ACTUATED INNOVATIONS

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March 27, 2016

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
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Re: ENSC 405W Design Specification including User Interface Appendix for a Pin Actuated Display System

Dear Dr. Rawicz,

Please find the design specifications document which outlines the design information for our Capstone Engineering project. The team at Actuated Innovations are in the process of designing and implementing *Relevo*, a system that displays depth data in 3D physical space, in addition to providing the user with tactile feedback.

The purpose of this document is to give a full breakdown of our proof-of-concept model in its physical, hardware, firmware, and software elements. Technical design considerations are written to justify and support the functional requirements of the overall product. In addition, a detailed test plan is included for product evaluation. Through detailed designed considerations of *Relevo* and its subsystems, this document will provide design references and details about future iterations.

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. Our team specializes in systems, electronics and computer engineering, and are motivated and passionate about our field of study.

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
Co-founder of Actuated Innovations

Enclosed: Design Specification including User Interface Appendix for a Pin Actuated Display System

DESIGN SPECIFICATION

"RELEVO" PIN ACTUATED DISPLAY SYSTEM

ACTUATED INOVATION INC.

Issue Date: March 27th, 2017
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ABSTRACT

This document details the design specifications for *Relevo*. The purpose is the give the reader a detailed design of each of the three subsystems in terms of hardware and software components. Justification is included explaining how our design choices meet the functional requirements specified in the document "Functional Requirements - Relevo Actuated Pin Display" [1].

Hardware choices are justified mainly on their alignment with the specific requirements and their component specifications. Software choices are built on our chosen hardware platform and design is justified based on processing speed and efficiency.

This document also provides a preliminary high level test plan to verify the functionality of *Relevo*. In addition a User Interface Appendix is attached discussing the usability of our product as well as a set of usability tests.

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GLOSSARY

PWM	Pulse Width Modulation is a way of digitally encoding analog signal levels
Flyback Diode	A diode that prevents flyback which is a high surge of current caused by rapidly changing voltage to an inductive load
SPI	Serial Peripheral Interface (SPI) is a synchronous serial data protocol used by microcontrollers for communicating with one or more peripheral devices quickly over short distances.
Multiplexer	A Multiplexer is a device that allows one of several analog or digital input signals which are to be selected and transmits the input that is selected into a single medium.
UART	Universal asynchronous receiver/transmitter is a block of circuitry responsible for implementing serial communication.
TX	Transmit
RX	Receive
USB	Universal Serial Bus
IC	Integrated Circuit
CPU	Central Processing Unit
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

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1 INTRODUCTION

The *Relevo* is the next multi-media tool for data visualization. The device utilizes actuated pins to display data including, but not limited to, geographical data and 2.5D images. The most commonly used language for the blind, Braille, is severely limited in the rate of information it can convey because it is binary. *Relevo* addresses this problem by actuating its pins to vary the levels of height allowing for more detailed forms of tactile communication. In addition, our tool is useful for researchers and engineers in the geospatial analytics field by providing users with another medium to perform geovisualization. The system employs an IR camera to give users a whole new interactive experience enabling them to scan and display their own objects. There are currently no solutions similar to ours on the market. Our aim is to create a durable and portable device that promotes data visualization by using an actuated surface of pins.

This design specification document will outline the following:

- The *Relevo* system and its subsystem design
- An overview of the proof of concept model
- Technical details of the system design
- A detailed test plan to ensure product functionality
- UI Design Appendix outlining product usability

1.1 SCOPE

The objective of this document is to define and organize the technical details regarding the design of the proof-of-concept system, prototype, and final product. The document will also explain how the design meets the functional requirements as described in the Requirements Specifications. The document divides the system into its hardware, software, and physical components, and further divides the subsystems into its components. In addition, this document will outline the high-level testing procedure needed to evaluate the performance of *Relevo*. Furthermore, a UI design appendix is attached which analyzes the usability of *Relevo*'s interfaces and provides a usability test plan.

1.2 INTENDED AUDIENCE

The Design Specification document is intended to be used by all members of Actuated Innovations. Design engineers shall refer to the specifications as an overall design guideline to ensure all requirements are met at all stages of design and production. In addition, test engineers will implement the functional and usability test plan to ensure the product's overall quality. The document also stands to help readers obtain a better technical understanding of *Relevo*.

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2 SYSTEM OVERVIEW

The *Relevo* will allow users to communicate basic shapes and forms through the use of its interactive tactile display and 3D object capturing capabilities. The main goal of *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.

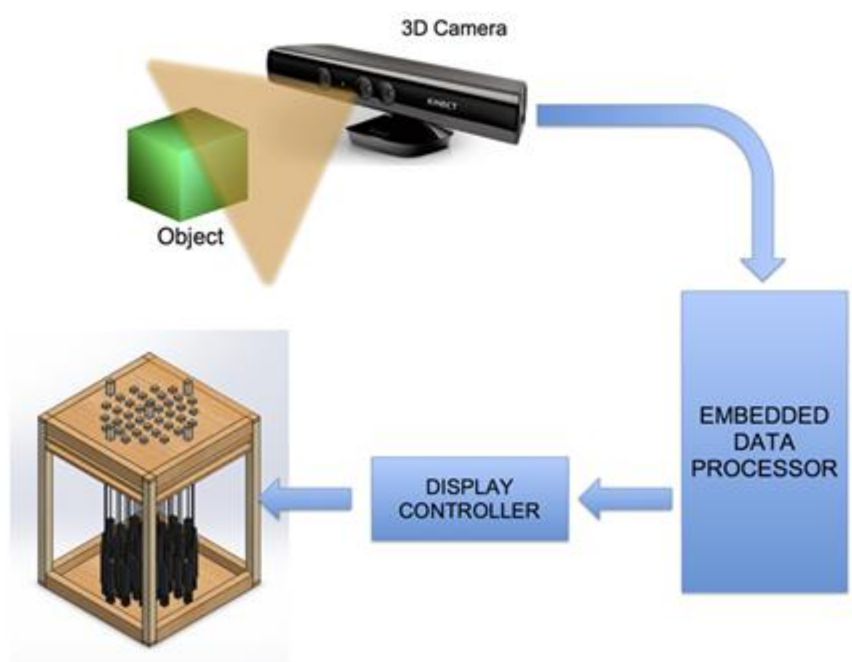

Figure 1 - User Level System Overview of *Relevo*

The *Relevo* will be composed of 3 subsystems that include: the core computation subsystem, the object scanning subsystem, and the pin display subsystem. The core subsystem will be responsible for all system computation such as image processing and user status information. In addition, it is responsible for powering the microcontroller and Kinect Camera. The object scanning subsystem will be responsible for retrieving user input in the form of object scanning. The pin display subsystem will be responsible for providing the user interface. The high-level layouts of these subsystems are shown in Figure 2 and a block diagram of hardware interconnections is shown in Figure 3.

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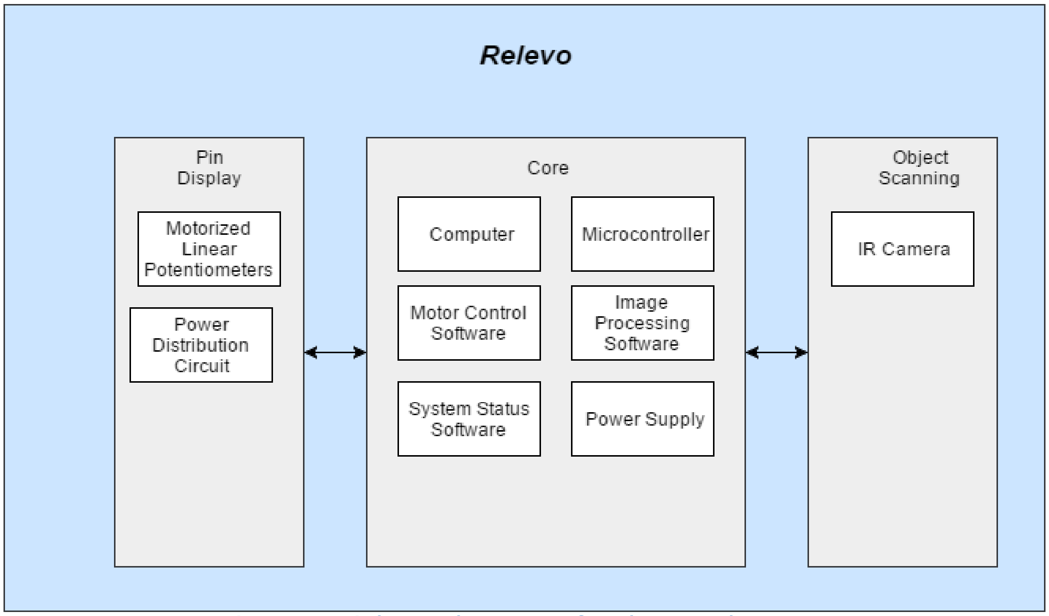

Figure 2 -High Level Layout of *Relevo*'s Subsystem

The three subsystems will operate using the below hardware components:

- Core subsystem: Embedded PC, Microcontroller, Power Supply
- Object Scanning subsystem: Microsoft Kinect
- Pin Display subsystem: Motorized Linear Potentiometers, Power Distribution Circuit

The Kinect Camera will deliver depth data to the computer/Embedded PC through a USB connection. The depth data will then be processed by the computer/Embedded PC which will be running Linux thus allowing support of Python programming and Arduino commands. After translating this depth data to height instructions for the pins, the instructions are then sent to the microcontroller (Arduino Due) also via USB connection. Based on the instructions received, the microcontroller will control the potentiometers and drive a set of LEDs which provide system status feedback to the user. A block diagram of the hardware interconnections is displayed in Figure 3 on the next page.

The Core subsystem will have feedback from the other two subsystems to allow monitoring of their status. The Core subsystem receives feedback to its microcontroller from the Pin Display subsystem via a variable output resistance which corresponds to the pin height of each potentiometer. This resistance is read by running a current through the variable resistance and sending the voltage as a feedback signal. On the other side of the diagram the feedback is built into the software for the Kinect Camera and it is received by the computer/Embedded PC.

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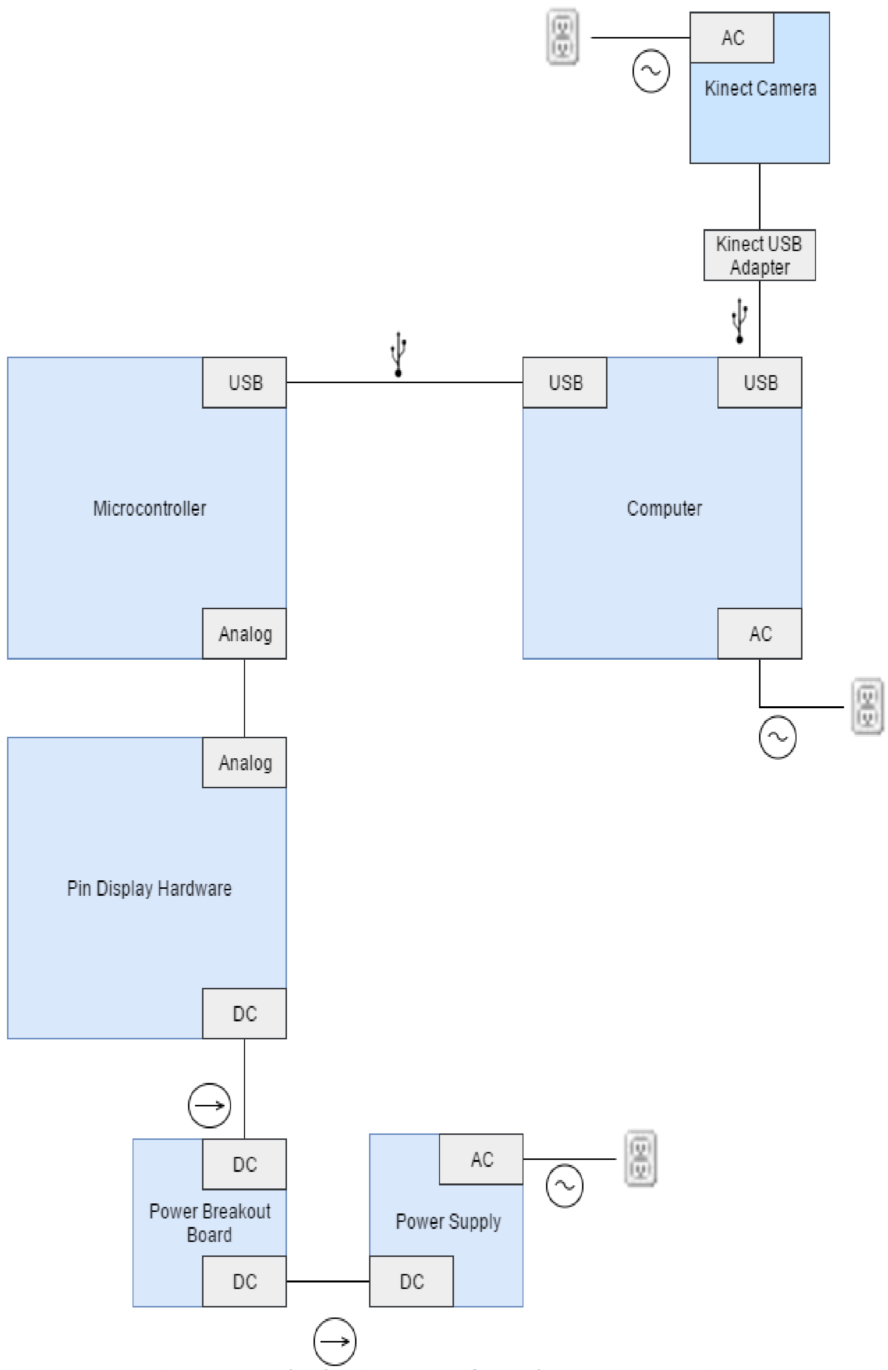

Figure 3 - Block Diagram of Hardware Connections

2.1 USE CASE

Figure 4 shows the interaction between the user and the three system components of *Relevo*. The user is in direct contact with the Object Scanning system and the Pin Display system. The Core subsystem will provide the user feedback based on the current state of the system.

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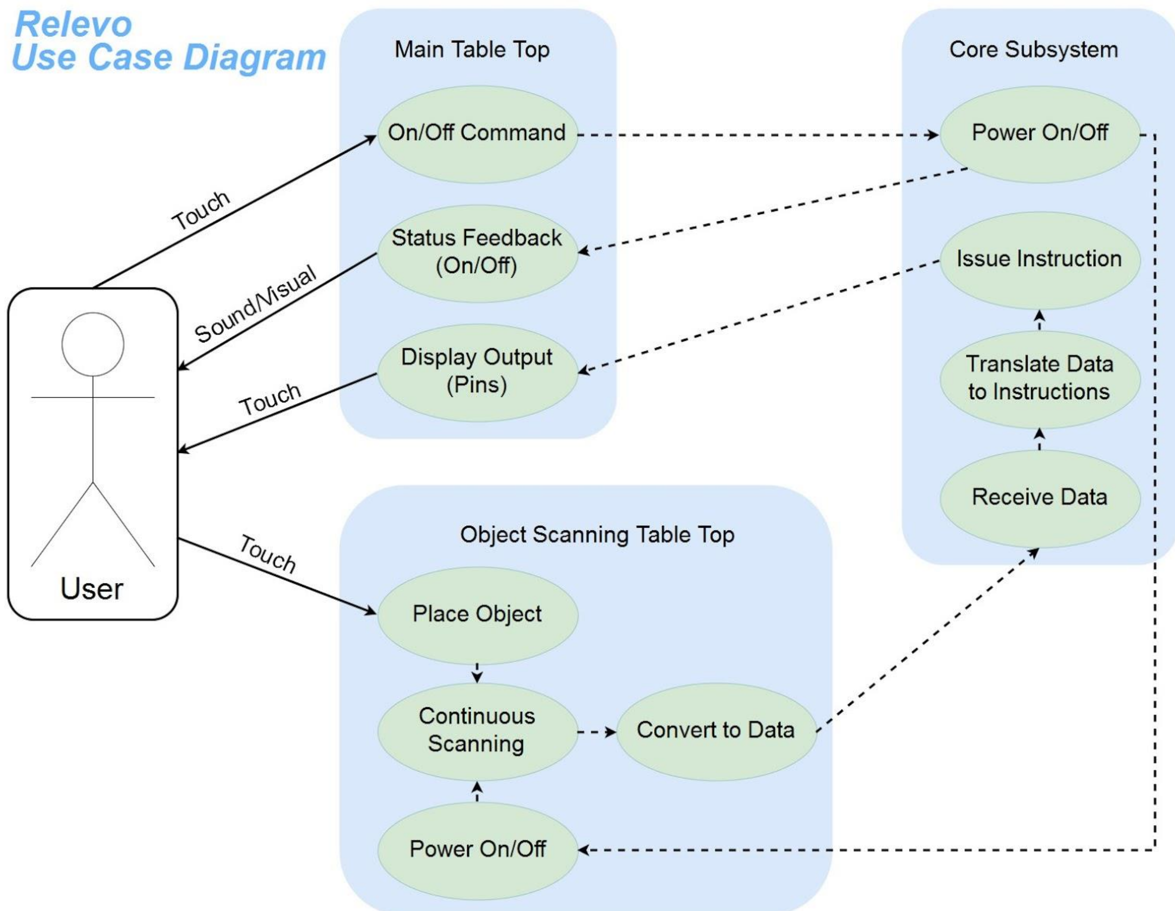

Figure 4 - Use Case Diagram

3 SYSTEM OVERVIEW

3.1. CORE SUBSYSTEM DESIGN

3.1.1 Hardware Design

3.1.1.1 NVIDIA Jetson TK1

As a part of the core subsystem, we will use the Jetson TK1 as the embedded computer. This will be used for our final product, whereas for the proof of concept and the prototype we will use a laptop to reduce initial costs. The Jetson TK1 development board was chosen for the following main reasons: it uses a NVIDIA Tegra K1 SoC which has its own integrated GPU, has multiple USB ports, has a pin expander to control our pin array, and runs a Linux based operating system.

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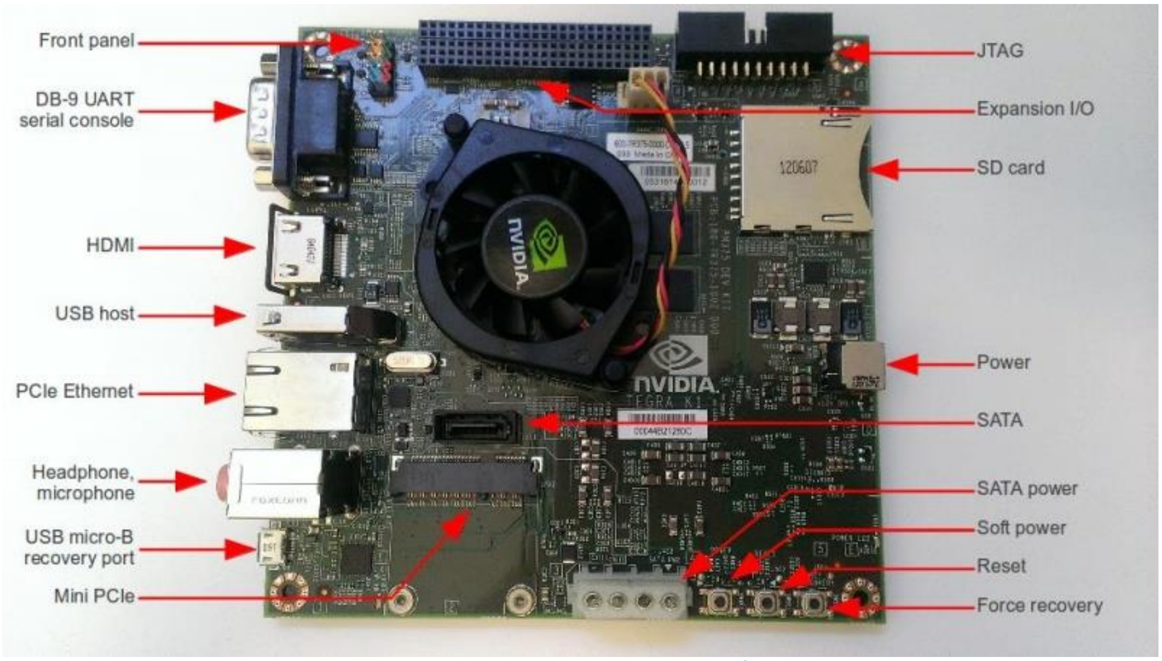

Figure 5 - Jetson TK1 component diagram

The detailed specs of the Jetson TK1 Development Board are outlined in the table below.

Table 1 - Jetson TK1 Specs [2]

Dimensions	5'' x 5''
Processor	Tegra K1 SoC
RAM	2GB DDR3l
Storage	SD slot, 16GB eMMC
PCIe	1 mini-PCIe
Audio/Video	1 HDMI, 1 Mic in and 1 Line out
Serial Communication	USB 2.0/3.0, RS-232, UART, SPI, I2C
Networking	1 Gigabit Ethernet port
GPIO	7 pins
SATA	1 SATA Data Port
Power	12V DC
OS	Linux4Tegra (basically Ubuntu 14.04 with preconfigured drivers)

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The Tegra K1 SoC contains both a CPU and GPU using an ARM Cortex-A15 as its CPU and a NVIDIA Kepler GPU with 192 CUDA Cores. This allows our system to perform intensive image processing, computer vision, and parallel computing. Additionally, the USB ports allow the Kinect to transmit its data to be processed while the GPIO input and outputs allow us to control LED's to display to the user the system's status. Because the development platform comes pre-installed with Linux, it allows us to easily develop software to control both the Kinect and our chosen microcontroller. With all this functionality, the Jetson TK1 is still able to keep its power consumption at 12V with an average of 7-11W when all CUDA processing cores are active during computer vision [3]. It is an ideal design choice for our final design as it is both powerful and compact.

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3.1.1.2 Circuit Design

Motor Control

Each potentiometer has a DC motor that controls the position of the pin. To accomplish this, a device called an H-Bridge is used. These devices basically act as four switches that determine if the motor receives from +9V (forward) to -9V (reverse) based on the applied input PWM signals from the microcontroller through the PWM driver ICs. The H-Bridge that Actuated Innovations is planning to use is the SN754410. This IC supports control of two motors and is rated at 1A and 4.5V-36V per motor. 13 H-Bridge ICs are to be used to control the 25 pins of Revelo.
One drawback of the SN754410 is that there are no internal diodes to eliminate flyback if the supply current is suddenly reduced or interrupted; therefore, external diodes are connected to the outputs of the SN754410.

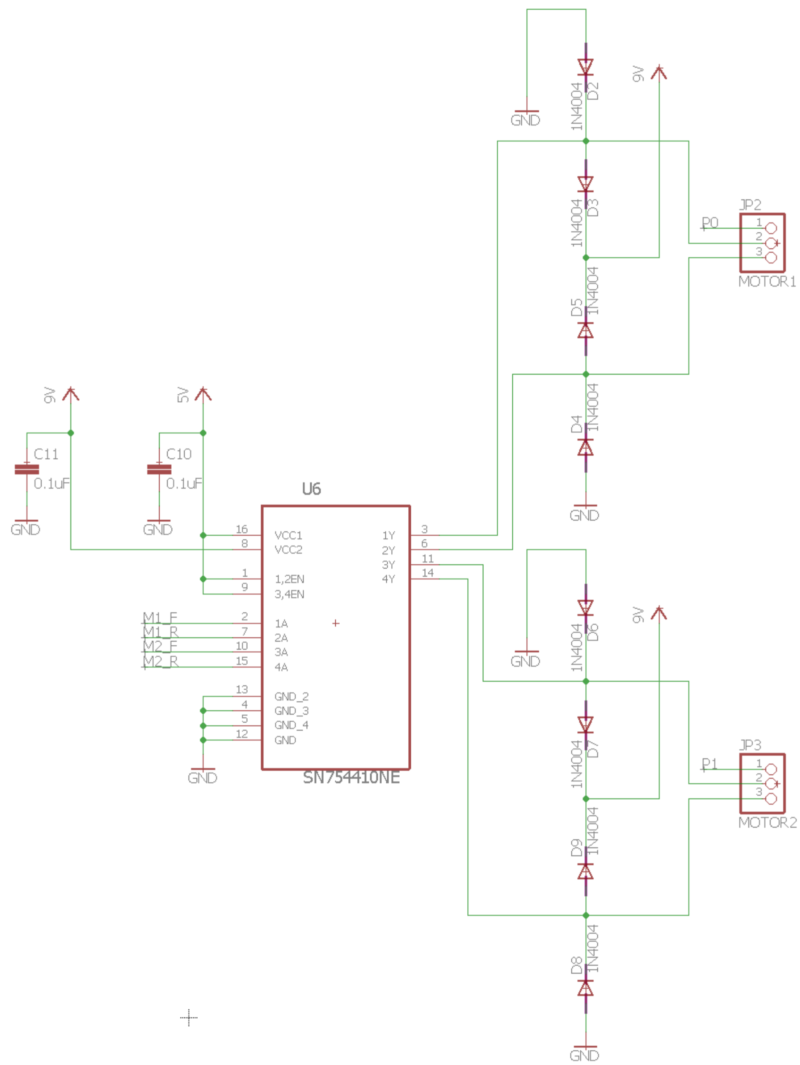

Figure 6 - Motor Control Circuit

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PWM Expansion

Revelo requires 50 PWM pins to address the 25 motors. There are currently no commercially available microcontrollers that have that many PWM output pins. To address this problem PWM driver ICs must be used to expand the amount of PWM pins of the microcontroller. Actuated Innovations has chosen to use four TLC5940 16-Channel LED Drivers which add an additional 16 PWM pins per IC. These ICs can be daisy chained and communicate with the microcontroller using the SPI bus. Pull-up resistors are used to invert the outputs of the PWM drivers since the H-Bridges require active high inputs while the PWM drivers are active low.

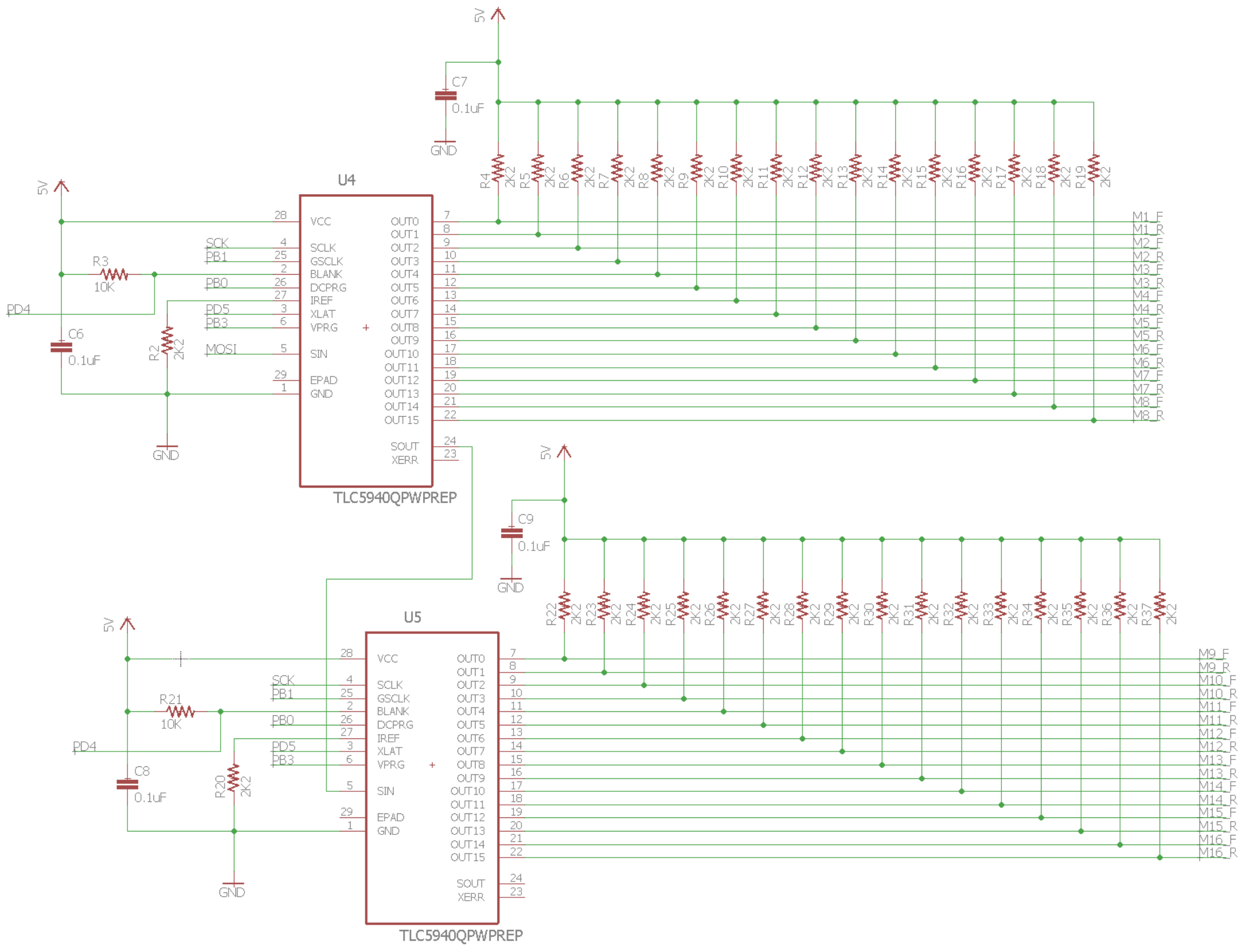

Figure 7 - PWM Circuit

R2 and R20 in the above figure determine the output current based the equation below.

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Equation 1 - Output current equation

$$I_{OUT(IDEAL)} = 31.5\left(\frac{1.24V}{R_{IREF}}\right)$$

$$I_{OUT(IDEAL)} = 31.5\left(\frac{1.24V}{2200\Omega}\right) = 17.8mA$$

This is within the input specification of the SN754410 H-Bridges.

Microcontroller

The choice of the microcontroller came mainly down to the correct number of I/O pins, clock speed, and internal memory size. With 25 display pins, we need eight pins to communicate with the PWM Drivers, two analog read pins, and eight more digital I/O pins to select which potentiometer to read from. The ATmega644 running at 16MHz fit all our requirements and gave us some lead way to possibly expand the number of peripherals we interface with in the future.

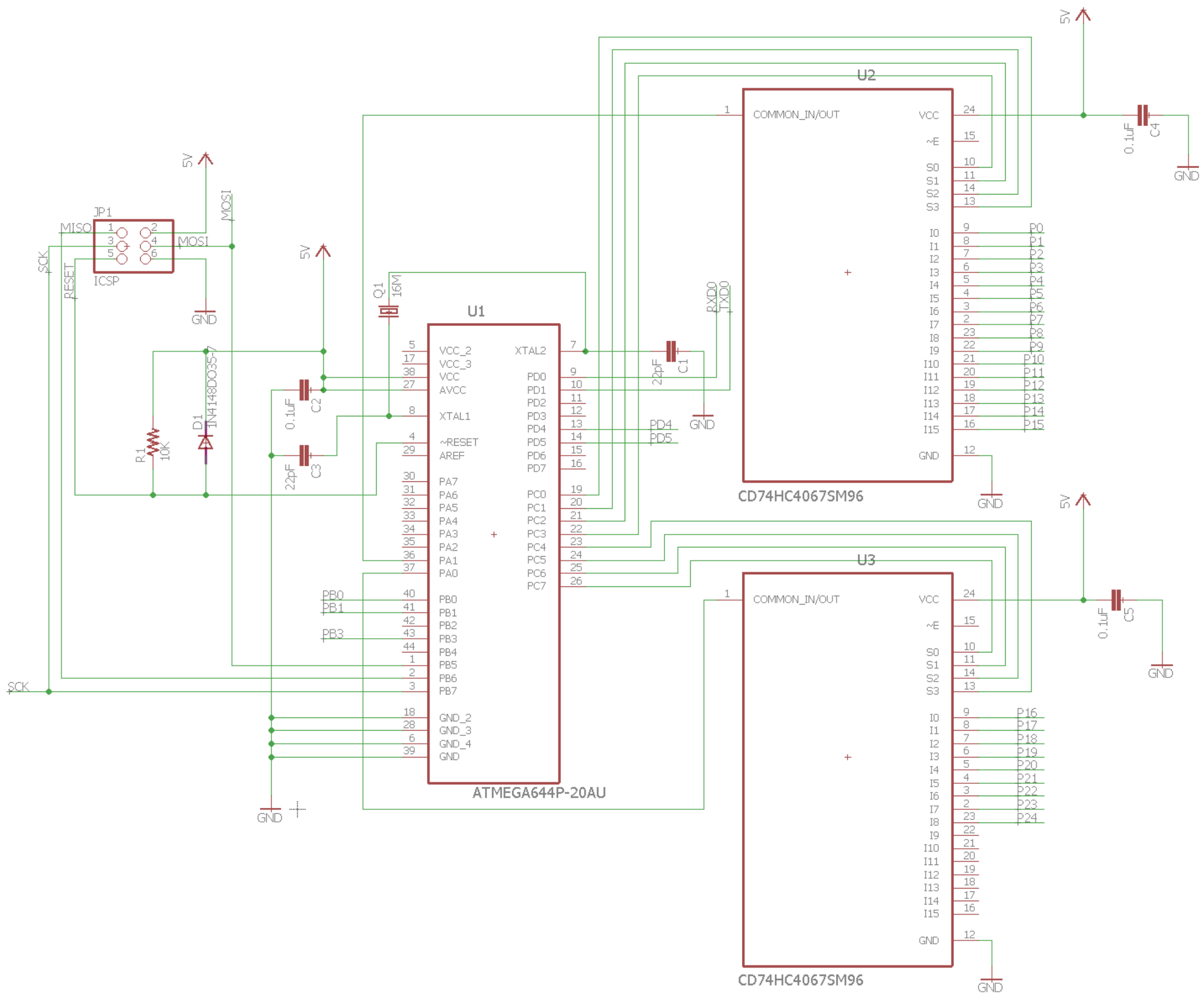

Figure 8 - Microcontroller Circuit

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Two multiplexer ICs, specifically two CD74HC4067 ICs, are used to address all 25 potentiometer positions since the ATmega664 only has eight analog read pins.

Communication with Computer

The microcontroller needs to receive depth data from the computer. To accomplish this Actuated Innovation has chosen to use serial communication via USB. The FT23RL chip is used to convert USB to serial UART and is connected to the RX and TX pins of the microcontroller.

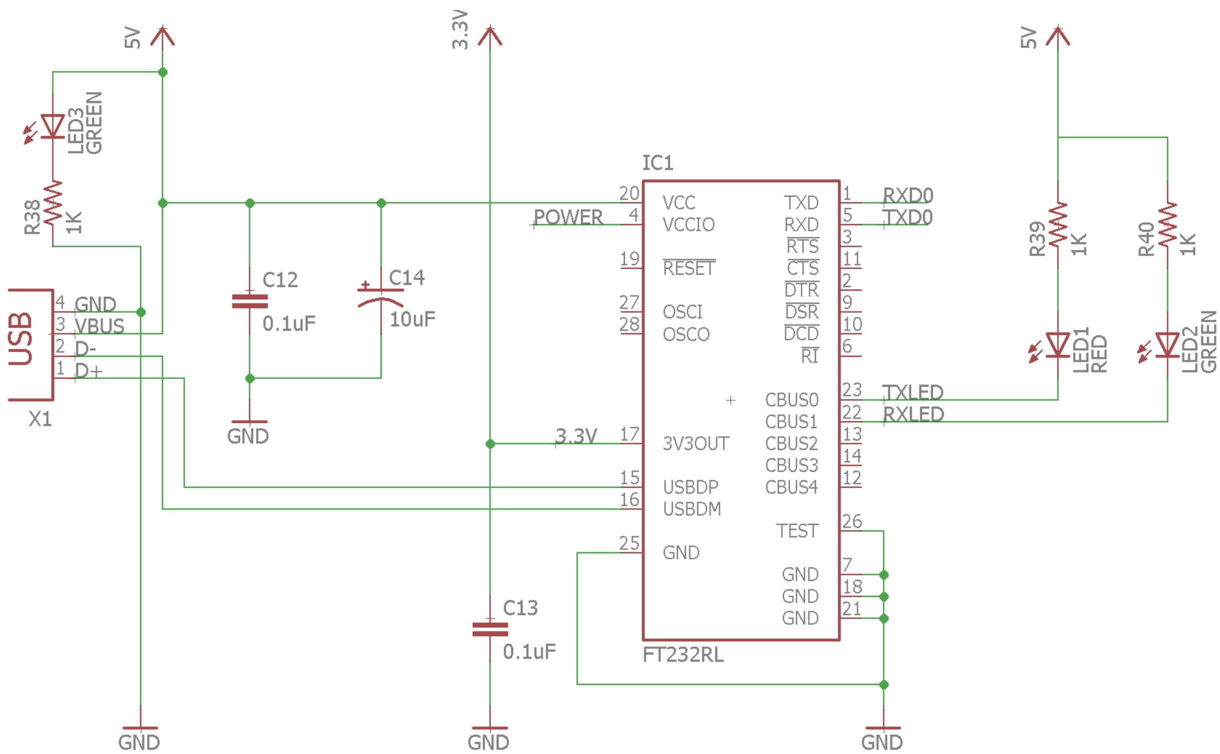

Figure 9 - USB to UART conversion circuit

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Proof of Concept

The proof of concept for Relevo is based on the Arduino Due consisting of four display pins and connected to the TLC5940 PWM Driver and two SN754410 H-Bridges. The diagram of the Ardunio and its given specs are outlined in Figure 10 and Table 2 below. These specs satisfy our prototype requirements defined in our documents specifically **R37-A, R38-A**.

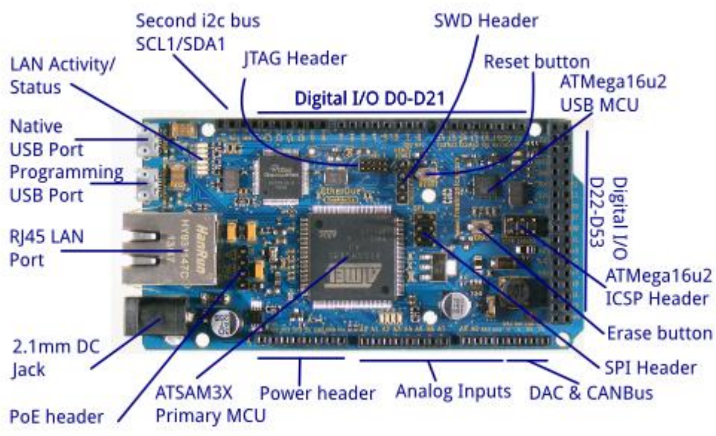

Figure 10 - Arduino Diagram

Table 2 - Arduino Specs [4]

Operating Voltage	3.3V
Input Voltage (recommended)	7-12V
Digital I/O Pins	54 (of which 12 provide PWM output)
Analog Input Pins	12
Analog Output Pins	2 (DAC)
Total DC Output Current on all I/O lines	130 mA
DC Current for 3.3V and 5V Pin	800 mA
Flash Memory	512 KB
SRAM	96 KB
Clock Speed	84 MHz
Length	101.52 mm
Width	53.3 mm
Weight	36 g

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Our designed prototype implemented using the Arduino is defined the circuit diagram in Figure 11.

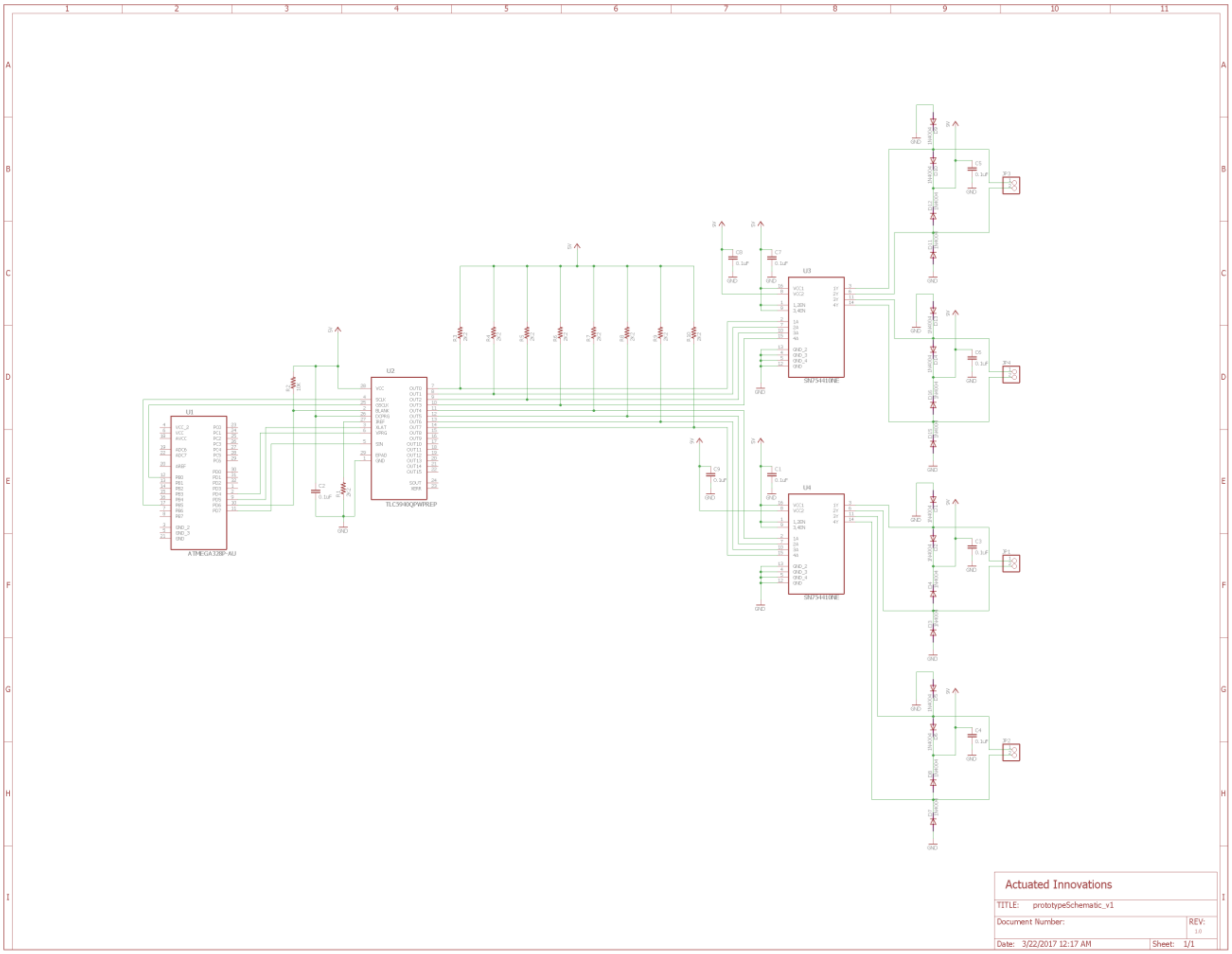

Figure 11 - Prototype Schematic using Arduino

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3.1.1.3 Power Supply Unit Thermaltake TR2 TR-600 600W ATX12V v2.3

To supply power to the potentiometers we will utilize the TR2 TR-600 600W ATX12V v2.3 power supply. This power supply is to be used for our proof-of-concept, prototype and final product.

Table 3 - Power Supply Specs [5]

AC Input	Input Voltage: 115 ~ 230V Input Current: 8A/5A Frequency: 47Hz - 63 Hz					
DC Output	+3.3V	+5V	+12V1	+12V2	-12V	+5Vsb
Max. Output Current	22A	18A	23A	20A	0.3A	2.5A
	600W					
Over Voltage Protection	15.6V Max					
Over Power Protection	Fold back at 540-720W					
Short Circuit Protection	All output to GND					
Output Connectors	Main Power (24-Pin), ATX 12V (4+4-Pin), PCI-E(6+2-Pin), SPCI-E (6-Pin), SATA (5-Pin), Peripheral (4-Pin), FDD (4-Pin)					
MTBF	100,000 hour(s) minimum					
Dimensions	3.40 " x 5.50" x 5.90"					
Hold-up Time	16ms					
+12V Rails	2					
Fans	1 x 120mm (2000 RPM +/- 10%)					
Type	ATX12V v2.3					
Efficiency	72% +					

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While supplying power to the system, due to the amount of current applied to the H-Bridges, a large quantity of heat is produced and therefore requiring heat sinks attached to the ICs. For proper thermal conduction silicon heat transfer pads need to be applied in between the ICs and heat sinks.

3.1.2 Software Design

3.1.2.1 OpenKinect

Relevo makes use of the Kinect camera as a way of reading user input. Our system primarily relies on its depth camera functionality. In order to interface the Kinect with our software system, we've elected to adopt the open source software OpenKinect[3]. OpenKinect is a cross-platform library supported by a community of researchers and hobbyists. At its core, it is a C++ library written using the OpenGL graphics library that can poll camera data. In addition to the base library, known as libfreenect, the community has provided numerous wrappers written in different programming languages.

In order to utilize OpenKinect libraries for our purposes we have decided to use the Python based wrapper in which to write the software needed to achieve our requirements. Using the provided Python wrapper will significantly decrease development time through the proof of concept and prototypes phases while still maintaining relative C like speeds. Using a higher-level more user-friendly language such as Python will also both increase the readability and maintainability of our source code for all members involved as well as allow our team to more easily make quick upstream changes to the code without worrying about lower level technicalities in the code and hardware. Although the use of Python presents an obvious tradeoff between development time, maintainability and speed, for our application we feel the speed limitations of Python are still well within the acceptable range for our design and therefore we will happily make this tradeoff for the benefits of code maintainability and reducing development time as our design is scaled up in the future.

3.1.2.2 System Architecture

Relevo's software system is comprised of three main components: data acquisition, data processing and microcontroller communication. The first stage is data acquisition, and involves asynchronous collection of depth data from the Kinect camera. This is done using the OpenKinect library discussed in section 3.1.1.0. In this stage, Relevo uses predefined callbacks that return whenever depth data from the Kinect camera is available. The result is a 480 by 640 array of integers with 10 bit precision. The depth data corresponding to the actuated pins is kept while other values are discarded to save memory. The remaining depth values are downsampled and averaged so that each element roughly corresponds to each actuated pin. The produced array is then pushed onto a buffer that is shared with the second stage of the software system.

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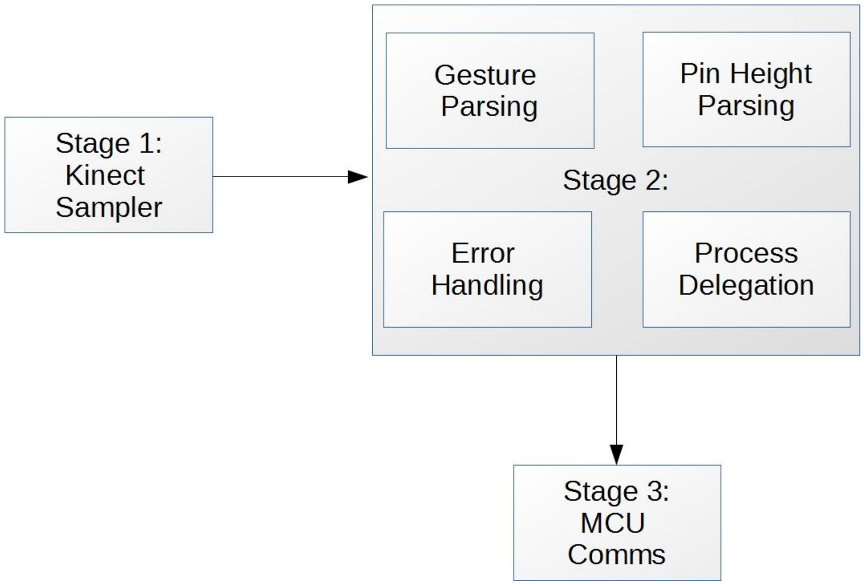

Figure 12 - Architecture Stage Diagram

The second stage contains the bulk of *Relevo*'s logic. Its main focus is the consumption of depth data produced by the first stage. This involves gesture recognition and the interpretation of actuated pin height. This stage is situated on the main CPU board: the Jetson TK1 detailed in section 3.1.0.1. The second stage processes and transforms each array of depth information to a format the microcontroller can use to actuate the pins. Any additional forms of user input reside in this stage, as well as the main error handling logic. From here, the Kinect sampler and microcontroller processes are restarted if they fail due to hardware communication errors. As a result, the second stage will be the most robust in terms of exception handling and code re entry. In the end, output is serialized to disk and transferred to the communication stage via a second final buffer.

The final stage of *Relevo*'s software system handles communication between the Jetson TK1 and the microcontroller actuating pins. Its main task is to grab incoming pin data from the shared buffer and transmit it over USB by way of the I2C protocol. This process is separated from the second stage in order to avoid synchronization issues that may arise when waiting for communication from the microcontroller. This stage utilizes I2C due to it's robust handshaking procedure. Since the integrity of the transmitted pin data is of high priority, the communication between Jetson and microcontroller should be redundant to avoid error.

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3.2 OBJECT SCANNING SUBSYSTEM DESIGN

3.2.1 Hardware Design

To scan objects as the display input to *Relevo*, the most efficient solution is to adapt and program Microsoft's Kinect sensor. The Kinect was chosen because its specifications meet with our prototype requirements from our Functional Specification, specifically clauses **R26-A, R27-A, R28-A, R29-A, R30-A**. It's IR camera and emitter match or exceed these requirements and the physical device is already fully developed as a market product with documentation and software support. This allots more time to spend on designing the system that surrounds the sensor and implement a more comprehensive and quality system instead of focussing on developing and integrating the sensor itself.

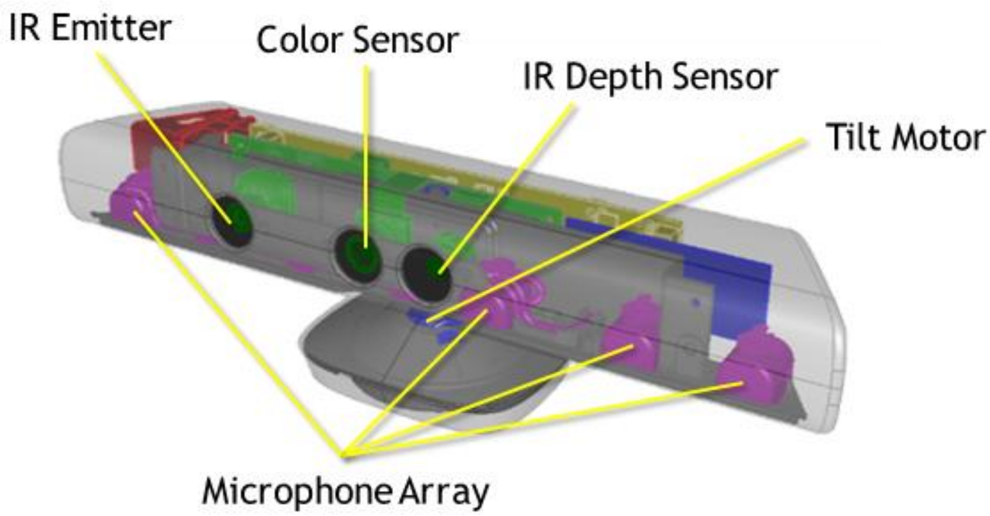

Figure 13 - Hardware Components of Kinect [6]

Table 4 - Kinect Specs [7]

Depth Data Range	Near (400, 3000 mm), Default (800, 4000 mm)
Depth FOV	70 x 60
Vertical tilt range	±27 degrees
Frame rate (depth and color stream)	30 FPS
Communication Interface	USB 2.0
Voltage Requirement	12V
Power Consumption	32 W

The main purpose of the Kinect is to utilize its IR Emitter and IR Depth Sensor as both are required to successfully scan depth data. A notable design limitation of the Kinect sensor is its range and field of view. However, when used in our system we are well within the product's field of view. From Table 4, the Kinect's 30 FPS is sufficient to create a real time environment for us to continuously scan the user's input. The Kinect requires a USB connection as a means of depth data communication. However, the sensor requires a separate power source to power on.

From a software perspective, the Kinect has a large open source community which allows us to create our own custom Kinect application. In addition, Kinect outputs depth data in the format of a numpy array of size 640 x 480 which makes it easy to process.

For our final product, an upgraded version of the Kinect can be considered.

3.3 PIN DISPLAY SUBSYSTEM DESIGN

3.3.1 Hardware Design

3.3.1.1 Motorized Potentiometer

The main hardware components of the pin display are the motorized potentiometers and the physical pin. There are several hardware components capable of driving a pin, however the motorized potentiometer provides us with a driving force and feedback allowing us to read the position of the slider and control how much the pin is raised. Therefore, they are the optimal solution. In our system we use the slide pot RSA0N12M9 provided by ALPS Electric Co. [2]. The slide pot is capable of traveling 10 cm, which is ideal for our table top design. The physical image, and dimension drawing is shown in Figure 14 below.

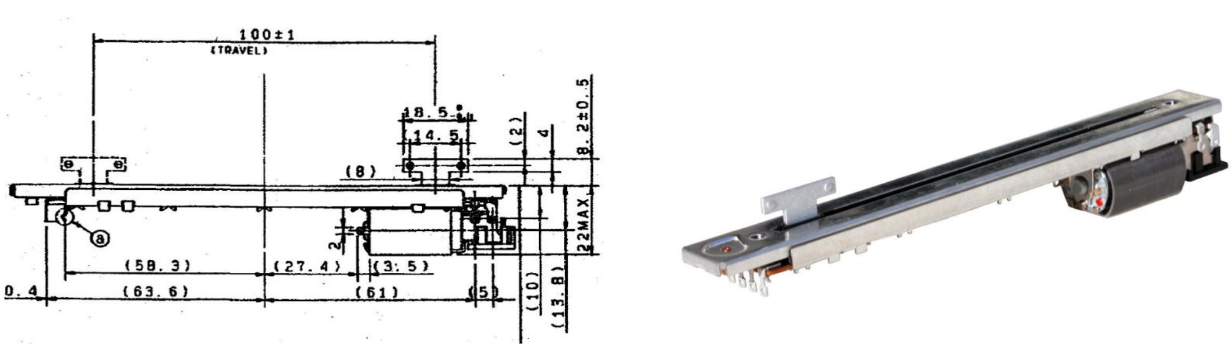

Figure 14 - ALPS RSA0N12M9 Dimensions and 3D image

With the slide pot's set of specifications is shown in Table 5 is it a great fit for our proof-of-concept, prototype and final product which allows for a good cradle-to-cradle design. In addition they satisfy the following requirements: [R40-B, R41-A, R42-B, R43-A].

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Table 5 - Potentiometer Specs [8]

Dimensions (l * w * h)	144 mm x 17 mm x 22 mm
Hole spacing	120 mm
Weight	70 g
Power Rating	0.25 W
Maximum Current	800 mA
Operating Supply Voltage Range	6 ~ 11V D.C
Rated Voltage	10V D.C, 350V A.C
Starting Current	800mA or less
Lever Travel	100 mm
Operating Force	0.8 3 0.5 N
Starting Force	0.2N or more
Traveling speed	20mm/ 0.1 sec
Sliding Life	30,000 cycles at 600 cycles/ hour

Based on our team's experimentation, the slide pot is capable of lifting and maintaining a weight of approx. 26g without jitter at an operational voltage of 10V. Any heavier and the slide pot has visible jittering and is not steady at holding the weight in place.

3.3.1.2 Pin Design

To display the information input by the Kinect and processed by the embedded CPU, *Relevo* uses an array of pins. Based on the slide pot dimensioning, spec and experimental results we custom designed our pin accordingly. The pin is made up of a combination of three components; T-bar pin socket, pin wedge, and pin pole. The pin is designed to attach onto the sliding T-bar and provide a socket for the actual pin material to connect. A wedge is provided to ensure a secure connection between the T-bar and the socket.

The T-bar pin socket is dimensionally designed to latch onto the slide pot's T-bar. Figure 15 shows the latch mechanism.

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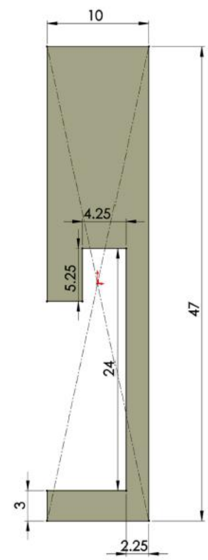

Figure 15 - T-bar Latch Dimension and Design

The socket's 3D design and dimensioning can be visualized in Figure 16. The top hole is the insertion point of the base of the pin, whereas the slot in the back side allows a wedge to be inserted to lock the latch in place.

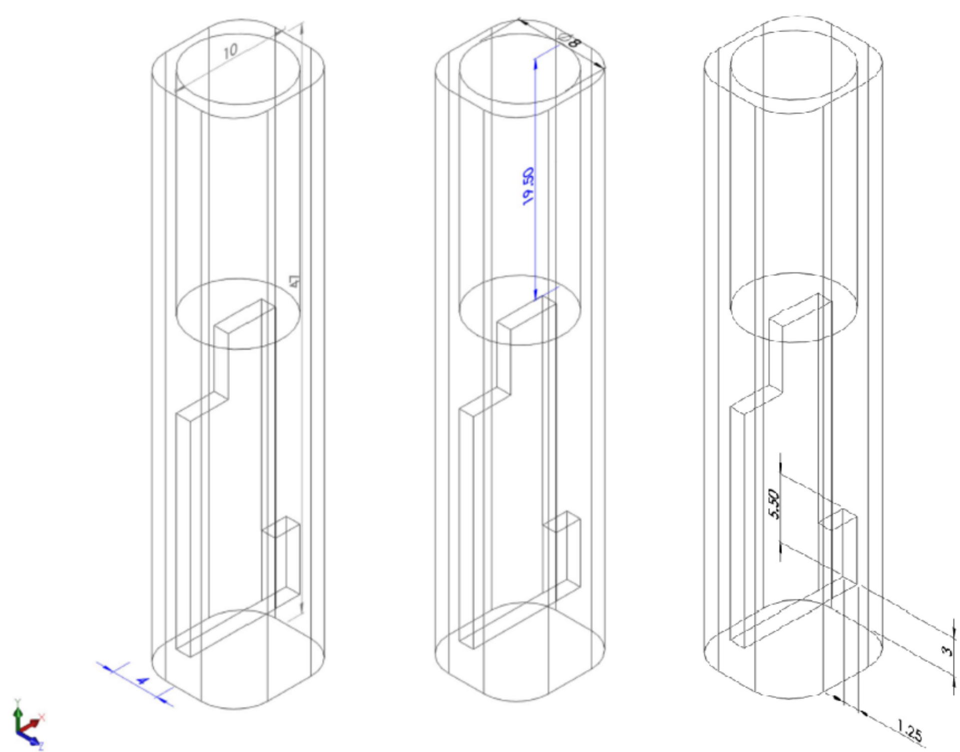

Figure 16 - Socket 3D Design and Dimension

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The final 3D model of the pin socket better showing the physical piece is pictured in Figure 17.

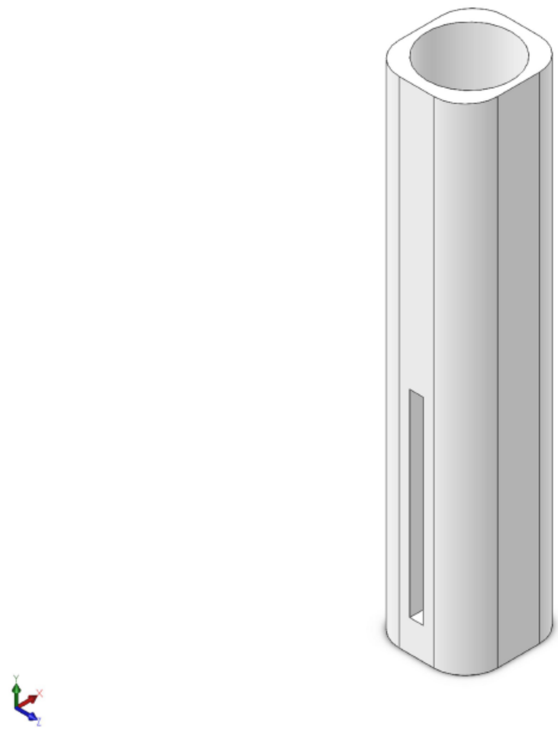

Figure 17 - Physical Socket Adapter Design

The pin wedge design is designed in such a way that the user can easily insert and detach the wedge form the socket. The dimensions and final 3D model to better visualize the wedge is shown in Figures 18 and 19.

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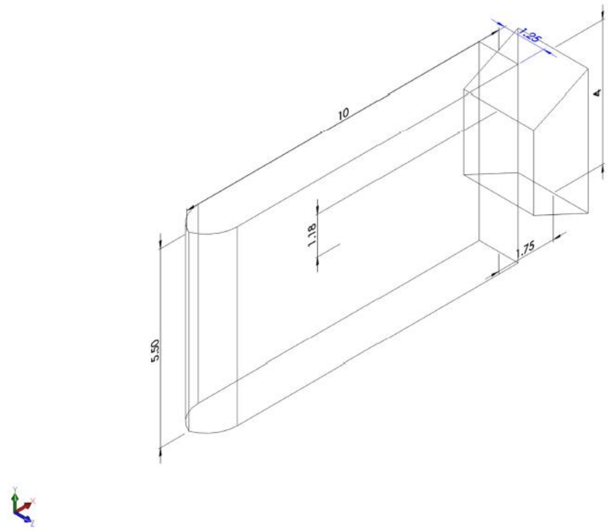

Figure 18 - Wedge Dimension

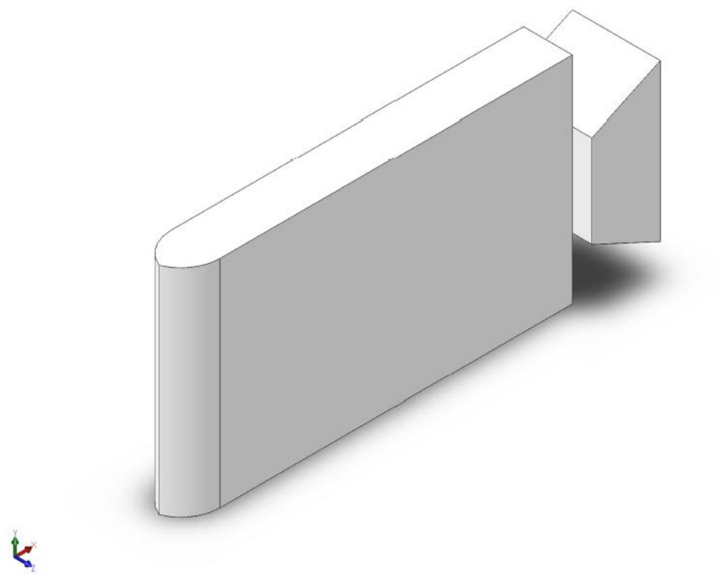

Figure 19 - Physical Wedge Design

The final component of the pin is the pole, which as an array display a 2.5D image. The pole consists of a pole stem to be inserted into the socket and a pinhead to increase the contact surface area. All three sections are modeled and dimensioned using SolidWorks in the figures below.

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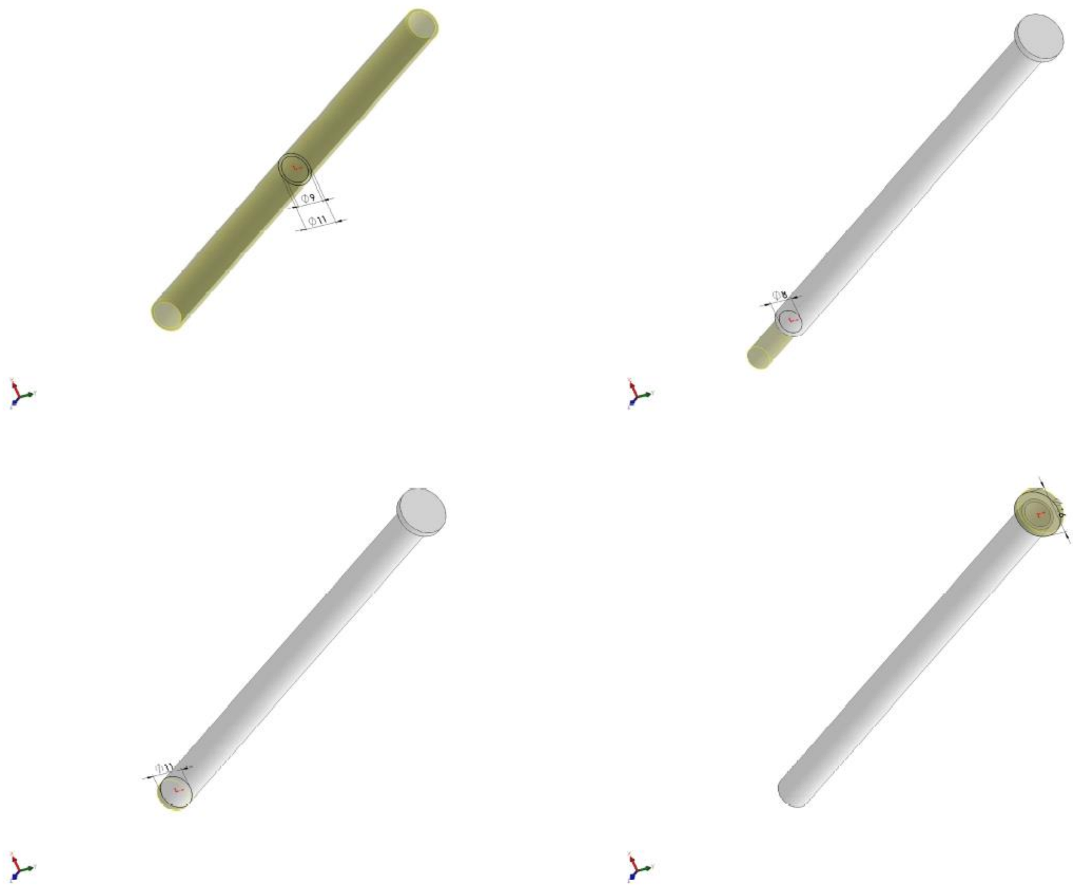

Figure 20 - Pin Pole Dimension and 3D model

The three components of the pin will be held together with frictional force. The final pin attached to the potentiometer is visually depicted below in Figure 21.

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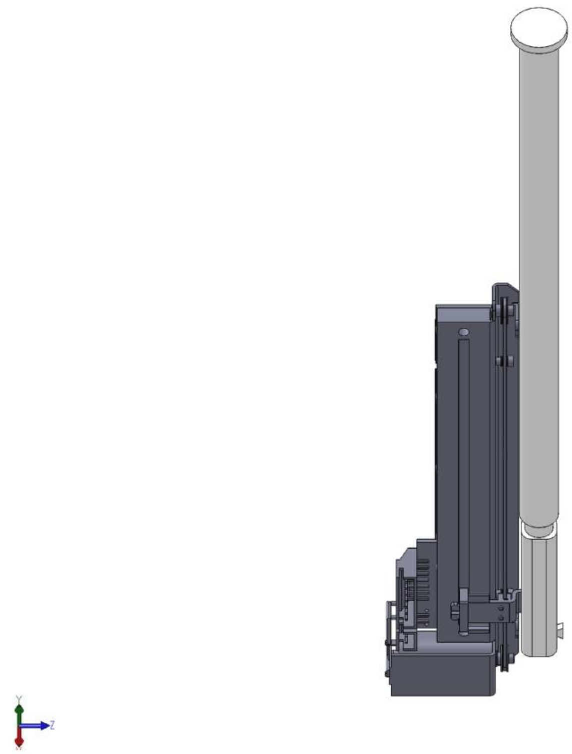

Figure 21 - Fully Assembled Pin attached to Potentiometer

The final pin based on the data from SolidWorks has no component interference and will have the following specifications. For our proof-of-concept and prototype we will be 3D printing our pins using PolyLactic Acid (PLA) as our material of choice. Not only is this material light but strong and rigid. In addition, it is a plant based product and therefore "Earth friendly".
Based on Tinkerine Suite 2's slicing software, we determined our pin to use 17g of filament which is an ideal weight for the sliding pot to actuate

Final Height	24.8 cm
Weight	17g
Material	PLA

Figure 22 - Full Pin Specifications

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4 PHYSICAL DESIGN

4.1 MECHANICAL TABLE DESIGN

The goal of *Relevo* was to design a lightweight tabletop display system capable of being scaled depending on its end purpose. The mechanical design consists of the pin array housing, processing enclosure, power enclosure, mounted Kinect and the guiding layers to ensure the pins actuated correctly. For the prototype, we chose mostly wood as its main material as it is easier to machine into the desired shape. For the final product we plan to use thermoset plastic such as urea formaldehyde as it is suitable for applications where heat is encountered such as TV's. Plastic makes not only hygienic and attractive surfaces, but is suitable for electrical insulation and heat insulation as it does not conduct electricity and can be made fire resistive through the use of flame retardant additives [9]. In addition, plastic allows us to design the final product with a modern look with multiple colours, textures and ergonomic curves.

Figure 23 - Relevo table with each enclosure

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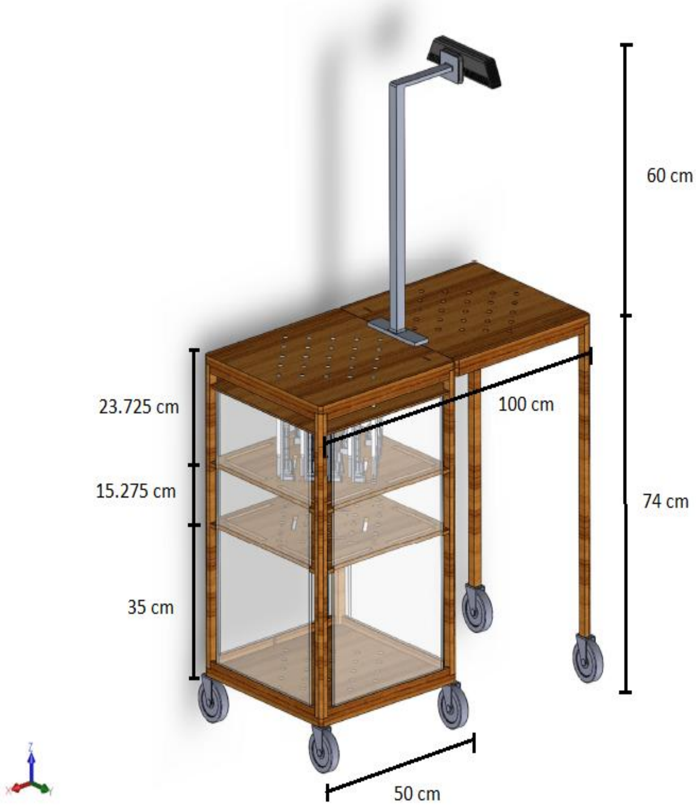

Figure 24 - Table Dimensions

The measurements for our table are designed to enclose all our hardware components safely with room for power cabling. In addition, the pin enclosure is measured such that our designed pin sits flushed to the table at rest. Our Kinect is mounted 60cm from the table abiding by the Kinect depth range yet not jeopardizing the user's view of the pin display. The pin display will also be 50 cm by 50 cm thus satisfying our table requirements R15-C, R16-B, R17-A.

The base of the table is set on lockable caster wheels to ensure portability while maintaining stability on flat surfaces. In addition, safety labels, warnings, and instructions will be attached to the table in the form of stickers. Braille formats and raised letters of the above stickers will be also attached to cater to the visually impaired.

4.2 ELECTRICAL DESIGN

The electrical design for our proof-of-concept device is mainly concerned with powering each of our hardware components. The computer, Kinect, and power supply unit require power from a standard, North American electrical outlet. These components will be plugged into a power bar with which the user can then use the single extension cord to plug into the wall, fulfilling the requirement for using the North American standard of 100-240V at 50-60Hz AC. The USB ports on the

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computer will be used to power the Arduino and in turn the Arduino 5V and GND ports will power the LED's required for the System Status Indicator.

In the prototype and final product, the main concern is maintaining the interconnections between the Kinect, computer, microcontroller, power supply, and pin array within the confines of our case. For *Relevo*, the entire system inside the case will be powered by a single cable to an electrical outlet. Table enclosures are designed to separate the processing unit from the power supply unit and allow space for cable management.

5 FUNCTIONAL TEST PLAN

5.1 GENERAL TESTING

Test Case 01 - Powering on the *Relevo*		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. Plug the power plug of the Relevo into the power source	- No response	
2. Flip the switch located on the *Relevo* Table to ON position from OFF position	- LED should stay off	
3. Wait. Record time taken.	- LED turns GREEN indicating the table is fully functional -Sound plays indicating the system is fully online	

Test Case 02 - Powering off the *Relevo*		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. With the *Relevo* powered ON, flip the switch to the OFF position	- Pins retract into table surface - LED light turns off, no light emitted - Power off should not be instant	

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Test Case 03 - Table Stability		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. Plug *Relevo* into a power source	- Nothing	
2. Flip switch to ON position	- LED lights up to RED - LED light changes to GREEN when computer is online - Sound plays indicating the system is online	
3. Lock the wheels and attempt to push the table	- Table remains stationary	
3. Unlock the wheels and attempt to push the table	- Table moves but pins remain stationary without wiggling	

5.2 OBJECT SCANNING TESTING

Test Case 04 - General Object Scanning Test		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. With the *Relevo* powered on, place an object in the scanning area	- Pins actuate to form the shape the object within 20 seconds	
2. Record the time it takes to shape the object	- Pins should hold shape	
3. Remove object from scanning area	- Pins should return to reset position	

Test Case 05 - Changing scanning objects		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. Power on Relevo	- LED light turns on	
2. Place object in scanning area	- Pins actuate to model the shape	

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3. Remove object in scanning area	- Pins reset ready for next image
4. Place another object into scanning area	- Pins reactuate to model the shape

Test Case 06 - Object Shape Testing		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. Power on Relevo	- LED light turns on	
2. Place square object in scanning area	- Pins actuate to model square that is proportional to the object	
3. Place triangle object in scanning area	- Pins reset and reactuate to a proportional triangle	
4. Place circle object into scanning area	- Pins reset and reactuate to a proportional circle	
5. Place a tiered 3d structure	- Pins reset and reactuate to a multi depthed object	

Test Case 07 - Changing scanning objects		
Actions/Steps	Expected Result	Test Result (Pass/Fail)
1. Power on Relevo	- LED light turns on	
2. Place object in scanning area	- Pins actuate to model the shape	
3. Remove object in scanning area	- Pins reset ready for next image	
4. Place another object into scanning area	- Pins reactuate to model the shape	

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5.3 PIN ACTUATION TESTING

Test Case 08 - Range of movement testing		
Actions/Steps	**Expected Result**	**Test Result (Pass/Fail)**
1. Power on Relevo	- LED light turns on	
2. Place object in scanning area that exceeds 10 cm in height	- Pins actuate to a maximum of 10 cm above the surface of the table - Pin actuate within 0.3 seconds	
3. Keep object on scanning table	- Pins remain steady without visible jitter	

6 CONCLUSION

The *Relevo* is a new addition to the multimedia market capable of visualizing objects in an innovative way. Throughout this design specification document, we have discussed the design choices made to create the product which will ultimately benefit the visually impaired and help with data visualization. Our design takes into account the future final product and the additions required to create the polished final product. Justifications for the chosen design approach are given with a focus on the technical details of each component of our product. In addition, to ensure product quality, a multi-staged test plan is documented to ensure *Relevo's* designed functionalities are met. Finally, an analysis of user interaction is done to ensure our product meets engineering standards and is usable to all user bases. Currently, the proof-of-concept is in its development stage while complying with all proof-of-concept requirements outlined in the functional specification document. We at Actuated Innovations hope that *Relevo* will be a unique and innovative addition to the data visualization and analytics market.

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7 REFERENCES

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Appendix A - User Interface Appendix

1.0 Introduction

This User Interface Design Appendix serves as a description and analysis of *Relevo* in terms of its design for and communication with its desired audience, the user. In this appendix, we will describe what prior knowledge users have that will allow them to interact with *Relevo* in an intuitive way and also discuss what signifiers and affordances are incorporated in its design to bridge the information gap via knowledge in the world. We will also analyze the technical parts of the interface using the "Seven Elements of UI Interaction" [1] as a guide. Finally, we will outline a usability test plan which is aimed at testing how intuitive *Relevo* is to its audience as opposed to the test plan provided in the Design Specification which is focussed on functionality.

2.0 User Interface Description

Relevo has two main components to its user interface: the pin array table and the object scanning table. Each table has its own unique design and role focussed on allowing users to interact with the system overall as follows:

- Pin Array Table:
    - Contains the pin-actuated display on its top surface to relay information to the user via touch
    - Equipped with ON/OFF switch with braille letters, power ON/OFF sounds, power ON/OFF LED indicator
    - Has lockable wheels for easier movement and stationary stability
- Object Scanning Table:
    - Automatic Kinect camera to capture user object and depth data
    - Flat surface for user object scanning
    - Attached to side of Pin Array Table to allow access without walking around table

Figure 1 depicts an isometric view of *Relevo* with the above-mentioned primary user interface components highlighted. All electrical and mechanical parts other than the NEMA wall plug to provide the power are contained inside the chassis and not designed for user interaction.

Of note, there are also warnings and signage written on *Relevo* conveying the power requirements and safety notifications.

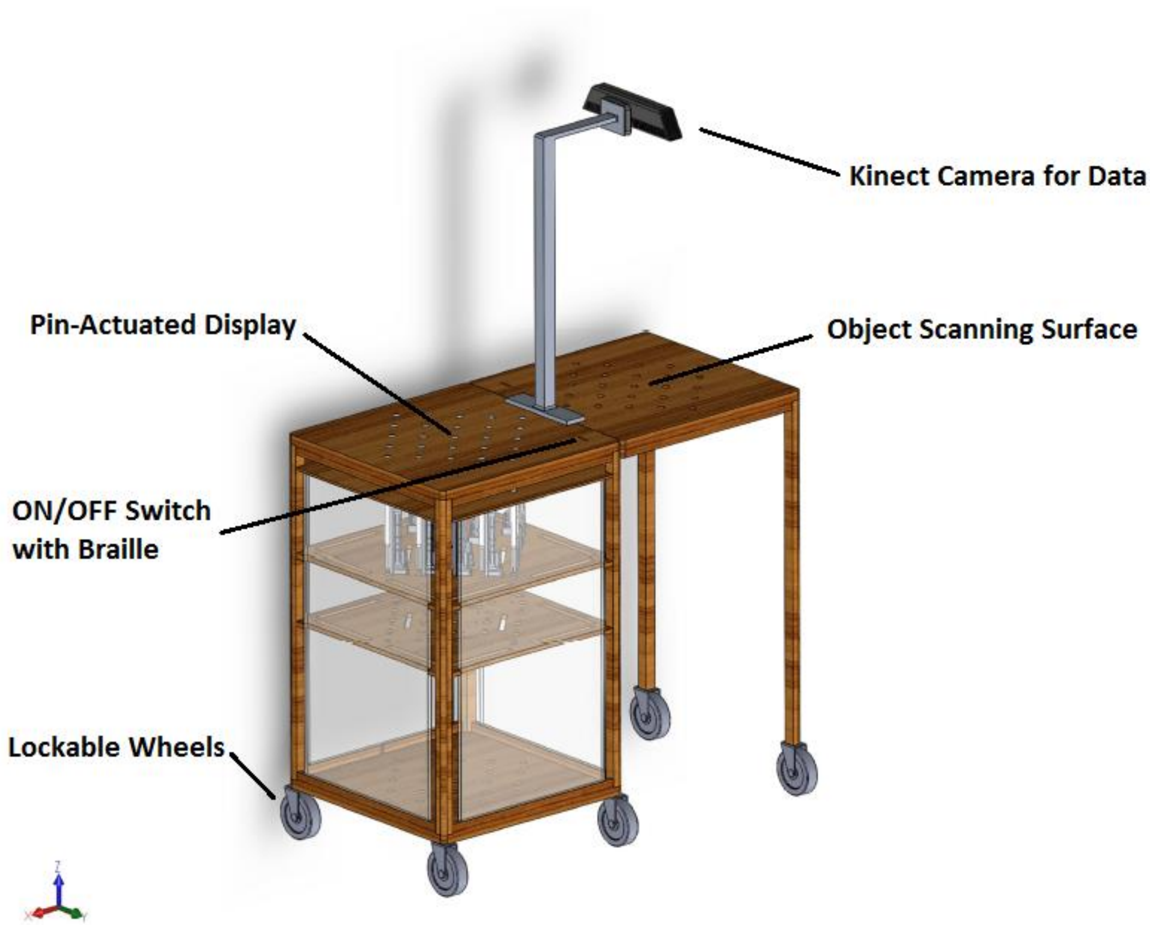

Figure 1 - Isometric View of *Relevo* including UI Component Labels

3.0 User Analysis

As outlined in the Design Specification, *Relevo* is a unique device that brings a new type of display to the marketplace. As such, the amount of previous knowledge and experience with a device similar to *Relevo* in functionality is severely limited.

In lieu of functionality-based alternatives, users will likely resort to relying on experience from using other objects that visually look similar to it instead. For older users especially, the outer finishing/chassis of *Relevo* could possibly be mistaken as a simple coffee table or night stand mounted on wheels. Suffering from visual impairment and lack of experience with this type of device exacerbates this problem as they may not notice any of the indicators, such as the switch or LED, which help to differential *Relevo* from the everyday table. This same phenomena could manifest itself as a slip even after much usage as again the design is very similar to a table and could be used as such leading to damage to the device from spilled liquids or dents. This is mitigated by the presence of the moving pins and the water-resistant design of *Relevo*.

As a target market of *Relevo* is the visually impaired, this creates a market barrier which must be overcome by aid of another individual who can read/see to interpret the purpose of *Relevo*. As with all devices aimed at this market, help is required to ingest the world knowledge required to operate a device. Depending on the severity of the vision impairment, it may be difficult or even impossible to read the signage or find the power switch even though it is immediately evident to a seeing user. When the basic world or head knowledge is transferred to the visually impaired user to use as their own head knowledge via a brief example of operation or description, a world of opportunity is opened up as *Relevo* is simple and intuitive in nature due to it being touch based with visual and audio indicators. One limitation of the signage of *Relevo* is that it only conveys language in English and Braille currently, in the future this feature could be adapted to accommodate expanded audiences by simply translating the pre-loaded language files and physical signs.

For visually enabled users, *Relevo* uses a simple design with only the necessities open for users to interact with. The inner workings are enclosed within the chassis with only only cable that plugs into a standard North American electrical outlet exiting it. Prior knowledge that helps first time users would include recognizing the camera, the generic power switch, and the wheel locks. All of this world knowledge can be gained by light inspection and operation. Any slips that could occur are low-danger as they would include things like leaving *Relevo* powered on.

Overall, the design of *Relevo* was implemented with the central idea of easy learnability. Behaviourally, users familiar with a computer or television can operate *Relevo* as it follows the same basic start-up and shutdown procedures. After finding the power switch and moving it to the on position, the device starts up and then visual and audio feedback is given when it is operational just like a computer/television. Switching the power off also is the same as for any other basic electronic device.

In terms of reflective processing, there is not any deep understanding required from the user standpoint. The user should be conscious of the device being powered on or off to allow them to operate it and where the camera points but these have clear indicators including the indicator LED, start-up and shutdown sounds, and the direction the camera faces. Once recognition of these simple indicators is transferred to head knowledge the simple design of *Relevo* is easily memorable and efficient.

4.0 Technical Analysis

This section will be divided into 7 subsections which parallel the analysis presented in the "Seven Elements of UI Interaction" [2]. Each subsection will go into further detail on the two main user interfaces of *Relevo*.

4.1 Discoverability

Relevo's design incorporates functionality with the key element of being simple to learn. The entire system is powered on and off using a single switch that has ON/OFF labels written in both English and Braille allowing users to easily control the system. In addition, the components that are not for use by the user are clearly closed off and those that are for the user are easy to access and touch/see. These parts for the user are in plain sight and their functions are straightforward to understand. The functions of the generic camera and moving pins happen automatically, as the user only needs to place an object to scan, and their purpose is evident immediately. The automation of the bulk of the system increases the discoverability as the user only needs to react at their own pace to the system.

Finally, there is also signage on the chassis of *Relevo* to give basic instructions to those who are visually enabled. Braille instructions is also a possibility in future development but at the current design phase it has been omitted as positioning is of utmost importance as it must be in a place the visually impaired can easily find.

All of these elements aim to help users bridge the Gulf of Evaluation by locking users out from parts that are not for user interaction and presenting openly part that are for them to interact with.

4.2 Feedback

As briefly touched on in Section 3.0 User Analysis, *Relevo* provides different forms of feedback to the user in order to accommodate the visual enabled and impaired audiences. Using the 3 senses of sound, touch, and sight, *Relevo* is designed to provide the user with information on its state that is accessible by both audiences.

For the visually impaired feedback in the form of sound and touch relays changes in state. As *Relevo* is powered on or off, audio feedback is given stating which state it has moved into. The feedback when powering on is given when the entire system is fully functional thus allowing complete usage including the embedded computer after booting up. When an object is scanned there is built in feedback due to the nature of the pins making sound as they actuate into their new position. Though the pins have been designed to mitigate this noise to avoid annoyance, enough has been left to convey when the pins are moving and when they are still based on sound. In terms of touch, the user can feel the pins for when they are moving or still as they have been design so that excess weight on them does not break the motors and they do not move fast enough to cause physical bruises or other injuries. Upon start-up, the pins will move into the initial position and then an object may be scanned.

For the visual user, *Relevo* supplies additional feedback via an indicator LED. The LED is off when the device is off. When the device is turned on and operational the LED turns to green. Know thing will take head knowledge but is easily discoverable by experimenting with *Relevo* briefly.

Together, these different aspects of feedback help the user overcome the Gulf of Execution by allowing them to know if *Relevo* responded in the desired way.

4.3 Conceptual Models

Relevo's uncomplicated design lends itself to a simple conceptual model for the entire device. As an object is placed for scanning in front of the camera, it is automatically scanned by the camera and the commands are generated for the pin display. The commands are then executed on the pin display for the user to feel and/or see. When the object is removed the pin display returns to the down position. The conceptual model can be seen in Figure 2.

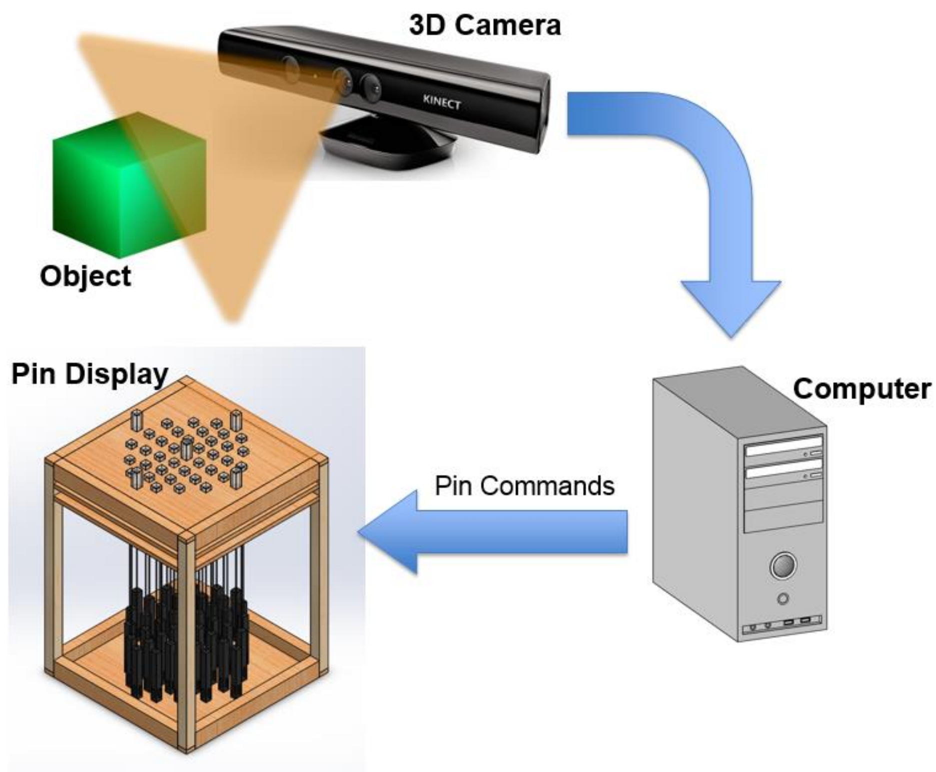

Figure 2 - Conceptual model of *Relevo*

4.4 Affordances

As *Relevo* has a simple purpose of relaying information it requires few affordances which are listed below. Firstly, an affordance is defined as “the possibility of an action on an object or environment” [3]. *Relevo*’s goal is to enable users to interact with objects in using a simple and intuitive touch-based media; the main purpose of *Relevo* then is as an affordance itself. To enable achievement of this goal, the following affordances have been integrated together to create *Relevo*:

- The power switch allows users to turn the entire system on or off using a single motion.
- The wheels allow easier movement of the system.
- Wheel locks enable the user to stabilize the system for safe usage.
- The camera allows users to read in data to display on the table.
- The standard electrical plug provides a widely recognizable tool to increase discoverability.
- The pins allow users to feel the shape of objects being scanned while remaining safe from sharp edges.
- Signage on the body gives instructions for usage of *Relevo* along with warnings against different types of misuse.

4.5 Signifiers

The signifiers on *Relevo* are of the form of written words on signs whether they be in English or Braille. Visual depictions are a possible substitution but cannot be easily adapted for use by the visually impaired thus lowering their effectiveness.

4.6 Mappings

The only control required for *Relevo* is the ON/OFF switch which is located on the top surface of the body. This is an example of second-best mapping as the control and its label is located on the top of the chassis as seen in Figure 3. Best mapping is not possible as the switch controls multiple individual subsystems to power them on and a single, unified switch cannot be located on all of the parts, especially because some of them are not open to direct contact by the user.

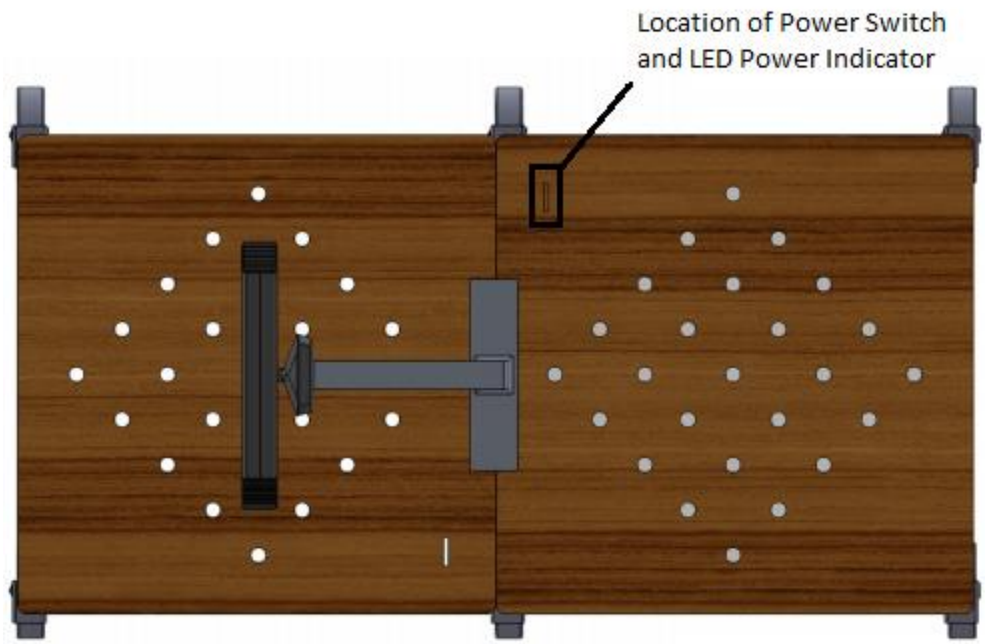

Figure 3 - Top View of *Relevo* Showing the Second Best Mapping

4.7 Constraints

As with all devices, *Relevo* has constraints which help dictate how users will operate it including those based on physical, cultural, semantic, and logical. We will explore each of these 4 types below.

4.7.1 Physical

As *Relevo* is based on touch it must be designed to survive extended physical contact and weight from users. This is achieved by a wood-frame body with durable plastic pins. Also, all electrical or sensitive parts which can be damaged are closed from user access.

In terms of users being able to deduce the purpose of *Relevo* from its physical appearance, it is aided by the limited amount of parts that are open for the user to analyze for system understanding. By seeing the pins move upon start-up and the presence of a camera, users can experiment and see the output via the pins moving when objects come into the the field of view of the camera.

4.7.2 Cultural

In North American culture, where *Relevo* is aimed for initial release, cultural constraints are centred around individuals recognizing the correct functionality. Individuals are accustomed to seeing tables and cameras used for everyday purposes so they may not pick up on the goal of *Relevo*. This is mitigated by the feedback and physical parts that are openly visible.

Another cultural constraint that is of utmost importance is adhering to the Engineering Standards that are valid in North America, these are available from the CSA/ISO webstore with specific standards listed in section 5.0 Engineering Standards.

4.7.3 Semantic

As already stated in section 4.3 Conceptual Models, the possible actions afforded by *Relevo* are easy to determine after light inspection and experimentation. Although it can be misused as a simple table, when the signage is read visually or by touch (Braille) the situations that can occur are easy determined.

4.7.4 Logical

The mappings of *Relevo,* as expanded on in section 4.6, are second best as first is not possible for the previously stated reasons. This is the best choice as logically the switch should be easy to find in an intuitive place on *Relevo*, the most logical choice is then on the top surface as close the main user interface which is the pins.

5.0 Engineering Standards

Relevo shall draw electrical power using a standard NEMA 5-25 electrical plug [4][5]

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)[6]

Relevo shall conform to all ISO/CSA/ANSI standards including but not limited to CSA 22.1 [7] and CSA 22.2 (Canadian Electrical Code) [8]

Relevo shall conform to IEC 60065 (Audio, video, and similar electronic apparatus – Safety) [9]

Relevo IEC 60950 (Information technology equipment– Safety) [10]

Relevo shall conform to ISO 14001 (Environmental management) [11]

6.0 Analytical Usability Testing

This section details the usability testing that is intended for the team at Actuated Innovations to perform themselves. As the team already knows how the device should work this type of testing yields shallower results of which cannot be fully relied upon for final design choices.

Also, as the device has not been created yet, this section will detail the action and desired result.

6.1 Basic Testing

Action: Team member will attempt to turn the device on
Desired Result: Team member can find the plug and the power switch, turns the power on and *Relevo* becomes fully functional, LED turns green

Action: Team member will attempt to scan object
Desired Result: Team member finds scanning surface and places object there, object shape appears on the pin display

Action: Team member will attempt to move the device
Desired Result: Team member unlocks wheels and pushes the device, it moves freely with two degrees of freedom (forward, left, right, backwards)

Action: Team member will attempt to turn the device off
Desired Result: Team member flips the switch to the off position and *Relevo* turns off, the LED indicator turns from green to off

6.2 Further Testing

Action: Team member replaces scanned object for another
Desired Result: Team member finds original object and removes it, the pin display lowers to lowest position, new object is placed to scan, pin display creates object shape

7.0 Empirical Usability Testing

For this section we intend to test *Relevo* with multiple areas of our user base. This mainly pertains to the level of visual impairment from user to user. It is our intention to test *Relevo* with at least one fully blind individual, one legally blind individual, one with visual impairment requiring optical aid such as glasses or contacts, and one fully sight-enabled individual.

Each individual, with the except of the fully visually impaired individual, will be inserted into the same testing environment without any prior description of the device in terms of layout or functionality other than the statement of what *Relevo*'s goal is. They will be led to *Relevo* and given the goal of discovering its functionality with the time it takes them to reach defined objectives measured. They will not be explicitly told the goals or specific functionality other than that provided by the signage on the chassis and that they must move it. The goals are as follows:

1. Turn *Relevo* on
2. Place object for scanning
3. Turn *Relevo* off
4. Move *Relevo*

Based on the time data gained from the testing and the feedback given by the individuals we will make changes to our design. Additionally, we will have a team member watch the experiment to note any mistakes or confusion that arise during the testing.

To find our test individuals, that are multiple resources we can tap into. One is the Canadian National Institute for the Blind which can give provide us with individuals for testing and with general feedback on the concept of *Relevo*. Another resource is elderly family members as they are a market of interest as *Relevo* could eventually be developed to allow them to “feel” objects that they cannot physically touch due to age-related physical disabilities.

8.0 Conclusion

Relevo utilizes a multitude of ideas to simplify and aid the user experience. By providing easy access to information via signage the discoverability factor is increased. Then by supplying feedback via sound, touch, and visuals, the user can ascertain whether *Relevo* is responding as predicted or if they must experiment further to unlock *Relevo*`s full potential by the affordances it provides.

Signifiers and mappings are an integral part of *Relevo* Signifiers of physical writing as opposed to images increases the difficulty of gaining information but at the valuable trade off of being able communicate with visually impaired users. Although both writing and images could be combined, it is not being investigated at this point as it is more of an additional feature as opposed to an essential one. Another trade off made is using second best mapping as it allows a unified power switch as opposed to multiple switches thus lower the initial head knowledge to simply make it operational.

All of these elements take into account the various physical, cultural, semantic, and logical constraints as these constraints themselves determine what is the best design as much as the stated purpose of the device itself. Finally, the Engineering Standards pertinent to this type of indoor, electronic media device were detailed and testing for both usability and functionality have been documented in their eponymously named sections.

The design process of *Relevo* has taken much thought and time to be suitable for market. A device is only as good as how it is able to be used by its audience which has led to this document explaining the thought process behind the user interface of *Relevo*. We at Actuated Innovations believe that although a design is never finished, this document provides a good building block for the user interface of *Relevo* to be built upon.

9.0 References

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