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March 6, 2008

Patrick Leung, P.Eng
School of Engineering Science
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RE: ENSC 440 Project Design Specifications for Portable Braille Display

Dear Mr. Leung,

Please find enclosed the design specifications for a small, cost-effective, portable device for storing and displaying Braille. The end objective of this project is a unit which will give individuals with visual impairments the ability to read material in a portable manner. The compact style of design will allow it to be used ubiquitously, and its ability to refresh will allow individuals to take large amounts of reading material without considerable bulk. The objective is to take digital content (or content converted to digital) and display it in Braille.

This document aims to outline the technical aspects of the system that will provide the functionality outlined previously for *Tiresias*. After taking design constraints under consideration, the design specifications will illustrate the proof-of-concept system, and in certain areas, some implementation algorithms will also be provided to give scope to the system.

The BDot team is comprised of five innovative and passionate engineering students who see the technology as an opportunity to make manifest a future where technology allows our society to reach its full potential. As engineers, it is our professional and ethical obligation to contribute not only in technical ways, but to apply our knowledge to alleviate the problems in our society as well. We are Jill Steele (CMO), Joan Thomas (CFO), Mei Young (COO), Dave MacLeod (CTO), and myself, Jessica Tang (CEO). If any questions, concerns, or problems should arise, please feel free to contact us at ensc440-braille@sfu.ca.

Sincerely,

Jessica Tang
BDot, Chief Executive Officer

Enclosure: Design Specifications for a Portable Braille Display
cc: Steve Whitmore, Bradley Oldham, Jason Lee

Tiresias

Portable Braille Display

Design Specifications

Management Team: Dave MacLeod
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Submitted To: Patrick Leung
Steve Whitmore
Bradley Oldham
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Executive Summary

The design specifications for the *Tiresias* Portable Braille Display provide comprehensive information on the design, development, and implementation of *Tiresias*. The aim of this document is to elucidate how BDot will provide users with the functions outlined in the *Functional Specifications* [1].

There are many key components to this device, and can be summarized by their functionality. Firstly, a system was required to raise and lower the dots, henceforth referred to as mechanical actuation. Secondly, a complex software interfacing system was necessary; the display needed to communicate not only with a computer, but also with some form of removable memory. Thirdly, there needed to be a way for the mechanical actuation to be controlled, and a way to interface all of the components together. For this some selection and direction circuits were required as well. Finally, the entire device required a portable, rechargeable power source that would sufficiently control all aspects of the display.

For mechanical actuation, it was decided that a combination of pager motors, springs, and pins would be the ideal components to perform rotational-linear actuation. The spring serves as the track, on which the pin actuates linearly, with the pager motor providing the required rotation. For control purposes, an Atmel AVR microcontroller was chosen as the main interfacing unit. For interfacing, the device was designed to have USB communication with a PC, and would use an SD card as the removable, non-volatile memory source. Finally, the device will be powered by rechargeable AA batteries.

For each of the aforementioned design choices, this document will provide full justification and comparisons where applicable. In order to give full scope to the design, implantation algorithms, as well as suggestions for future improvements will also be important elements of this document.

Supplementary to the system outlined in this document will be software that converts various file formats into text/ASCII format. This is not part of the *Tiresias* system, but will give the user further functionality with our device. For this document, it will be assumed that all data being saved to the SD card will already be converted to text format.

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Glossary

ADC	Analog to Digital Converter
ANSI	American National Standards Institute
CBA	Canadian Braille Authority
CPLD	Complex Programmable Logic Device
CSA	Canadian Standards Association
DPDT	Double Pole Double Throw
DPST	Double Pole Single Throw
FDD	Floppy Drive Device
Grade I Braille	Braille output is letter by letter – small words are spelled out entirely
Grade II Braille	Form of Braille shorthand – single characters represent whole words
IPMC	Ionic Polymer Metal Composite actuating polymer
NO	Normally Open
OCR	Optical Character Recognition – interpretation of an image to extract text
PC	Personal computer (Windows)
RNIB	Royal National Institute of the Blind (located in the United Kingdom)
SD	Secure Digital, type of removable memory card
UEB	Unified English Braille (Code)

1.0 Introduction

BDot's revolutionary system *Tiresias* is a portable, cost-effective Braille display for the visually impaired. ASCII characters will be read in, and translated into a corresponding Braille character by using compressible pins (in sets of six). Using an innovative refreshing system, these characters can be reset, to allow for continuous and seamless translation of digital information for the visually impaired. Small and lightweight, it can be used everywhere, giving the visually impaired the freedom every Canadian deserves. This document outlines the design specifications for the device. Referring to the requirements for each aspect, as highlighted in *Functional Specifications*, the design choices were made with emphasis on portability, usability and cost-effectiveness.

1.1 Scope

The design specifications laid out in this document describe in detail the design components for the prototype device. It also expands on the functionality of the final production model, and possible implementations. These design specifications are a direct result of the goals of this project, and ensure they have been met in terms of usability for the target market.

1.2 Intended Audience

This document will be used by various parties. Firstly, the BDot engineering team will make use of this to ensure a *Tiresias* prototype is created in a cost-effective and efficient manner, and for submission of standards applications. It will also be used by usability engineers and ergonomists to ensure the device can be conveniently used by the visually impaired. Finally, it will serve as an information source for interested parties, as it will outline the design of the display in detail.

2.0 System Specifications

Tiresias will display Braille characters by raising and lowering pins, and will be refreshable automatically and manually by the user. The user will have control of the direction of character display, as well as have the option to manually go backwards or forwards in the text, and it will automatically create a bookmark at the most recently viewed line of the text upon powering off. The device will interface with a PC via a USB connection, in order to download text documents onto the removable SD card. From this point, it is completely portable.

3.0 Overall System Design

In this section, each component of the system will be outlined thoroughly in a high-level manner, providing information regarding design choices that are specific to the system as a whole. More detailed sections on the mechanical, electrical, user interface, and enclosure design can be found in the respective sections following this overview.

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3.1 High-Level System Design

Figure 1 shows the various elements of the Braille display. Direction of communication is illustrated by direction of arrowhead; double-ended arrows suggest communication will be bi-directional on that particular line. Dotted lines indicate relationships that may need to be instituted, pending further testing.

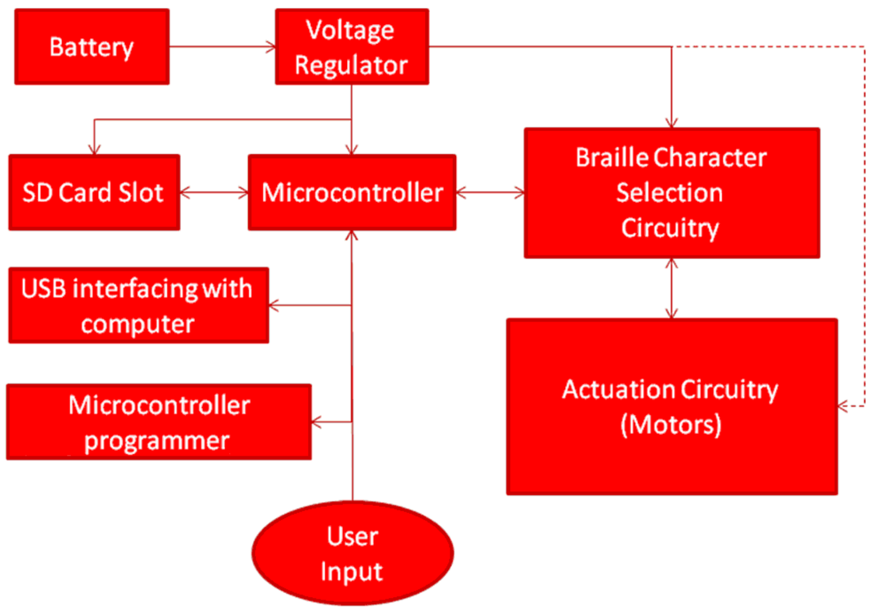

Figure 1: High-level system diagram

Generally speaking, the input comes in the form of digital text from a PC, which is saved to the SD card via a USB connection. The SD card slot is exposed, so the user can also load the text onto the SD card by themself and then insert it into the device if desired. This will be an added convenience if digital texts are manufactured onto SD cards in text format already. The microcontroller will process the text, and check to see if a bookmark has been saved, indicating the user was in the middle of the text when the device was last powered off. If this is the case, the text placeholder is loaded, and the user can then advance, reverse, or refresh the display. Depending on the input, the selection algorithm will then be used for character, pin, and direction selection, after which the output will be sent to the motors, and the characters will be displayed accordingly. Figure 2 shows this process in a graphical manner, progressing from left to right.

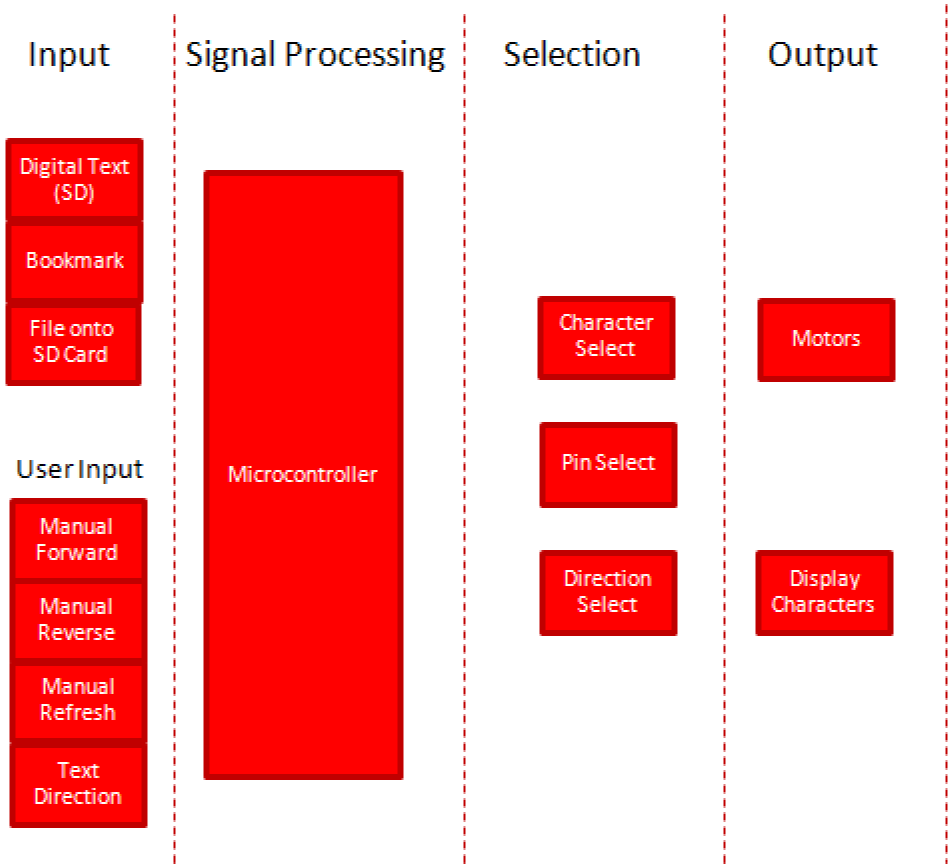

Figure 2: Block diagram of system stages

3.2 Mechanical System Design

The main component of the mechanical system is the ability to elevate and lower the dots of the Braille characters, or mechanical actuation. Many things needed to be considered, including:

- Dot placement
- Dot design
- Dot actuation

3.2.1 Dot Placement and Design

As per the *Functional Specifications*, the dots will conform to the English Giant Dot Braille size specifications, as in Figure 3 below. This gives the constraints that the actuation must be designed within.

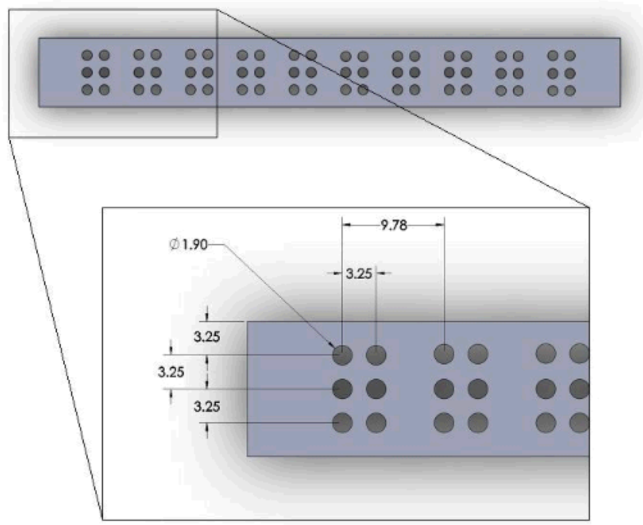

Figure 3: English Giant Dot Braille size constraints (mm)

Due to the very small nature of Braille cells, the mechanical actuation needs to be functional within a small space, and must also maintain the smallest footprint possible, since the dots need to be so close together. This immediately suggests that the components themselves must be quite small, to ensure that the full actuating circuit remains small.

To maintain continuity amongst Braille devices, the dots need to be hemispherical in shape, and of course within the size constraints set by the English Giant Dot requirements. There are few other limitations on the construction of the dots, which allows for much creativity when designing the actuation system.

3.2.2 Dot Actuation

The device will employ mechanical actuation to configure an array of spherical protrusions (henceforth referred to as 'dots') to represent Braille characters. Several methods of actuation have been researched and the solution that was best described by the functional specifications was selected. The designs considered were:

- Elevating dots using an actuating polymer
- Actuation using memory-alloy wire with stationary pins
- Actuating small pins using DC motors

After some research, it was found that actuating polymers that expand under applied electric potential, such as IPMC [7], are difficult to manufacture, expensive, and not readily available on the market. Although the use of an expandable polymer is ideal for the application of a portable Braille display, none of these materials did not meet cost constraints and were therefore not pursued as a viable solution.

The memory-alloy wire was subjected to direct testing in a laboratory setting; however, it was found to actuate by only 2% of its length, requiring a long length to meet the requirement of 0.7 mm of actuation per Braille dot. The wire also required 1A to actuate and quickly heated up. The memory-alloy wire also did not meet the size restraints of the portable Braille device.

The design that was found to best reflect the functional specifications and could be most easily implemented was actuating the pins using small DC motors. The comparisons amongst these methods can be found in *Section 4.0*, at which point the DC motor method of actuation is expanded upon.

3.3 Digital Design System

The main feature of the digital design system is the ability to manage incoming signal and respond accordingly. Many things needed to be considered, including:

- Management of input and output lines
- Control logic and algorithm
- Memory storage and interfacing

3.3.1 Control Unit

The main component of the digital system is a control unit. This hardware must be able to take input from memory, and translate it into characters on the display. To achieve this, two options were weighed: microcontroller unit (MCU) and field-programmable gate array (FPGA)

Of course, there are various manufacturers and specifications for both of these types of control units, so it was necessary to do a thorough comparison of functionality, cost, power constraints, and other important factors. Both are effective depending upon the environment and the requirements, and choosing a control unit was an integral part of the design process.

It was decided that a microcontroller unit would be more beneficial than an FPGA to power constraints and cost.

3.3.2 Memory & Memory Interfacing

The device must be able to store the textual data of a standard e-book. Making use of limited hardware memory would cripple the functionality of the device, so removable, non-volatile memory is required for storing data. There are many formats which meet this, such as:

- Flash memory sticks (USB)
- Small hard drives
- Digital memory cards

Flash memory sticks are widely available, and would thus be a feasible option for use with the device. However, the construction of manufactured memory sticks would make the device somewhat unwieldy, as it would be sticking out of a USB slot. Also, memory sticks are generally found to be one size, eliminating the option of buying a smaller one to facilitate its purpose. Small hard drives are available however the cost-effectiveness of them would make it quite difficult to incorporate into the device. Furthermore, their fragile nature would not lend itself well to wear and tear.

Digital memory cards integrate the useful characteristics mentioned in each of the above and provide the best solution for the outlined requirements. Memory cards are widely available, small, non-volatile, and have an affinity for resisting wear and tear. Furthermore, they come in a variety of capacities, without compromising size. Also, since card readers are also available, interfacing it within the system would be of minimal difficulty. To take advantage of its presence in the current market, SD cards have been chosen as the memory source for the device. Further details on its integration within the system can be found in *Section 7.0.*

3.4 Power System Design

In order to make the device portable and lightweight, the power system needs to also be portable and for convenience, rechargeable. Thus, batteries will be the portable power source for the device, and are responsible for powering the microcontroller, motors and interfacing circuitry. The design of the power system determines the rest of the device, and thus is pivotal for defining the power and current limits of the display.

A power supply voltage of 3.3V has been designed to output power to a majority of/if not all the device components. This should be sufficient for powering the display, and can also be readily achieved with small batteries. This is enforced by the mechanical actuation components not requiring continuously power. In order to conserve power and reduce current draw, only instantaneous bursts of voltage will be sent to the motors during actuation if the selection algorithm directs output there. Methods for monitoring the current draw will also be implemented.

Voltage regulation may be necessary to ensure a constant voltage output; however, this requirement will be reviewed upon further design and testing. Further details on the power system will be provided in *Section 4.0*.

3.5 Integration System Design

Electrical circuitry is required to connect the digital system to the mechanical system, consisting of ten characters with six dots per character. The most important part of the electrical system is determining which pin should get power amongst all of the characters. To achieve this, selection circuits are required. A *character select* line determines whether or not power goes to a character, and *pin select* line determines which pin within that character should be activated. One can think of each dot or pin requiring two signals in order to activate – one from *pin select*, and one from *character select*. This is shown in Figure 4.

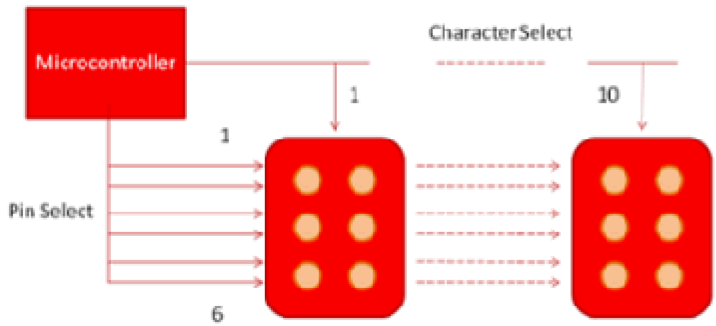

Figure 4: High-level diagram of character and pin (motor) selection

A more detailed description of the electromechanical implementation will be described in *Section 6.0*, and will be combined within *Section 7.0: Integration* as well.

In order to bring the various modules of the device together, a complex integration system is required, as per Figure 5. The largest task of this system is to facilitate data transfer, process the signals within the system, and aid in the electromechanical functions of the display.

Figure 5: Visualization of system connectivity [11]

3.5.1 Computer Interfacing

In order to be an effective device, a user requires some way to load data onto *Tiresias*. This implies that some sort of interfacing will be required with an external device, and the most ubiquitous is a personal computer (PC). There are many ways to complete this connection:

- USB (1.0/2.0)
- Serial

3.6 User Interface

This portion of the display is quite possibly the most important from a user-centered point of view; the inner workings of the device determine its usefulness, but the user interface determines its usability. The user interface consists of the buttons for changing user options, the device enclosure or casing, and also factors in ergonomics.

3.6.1 Buttons

The main input from users comes by way of the buttons located on the device. Through these buttons, the user can start displaying text (play), pause the display, fast forward one line at a time through the text, reverse to a previously read portion and stop the device.

The physical arrangement of the buttons is also an important factor. They must be placed in an area where they will not be inadvertently pressed, and must also be placed in a logical manner. The size of the buttons is also something important to consider. If they are too small, a user may press more than one button at a time, or it may not be possible to fit the title in both Braille and English. If they are too flat, a user may not be able to press it down fully.

For the final product, various controls such as joysticks and trackballs have been considered for their intuitiveness and ease of use.

3.6.2 Device Enclosure

Another important usability factor is the enclosure itself, specifically its shape, grip, and use by people of either handedness, in reference to requirements. Further details into the enclosure can be found in *Section 8.0*.

3.6.3 Ergonomics

In order to be an effective assistive device, it needs to be designed with ergonomic considerations, for handheld devices. Major things to consider were the grip on the device, the neutrality of the wrist during use, and the placement of the components within the enclosure. This is further discussed in *Section 8.0*.

4.0 Mechanical System

The configurable members will be designed to have two states:

- Flush with the display surface
- Raised to a height of 0.81mm at dot apex [3]

As mentioned in *Section 3.0*, several methods of actuation have been researched and the solution that was best described by the functional specifications was selected. The designs considered were raising dots using an actuating polymer, actuating small pins using memory-alloy wire and locking the pin in place, and actuating small pins using DC motors.

4.1 Ionic Polymer-Metal Composite Actuation

IPMCs expand under applied electric potential, so it is a possible method of actuation. The polymer can be manufactured in such a way that a flattened dot will expand upwards when an electrical potential is applied. Because of the low power consumption and light weight, IPMC is the ideal actuating material for Braille displays [7].

There were some issues with this method immediately, the most important being cost and availability. IPMCs are a relatively new material, and are thus seldom available. Furthermore, since it is a specialized material, the cost associated with it is extremely high, thus reducing the possibility of being incorporated into our system. As a result, the cost per device manufactured would be quite high as well. This method simply would not meet the cost constraints of the system, and for that reason was deemed unreasonable for the application of a cost-effective portable Braille device.

4.2 Memory-Alloy Wire Actuation

Memory-alloy wire is a special type of alloy that contracts upon the application of an electric potential. The current through the wire leads to a displacement, noticed as contracture. Depending on the gauge of the wire, different contraction lengths could be generated.

Memory-alloy wire met our cost constraints, and is also available worldwide, meeting our availability requirements. Furthermore, many different types of memory-alloy wires exist, with different physical properties, so at this point the next step was to determine the physical properties required for this application.

There are many design components to memory-alloy wire, including diameter, weight, resistance, power consumption, electrical rating and of course, contraction length. These are all important factors to take into consideration, and an appropriate analysis of which type of memory-alloy wire we required was completed.
For our implementation, the most important characteristics are pull force, current draw and contraction time, as these are the limitations of the memory-alloy. If it does not generate enough force, it cannot perform the actuation. If it draws too much current or heats up too much, it is not a reasonable design choice. If it takes too long to contract, it will not be able to actuate to the speed that Braille readers require. Table 1 shows a summary of these characteristics, as taken from the full Flexinol® technical datasheet, included in Appendix B. Only the gauges of memory-alloy wire tested are included.

Table 1: Flexinol memory-alloy technical specifications (summary)

Wire Name	Force (g)	Contraction Time (s)	Current (mA)	Off Time (LT) (s)	Off Time (HT) (s)
.001 LT	7	1	20	0.1	-
.003 LT	80	1	100	0.5	-
.005 LT	230	1	250	1.6	-
.006 LT	330	1	610	3.5	-
.006 HT	330	1	610	-	2.2

(LT: low temperature; HT: high temperature)

From the above table, it is clear that the most force generation occurs with a larger gauge wire, but also results in quite a high current draw. Since current draw is the most important out of all of those characteristics, the testing began with the smallest gauge, 0.001 LT Flexinol wire. A 100mm sample of memory-alloy wire was tested and found to actuate by 2mm, only 2% of its length. This implies that a long length of wire would be required to meet our requirement of 0.7 mm of actuation for each Braille dot. Because the wire works linearly, it is not possible to coil it in order to conserve space. Thus, the memory-alloy wire does not meet the size constraints of the portable Braille device, and was therefore not a viable actuation method.

4.3 DC Motor Actuation

The final actuation design was to actuate the dots using small DC motors. The selected DC motors and resulting pin design needed to meet a number of design requirements and constraints. The motor needed to be small enough to meet the standards for Braille characters [3], be lightweight and consume minimal power to be a part of a portable device, and be cost-effective at the same time. Among all the sourced motors, the only one which fell within the size constraints is the DC motor pictured in Figure 6.

Figure 6: DC motor size comparison [12]

Table 2 outlines the exact size specifications of the pager motors. With a diameter of 4mm, it falls within the diameter constraints of the Braille cells relatively well. For the prototype stage, a discrepancy of 0.75mm in width is barely noticeable; as long as the cell fits within the finger width of the average person, it is still useful.

Table 2: Pager motor specifications

Size (mm)	Weight (g)
15 x 4 x 4	1

Now that the motors meet the size constraints of the application, the power and current draw of the motors is the next most important factor to research. The motors conveniently operate within a voltage range of 1.5-5V; Table 3 shows the associated current and torque values.

Table 3: Pager motor electrical characteristics [9]

Input (V)	Unloaded Current (mA)	Stall Current (mA)	RPM
1.5	12.4	36.8	10100
3	17.6	73	20300
5	20.3	117	32500

(Solarbotics Manufacturer Product Description)

With the motors having been chosen, the actuating members now need to be considered. The actuating members need to respond quickly and resist mechanical pressure from fingertips. Since the output of the motor is rotation, there needs to be some form of transformation from rotational movement to linear actuation. To do this, a spring and pin system was considered.

The pin, created out of wire of a relatively thin gauge, employs a set of protruding bars, which rest on the spring. The spring is mounted on the motor, and serves as the helical track upon which the pin will linearly actuate as the motor rotates. However, to ensure that linear actuation takes place, some form of housing is needed to ensure the pin does not rotate along with the motor. This housing must be quite thin, as any increase in width of the actuating system will result in an increased width between the dots in the Braille cell, which is undesirable. Figure 7 highlights the various parts of the actuator in both exploded and collapsed views.

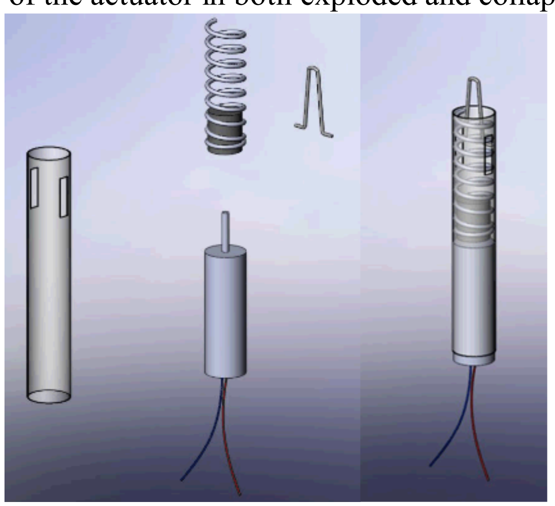

Figure 7: Full actuating member, exploded view and collapsed view

Appendix A: Mechanical Drawings contain full-page views of these drawings, as well as graphical representations of the motion of the system. After research and testing an actuating pin was designed and built using the components shown above. The pin design meets the requirements and constraints and was therefore the best option available for a cost-effective portable Braille device.

5.0 Digital System Design

The device requires a control unit system to control pin actuation and to provide the desired response for each user command.

5.1 Microcontroller Unit (MCU)

For the purpose of our device, very high speed processing power and advanced features (such as ADC's) were found to be unnecessary. Processing speed is not a big factor because speed bottlenecks at the actuation of the mechanical system. Therefore, factors that are weighted more heavily are the number of I/O and interrupt lines and the amount of Flash/EEPROM memory. Additionally, the microcontroller is constrained to operate at low voltages and have limited power consumption, due to device portability.

The microcontroller requires sufficient Flash memory to store the entire program and to act as a buffer for the text being read out of the SD card, while the data is being processed. It also requires EEPROM to store a look-up table that can convert the ASCII value of the text to the equivalent Braille matrix.

Several microcontroller families were considered, but due to the level of complexity of our system algorithm, as well as the factors discussed above, our choices were narrowed down to the Atmel ATMega microcontrollers.

5.1.1 Number of I/O lines

The actuation of the Braille pins can be divided into three components:

- Selecting which one of the 10 characters on the display is being activated
- Selecting which of the 6 pins in the selected character matrix are being activated
- Selecting the direction of movement of the pins (upward actuation or reset)

The MCU is also required to receive signals from the user controls and route the corresponding signals to the mechanical system via the interfacing circuit. We estimate these tasks would require the number of I/O pins outlined in Table 4.

Table 4: I/O pin requirements from MCU

I/O Signals	# of lines
Stop, ffwd, rwd Play/pause Command pressed (4 commands)	1 interrupt line 1 interrupt line 2 lines
Power supply (Vcc and Gnd)	2 lines
Character select (10 characters)	10 lines
Pin select (6 pins)	6 lines
Direction select	1 line
Total	**23 lines**

5.2 User Controls

The microcontroller uses two interrupt lines (INT0 and INT1) to determine which control option the user has selected. A high signal on INT0 implies either play or pause has been selected and a high on INT1 implies fast forward, rewind or stop has been selected. The flowchart in Figure 8 shows how the character display is controlled by the user selected options.

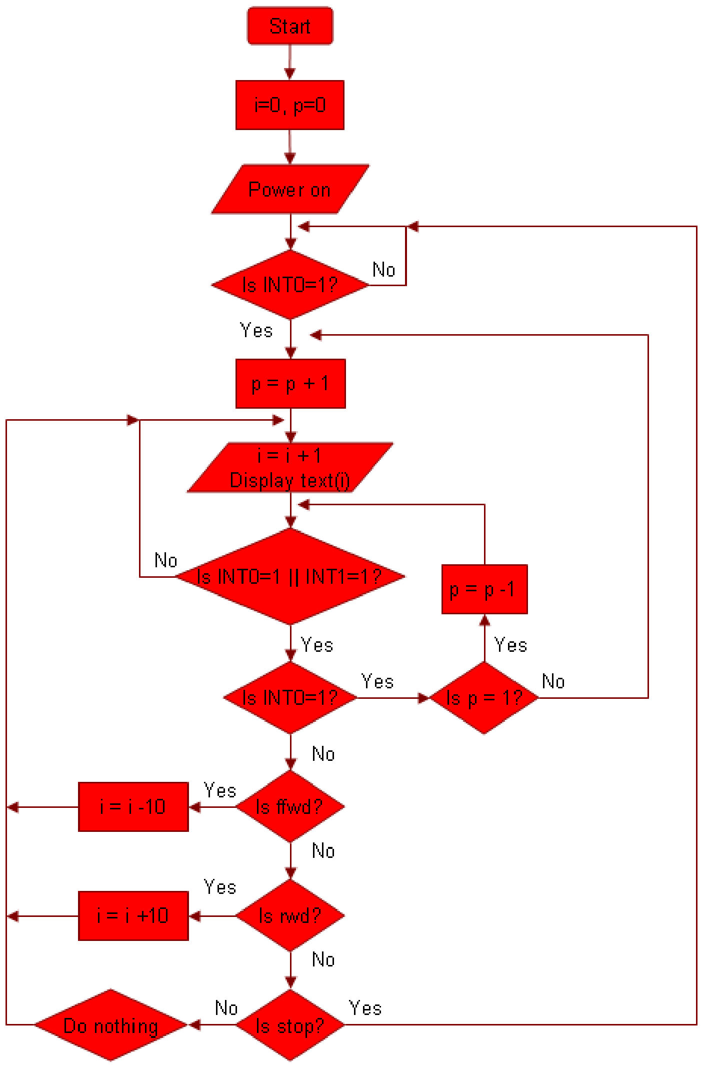

Figure 8: Display flowchart

5.3 SD Card Communication

SD was selected as the preferred method of storing text on the device. This requires a built in SD card reader, requiring seven input lines, four from the microcontroller for communication, a supply voltage, and two ground pins. The reader requires a supply voltage in the range of 2.7 V - 3.6 V, comparable to the supply for the microcontroller.

6.0 Power System

As the Braille display device is intended to be portable, it therefore requires a portable power source. There were several considerations in choosing a power source for the device, outlined below in Table 5. Please note the values for the motors were obtained through experimentation.

Table 5: Electrical Requirements [8],[9]

Components	Voltage (V)	Current (mA)
Microcontroller	2.7-5.5	1.1 (at 1MHz, 3.3V)
Motors	1.5-5	30-60
SD Card	2.7-3.6	--

The chosen power source will be a configuration of four 1.5V AA alkaline batteries in series to produce 6 V. Alkaline batteries were chosen since they are readily available to the consumer and, because of the small size and high energy density, are ideal for portable devices.

Power shall be monitored from the batteries via voltage regulation circuitry, ensuring even and safe power flow. This requires battery voltage be slightly greater than the defined Vcc. However, we will most likely step down the voltage to take advantage of the low power operation voltages for the chosen ICs and microcontroller.

Because the SD specification requires about 3.3V, the device will be designed so that most, if not all, circuitry can be powered with this Vcc.

7.0 Integration of Systems

There are many different systems that will require the ability to function together, and thus require integration.

7.1 MCU and Actuation Integration

This section outlines three suggested methods for completing this integration, a fully analog solution, a combined analog/digital solution, and a fully digital solution. These solutions need to allow for bidirectional control of the motors using a minimal number of I/O lines from the MCU, and with a minimized PCB footprint for size purposes.

7.1.1 Fully Analog Solution

For bidirectional control of the motors, a simple way of swapping battery polarity for the entire motor control system was explored. A way of achieving this is to wire a DPDT relay such that the two battery leads seen after the relay are swapped when the relay activates. Relays have the great advantage of creating a physical short, so polarity switching is lossless from the motor's point of view.

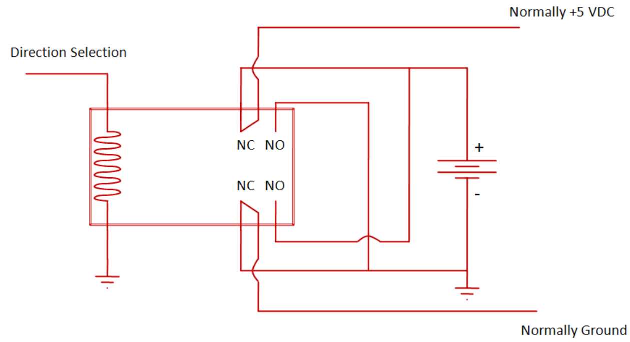

Figure 9 - DPDT relay for polarity swapping

After polarity is chosen, current must then be allowed to flow through one character cell only. This can be accomplished again with a relay (this time a single pole single throw), but an even less power intensive solution is a triac. The triac will activate with a pulse to its gate and remain active until the current running through it drops below threshold. [10] This is particularly advantageous because once open it can be treated as a simple voltage drop, knowing that it will remain open until another part of the circuit is altered – in this case, either the polarity relay or the pin selection mechanism discussed below. Figure 10 shows the pin selection mechanism for the fully analog solution.

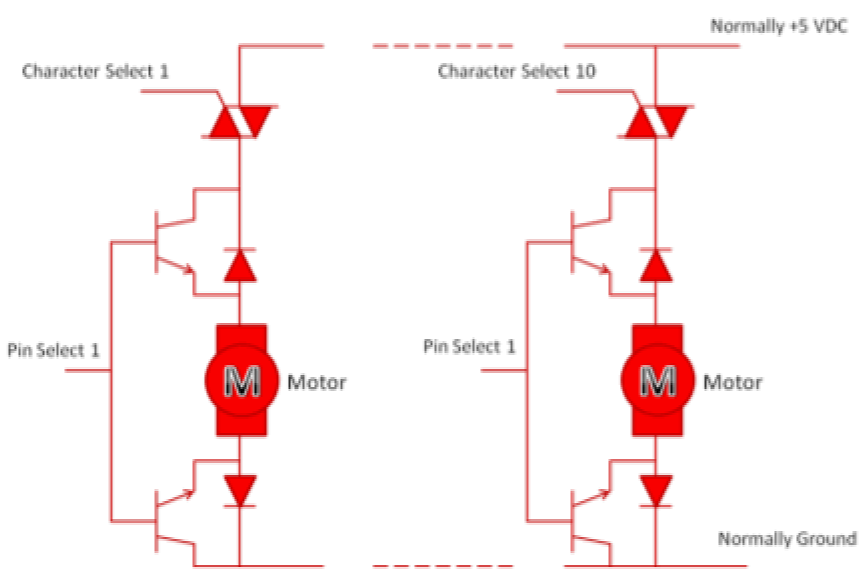

Figure 10: Pin selection for fully analog solution for integration

The pins of each character are connected together so that all pin ones are activated with one selection output pin from the processor. However, current can only flow when the character selection component (triac) is turned on. That means that only the pins in the character block selected will activate. The pin selection mechanism is a pair of BJTs. The emitter of each BJT is connected to one side of the motor, once a voltage is seen at the base (pin selection from the microcontroller) and the triac is pulsed, current will flow through. To increase the voltage measured across the motor, a BJTs with internal clamp or flyback diode can then be chosen.

7.1.2 Analog/Digital Solution

In order to minimize the number of I/O lines occupied by this integration circuitry, a manner that uses only one of the leads on the motors (other lead to ground) would be ideal. The first main component to the system is the polarity switch on the input voltage to the motor; by feeding in a positive voltage, the motor will turn clockwise, and a negative voltage would induce a counter-clockwise turn. This can be achieved in an analog manner by using a differential amplifier with rails that are higher than the desired output voltage (to avoid saturation). Since the amplifier takes the difference between the non-inverting and inverting inputs (effects of gain notwithstanding), it is possible to have it output either a positive or negative voltage. Using CMOS logic gates, three select lines will be sufficient to determine which input of the amplifier gets a ground signal (0V), and which gets the positive voltage signal coming from the microcontroller. Depending on which input gets the positive voltage, the output will be positive or negative. Figure 11 shows the circuitry of proposed solution.

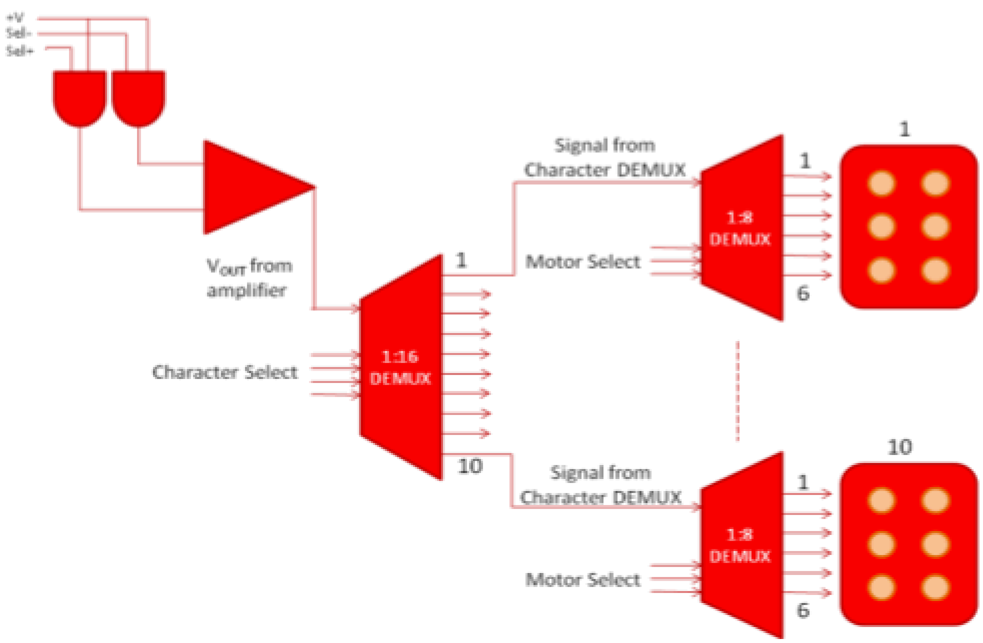

Figure 11: High level circuitry for analog/digital solution

Character select and *pin select* must also be performed, to pinpoint exactly which motor will be actuated (elevated dot). Ideally, this portion of the system would use analog logic, so as to avoid reverting back to digital logic after using an analog amplifier. Since all pins will be reset between refreshes, the device will never be in a state where some pins must to go down, and others need to go up. That is to say, the motors will all be turning in the same direction at all times. So, a 1:16 analog DEMUX can be used to route the output signal to whichever character requires it (10 lines from DEMUX1), which will require three *character select* lines from the MCU. These routed signals then act as the input for a 1:8 analog DEMUX, associated with every character. Six lines from these DEMUXs will correspond to the input of each of the six motors in the character. Each DEMUX2 will require three *pin select* lines (from MCU).

The footprint of this circuitry is quite small, amounting to a single –layer space of approximately 4cmx4cm, well within the size constraints of the device. It is also low power, with sufficient output currents and voltages.

7.1.3 Fully Digital Solution

Another option for interfacing the microcontroller with the motors is by powering the motors directly with the I/O of the microcontroller. The microcontroller can supply a voltage of 2.7-5.5V (depending on Vcc) and a maximum current of 80mA at the output pins. Since each motor requires only 1.5 V and approximately 20mA to run, the microcontroller output should be sufficient to power the motors. The microcontroller supplies 17 pins to determine the motor and the motor's direction: 10 pins to determine the character, 6 pins to determine the motor of that character, and one pin to determine the direction of the motor. Since there are 60 motors and only 17 output pins, this information needs to be translated to control each motor individually.

Using a CPLD, logic can be applied to the output of the microcontroller to supply each motor with two inputs that control the on and off state and direction of the motor, shown in Figure 12. The CPLD is ideal for portable applications because it is low on power consumption, and can supply enough pins to control 5 Braille characters. For 10 characters, 2 CPLDs can be used.

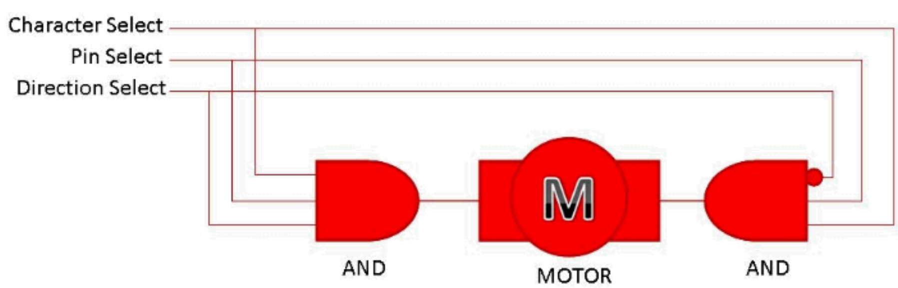

Figure 12: CPLD Digital Solution

The second digital design shown in Figure 13 requires a DEMUX to perform *character select*, direction select for the motor, and *pin select* to determine which motors will turn on. To turn the motors on one direction, a high signal can be sent from the DEMUX, and a low signal can be sent from the *pin select*. To turn the motors in the opposite direction, a low can be sent from the DEMUX and a high can be sent from the *pin select*. If the signal from the DEMUX and the *pin select* are either both high or both low, the motor will be off.

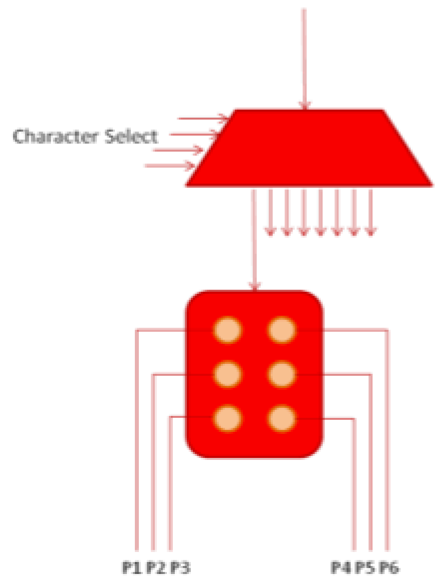

Figure 13: Selection circuitry for fully digital solution

7.2 USB and MCU Integration

Interfacing with a user's computer is essential for the device to obtain documents. USB was chosen to perform this communication because of its widespread use in modern personal computers. However, the complexities associated with implementing a direct USB to microcontroller interface were deemed to be beyond the necessary scope of the prototype. As such, a USB module will be used to perform interfacing with the computer. This module will be controlled by the microcontroller via commands defined on the module itself.

8.0 User Interface

The user interface unit is a set of buttons that allows the user to communicate with the device. It consists of 5 buttons to control the display movement and to power the device. Additionally, an audio and tactile feedback mechanism will inform the user regarding the state of the device.

8.1 Buttons

There will be 4 NO-DPST (Normally Open - Double Pole Single Throw) push buttons to control the Braille character display: play/pause, stop, fast forward and rewind. A toggle switch will serve to change the power state of the device.

Button locality will be such that a person of either handedness will have easy access. User should not be able to activate buttons accidentally in any of the various positions by which the device is expected to be used. Relative placement of buttons will be done in a way which makes button functions intuitive (rewind on left, play/pause in middle, fast forward on right).

8.1.1 Push Buttons

The *play/pause* push button will be directly connected to the INT0 interrupt line on the microcontroller and the *stop*, *fast forward* and *rewind* buttons will be encoded via a digital encoder and mapped to the INT1 interrupt line in the microcontroller. When any button is pushed, a hardware interrupt is generated and the microcontroller will enter an interrupt service routine and determine which button was pressed, thus executing the appropriate actions. Figure 14 shows a possible solution for the microcontroller to determine which button generated the interrupt on INT1.

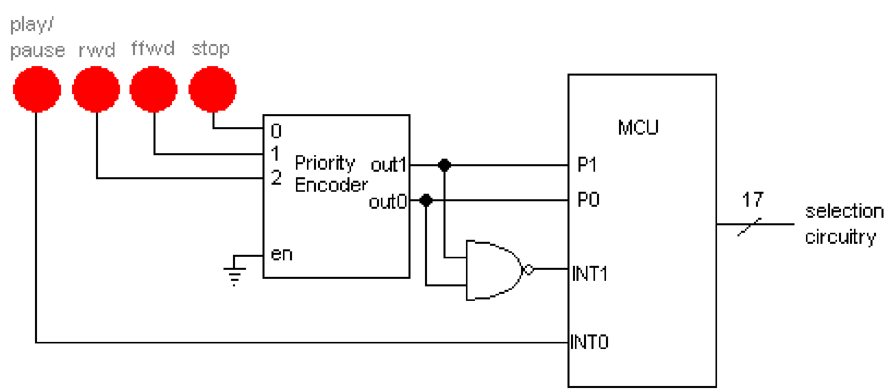

Figure 14: User Control Logic

A button debounce compensation algorithm has to be used to properly read the state of the button. This will be performed through a small delay based on the physical characteristics of the buttons. Additionally all NO buttons will be connected to either ground or Vcc via a pull-down or pull-up resistor, to prevent floating voltage values when the button is not depressed.

8.1.2 Toggle Switch

The power button, requiring persistence of state (On or Off), shall be implemented using a toggle switch. It will be oriented and labeled such that a user can determine the state without any further assistance.

8.2 Feedback Mechanism

A short audio signal and a vibration signal will provide a means of feedback to the visually impaired user. A short audio signal will play for each switching and a vibration signal will occur when the power state of the device changes.

8.3 Enclosure

Because the device is portable, enclosure specifications are very important. Size, shape, and weight of the enclosure will all be closely and carefully designed. The device must be easily stored in a bag or briefcase, which restricts its height to a few centimeters. The device shall not weight more than the specified 400g, also for the aforementioned reasons.

8.4 Ergonomics

The device is required to be comfortable to hold in either hand, yet it needs to also be steady when placed on a table or in someone's lap. To this end, handles which do not impede the steadiness of the device are integral. Also important for holding the device is the center of gravity, as the weight of the device should not greatly work against the user's grip.

The display surface should be angled to allow reading without wrist strain. The surface should be large enough to allow for easy reading, yet shaped such that a user can locate the characters and easily discern orientation. To perform this, the display should be placed in an inset cavity of depth no more than 5mm. This cavity should be smoothly rounded in a crescent, or otherwise shaped, as to convey natural orientation information about the display.

9.0 Test Plan

The system is composed of 3 main divisions: mechanical, digital and electrical. The mechanical division involves the physical actuation unit. The digital system can be further subdivided into 3 subparts: microcontroller control system, user controls unit and SD card interfacing. And the electrical system is the connecting circuit for the mechanical and digital system. Each digital subsystem will be tested individually then integrated progressively into the working unit. Subsequently, full system integration, with the working unit, electrical system and mechanical system, will be implemented.

9.1 Microcontroller Testing

To verify that the control system works, we will simulate the display of several lines of Braille characters through software. After software simulation, we will then emulate the display of the device through a set of LEDs that can show *character select*, *pin select* and direction control. The speed of display is timer based using the clock in the microcontroller. Each character will be displayed in a waterfall effect that displays each character every 0.2 seconds. The display time will be set as a variable that can be changed in the following stages of integration as necessary.

9.2 User Controls Unit Testing and Integration

The user interface unit has several components that has to work together to provide the logic required. The following steps outline the procedure of testing.

1. Verify that the encoded value corresponds to the correct button pressed.
2. Determine the maximum bounce time of the push buttons.
3. Create a delay to avoid reading during button bounce time.
4. Verify that the interrupt service routine perform the task corresponding to the button pressed.

9.3 SD Card interfacing and Integration

The device is required to read data from the SD card to have a set of Braille characters to display. The SD card will serve as the main memory storage of the device. We will first be checking is the SD card and the microcontroller are communicating. Then, we will verify that data has been read from the SD card. This will be accomplished by accessing textual data from the SD card and making sure that the correct Braille characters are displayed through the use of LEDs.

9.4 Mechanical System Testing

To ensure that the mechanical pin system functions correctly, we will test each pin individually. Each pin will be tested for proper up and down actuation, fast response time, and consistency.

9.5 Electrical System Testing

The electrical system consists of a selection circuitry for the Braille character to set, the set of pins to actuate and the direction of the pin actuation. It is essential that these 3 components are tested properly so that integrating the digital system (9.1-9.3) with the mechanical system (9.4) will produce the correct results.

Due to the complexity of controlling 60 pin actuators several different methods have been purposed. Of these methods main ideas have been formed and are waiting further testing. The first step of testing is fleshing out the schematics of each design. This includes sourcing components and performing simple analysis to confirm circuitry plausibility. This also includes considerations on additional requirements such as power and microcontroller output for control as well as feasibility parameters (cost, PCB footprint). Assuming that the designs are able to meet all external design constraints, the testing will proceed with OrCAD® (PSpice®) simulations of partial designs and followed up with real world testing with the sourced components. Where possible, observations on total power draw for operation, voltages achievable across motors and timing delays will be recorded. The final circuit design will be chosen using a weighting of these aforementioned observations and considerations.

9.6 Full System Integration

Integrating the digital system with the electrical system would be the first step. The voltage and current output depending on the character, pins and direction will be verified. Then it will be integrated with the mechanical system. Again, the timing, height and consistency will be checked with the corresponding logic from the microcontroller.

10.0 Conclusion

The functionality, coupled with the portability of this device makes it a viable product for the market. By conforming to all of the latest mechanical, electrical, and Braille standards, it is a cutting edge device that offers unparalleled performance, convenience, and functionality. All functional requirements are expected to be met by the end of the design cycle, and production requirements will be easily implementable after that point.

11.0 References

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Images

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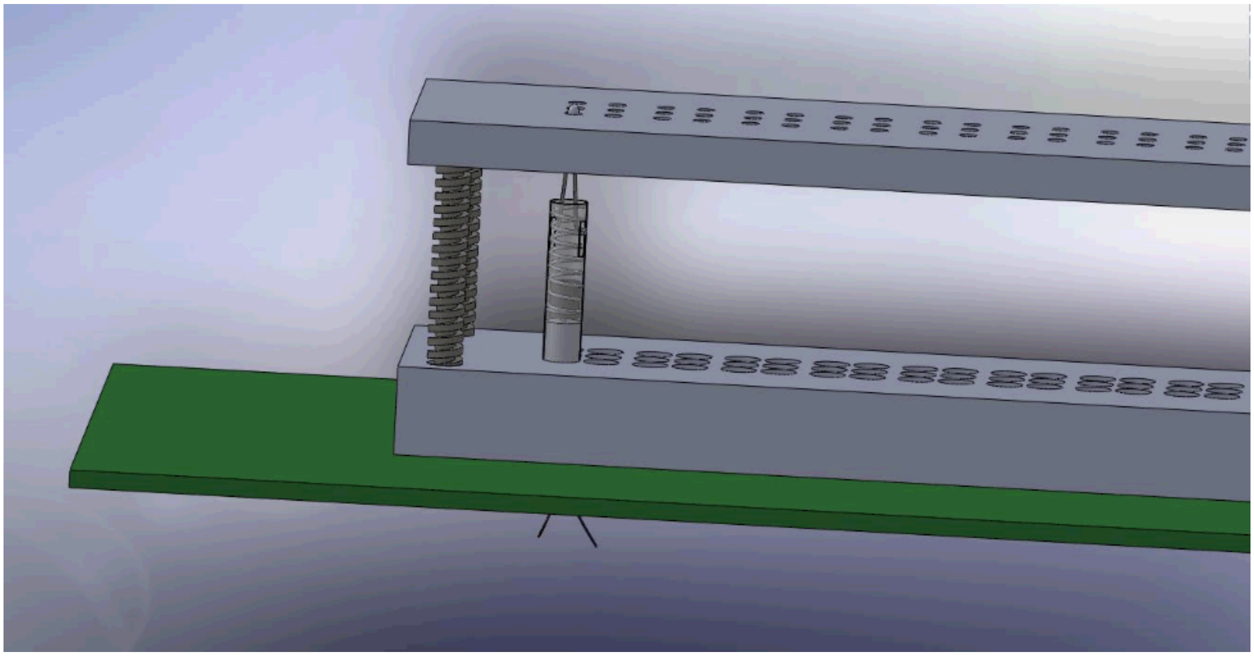
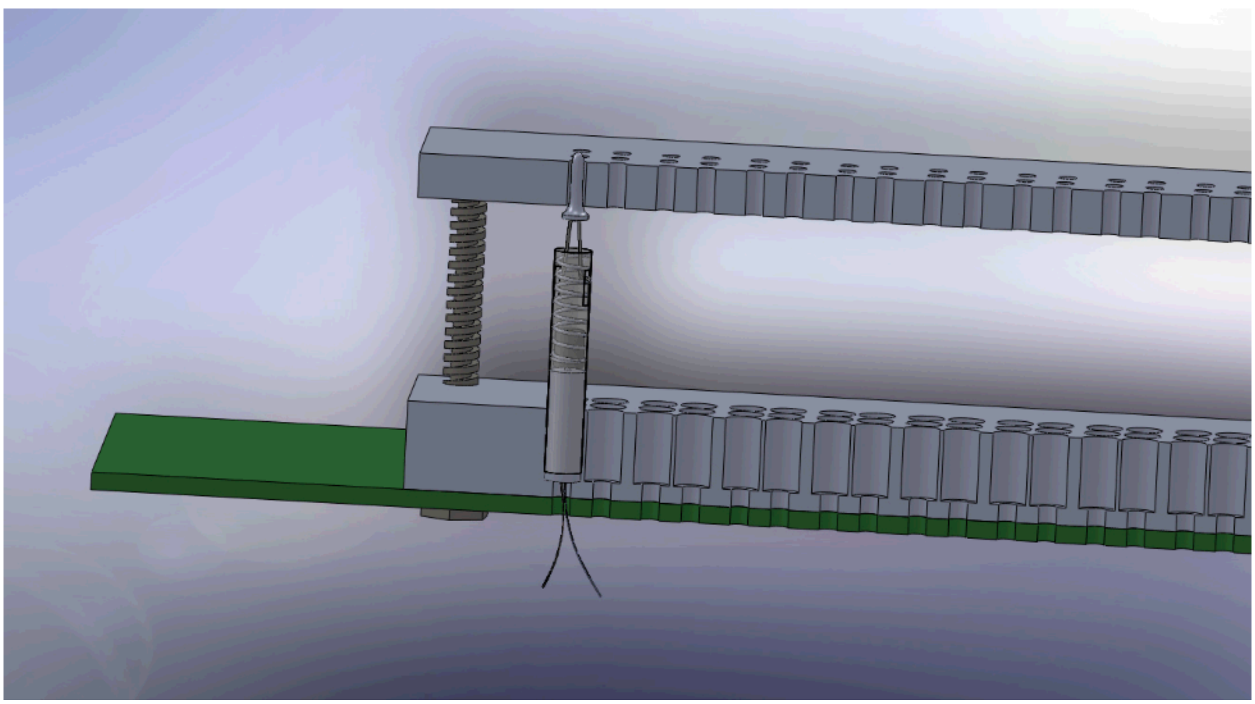
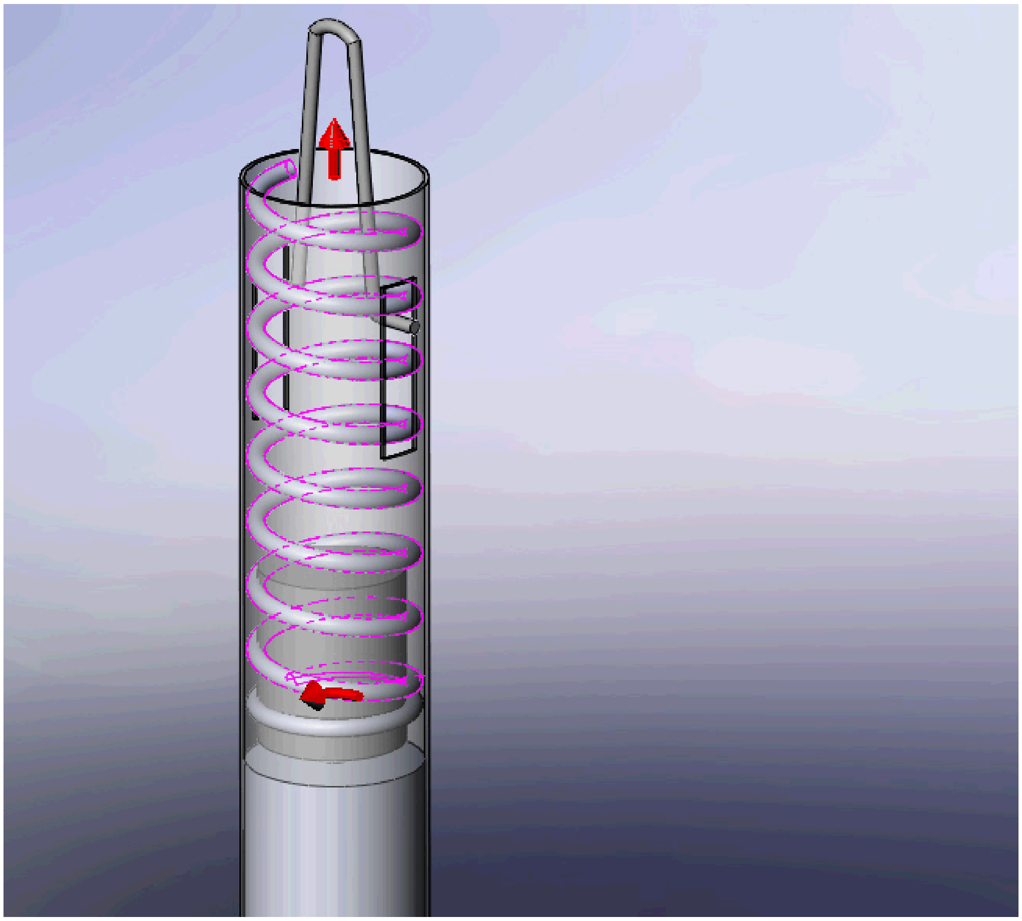
APPENDIX A: MECHANICAL DRAWINGS



Actuator placed in holder, mounted on PCB



Actuator shown in cutaway of mount



Actuator with rotational and linear motion vectors shown

APPENDIX B: DATA SPECIFICATION SHEETS

Flexinol® Memory Alloy Technical Datasheet

Diameter Size (Inches)	Resistance (Ohms/ Inch)	Maximum Pull Force (grams)	Approximate* Current at Room Temperature (mA)	Contraction* Time (seconds)	Off Time LT=70° C Wire** (seconds)	Off Time HT=90° C Wire** (seconds)
0.0010	45.0	7	20	1	0.10	0.06
0.0015	21.0	17	30	1	0.25	0.09
0.002	12.0	35	50	1	0.3	0.1
0.003	5.0	80	100	1	0.5	0.2
0.004	3.0	150	180	1	0.8	0.4
0.005	1.8	230	250	1	1.6	0.9
0.006	1.3	330	400	1	2.0	1.2
0.008	0.8	590	610	1	3.5	2.2
0.010	0.5	930	1000	1	5.5	3.5
0.012	0.33	1250	1750	1	8.0	6.0
0.015	0.2	2000	2750	1	13.0	10.0
0.020	0.16	3562	4000	1	17.0	14.0

(Robot Shop: Dynalloy Flexinol Sample Kit, Product Page. Retrieved Feb 15 2008, Flexinol® Technical Data, www.robotshop.ca/PDF/flexinol-technical-data.pdf)