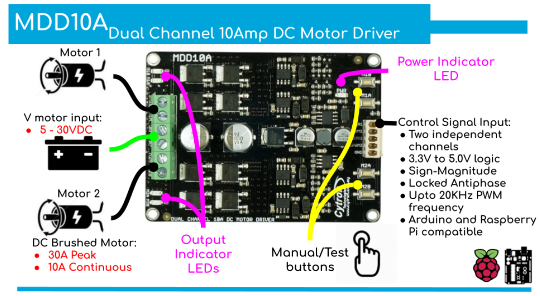

Figure 4.6: *MDD10A Board*

Design ID	Design Description	Corresponding Requirement ID
Des 4.5.1-A	Motor drivers will support maximum current of components through each channel.	**[Req 3.3.4-A]**
Des 4.5.2-A	Motor driver will accept control inputs from the microcontroller.	**[Req 3.1.1-A]**

Table 4.9: *Motor Driver Design Specification*

4.6 Power Supply

In order to power the EZ Table, we have decided to go with a single 12V SLA battery and step down the voltage to 5V to power the Raspberry Pi using a buck converter. As shown in Table 4.10, the highest voltage requirement in the system is 12V, which is a standard voltage for sealed lead-acid batteries.

Component	Voltage (V)	Current	Power
Raspberry Pi 400	5	$500mA \leq I \leq 3A$	$2.5W \leq P \leq 15W$
Camera	5	$\leq 500mA$	$\leq 2.5W$
Wheel Motor	12	$5A$	$60W$
Linear Actuator	12	$3A$	$36W$

Table 4.10: *Power Requirements of Components used in EZ Table*

As per our requirements specifications, we are interested in a battery that will allow the EZ Table to perform under load continuously for one hour. Under load, as the Raspberry Pi is running in headless mode in the robot, we can estimate it will draw at most 10W of power at a given time taking into account buck converter efficiency, thus giving us a total system power of 169W.

Knowing the total wattage of the system, we can set an arbitrary capacity for the battery that's larger than the total draw of the system. In order to run the EZ Table for an hour under full load, a battery larger than 169Wh (15Ah) is required.

Additionally, an external switch will be present in order to power on the device when it is in reach of the user. A charger will also be implemented to charge the battery.

Design ID	Design Description	Corresponding Requirement ID
Des 4.6.1-A	The battery will supply 12V to the entire system.	**[Req 3.3.4-A]**
Des 4.6.2-B	The battery will support an output of 15A continuous.	**[Req 3.3.4-A]**
Des 4.6.3-B	The battery will be rechargeable.	**[Req 3.3.5-B]**
Des 4.6.4-B	A power switch for the Raspberry Pi will be available for the user to turn on the device.	**-**

Table 4.11: *Power Supply Design Specification*

4.7 Camera

In order to provide a low-latency video feed to the user, EZ Table will be equipped with a USB webcam connected directly to the Raspberry Pi 400. Our camera of choice is the PAPALOOK AF925. The webcam will be run at a frame resolution of 800x600 pixels and a frame rate of 30 frames per second for optimal video latency.

Figure 4.7: *PAPALOOK AF925 Webcam*

4.8 Switch

The EZ Table will be equipped with a hardware power switch in order to turn the device on/off. The switch will be a basic I/O power switch conveniently located and properly labeled on the robot housing. This switch will be connected to the power supply of the system and control the overall power input/output of the device.

Figure 4.8: *Gardner Bender Toggle Switch[29]*

5. Mechanical Design

5.1 Body Structure

For the proof of concept robot housing, we will use lightweight medium density fiberboard plywood as the top and bottom sections, which are connected with a 3D printed section for the middle and covering the internals. The top and bottom sections will have cutouts for the wheels and linear actuator. Additionally, the middle 3D printed section will also need to have a cutout for the camera, as well as the hardware switch used to turn the EZ Table on/off.

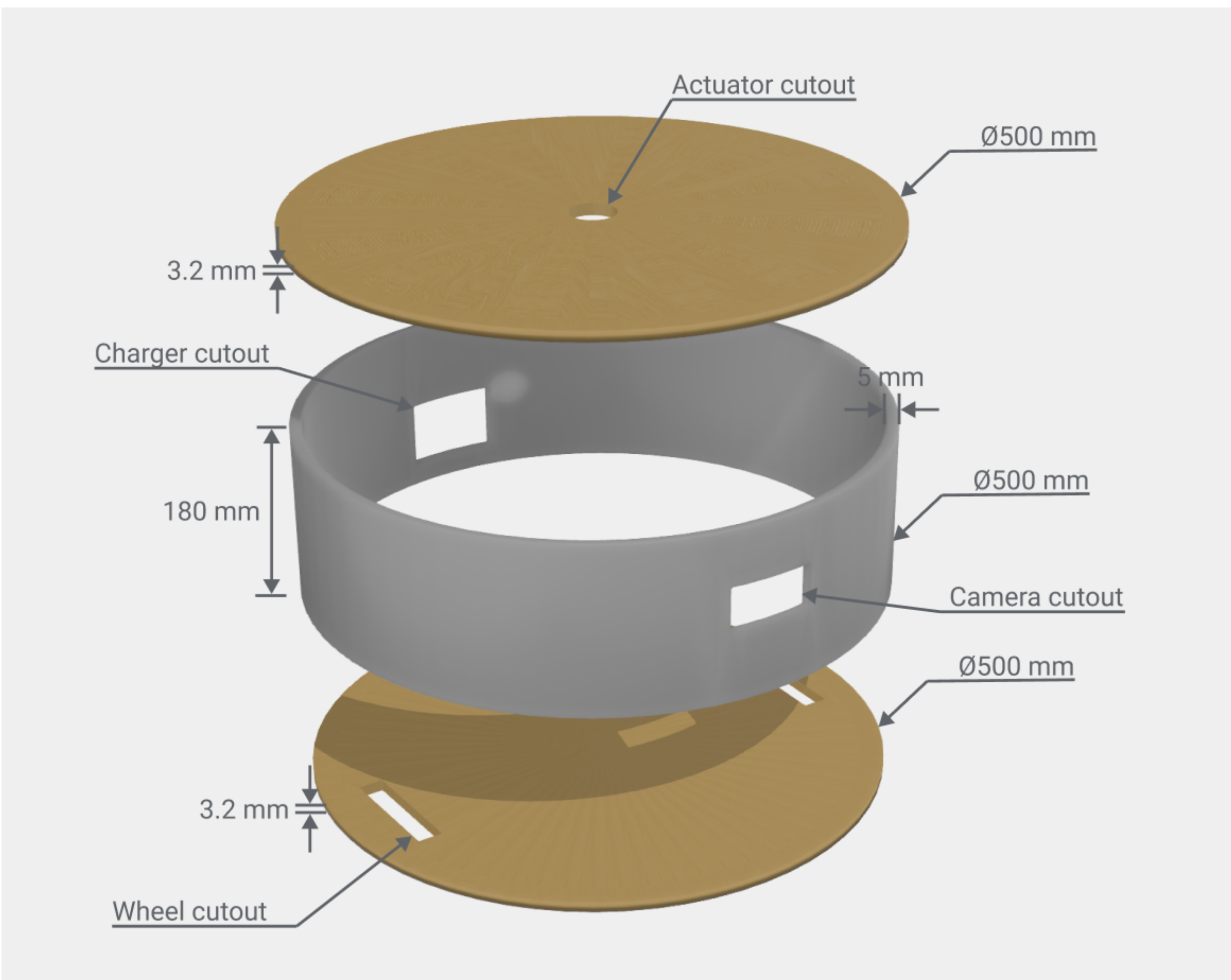

Figure 5.1: *CAD model of the PoC robot housing*

We chose to use a fairly lightweight but cheap option for the proof of concept, which led us to using medium density fibreboard as suggested by Mike in the second progress review meeting.

For the final version of EZ Table, we plan to use an acrylic plexiglass as the robot housing and have laser cut holes for the camera and switch.

5.2 Chassis Structure

The chassis of the design will need to be structurally rigid but also a relatively cheap option. Our choice of material involving a 3D printed section, and medium density fibreboard means that our system structure should be relatively rigid and stable when put together. This is because most of the weight of the EZ Table system will be in the base housing area where all the important hardware components sit. To ensure that it is rigid, we can make the material used for constructing the base relatively thicker when compared to the table top since there are less components at the top.

All components will be fastened onto the bottom medium density fiberboard section of the body with screws and brackets for the linear actuator and motors. The motors will be coupled onto the wheels, and the casters will be mounted under the bottom panel for stability.

5.3 Tabletop

The table top of the EZ Table rests on top of a linear actuator which allows for it to be adjusted up or down, allowing for a lower center of gravity in the lowered position while traveling. Medium density Fibreboard is the planned material, because of its lightweight but relatively strong construction. Railings or compartments for storage are also planned to be a part of the tabletop, so that items do not fall while the EZ Table is being remote controlled.

Figure 5.2: *Benefits of medium density fibreboard [5]*

6. Conclusion

This document describes the design requirements and the technical specifications that need to be met for a successful implementation of EZ Table. The EZ Table is a remote controlled table which is intuitively designed such that when successfully paired to a smart device, the user can control its movements, and height adjustable table through the live camera feed shown from the user interface. The EZ Table uses modern processing microcontrollers such as the Raspberry Pi 400, which allows for a low latency user-controlled experience viewed anywhere from its live camera. The EZ Table is designed such that anyone who has a smart device can control its features through the easily laid out user interface. The document details the EZ Table in three major sections which are software design, hardware design, and mechanical design.

The software design of the EZ Table corresponds to the user interface, which will control the EZ Table when successfully paired to a smart device. Our goal with the user interface of the EZ Table is to make it intuitive, and easy to use such that users with no prior experience can understand how it works after a simple look through. We achieve this by designing features such as low latency live camera, clear and labeled control arrows, and good feedback to control inputs.

The hardware design of the EZ Table corresponds to the electrical hardware which comprises the system. Our goal when choosing the hardware was to make sure that it had fast processing capabilities such as the Raspberry Pi 400. It also had to be able to move a certain amount of load, that is why we chose two motors with low RPMs, which prioritized torque and safety of speed.

The mechanical design of the EZ Table corresponds to its choice of material for construction and shape. Our goal with the mechanical design was trying to make sure that it was strong, and lightweight. We chose MDF as our main building material due it meeting both characteristics. The shape and design of the EZ Table is relatively small and compact which allows it to have a lower center of gravity since most of the weight is focused near the bottom.

This document details the three major sections of design specification. It will also serve as a reference document for the EZ Move Company, when it begins developing the proof of concept prototype which is to be unveiled soon. These design specifications are subject to change as the EZ Move Company is developing the EZ Table.

7. References

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Appendix A: Alternative Design Options

A.1 Software Design Alternatives

In this section, we will list all of the choices considered for designing the software aspect of EZ Table. A proper justification will be stated for our selection of the component.

A.1.1 Web Server

Since the EZ Table is going to be controlled using a WiFi connection, we will need to host a web server on the Raspberry Pi to be able to transmit and receive actions from the client application to the EZ Table. We have highlighted some of the design choices for this component in the table below.

Phase	**Design Options**	**Description**
Alpha	Python Flask	Flask is a very lightweight micro framework built with high customizability in mind. The benefit of using Python as the backend language is that it is very simple and quick to code, as well as being able to manipulate the GPIO pins on the Raspberry Pi more seamlessly, since we need the user's inputs translated to an action/motion on the EZ Table.[6]
Alpha	Node.js	Nodejs is a highly popular JavaScript backend framework. This could also be used as an alternative to Flask if the desire to be purely JavaScript code for the backend arises. In addition, there is lots of community support and plugins readily available to use.[7]

A.1.2 Client Application

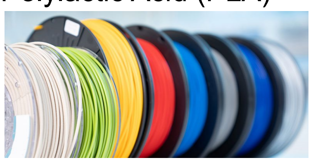
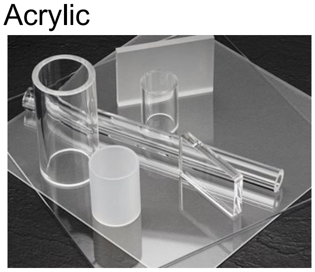
The client application will be the user's main way of communicating with the EZ Table. As such, it should be intuitive and fast to initiate controls to the EZ Table. As we have a web server, we have some options in terms of how we want the client application to look and feel. Some of these design options are covered in the table below.

Phase	**Design Options**	**Description**
Alpha	Web Page	The simplest and easiest to set up for a client application would be for the user to access a web page in their browser and control the EZ Table through this interface.
Alpha	React Native	React native is a way to code a mobile application using the React framework. This is better oriented towards the mobile application, if the product was purely on the phone.[8]
Beta	Progressive Web App (PWA)	A progressive web app is an alternate design choice for the client application as it is platform independent and works with most if not all devices including both desktop and mobile devices. However, this way we are able to also deploy an app which can be installed on the user's computer or mobile device rather than navigating to a web page.[9]

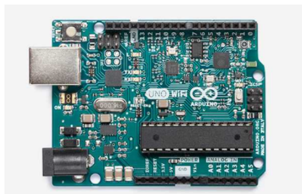
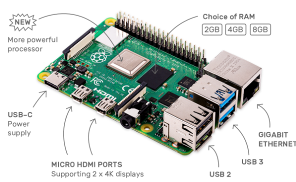
A.2 Hardware Design Alternatives

In this section, we will list all of the choices considered for designing the external and internal hardware components that will be used in development of EZ Table.

A.2.1 External Housing Material

Phase	**Design Options**	**Description**
Beta	Polylactic Acid (PLA) 	PLA is a thermoplastic monomer derived from renewable, organic sources such as corn starch. Due to the slow degradation rates of the material, PLA is considered the least environmentally friendly option.[11]
Beta	Medium Density Fiberboard (MDF) 	MDF is a composite product, known for its strength, consistency and smooth finish.[12]
Beta	Acrylic 	Acrylic is a transparent plastic material with higher strength, durability and stiffness.[13]

A.2.2 Microcontroller

Phase	**Design Options**	**Description**
Alpha	Arduino UNO WiFi 	Arduino Uno is an open source microcontroller board developed by Arduino which is equipped with multiple Input/Output pins which can be used to communicate with other expansion boards or circuits.[14]
Alpha	Raspberry Pi 4 	Raspberry Pi 4 is a low cost, energy efficient and huge computing power micro computer, embedded in a compact board. This supports Linux and Python to build easy to use applications.[15]
Alpha	Raspberry Pi 400 	Raspberry Pi 400 is an overclocked version of Raspberry Pi 4, equipped with a huge cooling system in a keyboard form factor.[16]

Since our choice of microcontroller should host a web server, displaying real time camera feedback (according to the **Req 3.2.4 - A**), Raspberry Pi 400 is chosen due to its availability in the consumer market and increased computing power than other alternatives. Although all of the above listed options meet this requirement, Raspberry Pi 400 makes a better choice for our needs. Our first preference was to choose the Raspberry Pi 4 as our microcontroller, but due to high demand and low supply for Raspberry Pi 4, we have chosen the Raspberry Pi 400 as our microcontroller for development of EZ Table.

A.2.3 DC Motors

Phase	**Design Options**	**Description**
Alpha	Makermotor ⅜” Shaft (PN01007-38)	PN01007-38 is a 12V powered reversible electric powered gear motor with a rated torque of 6 N-m and a speed of 50 RPM.[17]

		
Alpha	BEMONOC Angle Gear Motor (43237-2) 	43237-2 is a 12V powered angle gear Motor with a rater torque of 6 N.m and a speed of 50 RPM.[18]

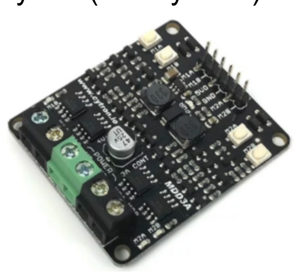
As per **Req 3.1.9-A and Req 3.1.11-A**, we need to be able to have an EZ table stable with just 2 wheels and ball caster(s). The device must also have zero turning radius. So, we need to use these two wheels to turn the EZ table in any direction. To achieve this, we have chosen *MakerMotor (PN01007-38)* as our DC Motor.

A.2.4 Linear Actuator

Phase	**Design Options**	**Description**
Alpha	Artilife Linear Actuator 	Artilife Linear Actuator is a 12V powered aluminum alloy, with a stroke force of 40cm and a maximum load of 90Kg.[19]
Alpha	Mini Linear Actuator 	Mini Linear Actuator is a 12 V powered actuator, with a stroke force of upto 100 cm and a duty cycle of 25%. Maximum possible load on a mini linear actuator is up to 68Kg.[20]

According to the **Req 3.3.1-B and Req 3.1.4-B** , EZ Table must be able to lift the table top upto 2 feet and support load of upto 25 kg. Above listed options meet this requirement. However, due to the option to loan Artilife Linear actuator from previous capstone library parts, we will be using *Artilife linear actuator* to eliminate the longer shipping time with Mini Linear Actuator.

A.2.5 Motor Drivers

Phase	Design Options	Description
Alpha	Cytron (MD10C) 	MD10C can be used to control Bi-directional movement for one Brushed DC motor (Single Channel), designed to drive high current DC motor upto 13Amps.[21]
Alpha	Cytron (MDD10A) 	MDD10A is a dual channel version of MD10C, supporting maximum current up to 10A continuous and 30A peak (10 seconds) for each channel.[22]
Alpha	Cytron (RB-Cyt-260) 	RB-Cyt-260 can control two brushed DC motors, driving up to 3A per channel continuously.[23]

We need at least 3 channels to control 2 DC motors and 1 Linear actuator as per **Req 3.1.4-B and Req 3.3.1-B**. MD10C (one Channel) and MDD10A (Dual channel) meet the current requirements to drive multiple brushed DC motors and linear actuator at the same time. We have chosen two of the *MDD10A Cytron Motor Drivers* to have one extra channel for any future developments.

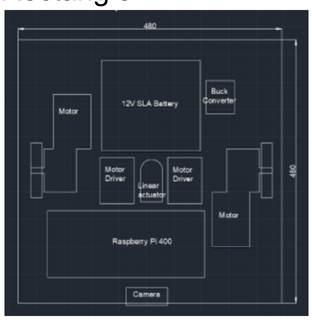
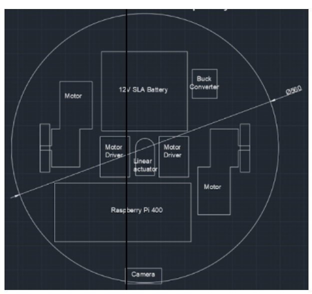
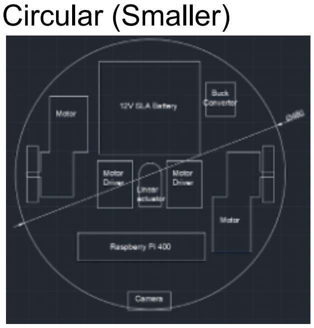
A.2.6 Battery

Phase	Design Options	Description
Alpha	12-Volt 18 Ah SLA Battery 	With 18Ah, the system should be able to run 8 hours when in standby. [24]
Alpha	36V 10Ah Lithium-ion 	Lithium-ion battery with 10Ah Capacity, more light weight battery option, but much more expensive for the capacity. [25]

A.2.7 Wheels

Phase	Design Options	Description
Alpha	Caster Wheels 	Caster wheels are light and durable, but have a greater friction coefficient on some surfaces such as carpet. [26]
Alpha	Semi Pneumatic Wheels 	Semi-pneumatic wheels which have low friction coefficient on mostly all terrain, but are a little heavier compared to caster wheels. [27]

A.2.8 Base Structure

Phase	**Design Options**	**Description**
Alpha	Rectangle 	Simple rectangular base structure to house all the electrical components. Enough space is left out to dissipate heat and to include any further components that we plan to include during development of EZ Table.
Alpha	Circular 	Circular base structure to reduce the free space which could account for the overall shape of the device.
Alpha	Circular (Smaller) 	Similar to the Circular structure mentioned above, but removed the keyboard form factor that houses Pi 400. This was to reduce the base, and in turn make EZ Table smaller.

Appendix B: Supporting Test Plan

B.1 Software Test Plan

Preconditions: The device is turned on and connected to WiFi. User is connected to the main controller page through a web browser on a smartphone or computer through the predetermined address.

Design Specification Tested	Test Procedure	Expected Outcome	Result	Comments
Des 3.1.4-A **Des 3.2.2-A** **Des 3.2.3-A**	Press each of the buttons corresponding to movement or elevation.	The robot will move or elevate in the specified direction when each of the buttons are pressed.	Pass: ❐ Fail: ❐	
Des 3.2.6-B	Plug the charging cord into the device and flip the switch to enable charging mode. Press any of the movement or elevation buttons	No movement or elevation change occurs on the device and an error message appears on the controller page.	Pass: ❐ Fail: ❐	
Des 3.2.5-B	Press the button until the table elevation is at least 5 cm above it's minimum height. Press any of the movement buttons.	The device does not move when the movement button is pressed. An error message appears on the controller page.	Pass: ❐ Fail: ❐	
Des 3.1.5-B	For each of the movement or elevation buttons, press the button and immediately start a timer. End the timer when the corresponding motor(s) responds to the input.	The correct motors respond to the input within two seconds.	Pass: ❐ Fail: ❐	

B.2 Hardware Test Plan

<u>Preconditions:</u> The device is turned on and connected to WiFi. User is connected to the main controller page through a web browser on a smartphone or computer through the predetermined address.

Design Specification Tested	**Test Procedure**	**Expected Outcome**	**Result**	**Comments**
Des 4.3.6-B	Press and hold the button for 30 seconds. Measure the starting and ending distance.	The device continuously moves for the 30 second duration. The total distance is at least 12.5 meters.	Pass: ❒ Fail: ❒	
Des 4.4.1-A	Ensure the device is at its lowest height and measure the height. Press and hold the button until the height stops increasing and measure the new height.	The difference in height measurements is at least one foot in length.	Pass: ❒ Fail: ❒	
Des 4.3.6-B	Load the lowered tabletop with its maximum supported weight. Hold the button for 5 seconds then immediately hold the button for 5 seconds	The device moves from its starting position and stays upright when switching directions	Pass: ❒ Fail: ❒	
Des 4.3.7-B	Record the current position of the device. Hold the button until the device does a half rotation and record the new position. Repeat with the button.	For both rotations, the device does not deviate from its starting position by greater than 5 cm.	Pass: ❒ Fail: ❒	