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February 16, 2015

Dr. Andrew Rawicz
School of Engineering Science
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Burnaby, British Columbia
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Re: ENSC 440 Functional Specifications for a Rehabilitation Exoskeleton Hand Device

Dear Dr. Rawicz:

The attached document, *Functional Specifications for a Rehabilitation Exoskeleton Hand Device*, describes the functional requirements of our device. The aim of our project is to design and build a product to provide power assistance to a person's hand through the use of an exoskeleton device. Such a device will vastly improve the quality of life for a user with limited hand mobility.

Our functional specifications provide a set of requirements for the functionality of our device, both the proof-of-concept model and the final prototype. This document will include a general system overview, as well as include more specific sections that highlight the requirements for the frame, microcontroller unit, and motors.

Our team at Rexos is composed of several dedicated and experienced students of various engineering backgrounds: Anton Khomutskiy, Joshua Law, Tony Lee, Seungjun Lee, and Doug Tao. If you have any questions or concerns about our document, please do not hesitate to contact me at (604) 805-7561 or by e-mail at leetonyl@sfu.ca.

Sincerely,

Tony Lee
Chief Executive Officer
Rexos Ltd.

Enclosure: *Functional Specifications for a Rehabilitation Exoskeleton Hand Device*

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Functional Specifications for a

Rehabilitation Exoskeleton Hand Device

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Executive Summary

The human hand is one of the most important parts of the body. The dexterity of the hand allows us to do many things. Without the functionality of one's hand, one's lifestyle becomes extremely hampered, greatly limiting them to the tasks a person can perform.

The aim of our project is to create a device that will be useful to people with limited hand mobility. By aiding people with limited hand functionalities to allow them to expand their capabilities, we hope to improve their lifestyle by allowing them to do more tasks by themselves.

The development of our device will be done in several stages. The first stage will be to succeed in a proof-of-concept device. After that stage has been completed, our team can progress to expanded capabilities.

The proof-of-concept stage will have the following features:

- Approved frame design that provides power assistance to the index finger
- Functional microcontroller unit
- Functional finger sensors
- Functional motor control

Following the proof-of-concept stage, the first development stage will consist of putting together all the components to achieve the following features:

- Integrated system for index finger movement
- Software designed for index finger
- Enclosure for microcontroller unit
- Mobile power supply

The second development stage will see expanded capabilities of our product to provide power assistance to additional fingers. We will implement support for the remaining fingers in the order: middle finger, ring finger, pinkie, and thumb.

By following this schema for the development stage, we can ensure that our team can deliver a working prototype of our product by the beginning of April.

Table of Contents

Executive Summary ii

List of Figures iv

Glossary v

1 Introduction 1

1.1 Scope 1

1.2 Intended Audience 1

1.3 Classification 1

2 System Requirements 2

2.1 System Overview 2

2.2 General Requirements 2

2.3 Physical Requirements 3

2.4 Electrical Requirements 3

2.5 Mechanical Requirements 3

2.6 Environmental Requirements 3

2.7 Standards 3

2.8 Reliability and Durability 3

2.9 Safety Requirements 4

2.10 Performance Requirements 4

2.11 Usability Requirements 4

3 Frame 4

3.1 General Requirements 4

3.2 Physical Requirements 4

4 Microcontroller Unit 5

4.1 General Requirements 5

4.2 Physical Requirements 5

4.3 Electrical Requirements 5

5 Software 5

5.1 General Requirements 6

6 Motor 7

6.1 General Requirements 7

6.2 Physical Requirements 7

6.3 Electrical Requirements 7
7 Power Supply 7
7.1 General Requirements 7
7.2 Physical Requirements 7
7.3 Electrical Requirements 7
8 User Documentation 8
9 System Test Plan 8
9.1 Functional Tests 8
9.1.1 Post Assembly 8
9.2 Parametric Tests 9
10 Sustainability and Safety 9
11 Conclusion 10
12 Works Cited 11

List of Figures

Figure 1 - System Overview of the RexoGrip 2
Figure 2 - Software Flowchart 6

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Glossary

Amps - {Amperes}, the unit of current measured as coulombs/second

CSA – Canadian Standards Association

IEC – International Electrotechnical Commission

ISO – International Organization for Standardization

LED – Light emitting diode

Motor Position Limit Sensor – A sensor which engages into an "on" state when a mechanical lever is compressed.

Motor Shield – Motor controller board that acts as the interface between the microcontroller board and the motor(s).

Newtons - The unit of force measured as kg/m^2.

RexoGrip – Product name for Rexos' exoskeleton hand device with power assistive functionalities.

Typical Weather Conditions – Normal weather conditions on an average day in Vancouver, British Columbia.

UNO – Universal Network Object

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1 Introduction

The RexoGrip is a powered exoskeleton device that is designed to fit over a user's hand. The RexoGrip will provide the user power assistive capabilities on each finger to perform curling of the fingers to mimic a gripping motion. The RexoGrip will have the ability to detect upwards or downwards movement of individual fingers to actuate the device. In this functional specification proposed by the team at Rexos, the requirements for the RexoGrip will be outlined.

1.1 Scope

The document details the requirements that must be met by both the proof-of-concept model and the production system of our device, the RexoGrip. The requirements will be used as a reference through design and implementation phases, as well as referred to in future documentation.

1.2 Intended Audience

This document is intended for use by all members of Rexos Ltd, and as reference for potential shareholders. Both the project lead and shareholders can refer to the functional specification as a basis of measure for the progress of the project. Throughout the development phase, the design team shall refer to the requirements to ensure the prototype meets each and every standard. At the end of development, test engineers' assessment of the final product shall be based on the specifications.

1.3 Classification

The following convention will be used to denote functional requirements:

[Rn-P] *A functional requirement*

Where **R** is an abbreviation for "requirements", **n** is the requirement number, and **P** is the priority of the requirement denoted by one of the following:

I. This requirement applies to the proof-of-concept system only
II. This requirement applies to the proof-of-concept as well as the production model
III. This requirement applies only to the production model

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2 System Requirements

2.1 System Overview

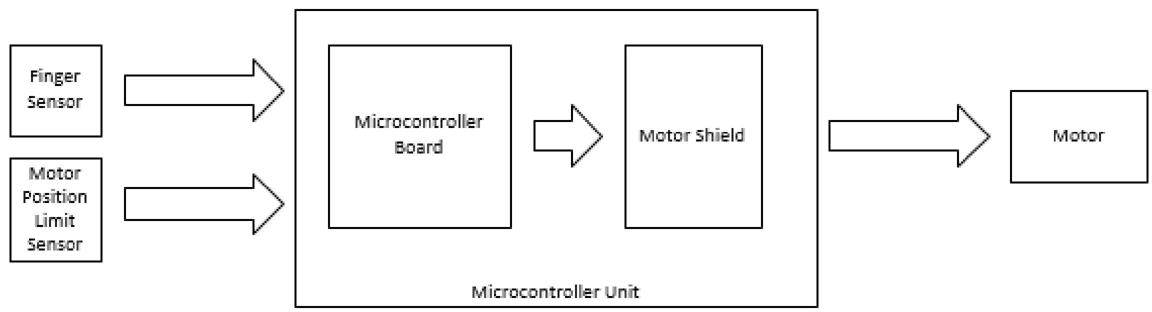

Figure 1 - System Overview of the RexoGrip

As shown by Figure 1 above, the RexoGrip system contains three core components. These three components are the sensors, microcontroller unit, and the motors.

For each finger, there are two finger sensors which correspond to either an upwards or downwards movement of the finger. These sensors will always be in either an on or off position. When the sensor is in on position, it will send a signal to the microcontroller unit.

There will also be a Motor Position Limit Sensor on each motor, which will allow the device to know that the motor has reached a limit on the distance that it can travel. When the microcontroller receives a signal from the finger sensor, the program will check the position of the motor. If the motor can move in the desired direction, the motor shield will then pass on the signal to the motors to actuate a set amount.

If the motor has reached the travel limit in the desired direction, the motor shield will not send the actuation signal to the motor.

Due to the time limitation of our project, we will first aim to have a single finger functioning will the required sensors. After that has been completed, our team will then scale up and implement additional finger functionalities as time permits. The priority in which finger exoskeleton components will be prototyped will be in the following order: index finger, middle finger, ring finger, pinky, and thumb.

2.2 General Requirements

[R1-III] The device will not exceed a retail price of $1000 CAD.
[R2-II] The device must have a dedicated on/off switch.
[R3-II] The device must have an LED indicator for power on.
[R4-II] The device must have two input sensors per finger, to control upwards movement and downwards movement.
[R5-III] The device shall be produced using certified components where possible.

2.3 Physical Requirements

[R6-I] All wire connections and ports should be easily accessible.
[R7-II] The device should be lightweight.
[R8-III] The device must be modular, consisting of parts that can be easily replaced.
[R9-III] The device must be easily maintainable by the user.
[R10-III] The device must be fully enclosed and waterproof.
[R11-III] The final iteration should look sexy.

2.4 Electrical Requirements

[R12-II] The power supply must be able to supply sufficient power to operate the microcontroller unit, motors, and sensors.
[R13-II] All wiring must be electrically insulated from the rest of the device.
[R14-II] Any exposed cables must be neatly tied together.
[R15-II] The power supply shall be rechargeable from a standard wall supply of 120V at 60Hz AC or provide an adapter for international standards.
[R16-III] The power supply will last for 16 hours of intermittent use before requiring recharging.
[R17-II] The device must use stranded wiring when possible.

2.5 Mechanical Requirements

[R18-II] The device must have a mechanical limiter to prevent injury.
[R19-III] The device must be manually adjustable to allow for differing physical dimensions.
[R20-III] The mechanical frame of the device must not be visually intrusive.

2.6 Environmental Requirements

[R21-II] The device must be fully operational under normal temperatures (-10°C to 30°C).
[R22-III] The device must be fully operational under typical weather conditions.
[R23-II] The device must be operable under continuous use.
[R24-III] The device must be made of biodegradable or recyclable components.
[R25-III] The device shall be silent when inactive.
[R26-III] The device shall not generate noise greater than 80dB.

2.7 Standards

[R27-III] The device must meet CSA standard 22.2 No. 125 for electromedical devices [1].
[R28-III] The device must meet CSA standard Z32-09 for electrical systems [2].
[R29-III] The device must meet Health Canada standards of documentation for medical devices [3].
[R30-III] The device shall meet applicable standards for medical devices, including, but not limited to: CSA C22.2 NO 60601-1-08, CSA C22.2 NO 60601-1-2-08, IEC 60529:2001-Ed.2.1, IEC 60601-1-4:2000-Ed.1.1, IEC 61000-4-2:2008-Ed.2.0 [4].

2.8 Reliability and Durability

[R31-III] The device will be able to withstand daily use for at least 3 years before maintenance.
[R32-III] All components are safe to use under normal operating conditions.

[R33-II] The device must be resistant to electrostatic discharge.
[R34-II] The microcontroller unit must be operational as long as it is not turned off manually or its power supply is not disconnected.
[R35-III] The device must be serviceable by a trained technician.
[R36-III] The device shall be resistant to electronic and mechanical damage caused by spills or light collisions.

2.9 Safety Requirements

[R37-II] All electronic components of the device must be properly secured.
[R38-II] The microcontroller unit must have a case to prevent physical damage.
[R39-II] The device must have an electrical emergency stop.
[R40-II] Under normal operating conditions, the device must not overheat or catch fire.
[R41-II] The battery of the device must not have any leakage.
[R42-II] The device must not cause bodily harm to the user during operation.
[R43-II] The failure of any mechanical components of the device must not cause any harm to the user.

2.10 Performance Requirements

[R44-I] The device must be able to operate continuously for 20 minutes.
[R45-III] The device must be able to operate intermittently for 16 hours.
[R46-II] The device must accept pressure sensitive input from the user's finger movements.
[R47-III] The device must be able to exert a grip force of 267 Newtons minimum.

2.11 Usability Requirements

[R48-II] The user should have no difficulty putting on the device.
[R49-II] The user should have no difficulty taking off the device.
[R50-II] The device should not be intrusive.

3 Frame

The frame will consist of a rigid material over-lacing the user's hand. To ensure the safety of our user, the frame will feature a hardware hard stop, in the case where a software or electrical stop fails to respond.

3.1 General Requirements

[R51-III] The frame's material must be made of a biocompatible polymer.
[R52-III] The frame's material must be non-reactive to common household chemicals.
[R53-II] The frame's material must not cause catastrophic failures.
[R54-II] The frame must account for structural stresses.

3.2 Physical Requirements

[R55–II] There must be no protrusions that can snag and cause harm.
[R56-III] The frame must be fastened securely when in use.

4 Microcontroller Unit

The main functions of the microcontroller unit will be to transmit and receive input signals from the finger sensors and Motor Position Limit Sensors to the motors when needed.

The microcontroller unit will consist of an Arduino Uno microcontroller board and three Adafruit motor shields. The microcontroller unit will house the software necessary for our device to operate [5] [6].

4.1 General Requirements

[R57-II] The microcontroller unit must be able to operate in real-time.
[R58-II] The microcontroller unit must be able to accept input from ten analog sensors.
[R59-II] The microcontroller unit must accept up to five simultaneous inputs.
[R60-II] The microcontroller unit must output signals to control up to five motors simultaneously.

4.2 Physical Requirements

[R61–I] The connection ports of the microcontroller board must be easily accessible.
[R62-III] The microcontroller unit must be electrostatically insulated [2].
[R63–II] The microcontroller unit must be in an enclosure.
[R64–III] The microcontroller unit enclosure must be waterproof, shockproof, and thermally insulated [1].

4.3 Electrical Requirements

[R65-II] The microcontroller board shall use a 9V power supply.
[R66-II] The motor shield shall use a 12V power supply.
[R67-II] The motor shield must be able to supply a minimum of 0.15 Amps of current per motor.

5 Software

The main purpose of the software written for this device is to take the signals from the input sensors controlled by the user to control the motors of the device. After the start up sequence, the program should enter a standby state, where it awaits for user input through the sensors.

The user will first activate the sensor, which will send an active high signal to the Arduino microcontroller board. The program will then recognize which sensor has been activated and determine the direction of intended movement. If the motor has not reached the travel limit in that direction, the program will instruct the microcontroller board to send a movement signal. This movement signal will be sent through the motor shield to the motor, which will then actuate a set distance.

A software flowchart of the general program is shown in Figure 2 below.

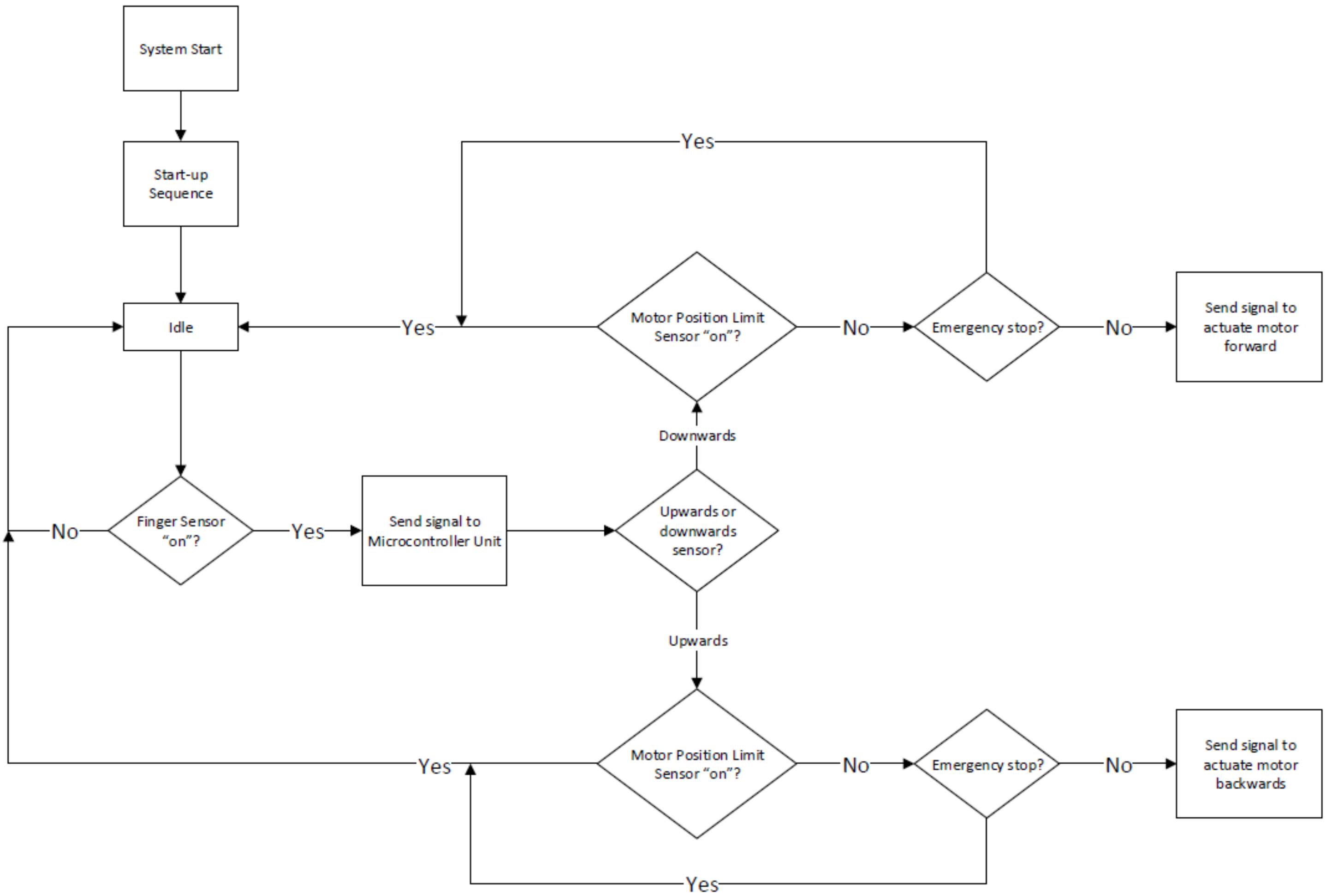

Figure 2 - Software Flowchart

5.1 General Requirements

[R68-II] The program will run on the Arduino platform.
[R69-II] The program must be able to read input data from sensors.
[R70-II] The program must be able to control stepper motors.
[R71-II] The program will send output signals to control up to five motors.
[R72-II] The program must be able to track the position of the motors.
[R73-II] The program should have a start-up sequence to calibrate the device to a default position.
[R74-II] The program must have a software stop to prevent injury.

6 Motor

The device will be mounted with up to five motors which will actuate linearly to move the frame, mobilising individual fingers.

6.1 General Requirements

[R75-II] The motor must be able to actuate a mechanical device.

[R76-II] The motor must meet or exceed the performance specifications stated in the manufacturer's datasheet [7].

6.2 Physical Requirements

[R77-II] The motor must actuate in a linear motion.

[R78-II] The motor must be controllable in speed and direction.

[R79-II] The motor must have enough torque to move a finger without resistance.

[R80-II] The motor must be lightweight.

[R81-III] The motor must be thermally insulated from the user.

[R82-III] The motor must be waterproof.

6.3 Electrical Requirements

[R83-II] The motor must be powered by a 12V power supply.

7 Power Supply

7.1 General Requirements

[R84-II] The power supply should not be an explosive hazard under normal use.

[R85-II] The microcontroller must have a separate and standalone power supply.

[R86-II] The motor control board must have a separate power supply.

[R87-III] The lifetime per charge must be suitable for a day's worth of use.

7.2 Physical Requirements

[R88-II] The power supply must be easily accessible.

[R89-III] The power supply must be lightweight and portable.

[R90-III] The power supply must include a fuse.

[R91-III] The power supply must be waterproof.

7.3 Electrical Requirements

[R92-II] The power supply must be rechargeable.

[R93-II] The power supply for the microcontroller must be rated at a maximum of 9V.

[R94-II] The power supply for the motor control board must be able to provide at least 12V.

8 User Documentation

[R95-III] User documentation shall include a website with general and technical support information, and a user manual, both written in English.

[R96-III] The user manual shall be written for an audience with minimal knowledge of electromagnetic devices and kinesiology.

[R97-III] User documentation shall be provided in English, French, German, Simplified Chinese, Japanese, and Korean to satisfy product language requirements for the international market.

[R98-III] An installation and maintenance guide for technicians and vendors shall be provided.

9 System Test Plan

The system test plan for the RexoGrip will comprise of sets of parametric tests and functional tests. Tests will be carried out in a modular approach, first testing individual components of motors and subroutines, and then gradually progressing to whole system tests. This section will describe these tests in detail.

9.1 Functional Tests

Finger Sensor to Microcontroller Unit: The finger sensor will be pressed to an "on" position, which will send an input signal to the microcontroller unit. Upon receiving the signal from the sensor, the microcontroller will then send a voltage to turn on a LED to indicate that it has received the input signal. This LED will only be available for this specific test and will not be present on the final prototype or final product.

9.1.1 Post Assembly

After the above modules have been tested and approved, the project can move onto the next set of test plans to look into different usage scenarios. These scenarios are listed below.

Scenario 1. Index Finger Upwards Actuation: The upwards Finger Sensor will be actuated by the index finger moving upwards, sending the signal to the Microcontroller Unit. The Microcontroller Unit will then send the signal to move the motor backwards, causing the frame to pull upwards on the user's index finger. This sequence of actions will continue until the motor activates the Motor Position Limit Sensor. The same test plan can be actioned similarly for downwards actuation.

Scenario 2. Multiple Finger Upwards Actuation: Additional tests that use the basic principles outlined in the above test case will be used for this scenario. This case will test the simultaneous upwards actuation of two, three, four and five finger actuation using the sequences of outlined in Scenario 1. The purpose of this test is to ensure the maximum current drawn by all motors can be safety handled by the device.

9.2 Parametric Tests

Motor Position Limit Sensor to Microcontroller Unit: A specific software plan will be written to implement this test. For this test, the motor will actuate forward a set amount forward that does not reach the travel limit. The motor will then actuate backwards the same distance to return to the beginning position. This sequence will be looped continuously while the device is on. When the Motor Position Limit Sensor is turned "on", the motor should stop for as long as the sensor is in the "on" position. The motor will actuate again when the sensor is in the "off" state.

Microcontroller Unit to Motor: A specific software plan will be written to implement this test. Upon pressing the reset button on the Microcontroller Unit, the motor will run a one-time sequence. This sequence will consist of the motor actuating forwards 5000 steps, followed by a 3 second delay, and then actuate 5000 steps backwards to return to the beginning position.

Force Exertion: A specific hardware plan will be implemented to test for force exertion per finger. Using a load cell, we will move the index finger driven by a motor, and exert a force onto a load cell.

Finger Movement speed: A specific software plan will be written to implement this test. Upon pressing the reset button on the Microcontroller Unit, the motor will run a one-time sequence. This sequence will consist of the motor actuating towards the upper movement limit, and then towards the lower movement limit, and then return to resting position. This will repeat 10 times to ensure reliability and repeatability.

10 Sustainability and Safety

We, at Rexos, strive to limit the negative impact on the environment by making it as sustainable as possible. To reach this goal, our design will reflect the importance of sustainability.

The RexoGrip will be designed to have parts that can be easily interchangeable, so that maintenance of the device can be performed without too much difficulty. Additionally, the components of the device will be made up of recyclable materials when possible to reduce the environmental footprint. To avoid waste, our device will feature a rechargeable power supply that will have a long life cycle.

To ensure the safety of the user, the device will contain fail safes to account for electrical and mechanical failures. Our device will not have any sharp edges which may cause the user or other people in the operating environment harm. By meeting the safety standard requirements listed in this document, we can ensure the safety and integrity of the device under normal operating conditions.

11 Conclusion

In this functional specifications document prepared by Rexos, the requirements for the RexoGrip are outlined in several sections. By following the requirements outlined in this document, our team can ensure the integrity of our final prototype. The team at Rexos aims to be able to deliver a working prototype by April 1st, 2015

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12 Works Cited

[1] Canadian Standards Association, "C22.2 No. 125-M1984 Electromedical Equipment," 2009. [Online]. Available: http://ccinfoweb2.ccohs.ca/legislation/documents/stds/csa/celeq84e.htm. [Accessed 2 February 2015].

[2] Canadian Standards Association, "Z32-09 Electrical safety and essential electrical systems in health care facilities," 2014. [Online]. Available: http://ccinfoweb2.ccohs.ca/legislation/documents/stds/csa/cesel09e.htm. [Accessed 2 February 2015].

[3] Government of Canada, "Justice Laws Website," 26 December 2011. [Online]. Available: www.laws-lois.justice.gc.ca/pdf/sor-98-282.pdf. [Accessed 2 February 2015].

[4] Health Canada, "List of Recognized Standards for Medical Devices," 26 September 2014. [Online]. Available: http://www.hc-sc.gc.ca/dhp-mps/md-im/standards-normes/md_rec_stand_im_norm_lst-eng.php#a26. [Accessed 2 February 2015].

[5] Arduino, "Arduino Uno," [Online]. Available: http://arduino.cc/en/Main/ArduinoBoardUno. [Accessed 20 January 2015].

[6] Adafruit, "Adafruit Motor/Stepper/Servo Shield for Arduino v2 Kit - v2.3," [Online]. Available: http://www.adafruit.com/products/1438. [Accessed 20 January 2015].

[7] Portescap, "26DBM-L," 2013. [Online]. Available: http://www.portescap.com/sites/default/files/26dbm_l_specifications.pdf. [Accessed 20 January 2015].