MOBILITATE

November 9, 2015

Dr. Andrew Rawicz
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RE: ENSC 440 Design Specifications – R2000 Rehabilitative Exoskeleton

Dear Dr. Rawicz,

The attached document contains the design specifications for our R2000 exoskeleton. The R2000 is designed to assist the user in performing a simple stretching exercise, which is to raise and lower the calf and foot while sitting, in order to help rehabilitate weakened leg muscles. The user selects repetitions, sets and using a controller, which then commands the exoskeleton to assist the user in performing that exercise.

This design specification document details the characteristics of the various components and materials to be used for the R2000 exoskeleton. The components and materials will have justifications on why they were chosen, as well as justifications on why other alternatives were not considered. Also discussed in this document is the system test plan to be used for the demonstration.

Mobilitate is comprised of four Simon Fraser University Engineering Science students: Jialiang Ou, Lucia Zhang, Ryan Villanueva, and Chantal Osterman. If you have any questions or concerns, please feel free to contact us at chantalo@sfu.ca

Sincerely,

Chantal Osterman
CEO

MOBILITATE

Design Specifications for the R2000 Rehabilitative Exoskeleton

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Abstract

The design specifications for the R2000 rehabilitative exoskeleton are discussed in this document. A high-level system analysis is first introduced to give a reader a sense of the overall design. The entire system is broken down into two main submodules: the exoskeleton and the UI unit. The exoskeleton is the module that performs the lifting of the shank. It consists of an attachment straps made of Velcro to attach to a pre-existing knee brace, an aluminum bar system to assist with lifting the shank, and an aluminum housing for the servo motor to place on top of the knee. The servo motor to be used is a high-torque i00600 servo motor capable of lifting 115 kg*cm and is connected to the aluminum bar system. The servo is directly controlled by a jrk 21v3 motor controller using an 0-5V PWM signal from the UI unit. Added features include an IR Distance Sensor to detect any objects around the R2000 that may pose a danger, and an ACS712 Low-Noise Current Sensor to prevent the servo from over-heating.

The UI module provides a visual display for the user and also accepts inputs from the user and outputs it to the jrk motor driver. The hardware for the UI module consists of an Arduino Uno, programmed in C, to process the user inputs and motor driver outputs, an Arduino LCD shield to provide visual displays to the user and which also provides five push buttons to allow user input, and an emergency switch and red LED to handle dangerous situations and problems with the R2000 respectively.

The corresponding R2000 system test plan is then presented to test the entire system and prove that the R2000 is capable of accomplishing its main tasks.

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GLOSSARY

Arduino	A microcontroller.
Extension	Moving the calf from 90 to 180, where 90 degrees is the position in Figure 1 and 180 is parallel to the ground.
Flexion	Moving the calf from 180 to 90.
I/O	Inputs and outputs.
LCD	Liquid crystal display. A monitor to present the user with information.
LED	Light-emitting diode. A small light used to indicate low battery status.
PAMs	Pneumatic artificial muscles. By allowing air to flow into a rubber tube, the increased pressure will cause the tube to contract. This system can be used to lift heavy weights.
PCB	Printed circuit board.
PWM	Pulse width modulation. Digital signals of high and low are used to toggle the state of something, such as an LED or a motor.
R2000 user	A user with the following characteristics: • will weigh no more than 73kg, • will have a height between 157-170cm, and • will be seated as demonstrated in Figure 1.
Rotary Encoder	A dial that transmits a certain digital or analog code corresponding to its current rotation angle.
Stall torque	The maximum amount of force a motor can provide safely.
UI Unit	The user input interface where the user inputs exercise parameters. This includes a microcontroller, LCD, LED, buttons, rotary encoder, emergency stop switch, and power switch.

1.0 Introduction

Mobilitate's R2000 is an attachable exoskeleton to aid in leg rehabilitation. The product can be used in conjunction with some pre-purchased compression braces. By simply inputting parameters, such as degree of extension and number of repetitions, the R2000 will provide the power and assistance required for the user to reach their rehabilitative goals. The R2000 is designed for home usage, so it will be implemented with an intuitive interface and a less clunky design than many competitor's products.

1.1 Scope

The design specifications outlines the requirements that must be met for Mobilitate's R2000. This document details how all requirements for the proof-of-concept system outlined in *Functional Specification for a Rehabilitative Exoskeleton* [1]. As the focus is on the proof-of-concept system, only design considerations pertaining to the functional requirements marked with I or II will be explained.

1.2 Intended Audience

This document is intended for use by the members of Mobilitate. The design specifications will be referred to during the design and implementation phases to guarantee consistency and compliance with all standards. During testing, engineers will refer to this document to implement the test plans and confirm correct behaviour.

2.0 Overall System Design

The overall design of the system will be described in this section. For future reference, the proper sitting position when using the R2000 is shown in Figure 1.

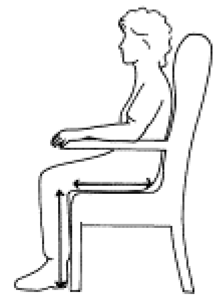

Figure 1: Proper seating position of R2000 user [2]

2.1 Mechanical Design

While designing the mechanism that would allow extension and flexion, a number of options were considered:

- hydraulics,
- pneumatics, in particular PAMs, and
- electric motors.

Hydraulics was ruled out quickly, as it is much more expensive than the other proposed methods. PAMs were considered due to their cheap construction costs, as well as the fact that it would be incredibly light compared to motors. For reference, a PAM would weigh approximately ½ kg, whereas motors could weigh as much as 5kg. The ends of the PAMs would be attached to the top of the user's leg, and when air flows into the PAMs, it would contract, pulling the leg up. However, the R2000 requires precise movements, which would be very difficult to implement with pneumatics. Furthermore, the air tank required to power the pneumatic system would be physically larger and more obtrusive than a motor power supply. Refilling an air tank is also less convenient than recharging a battery. For these reasons, pneumatics was also ruled out.

After coming to the conclusion to use electric motors, the decision of what type of motor needed to be made. The initial choice was to use stepper motors due to their high precision and easiness to control. However, we soon found that most stepper motors have a maximum stall torque of approximately 60kg-cm. These motors also required between 24-48 volts and 2-5 amperes. Coupled with the fact that we require some extra torque for contingency, two stepper motors would be required to implement the R2000. This would double the weight of the system, and require rapid feedback to ensure both motors are aligned at all times. Failure to do so could either break the system or injure the user. High-torque stepper motors also weighed up to 3.6kg not including a gearbox, which would prove to be obtrusive to the user. For these reasons, the lower mass of servo motors was favoured in lieu of the high accuracy of stepper motors.

Figure 2 provides a mechanical overview of the R2000. The knee brace used in the figure is the one used in the proof-of-concept, however the R2000 is designed to be compatible with most knee braces. For more views, please refer to Appendix D: Mechanical Drawings.

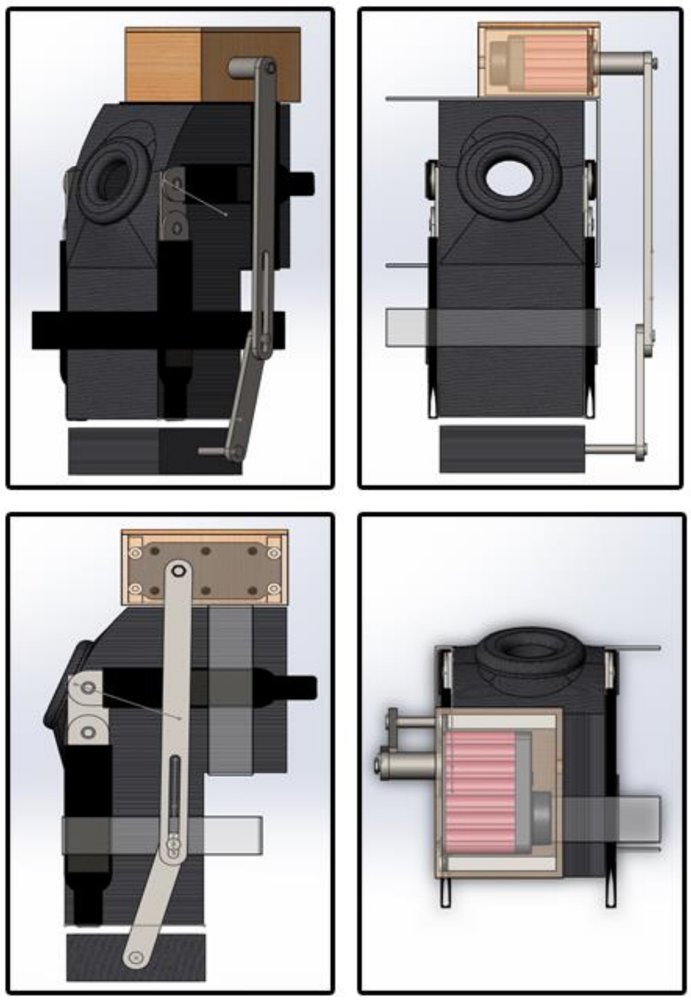

Figure 2: Mechanical overview of the R2000

Each component shown, including the prismatic joint system and the motor, will be described in-depth in subsequent sections.

2.2 High-level System Design

Figure 3 presents a block diagram showing the relationships between the inputs, outputs, and corresponding subsystems.

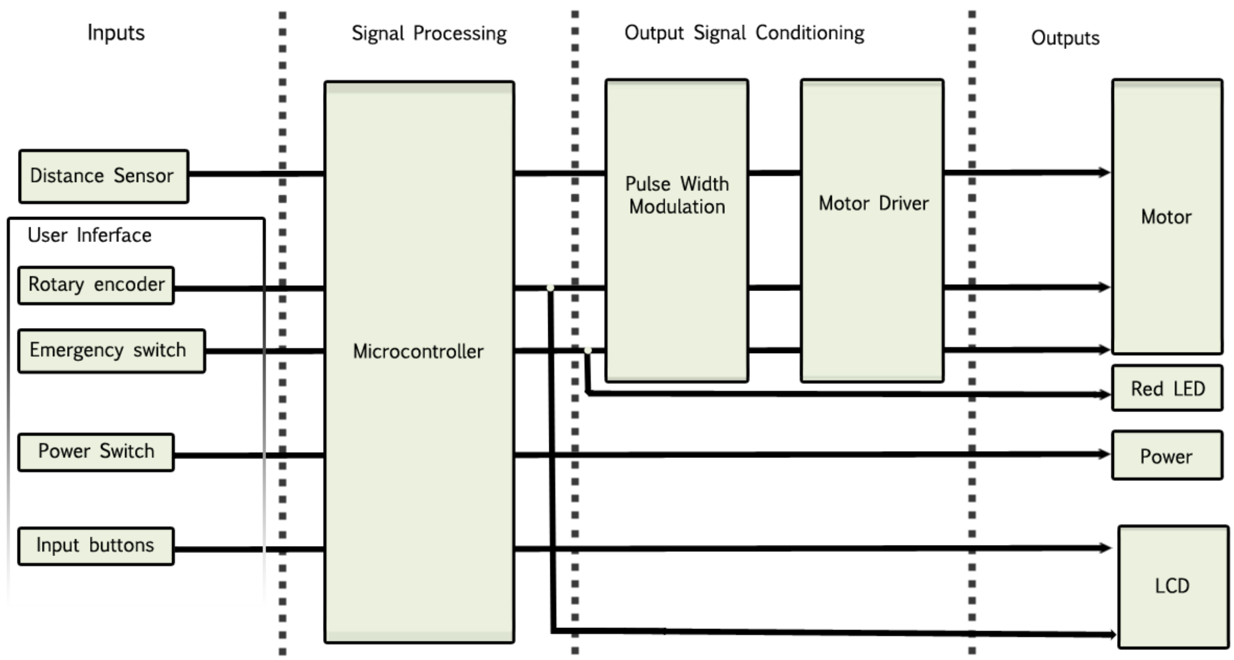

Figure 3: Block-diagram for high-level system design

Inputs come from both the UI and the peripheral sensors. The Arduino microcontroller will handle any filtering, signal conversion, and debouncing required for signals it receives and signals it sends. These signals will then either go directly to a UI output, or undergo PWM, also done by the microcontroller, before going to the motor driver, which then actuates the motor accordingly.

2.3 Power Supply

There are two separate power supplies for the system. The first is for the UI interface, which must meet the following requirements:

- Between 7-12V for safe operations [3]
- Small, lightweight so it can be placed inside the UI interface and carried
- Mounted to avoid shifting during usage
- Rechargeable if possible, to be environmentally friendly

Using online sources, a 9V battery was found to be best suited [3].

The second power supply is to be used to power the motor and the microcontroller that regulates it. The requirements it must meet are:

- Voltage: minimum 10V DC for the motor, and within the range of 5-28V DC for the controller
- Light enough to mount on the user without being intrusive

Due to their relative lightweight and high-power capacity, an 11.1V 3S LiPo battery suits our application.

2.4 SUSTAINABILITY

As mentioned in the functional specifications, a number of actions will be taken to produce a sustainable product. All batteries used will be rechargeable, therefore decreasing any waste. Furthermore, as detailed in section 3.1.3, the motor enclosure will be made of wood. This is because wood, compared to metals and plastics, is much more biodegradable and not toxic to the environment. Other materials will be bought or retrieved from local businesses or scrap yards.

3.0 Exoskeleton

This section describes the mechanical and electrical structures of the exoskeleton, and how they interact with each other to result in angular motion.

3.1 Mechanical Design

The mechanical portion of the R2000 consists of main parts:

- a system of rigid bars to allow rotation using the motor's output,
- straps to attach said bars to the user's knee brace, and
- a container for the motor to prevent user interference.

As detailed in the functional specifications [1], the user will have to own their own knee brace to use in conjunction with the R2000. The main reason for this is that many users will have already purchased expensive braces customized to their legs. Rather than providing a general knee brace, the Mobilitate team feels that a pre-purchased knee brace will be more comfortable and useful for the user. The following section will further explain the design and choice of materials for these components.

3.1.2 Rigid Bars and Materials

In order to have adjustable rigid bar lengths, the system has been designed with two segments:

- the top piece, which connects to the output of the motor, and
- the bottom piece, which connects to a Velcro strap tied around the user's calf.

The main issue with designing the system was that the bar length must extend during extension and shorten during flexion. However, both ends of the rigid bar must remain fixed at the motor output and Velcro on the calf. Therefore, a prismatic joint was used to dynamically adjust the length of the bar. The bolt will slide down the slot during extension, and up during flexion. This system also allows the bar to change length depending on the size of the brace, and where the user wishes to tie the bottom Velcro.

As the functional specifications document requires the user to be between 157-170cm tall, the rigid bar system's length will have a range between 25-33cm. These values were found using information presented in Appendix A.

While determining which material to use for the rigid bar system, the three main factors we considered were weight, price, and strength. While we could obtain plastic for free, it may be too brittle to lift the user's leg, especially with a slot drilled into it. Titanium, while quite strong, is much more expensive and dense than aluminium. Minimizing the weight of the rigid bar structure is imperative, as it must be both worn by the user and lifted by the motor. Steel, too, was considered. However it is more expensive and less workable than aluminum. Therefore, the final decision is to use aluminium.

3.1.2 Attachments to Knee Brace

Velcro will be used for attachment straps, as it is flexible to fit around any leg size and is cheaper than Kevlar. To counter any slippage issue with attaching a metal bar to Velcro, silicone gel will pasted on the exterior of the calf Velcro strap, where the rigid bar system is connected.

3.1.3 Motor Enclosure

The enclosure of the motor should not be ductile, and have:

- good heat dissipation,
- non-flammable,
- minimal mechanical and electrical noise, and
- electrical insulation.

Initially aluminum, titanium, steel, and wood were considered. Due to the price of titanium, it would not be a good choice for this project. For steel, although the price is similar to aluminum, there are concerns with rust and corrosion. Both aluminium and wood meet the above requirements. However, wood was chosen for the proof-of-concept enclosure as it is easier to work with, less ductile, and more readily available than aluminium sheet metal. For the final production product, aluminum will be used. To minimize mechanical and electrical noise from the motor, foam or coating used to muffle noise in ship engine rooms were considered. The preference for this choice is coating, due to the foam posing problems with heat dissipation and requiring more space. These considerations are summarized in Table 1.

Table 1: Material considerations for the motor enclosure

Components	Possible Material	Material (final decision)
Motor enclosure (outer)	Aluminum, Titanium, Steel, wood	Aluminum
Motor enclosure (inner)	Silent Running SR1000 Coating, Silverstone Silent Foam	Silent Running SR1000 Coating

Figure 4 presents the motor enclosure design, where the two vertical components on the sides represent the sound-minimizing foam.

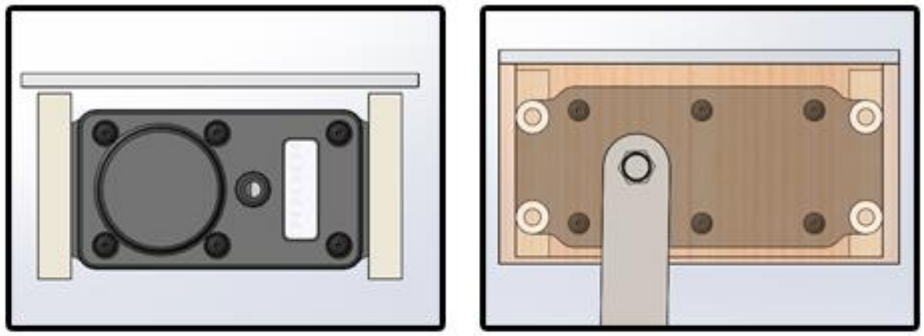

Figure 4: Motor enclosure

3.2 ELECTRICAL DESIGN

The system's main electrical components are: a Torxis Servo i00600 motor, a displacement sensor, a current sensor, a microcontroller and one encoder. Torxis servo motor provides the rotational motion for the rigid bar. For safety concern, the sensors, such as current sensor, will be used to ensure R2000 works in the proper way.

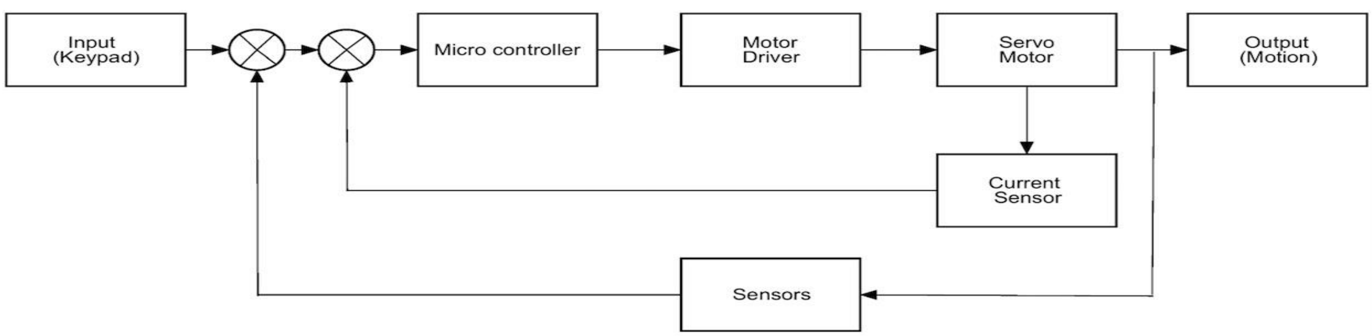

Figure 5: Electrical design overview

3.2.1 MOTOR

To calculate the required motor torque, the equation below was used with values taken from Appendix A. As detailed in the functional specifications, the maximum height of the user was assumed to be 170cm, and 73kg the maximum weight. To approximate the torque, the entire mass of the calf was treated as a point halfway down the calf, and the entire mass of the foot halfway down the foot. These assumptions are shown in Figure 6.

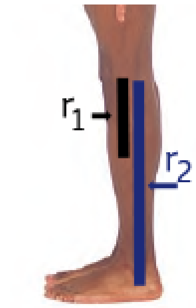

Figure 6: Visual depiction of torque calculations

$$\tau = F\ x\ r = (73)(0.042)(9.8)\left(\frac{170-81.93}{(2)(2.42)}\right) + (73)(0.0135)(9.8)\left(\frac{170-81.93}{2.42} + \frac{170-81.93}{(4)(2.42)}\right) = 986.08\frac{N}{cm} = 100.55\frac{kg}{cm}$$

Equation (1)

A contingency of 10% was added for safety, resulting in the desired 110 kg-cm torque required for the motor. Other important factors in choosing a motor are the weight, size, current drain, and operating voltages. In the end, the motor chosen was the i00600 Torxis Servo. The main specifications for it are provided in Table 2.

Table 2: Important characteristics of i00600 Torxis Servo

Stall torque @12V (kg-cm)	Speed @12V (sec/60°)	Dimensions (cm)	Weight (kg)
115.2	1.0	13.97 x 6.1 x 11.84	1.07

Since knee exercise is mostly angular motion, servo motor (i00600 Torxis Servo), which has smaller size and light weight, is chosen. I00600 Torxis Servo has a torque of 115kg-cm under a continuous duty condition. It is able to travel 90 degree in only 1.5 seconds.

3.2.1.1 Noise Considerations

The i00600 Torxis Servo operates quite loudly. To decrease the noise level, capacitors will be soldered across motor terminals [5]. The box for the motor will also be padded by sound-proof insulation foam to reduce mechanical noise.

3.2.2 Motor Driver

A number of specifications for the motor driver must be met:

- The driver must be compatible with the motor type (eg. brushless DC controller for brushless DC motor, brushed DC for DC gear motors, etc).
- The voltage range must accommodate the required voltage of the motor.
- If stall current of the motor is provided, the driver must be able to continuously supply at least 25% of the highest stall current value [6].

- The control method should be through PWM or other signal methods that can be received from a microcontroller.
- If there is no built-in over current and thermal protection, appropriate sensors will be used to avoid overheating and over-drawing.

The i00600 Torxis Servo has an embedded motor driver board, the jrk 21V3, therefore there are no compatibility issues between the driver and motor. Important specifications about it are listed below in Table 3.

Table 3: Main characteristics of the jrk 21V3 motor driver

Operating Voltage (V)	PWM frequencies (kHz)	Logic Voltage (V)	Output current per channel (A)
5 - 28	5 - 20	4 - 5	3 - 5

As current-sensing capabilities and reverse voltage protection are already included, these safety features have been achieved.

3.2.3 Distance Sensor

One proximity sensor would be used to detect any obstacles on the pathway of R2000 when the user is exercising with the brace. The sensor would be mounted at the front of the brace around middle point of the calf. However since the brace is only covering the halfway of the thigh and calf, to prevent the sensor from sensing the user's foot as an obstacle is the main concern. Therefore, the detecting start point of the sensor can be varied by different people with different foot sizes.

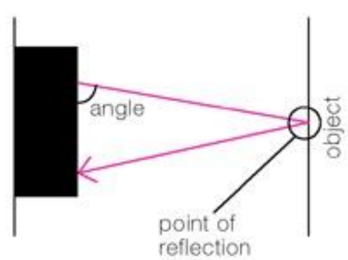

Figure 7: IR Proximity Sensor [7]

Since IR Distance Sensor can detect any obstacles at 45 degrees, there is only on sensor be needed and it is placed on the side of the rigid bar. Therefore, the maximum covered width would be,

$$\tan\frac{45}{2} = \frac{\frac{w}{2}}{l} \qquad \text{Equation (2)}$$

$$w = (2)(l)(\tan(\frac{45}{2}))$$

Using the table in Appendix A, the average calf length of a 170cm tall person is approximately 40cm. Therefore, any obstacles in front of the person that fall within a 45cm range can obstruct the exercise. If any obstacle is detected, the exercise will not begin until the object is removed. Using the table in Appendix B: IR Sensor Detected Width, the sensor will have a horizontal field of view of approximately 37cm. This is more than enough to ensure no obstacles will interfere with the exercise.

3.3 Software Design

The same Arduino Uno used in the UI unit will also be used to send PWM signals to the motor driver. By controlling the pulse width of each PWM signal, we can control the motor's rotation direction. The correlation between pulse width and servo rotation is shown in Figure 8.

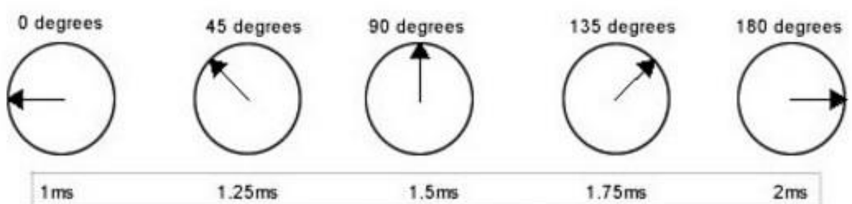

Figure 8: Relationship between pulse width and servo motor rotation [8]

4.0 User Interface Unit

The user interface allows users to input the maximum angle they can perform, and the repetition time they want for the exercise by using buttons and rotary encoder. When exercise starts, it communicates with the other microcontroller which controls the motor and displays exercise information on LCD screen display. The unit also contains an emergency switch so that when the motor is out of angle range, the controller will cut off the motor power.

4.1 Hardware Design

The main component of the UI interface is its microcontroller. A number of considerations were taken into account when choosing which brand and model should be used. Some examples are, but not limited to:

- number of inputs and outputs,
- ease of programming,
- small size,
- low price,
- high community support, and
- accessory and component compatibility.

With these characteristics in mind, the decision came down to the Arduino Uno, Arduino Pro Mini, Teensy 3.2, and the MSP-430G2 LaunchPad. All of these boards are compatible with Arduino software, so community support was not as issue. Other pros and cons are presented Appendix C: Microcontroller Consideration.

Since the microcontroller will be mounted on the user's waist, small size was not a priority. As the prices are relatively similar and each microcontroller met the minimum number of I/O pins required, the deciding factor came down to learning curve and previous experience. As one member of Mobilitate had previous experience with Arduinos, this brand was chosen.

One of the drawbacks of the Arduino Pro Mini is the lack of a UART port. Furthermore, since the Arduino will also be used to control the motor driver, it must be able to support peripherals at 5V. For these reasons, coupled with its incompatibility with Arduino shields, the Pro Mini was discarded for the proof-of-concept in favour of the Uno. For production, a different microcontroller may be considered instead.

A summary of each component and its corresponding signal type and pin on the Arduino are presented in Table 4. For a full schematic, please refer to Appendix E: UI Schematic.

Table 4: Summary of components and their connections to the Arduino

Component	Signal Type	Pin
LCD	Digital	4-9
Push buttons (x5)	Analog	A0
Rotary Encoder	Analog	A1, A2
Red LED	Digital	2
Yellow LED	Digital	11
Emergency Switch	Digital	3
Power Switch	N/A	Between input and ground

Please refer to Appendix E: UI Schematic for a full diagram of the UI unit. For safety concerns, all grounding of electrical components will be connected back to power supply. We will also be designing and manufacturing our own prototype PCB for the proof-of-concept. For the final production product, the PCB will be designed in Eagle and sent to professional manufacturers.

4.1.1 Arduino LCD Keypad Shield

The proof-of-concept will use an Arduino shield for the display and part of the user input. The shield consists the first two components of Table 4. The push buttons will be used to navigate through the UI unit menu.

4.1.2 Rotary Encoder

Rather than using a bulky number pad to input the degrees, we have opted to use a smaller and more responsive method of a rotary encoder. Users can simply rotate the encoder until they reach their desired exercise angle.

4.1.3 Red LED

A red LED will be used to indicate any problems. It will light either when the emergency switch has been activated, or if issues have been detected automatically. Examples of issues include the motor overheating or any mechanical problems.

4.1.4 Yellow LED

The yellow LED will indicate low battery, specifically when battery is equal to or below 25% of its full capacity.

4.1.5 Emergency Switch

Once the emergency switch is on, the Arduino will light the red LED, then send a signal to the motor driver to turn the motor slowly back to default position.

4.1.6 Power Switch

One power switch will be used to control both the power supply to the motor, as well as the power supply to the UI unit.

4.2 Software Design

The program is a two-level menu. The user will first be asked to enter the desired exercise angle, followed by the number of repetitions. The Arduino will then convert this angle to the appropriate PWM sequence and send this to the motor driver. A variable will be used to keep track of how many times the servo motor returns to its default position, and when this equals the number of repetitions entered by the user, the exercise will end. The UI unit then returns to the first menu level again for the next exercise. Figure 9 provides a visual depiction of this process.

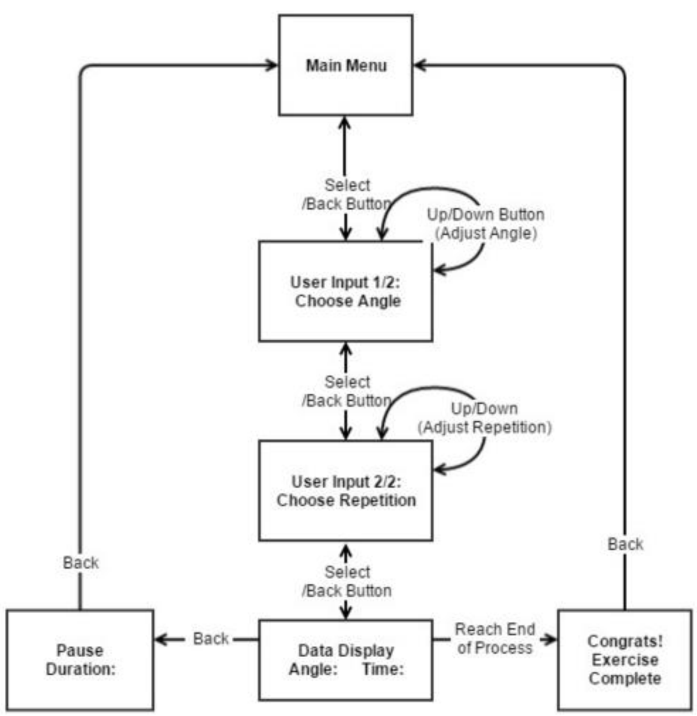

Figure 9: Flowchart of the UI process

4.2.1 Button Identification

Each push button has a different resistance value. When a button is pushed, it sends a signal that falls into specific voltage range and can be identified by the analog pin of microcontroller.
To track whether a button has been pushed or released, its current state will be compared to its previous state. A short delay is introduced before sampling the state for debouncing.

4.2.2 Rotary Encoder

Two square wave signals, with a phase difference of 90 degrees, are read from the rotary encoder. A built-in Arduino function will sense when the encoder is rotated, and use the relative position difference between the two signals to determine whether the rotation was clockwise or counter-clockwise. The angle value is then incremented or decremented, respectively.

4.2.3 Emergency Switch

If the user wishes to stop the exercise at any time, they may activate the emergency switch. This will activate an interrupt using Arduino's Timer library, halting any queued exercise movements. The R2000 will then slowly return to its default position. This action was chosen over shutting the system down, as once power ceases, the servo motor will not hold its position and the user's calf will fall, which could result in harm.

4.2.4 Low Battery Indication

A voltage divider will be used to will be continuously read current while the R2000 is powered on. When the returned value falls under 25% of the total battery current, the UI Arduino will send a high signal to the red LED pin.

4.3 UI Enclosure Design

Factors considered when choosing the material for the UI unit box are presented in Table 5.

Table 5: Material Consideration For Shield of UI Unit

	Ceramics	Plastics	Metals	Wood
Stiffness	High	Medium	High	Low
Conductivity	Low	Low	High	Low
Heat Dissipation	Medium	Bad	Good	Bad
3D printing available	No	Yes	No	No
Price	High	Low	Medium	Medium

Since the UI will not generate an abundance of heat, lining the inside of the enclosure with thermal tape is sufficient. The design and fabrication of the UI must also be precise, as the push buttons on the Arduino shield are small and unmoveable. Precise design can be done in Solidworks, and since plastics have low conductivity, we have opted to 3D print our proof-of-concept UI unit. For the final production product, insulated metal may be used instead.

5.0 System Test Plan

5.1 Unit Testing

The R2000's UI and exoskeleton will be rigorously tested before integration, ensuring that the inputs and outputs will match correctly. Upon integration of the sub-modules, the following tests will be conducted upon the completed R2000 exoskeleton system.

5.2 Calibration Testing

Calibration mode will be used to verify the system is responding properly prior to use:

1. UI prompts user to push one of the five buttons on keypad. User presses the corresponding keypad, and the UI displays a verified message. The UI repeats this five times for the other keys.
2. UI prompts user to turn the rotary encoder. User will move the encoder all the way around, while the UI displays the corresponding angle. UI displays a verified message.
3. UI prompts user to toggle the emergency switch to the on position. User toggles the emergency switch to the on position. UI displays a verified message, and prompts the user to move the emergency switch to the off position. UI again displays a verified message.
4. UI cycles the red and yellow LED on and off.
5. Calibration mode is complete.

5.3 Normal Case 1: User goes through entire exercise

In the case where conditions are normal and the user is comfortable to carry out the entire routine:

1. UI confirms the user's desired range of motion, in degrees, number of repetitions, and sets.
2. UI gives a visual countdown when the exoskeleton begins.
3. Exoskeleton lifts the user's shank to the desired angle.
4. Exoskeleton repeats the exercise to the desired number of repetitions.
5. Exoskeleton returns to the neutral position.
6. UI waits 15 seconds, and gives a visual countdown, to avoid overheating the servo.
7. User performs next set, and returns to Step 3.
8. User either shuts off system or enters new data if exercise is complete.

5.4 Normal Case 2: User must stop exercise

In the case where conditions are normal, but the user is uncomfortable in carrying out the rest of the exercise (starting from point three from Normal Case 1):

1. User feels discomfort and switches the emergency switch to the active position.
2. UI gives visual feedback that emergency switch has been activated and cancels any remaining repetitions.
3. Exoskeleton returns to the neutral position.
4. User either shuts off system or enters new exercise data.

5.5 Normal Case 3: Battery runs low

In the case where conditions are normal, but the battery life has reached a critical level (starting from point three in Normal Case 1):

1. Microcontroller detects battery life is below 25% and notifies user via LCD screen.
2. Microcontroller detects battery life is at 5% if the user continues use of the R2000.
3. UI notifies user that their exercise will now end due to low power and cancels any remaining repetitions.
4. Exoskeleton returns to the neutral position.
5. R2000 shuts down and the user must switch the UI interface off.

5.6 Extreme Case 1: Potential Servo Overheating

In the case where conditions are abnormal and the servo starts drawing too much current (starting from point three in Normal Case 1):

1. Microcontroller detects servo is continuously drawing 3.0A or more while lifting shank.
2. UI notifies user that the load is too heavy for the R2000 to lift.
3. UI notifies the user that the exercise will now end and cancels any remaining repetitions.
4. R2000 shuts down and the user must exit the R2000.

6.0 Conclusion

The R2000 rehabilitative exoskeleton will be designed with two major units, the UI and the exoskeleton. The UI will be developed with:

- An Arduino Uno
- An LCD Keypad shield for the Arduino (with five buttons)
- An emergency switch
- A rotary encoder

Whereas the exoskeleton will be developed with:

- Aluminum bars
- Velcro
- Jrk 21v3 motor driver
- I00600 Torxis Servo

Upon integration, the user will be able to use the five buttons and the rotary encoder to command the exoskeleton to perform their desired exercise. This data will be converted to a PWM signal that will go into the jrk servo driver. This driver instructs the servo to lift the calf to the user's desired angle. The UI cycles through lifting and lowering the calf until the exercise is done. If an emergency arises, the emergency switch can be switched on to return to the neutral position.

The test plan will ensure that the R2000 meets all of its declared requirements before entering the market, enforcing the safety and integrity of our product.

7.0 APPENDIX

7.1 APPENDIX A: SEGMENTAL MASS TABLE

Table 6: Segmental mass and length of an average person's lower body [9] [10]

Segment	% Mass	Average Length (cm)
Calf	4.20	$\frac{Height - 81.93}{2.42}$
Foot	1.35	$\frac{Calf\ length}{4}$

7.2 Appendix B: IR Sensor Detected Width

Table 7: IR Sensor Detected Width

Distance from the sensor to obstacles (cm)	Detected Width (cm)
10	8.28
20	16.6
30	24.8
40	33.1
50	41.4
60	49.7
70	58.0
80	66.3

7.3 Appendix C: Microcontroller Consideration

Table 8: Factors for considered microcontrollers

	Arduino Uno	Arduino Pro Mini	Teensy 3.2	MSP-430G2 LaunchPad
I/O pins	20	20	34	20
Size (mm)	68.6 x 53.4	25.4 x 33	35 x 18	68 x 51
Price (CAD)	$33	$23	$30	$15
Learning Curve	Low	Low	Medium	High
Member Experience	Yes	No	No	No

7.4 Appendix D: Mechanical Drawings

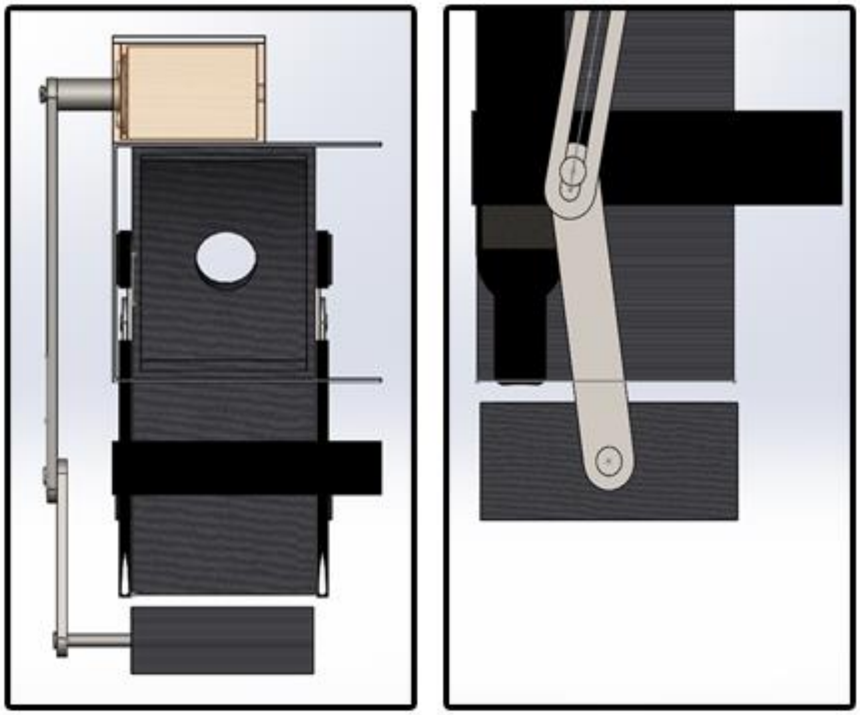

Figure 10: Alternative angles of the exoskeleton

7.5 APPENDIX E: UI SCHEMATIC

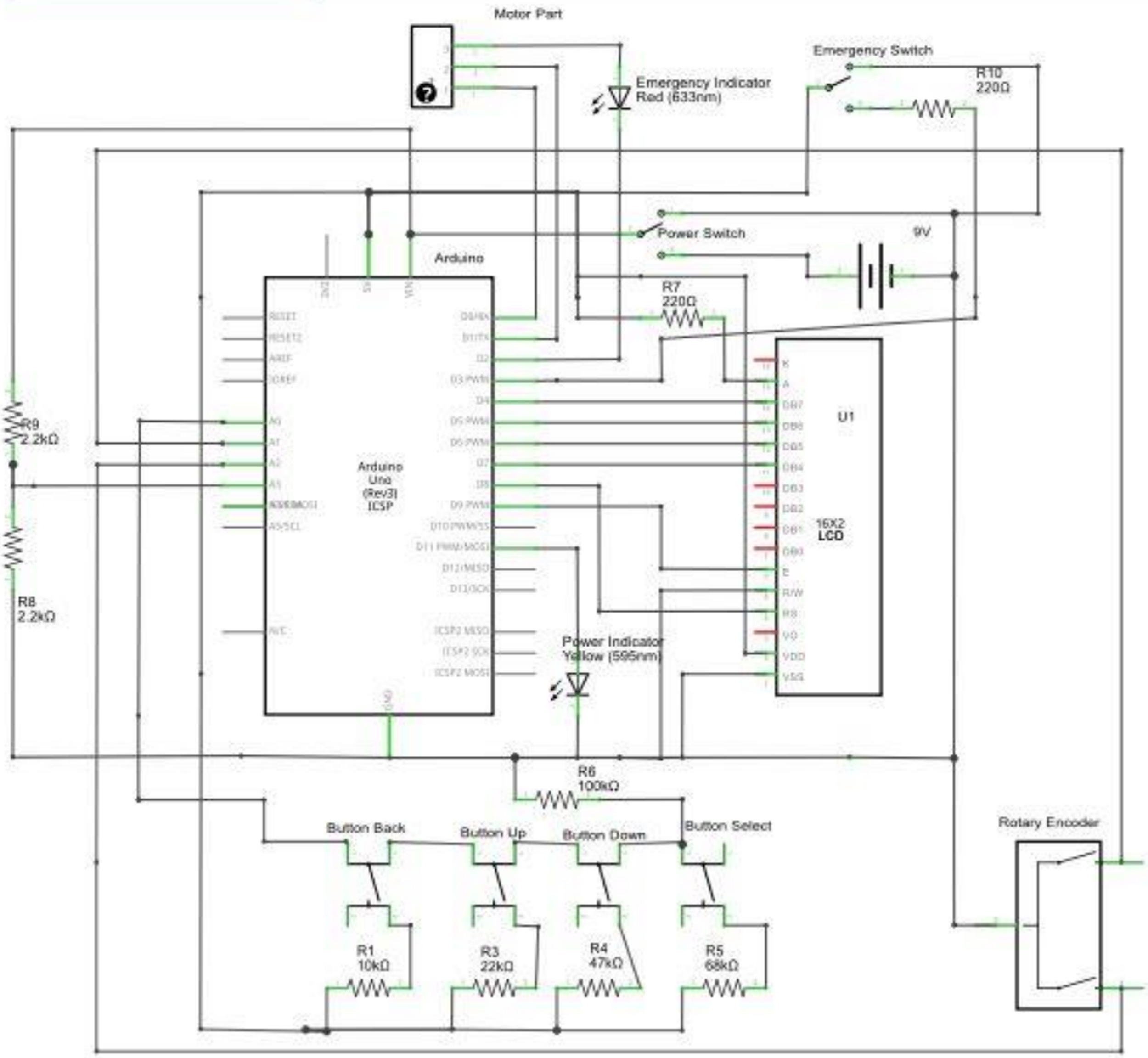

Figure 11: Schematic of the UI unit.

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