ACTUATED INNOVATIONS

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February 23rd, 2017

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
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Re: ENSC 405W Functional Specification for a Pin Actuated Display System

Dear Dr. Rawicz,

The enclosed document is our *Requirements Specification* for a *Pin Actuated Display System*, proposed by Actuated Innovations. Our goal is to design a multimedia tool that combines tactile feedback with visual technology to aid in data analysis and communication. *Relevo* creatively utilizes a matrix of pins to aid in the visualization of data.

This paper covers the functional specifications of our product, outlining the general, hardware, mechanical and software requirements of *Relevo*. The requirements are broken down into three priorities/stages: proof-of-concept, prototype and final product. It will also include the design standards and safety and sustainability requirements.

The Actuated Innovations team is made up of six Simon Fraser University Engineering students; Brian Hanley, Alec Lu, Anthony Fung, Dennis Huebert, Zachary Wong, and Jonathan Wong. Together we aim to create a working product that will not only satisfy all requirements specified in the document. As the primary contact for Actuated Innovations, feel free to contact me by email at bhanley@sfu.ca, or by phone at 778-877-0144 if you have any questions or concerns. We appreciate your time and consideration of this document.

Sincerely,

Brian Hanley

Brian Hanley
Co-founder of Actuated Innovations

Enclosed: Requirements Specification for the Actuated Display System

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REQUIREMENTS SPECIFICATION

"RELEVO" PIN ACTUATED DISPLAY SYSTEM

ACTUATED INOVATION INC.

Issue Date: Feb 23rd, 2017
Revision: 1.3

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ABSTRACT

Today, multimedia is generally dependent on two sensory components: visual and auditory. Modern digital multimedia generally serves as both a powerful method of communication between people and a medium for entertainment. With each passing year, we see the advancement of both audio and visual quality in retail products. As such progress accelerates, we are quickly approaching the limits of human perception. Eventually, engineers in the multimedia industry will be forced to look towards new innovations in order to continue to improve upon the human sensory experience.

At Actuated Innovation, we believe that the next step the industry must take is to add tactile feedback to traditional visual systems thus merging the two into a single, complete product. Our firm belief has led to the design of our first commercial product: *Relevo.*

Relevo is what we refer to as a pin actuated display. Like a traditional display, it's mainly used to communicate information with the end user. The system will follow a modular design, with each subsystem developed and tested before being integrated together as a final product. In addition, our development cycle includes designing a proof-of-concept, prototype, and final product. Our team follows the cradle-to-cradle design method ensuring we reuse parts as we iterate through the stages of design.

This document outlines the functional specifications, design standards, and safety and sustainability standards. Testing and design will adhere to the guidelines listed within this document. In addition, compliance to specific safety and sustainability standards is a must.

Our goal is to provide a profitable new means for users to communicate ideas or to visualise otherwise difficult problems. In this document, we aim to clearly outline the functional requirements and safety and sustainability requirements for the *Relevo*

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GLOSSARY

3D	Three Dimensional
Potentiometers	Three terminal resistor with slides or rotating contacts that form an adjustable voltage divider
Geospatial Data	Information about a physical object that can be represented by numerical values in a geographic coordinate system
LED	Light Emitting Diode
NEMA	National Electrical Manufacturers Association. A trade association of electrical manufactures in the United States
IEC	International Electrotechnical Commission. A non-profit, non-governmental, international standards organization for electrical and electronic related technologies
ISO	International Organization for Standardization
CSA	Canadian Standards Association. A non-profit standards organization in Canada
ANSI	American National Standards Institute
IR	Infrared
I/O	Input/Output
CPU	Central Processing Unit
FIFO	First in First Out. A method for organizing and managing a data buffer
Re-entrant Code	Code that be interrupted in the middle of its execution, and then be safely called again before its previous invocations complete execution
RDT	Redundant Data Transmission

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1 INTRODUCTION

Relevo is an actuated pin display system which utilizes the concept of relief imaging. The system consists of a pin display, a 3D camera and an image processing unit. With *Relevo*, the users will be able to recreate objects in real time. In the following pages a list of requirements and specifications will be described.

1.1 SCOPE

This document outlines the functional requirements and specifications that must be met by the product at various stages in its development. The document contains the functionality overview, software and hardware requirements, as well as sustainability and safety concerns. It provides a detailed description of the required functionality for a proof-of-concept, prototype, and final product.

1.2 INTENDED AUDIENCE

This document is intended for all Actuated Innovation team members for product development. All members shall refer to this document as a guideline for both development and testing. The hardware, software, and design engineers will refer to the requirement details contained in this document. When testing for quality assurance, the requirements will be referenced for test plan creation with a focus on the safety and sustainability section. Any requirements that are not met indicate a flaw in the system design and result in a revision of the system.

1.3 CLASSIFICATION

The following format convention will be utilized throughout the document to number and prioritize the functional specification:

[Rn-p] A functional requirement

Where *n* is the functional requirement number and *p* is the priority of the requirement. The priority can have one of the following defined values:

A – High Priority; the requirement strictly applies to the proof-of-concept design.
B – Medium Priority; the requirement applies to the prototype but does not affect main functionality.
C – Low Priority; refinements and finishing features that will be adhered by the final product

For example, **[R2-A]** would indicate the second requirement with a high priority.

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2 SYSTEM REQUIREMENTS

2.1 SYSTEM OVERVIEW

The *Relevo* will allow users to communicate basic shapes and forms though the use of its interactive tactile display and 3D object capturing capabilities. The main goal with *Relevo* is to capture and convey the world in a new and innovative way, putting it at the user's fingertips.

The user level system overview of *Relevo* is illustrated in Figure 1 and describes the high-level system elements and flow.

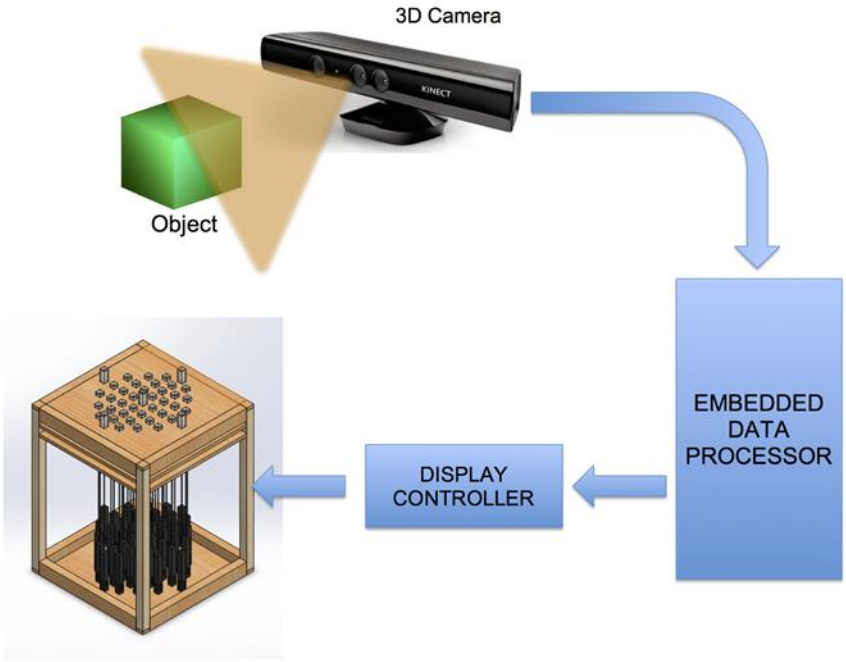

Figure 1: Model diagram of *Relevo*

The *Relevo*'s primary input will be via a 3D camera capable of capturing 3D data from a scanned object. The camera will be fixed in a set position and has 2 functionalities:

1. Capture 3D depth data of an object placed in the camera field of view
2. Transmit the data to an interfaced embedded data processor

The data that the camera captures is input into an embedded data processor. The embedded data processor has 3 functionalities:

1. Controls the 3D camera in order to acquire data
2. Process the data
3. Transmits the data to the display controller

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The display controller is interfaced directly with *Relevo*'s actuated tactile display providing control over the many electrical and mechanical components of the display. The display controller uses the transmitted data from the data processor providing 2 functionalities:

1. Power each individual actuator in the display
2. Read the state/level of each actuator to provide feedback to the system.

This will enable the display, consisting of 30 pins, to create a relief image of the scanned object that is capable of being touched and felt by the user.

Relevo's data transmission system can be modeled as shown in high-level functional block diagram (Figure 2).

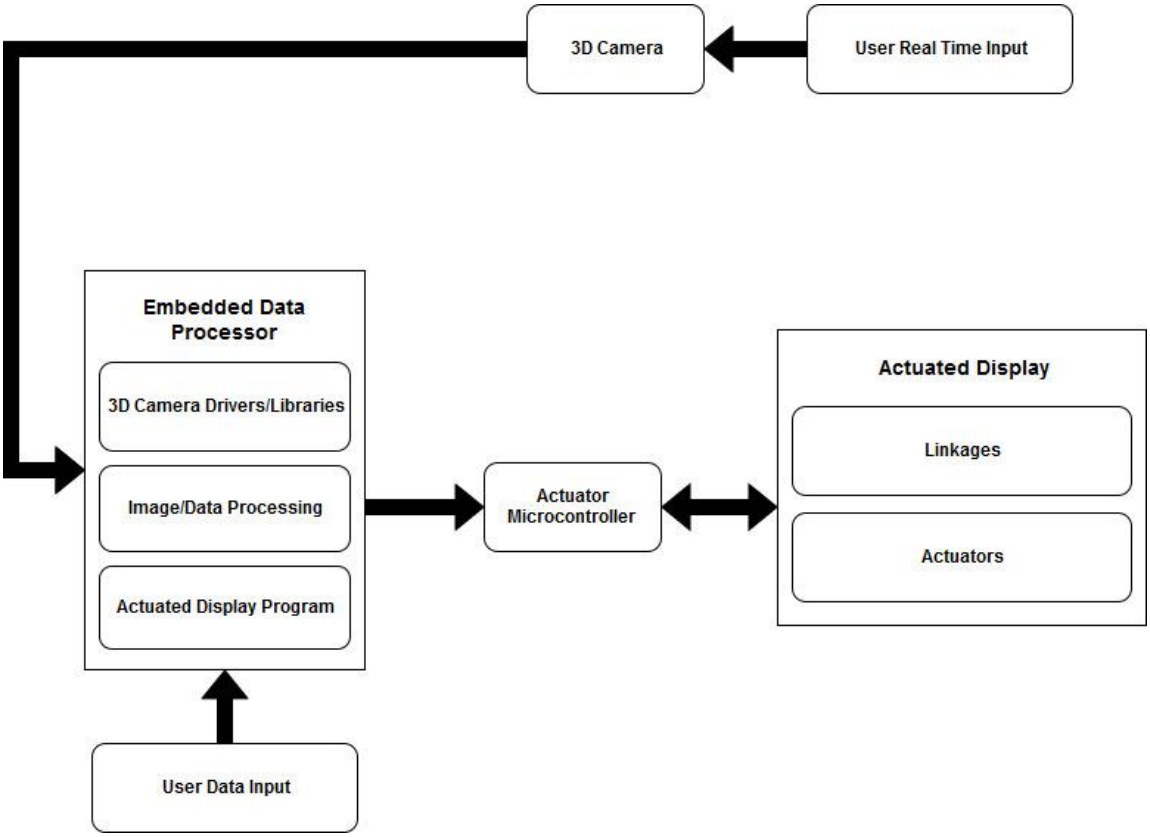

Figure 2: High-level functional block diagram of *Relevo*

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2.2 GENERAL REQUIREMENTS

[R1-B] The noise output from the product when operational shall not exceed 45 decibels

[R2-A] When powered on, the table shall be operational within 1 minute

[R3-A] The heat output from the product when operational should not exceed 40 degrees Celsius

[R4-A] When there is power supplied, a status-indicating LED shall turn green when the system is on and red when the system is off

[R5-B] The system must have a dedicated on/off switch

2.3 PHYSICAL REQUIREMENTS

[R6-A] *Relevo* shall have warnings to prevent physical injuries to the users

[R7-B] *Relevo* shall be mounted on lockable wheels to mitigate the device's weight for transportation while still allowing safe usage

[R8-C] *Relevo* shall consist of enclosures mounted on a common base with only the controls available for the user

[R9-B] All inputs, outputs, and controls must be clearly labeled

[R10-B] The base must be stable on flat surfaces

[R11-B] The camera shall be mounted in a non-vision jeopardizing fashion so that it doesn't block the user's vision of the pin actuated display

[R12-B] The actuated pin display table surface shall be at least 50x50cm

[R13-A] The pins shall be light enough to prevent damage due to strain to the potentiometers

[R14-B] The covering fabric shall have enough area to cover each pin without slack between the pins when they are all at their lowest position to provide a complete surface for the user to interact

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[R15-C] The sensor table height shall be close to 60 cm which is the average waist height of a North American person

[R16-B] The camera shall be mounted in a non-vision jeopardizing fashion so that it doesn't block the user's vision of the pin actuated display

[R17-A] The actuated pin display table shall have enough surface space to allow all pins and spacing between pins, plus an extra table edge around the entire pin actuated display

[R18-B] The pins shall weigh no more than 50 grams to prevent damage due to strain to the potentiometers

[R19-B] The covering fabric shall have and area of at least 60x60cm (matching to the table size) to cover each pin and provide a complete surface for the user to interact with

[R20-B] The covering fabric shall be elastic enough to stretch to 100x100cm to allow the pins to move their specified distance without damaging the potentiometers and return to a flat position

2.4 ELECTRICAL REQUIREMENTS

[R21-A] *Relevo* shall draw electrical power using a NEMA 5 electrical plug [1][2]

[R22-A] *Relevo* shall conform to IP-30 found in IEC standard 60529 while device is operable (resistant to objects the size of tools or larger – e.g. screwdriver head) [3]

[R23-C] *Relevo* shall be grounded to avoid injury to the user and/or damage to the system

2.5 STANDARDS

[R24-A] *Relevo* shall conform to all ISO/CSA/ANSI standards including but not limited to CSA 22.1[4] and CSA 22.2[5]

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3 HARDWARE REQUIREMENTS

3.1 HARDWARE OVERVIEW

Relevo integrates multiple modules to form a single, integrated system. The main hardware consists of a sensor to take in data that will be processed before being fed to the microcontroller which will in turn control the motorized potentiometers. The sensor will be able to accept 3D and 2D information which will determine the heights of the pins at any given time during operation. In turn, the microcontroller will have to be able to control the pins fast enough to allow the conversion of the sensor input to the pin heights in real-time. This will take software support in terms of addressing/multiplexing but nevertheless the components must be able to match this time specification as a minimum. Included in these components is that the potentiometer motors must be able to actuate fast enough to create the image without excessive time delays yet at a speed safe for users. To support this, the pins and the table should be designed to minimize risk to users.

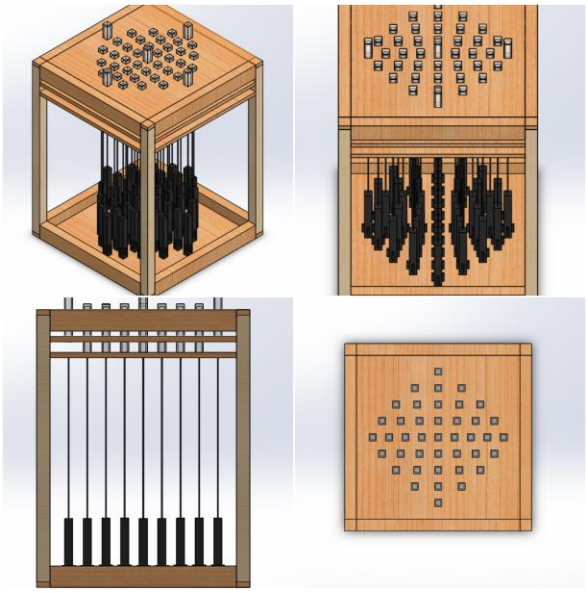

Figure 3: CAD simulated view of *Relevo*

For the first construction phase of the proof of concept the hardware must have a functioning pin controlled by the microcontroller. This includes the pin, linkage, motorized potentiometer, and microcontroller but does not include the system being contained in its market-ready chassis or all safety warnings in place. The system will be safe for basic function at this point though. The prototype, after the second construction phase, will include the entire array of pins with the sensor to image capabilities fully functioning. At that time the system will also be fully contained in its chassis.

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3.2 SENSOR REQUIREMENTS

[R25-A] The sensor will use an IR camera

[R26-A] The sensor will be capable of capturing 2D depth data to produce a 3D virtualization

[R27-B] The sensor will be able to distinguish the depth and location within a 2 meter range

[R28-A] The sensor will capture video in real time with less than 1 second delay to the user

[R29-A] The sensor shall be capable of producing a depth image within 20 seconds of data capture

[R30-A] The sensor shall operate at the power demand of 12 watts

3.3 DISPLAY INTERFACE REQUIREMENTS

[R31-A] Each actuated pin shall be capable of linear movement ranging from 0cm to 10cm above the surface of the table

[R32-A] The pins shall be circular in their horizontal cross-section to minimize the amount of sharp corners that could pose a risk to users or *Relevo*

[R33-B] The display shall have a minimum of 30 actuated pins to ensure a high enough resolution for accurate representation of the data received from the display inputs

[R34-B] The magnets will be strong enough to attach the covering fabric to the pins and hold them in place during operation to allow each pin to show its height independently regardless of the surrounding pins

[R35-B] The pins shall be physically durable enough to last 4800 hours of operation to minimize user maintenance

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3.4 MICROCONTROLLER REQUIREMENTS

[R36-A] The microcontroller shall have enough I/O pins to control no less than 30 linear motorized potentiometers and send/receive data from the computer

[R37-A] The microcontroller shall be fast enough to control no less than 30 motorized linear potentiometers within a time frame of no greater than 0.15 seconds

[R38-A] The microcontroller shall have enough memory to address no less than 30 motorized linear potentiometers plus a queue of incoming display data

[R39-B] To facilitate quick pin movement and fair processor time, the microcontroller shall implement a simple first-in-first-out (FIFO) task system

Due to lack of a processor scheduler on the microcontrollers, a task system will need to be implemented to handle incoming control signals from the controller CPU. Since this is a real-time system where pins must be immediately actuated after an instruction has been given, the task system will be first-in-first-out. Tasks will be run from start to finish without being pre-empted by other tasks (system will not use “round robin” scheduling to share processor time).

3.5 POTENTIOMETER REQUIREMENTS

[R40-B] The linear motorized potentiometers shall be fast enough to perform a full actuation within 0.3 seconds of receiving a signal

[R41-A] Linkages between pins and potentiometers shall be light enough for the potentiometer to actuate the whole pin system upwards within 0.3 seconds

[R42-B] Linear motorized potentiometer shall provide no less than 0.6 N of resistance

[R43-A] Linear motorized potentiometer shall not produce excess quantities of heat

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4 SOFTWARE REQUIREMENTS

4.1 SOFTWARE OVERVIEW

The core operation behind our software is the translation of 2D/3D data to a format *Relevo* can use to actuate its pins. This involves three main stages:

1) 2D/3D data acquisition.
2) Serialization and translation of 2D/3D data to transmission ready depth data.
3) Pin actuation using transmitted depth data at the pin Microcontroller.

The first stage of our system implements support for different types of data sources. The goal for this stage is to have a fairly general/encapsulated approach to data input, so that developers need not worry about the inner workings of our system. *Relevo* will offer some basic methods of data conversion, such as direct input of Google maps data for geospatial analysis.

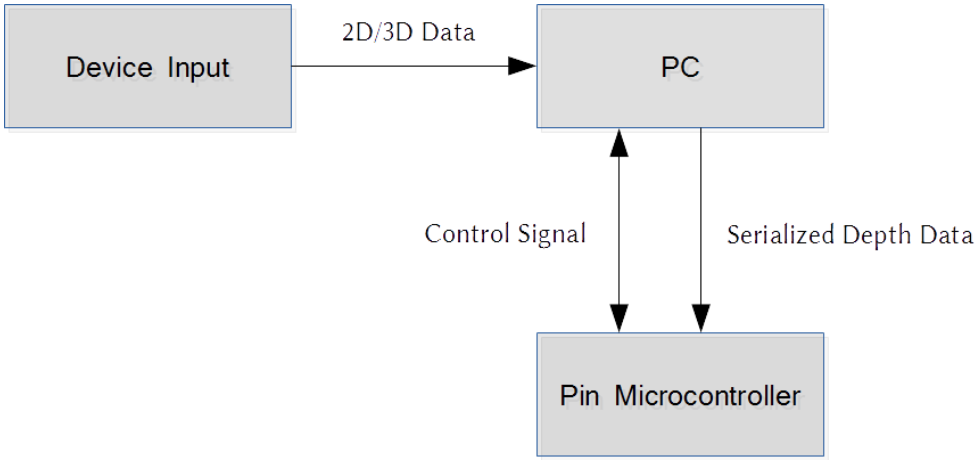

Figure 4:Software system block diagram of *Relevo*

The second stage performs both bulk data transformation and microcontroller facilitation. It maintains “tasks” for the pin microcontroller using a first in first out approach. Data is serialized and transmitted to the microcontroller using a redundant data transmission protocol. In addition, the second stage issues commands to the microcontroller using a bidirectional control signal. Anything computationally complex will reside in this stage.

The third stage involves the pin microcontroller. It receives serialized depth data from the second stage and uses it to place pins at the appropriate level. It can also receive additional instructions in the form of a bidirectional control signal originating from stage 2. This allows the second stage to poll for pin level and issue new tasks based on the resulting information.

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A huge priority with *Relevo*'s design is to maintain a short period between data input and pin actuation. As a result, most of the system logic has been delegated to stage 2 to allow the microcontroller to focus on pin actuation and polling. Stage 3 will be required to block while waiting for more tasks to be issued from stage 2. Stage 3 will also need to implement the redundant data transmission protocol stage 2 uses to transmit serialized depth data. In aiming for pin responsivity, a balance will have to be struck between data redundancy and transmission speed.

4.2 GENERAL REQUIREMENTS

[R44-B] Software modules should support the processing of both 2D and 3D data

[R45-A] All software modules are to be written with re-entrant code

[R46-C] System shall ideally be capable of saving current pin level information to disk

[R47-A] Data transfer protocol responsible for communication between microcontroller and main control CPU should be both redundant yet responsive.

Relevo should be able to translate both 2D and 3D information into a control signal for the actuation of its pins. Examples of data sources are Google maps and mathematical functions under analysis. Data translation should be fully encapsulated from the rest of the system. That is, translation from data to control signal should be a black box. Also, *Relevo* should be capable of processing camera data and producing a response in about 1s second. This is to improve user experience by giving a higher precision of control. Given that errors in the transmission of control signals or approximations during image processing is inevitable and may accumulate, the system should be able to handle critical software failures that may rarely occur gracefully, allowing itself to reset with minimal impact to the user.

A prime use of *Relevo* is in the analysis of geospatial data. In addition to displaying 2D and 3D data, users will be able to manipulate individual pins in the display. Users should be able to save this information to disk, so as to be able to refer back to the model at a later time.

The transmission of the control signal between the controller CPU and microcontrollers should be redundant. Error in control signal could result in the actuation of pins to incorrect levels. For folks struggling with vision impairment, this could mean giving the individual incorrect information. For data scientists using *Relevo* during analysis, this could lead to errors in computer models. Thus, the protocol used should be a fully redundant data transmission protocol (RDT). In addition to being redundant, the transmission protocol should be reasonably responsive. Fast pin actuation is a core requirement of this product, and should be a high priority.

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5 SAFETY AND SUSTAINABILITY

In order to power the underlying software system and actuators, *Relevo* makes use household line voltage. As a result, it must satisfy standards put forth for electrical equipment in Canada. The Canadian Electrical Code (CSA C22.1) specifies a list of requirements that all electronic devices must adhere to. In particular, section 10 rules 10-102 and 10-116 detail how any metal exterior *Relevo* may have must be properly bonded together and tied to ground. This is to prevent any unintentional shock that may occur when a user comes into contact with the device. In addition, *Relevo* should prevent user access to servo motors during operation, since they could unintentionally heat up and cause burns when in contact with skin.

As part of Actuated Innovation's commitment to sustainability and safety, *Relevo* will be made with non-toxic materials. In particular, harmful plastics will be avoided for all phases of development, and only untreated wood will be used during the proof of concept and prototype phases. This is to prevent both inhalation of toxic fumes and damage to the surrounding environment.

The final product will be designed in such a way as to avoid harming the user on contact. This includes rounding corners and edges, and eliminating any potential trip hazards for the user.

5.1 SAFETY REQUIREMENTS

[R48-B] All circuitry and electrical components must be properly isolated with no conducting surfaces exposed to human body parts

[R49-B] Components that may heat up must not be accessible to the user

[R50-B] The hardware components shall be secured properly to prevent loose components

[R51-A] All components must not melt or emit toxic fumes under operational temperatures

[R52-C] The enclosure shall be water resistant to prevent electrical hazards

[R53-A] *Relevo* shall have warnings to prevent physical injuries to the users

[R54-A] *Relevo* shall have easily visible signage detailing its power requirements

[R55-B] *Relevo* shall have warnings against user access to the electrical power supply components

[R56-C] *Relevo* shall have all electrical and electronic wiring enclosed from user access

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[R57-B] *Relevo* shall minimize all corners and sharp edges on the exterior to minimize the risk of injury to users

[R58-B] The motors shall not be operable when they are accessible for maintenance

[R59-C] *Relevo* shall be physically designed to be structurally stable to avoid user injury or damage to itself – i.e. low centre of gravity, wide enough base to avoid tipping

[R60-B] *Relevo* shall conform to IEC 60065 (Audio, video, and similar electronic apparatus – Safety) [6] and IEC 60950 (Information technology equipment – Safety) [7]

5.2 RELIABILITY REQUIREMENTS

[R61-C] The system shall be fully operational for a lifespan of 2 years

[R62-C] The enclosure shall be water resistant

[R63-B] The product will have replaceable motors, linkages and pins

5.3 SUSTAINABILITY REQUIREMENTS

[R64-B] Final product hardware should be easily reparable given eventual component failure

[R65-C] Where possible, *Relevo* should avoid the use of harmful plastics

[R66-A] The software system should be modularized to encourage repair versus replacement

[R67-C] Pin CAD models for 3D printing will be released free of charge in the event pin damage occurs during operation

[R68-B] *Relevo* shall conform to ISO 14001 (Environmental management) [8]

With *Relevo*, Actuated Innovation aims to take a cradle-to-cradle design approach. Electrical hardware should be easily accessible for maintenance once operation has ended. This allows for replacement of blown servos, or re-soldering of damaged electrical connections. In addition, the software system should be heavily modularized to reduce the cost and difficulty of replacement. Actuated Innovation will also provide users with any relevant cad models to facilitate 3D printing of any plastic parts that may become damaged over time.

Since *Relevo* has a wide range of potential applications, Actuated Innovation wants to foster a culture of repair and reuse amongst its user base. A *Relevo* unit that may no longer be needed by a data analyst could see further more use after being

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repaired and donated to an elementary school. Used devices could also be repaired and donated to groups assisting folks with vision impairment.

All electrical components will be reused between the proof of concept and prototype phases to reduce the development footprint. Any wooden surfaces used for either phases will be made with untreated material to increase safety and reduce environmental impact. In addition, any wood material that cannot be reused for the prototype will be recycled in an appropriate manner.

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6 CONCLUSION

Relevo is a system with many components. Many requirements must be considered in detail to ensure a defined product. From general to hardware to software, these requirements must be upheld during system design and test. This document has outlined the various requirements and capabilities of our system including its components. The requirements have been divided based on priority allowing the development team to work efficiently.

This document will be used through the design and development cycles as a reference. It will also hold as a testing reference to ensure all requirements have been met. At Actuated Innovations, we keep sustainability and safety as a key issue during the design and testing of our product. The proof-of-concept, prototype and final product will meet all safety standards as well as sustainability issues.

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REFERENCES

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