Technical Development of an Electromechanical Braille Labeler

by

Adelaide S. Calbry-Muzyka

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Abstract

The work presented in this thesis concerns the development of an electromechanical device that prints labels in braille. For blind and visually impaired people, differentiating between similarly-shaped objects – CDs, medication bottles, food cans, etc. – is a challenge that can be solved by affixing braille labels to the surface of these items. However, the existing technology for making braille labels is either fully manual and slow, or too large to be portable. As a result of this identified need, the first prototype of a braille labeler was developed in the fall of 2008. However, several outstanding mechanical and design issues remained. During this thesis, the first prototype was tested with focus groups to identify these issues. These included the lack of a cutting mechanism for the tape, the uncomfortable shape and size of the device, and the ease of manufacturing of some components. A second prototype was designed and built, resolving these problems.

Thesis Supervisor: David Wallace
Title: Professor of Mechanical Engineering

Biographical note

The author of this thesis came to MIT as a math major, but was soon convinced that she could be more useful in engineering. After experimenting with various aspects of mechanical engineering and completing more problem sets than she would care to remember, she finally found a captivating project in her final year as an undergraduate. This thesis comes from that.

When she has free time, she likes to learn new languages, and play the guitar badly. After graduation, despite having enjoyed Boston and its adorable obsession with a certain baseball team, she will be relocating to California to pursue graduate studies at Stanford University. She is told that the weather there is nicer, although being Canadian, she isn't so sure that "no snow" is necessarily equivalent to "good weather".

Acknowledgments

Since the work presented in these pages was largely a team exercise, I would be remiss if I did not begin by thanking the other members of the group: Karina Pikhart, Rachel Tatem, Trevor Shannon, Josh Karges, and Maria Prus. Similar thanks go to the members of the 2.009 Blue Team who were there for the early days of the project. Thank you all for the fantastic experience – if there is any measure of true teammate-ship, personal compatibility, and mutual dedication to a project, it has to be the number of consecutive hours spent in lab without ever losing patience with each other. By that metric, I can't imagine ever finding a better group of people to work with.

The advice of several people, both on MIT's campus and off of it, has been crucial. The engineering guidance, of course, has been absolutely wonderful. Here I thank first of all my thesis advisor and 2.009 professor David Wallace, and then all the others who helped along the way: Barry Kudrowitz; Profs. Culpepper, Terman, and Sarma; Pat McAtamney; Dave Dow; the Pappalardo staff; Ron Hoffeld; and Greg Cappiello. Without the financial support of MIT Mechanical Engineering and the MIT Public Services Center, the second prototype might not have existed, nor would we have been able to take the first prototype to conferences across the country. Finally, I am extremely grateful to the people across departments who scrambled to let us use their 3D printers in the final weeks of production: John Clarke at Clariant, Mike Tarkanian, and the d'Arbeloff Laboratory.

Most importantly though, when one is developing a product for a group of people one is not a part of, the acceptance and input from within that group is essential. To the many members of the blind and visually impaired community who took a personal interest in our labeler, I'd like to extend my sincerest thanks. You took us seriously even when we were completely ignorant of anything relating to reading and writing in braille. When we made design decisions based on entirely incorrect assumptions, you took us by the hand and gently explained to us where we went wrong. Personal thanks go to Paul Parravano, Kim Charlson, Brian Charlson, Jim Denham, Perkins School for the Blind, and the National Braille Press. We would not have continued this project had you not demonstrated such an enthusiastic level of interest in it.

Last but certainly not least, I need to state my appreciation of the people who have supported me personally throughout this process. Without my parents, my sister Amelia, and my family-away-from-home on Conner 2, I just might have become so stressed that I would have inadvertently broken the prototype or done something similarly terrible. Thank you.

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1. Introduction

This thesis presents the work done under the supervision of Professor David Wallace towards the completion of an undergraduate degree in Mechanical Engineering at the Massachusetts Institute of Technology (MIT). It concerns the development of an electromechanical braille labeler prototype. In the fall of 2008, the first prototype was completed as part of the MIT Mechanical Engineering course 2.009: The Product Engineering Project. However, there were still some significant design and mechanical issues to resolve before having a prototype ready for the next stage of production. In this thesis project, the outstanding issues with the first prototype are identified and addressed, culminating in the building of a second-generation alpha prototype. This paper will begin by explaining the need for an electromechanical braille labeler, followed by an overview of the first prototype, a review of the user feedback gathered on this prototype, and the design changes incorporated into the second prototype as a result of this feedback. Finally, the future work already in process for this project will be presented.

The focus on braille and braille-related devices at MIT is not a new one. In the 1960's and 1970's, the Center for Sensory Aids Evaluation and Development was founded and led by Professor Robert Mann, and was one of the centers of innovations in braille research.[1] From this lab came the first high-speed braille embossing printer, known as the MIT BraillEmboss, as well as the early braille translation software DOTSYS.[2] During these years, several theses at MIT dealt with the development of braille devices, both from a technical standpoint in the Department of Mechanical Engineering,[3] and on the business and implementation side at the Sloan School of Management.[4] Even after the Center was closed, there continued to be theses written relating to braille and the technology surrounding it. The work in this thesis therefore hopes to continue a decades-long tradition at MIT of developing assistive devices for braille-literate people.

2. Background

2.1. The need for a braille labeler

For the nearly two million Americans who are blind,[5] daily life requires a series of adjustments, some of which are not immediately apparent to sighted friends. Many rely on guide dogs or canes to feel for unfamiliar obstacles ahead. Sound cues have been added to many systems in public use. People can thus rely on the beeping of street crosswalks, on the announcement of stop names in buses and subways, and on automated computer screen readers. Recognizing people in a group conversation falls largely on being able to recognize the particular timber and intonation of each person's voice, and the direction from which that voice is heard. Some common patterns become second nature: there might be five steps forward and one to the right from the bedroom to the bathroom, and the door of city buses will usually be a certain distance away from the curb. When digging through the medicine cabinet, it helps to memorize that of the four pill bottles on the shelf, the second from the left would always be the position of the painkillers, and so on.

Tactile interactions are obviously ubiquitous and essential. A person could use his sense of touch to feel for the smoother fabric of his business clothes in his closet, just as another could reload her electric toothbrush by remembering that the negative end of the battery always mates to the spring-like side of the battery holder. The temperature dial on an oven usually has a raised mark to indicate its position; sticking some small raised stickers by the printed temperature readings will allow someone to turn the dial to the desired position.

However, there remain many household items that cannot be easily differentiated simply by holding them in one's hand. What if the person described earlier looking for painkillers in her medicine cabinet had accidentally reached for her vitamins instead? In this case the mistake would certainly not be fatal, but the risk of confusing medication is not one to be taken lightly. Over the course of this project, many people with low vision came forward to explain some of their frustrations with identifying objects. One had just downloaded iTunes® onto his computer, and had trouble sorting through his CDs to know what was inside each case and whether or not he'd already added that music to his library.[6] Wine connoisseurs would bemoan the fact that they needed sighted friends to help them find a particular vintage in their cellar.[7] And to return to the example of pill bottles, one woman once double-dosed on medication because she couldn't identify the right packaging, and was rushed to the emergency room.[8]

A simple way to solve this problem is to use labels. This is already a common technique within the blind and visually impaired community. It is included in several published guide books about living with vision impairments. Thus, Maureen Duffy's *Making Life More Livable: Simple Adaptations for Living at Home after Vision Loss*, which deals specifically with living with vision loss later in life, devotes a full section to the importance of labeling and the different methods to do so.[9] Judy Dixon, chair of the Braille Authority of North America (BANA), has written *Label It! Braille & Audio Strategies for Identifying Items at Home & Work*, an informative and entertaining book that details the various ways of labeling she has acquired over the course of her life.[10] Both authors discuss different methods of labeling items, from using a raised-marking substance to write large numbers or letters that can be felt easily,[11] to using a code of sewing buttons of different shapes into clothing to indicate colors (for example, a square could represent black).[12] However, better specificity is often necessary, and for this both authors turn to printed braille labels.

Braille has become easily the most widely-accepted method of writing for visually impaired people since Louis Braille developed the system in 1824 (the word *braille* is capitalized when referring to the person, but left in lowercase when referring to the writing system).[13] It uses a combination of raised dots in a 3 by 2 matrix to represent a letter, number, punctuation mark, or even a commonly-occurring group of letters (thus, there is one braille symbol for the double letter *dd*, and another for *ea*). The 3 by 2 matrix is referred to as a *braille cell*, and each of the six dots have conventionally been numbered according to the diagram in Figure 1 below. The braille alphabet and some common contractions are included in the Appendix.

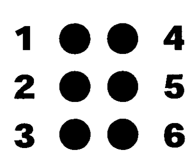

FIGURE 1: Braille cell and dot numbering convention

Using braille to label allows people to have specific information about an item, in a written type they are comfortable using. If someone is looking through his or her spice rack for cinnamon, simply labeling with a large raised "C" will not be too helpful – what about the chili powder, cumin, coriander, or cardamom? More details are needed. Moreover, labeling in braille is something that is very personal. People are free to make their own labels according to their needs, instead of relying on a discrete set of options in a kit (such as the color-coding shaped buttons described earlier). Some people will want to distinguish between their horizontally striped aquamarine shirt and their crimson flower-patterned one, while others will be content to know that the first is blue while the other is red. With braille labels, people can lose the frustrating sense of depending on sighted friends to identify items around their own house.

Educators and parents of blind children also find braille labels useful as a teaching tool. When sighted children learn to read and write, they are already familiar with the letters of the alphabet – they see them on every billboard, magazine, and computer and television screens. Using braille to label objects around the house and school helps create what author Diane Wormsley refers to as a "braille-rich environment", so that blind children can begin to recognize braille characters and words through sheer force of practice.[14] Braille labels can therefore help people gain independence, at any stage of their braille-learning process.

2.2. Review of prior art

Assistive technology for blind and visually impaired people naturally follows trends in technological advances, and as such, has seen a bit of a boom during the second half of the twentieth century. The passing of the Americans with Disabilities Act (ADA) in 1990, which prohibited discriminatory employment practices on the basis of disability, further contributed to this process. As a result of the ADA, businesses across the United States found themselves bound by law to make any required adjustments to their workplace to guarantee their accessibility to employees with disabilities.[15] This included, though was not limited to, placing braille labels where appropriate.

Existing braille labeling technologies can differ in their printing mechanism, as they can differ in their printing medium. People can emboss braille onto entire sheets of sticky label material which can then be cut to size, and which can therefore hold multiple rows of words. Braille-embosser manufacturing company Enabling Technologies sells the Romeo Pro-LE, a high-powered embossing printer originally targeted at the pharmaceutical industry for this purpose. Quicker and more personal labeling jobs, however, are more easily achieved on standard ½" labeling tape. This is a relatively thick (0.012", compared to 0.004" for a sheet of paper) plastic tape with an adhesive side protected by a thin backing which the user peels off when he or she is ready to place the label. It is easily available, manufactured by both Scotch™ and DYMO®, and sold in rolls at common office supply stores. The thick plastic holds braille well, compared to thinner materials which tend to become smoothed down over time, making the braille less legible.

Unlike writing in print, writing in braille is not as straightforward as picking up a pen and putting it to paper. One of the oldest tools for writing braille is a slate and stylus (Figure 2), a simple hand-held mechanical method still in use today. The slate is a two-fold die made of thin sheet metal, so that a user would place a piece of paper (or a piece of label tape) between the upper portion, which holds it in place, and the lower portion, which has inset dots to form braille cells. A person would then pick up the stylus, a short, thin metal rounded pin held like a pen by its wooden handle. He or she would use the stylus to press down through openings in the upper portion of the slate and emboss dots in specific locations. As a result, the user has to think and print in reverse, as each push of the stylus will create a dot embossed downwards. Lines need to be written from right to left, and characters need to be written as their mirror image. Although a slate and stylus are portable and inexpensive, this inconvenience as well as the slow speed of manual embossing combine to create a non-ideal labeling device.

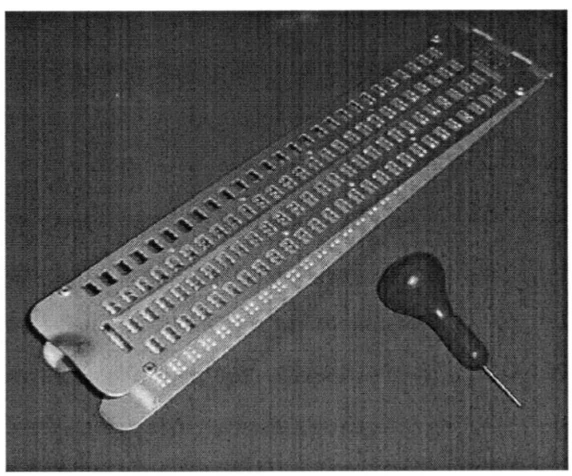

FIGURE 2: Slate and stylus

In 1892, Frank H. Hall, the superintendent of the Illinois School for the Blind, invented the first personal braille typewriter.[16] Known as the Hall Braillewriter, it was based on a system of six keys and a spacebar to emboss dots, and it has inspired newer advances in braille-printing technology. The braille writer currently produced by Perkins Products, the Perkins Brailler®

(Figure 3), is one of the current existing personal braille writers. Today, an add-on feature can be purchased for the Brailler that allows the user to position a strip of label tape across the typing area and produce a label faster and more simply than with a slate and stylus. The Brailler's interface is designed specifically with braille in mind: the keyboard uses only six keys, which map to each of the dots in a braille cell. While a familiar computer-type keyboard would allow a user to write letters and numbers, the six-button keyboard allows for any of the sixty-three braille characters. Nevertheless, the Brailler is large and too heavy to be portable, and the label extension must be removed and replaced any time one wants to use it as a typewriter, its primary function. Moreover, at approximately $700 it is expensive to justify the purchase if one is merely looking for a labeling tool.

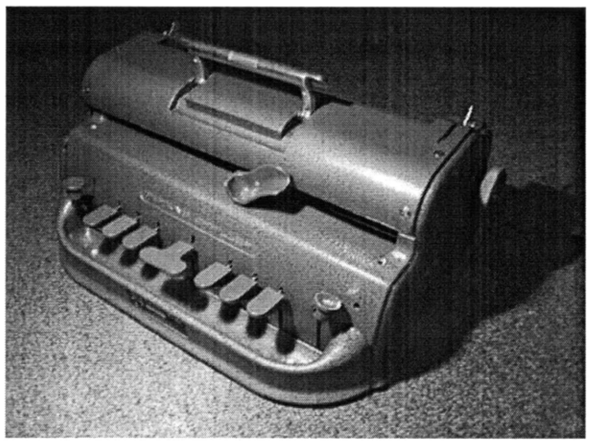

FIGURE 3: Perkins Brailler®

Meanwhile, Japanese company KGS has developed the BL-100 Braille Labeler, a small, fully electronic label printer that prints on rolls of tape. User input is received through interactions with a keyboard panel and an LCD screen display, with no sound feedback. In other words, while this labeler is useful for sighted people aiming to increase the accessibility of their home or work environment for blind friends and colleagues, it cannot be used by someone with low or no vision.

For blind and visually impaired people, 3M has released a hand-held labeler that prints in braille (Figure 4). However, according to a survey of several dozen blind people conducted as part of this project, the 3M labeler can be frustrating for several reasons. First, although its purely mechanical system makes it light and inexpensive, it sometimes leads to inconsistent braille, linked to the variable strength with which each user can squeeze the embossing handle. The interface consists of a palm-sized round dial on the edge of which are braille symbols for the letters of the alphabet, and a few of the standard braille contractions. The user feels around the edge of the dial until he or she finds the desired character, and then turns the dial to align that character with the embossing slot. It is difficult to know when the braille character is aligned properly, and the device frequently embosses the character that is directly to the right or left of the correct one. The user then has to type a new label to correct the mistake. Furthermore, as the labeler includes only a few of several dozen braille contractions, people cannot type shortened versions of words and must spend longer labeling. These issues are frustrating enough that many survey respondents reported ultimately abandoning their 3M labeler in favor of a return to the slate and stylus.

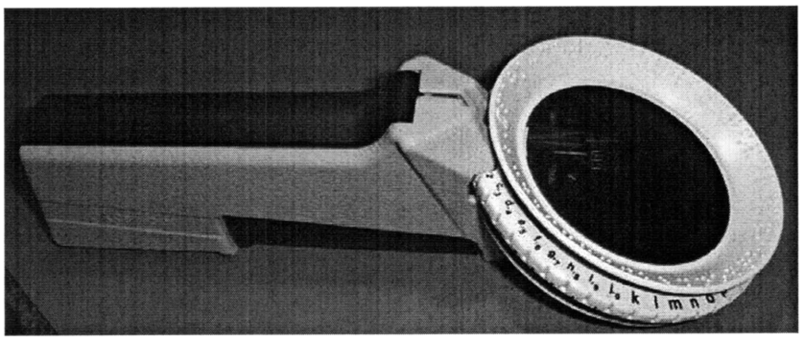

FIGURE 4: 3M labeler

The solution proposed by this thesis is a braille labeler that is electromechanical and portable. The electrical aspect allows for consistent and fast braille typing, and the chosen mechanical embossing method allows for the typing of any of the 63 braille characters (letters, numbers, and contractions). Ideally, the labeler would combine the portability of the 3M labeler, the ease of printing of the KGS labeler, the quality of printed braille of the Perkins Brailler, and the Brailler's easy-to-use and familiar six-key interface.

3. First prototype

3.1. Background of project

Having identified the need for an improved braille labeler in the blind community, a team of mechanical engineering students at MIT, the author of this thesis among them, began to develop a first prototype as part of a senior design class (*2.009: The Product Engineering Project*) in the fall of 2008. Several designs were considered, to eventually settle on the prototype described in Section 3.2. Design decisions were made on the basis of tests at all levels of prototyping: sketch modeling, CAD simulation, and eventually testing of individual modules of the prototype. The input from potential users was a significant source of inspiration and the basis for some design choices. This consisted of a survey of several dozen blind and visually impaired people around the world about their labeling techniques, followed by a focus group session after completion of sketch models.

3.2. Presentation of the first prototype

The second prototype developed during this thesis makes modifications and improvements on the first prototype. Therefore, as many of the internal systems of the second prototype are heavily based on the problems with the first prototype, it is necessary to present this in some detail to identify the source and location of the various improvements.

The labeler is an electromechanical system. Shown in Figure 5, it has an 8.5" by 8.5" footprint, is 3.5" tall, weighs 3 lbs, and uses four AA batteries. When users interact with it, they would begin by flipping the switch underneath it to turn it on. A roll of label tape is loaded into the device by opening a magnetically-sealing door on the back edge of the shell, inserting the roll horizontally, and advancing an initial length of tape into the mechanism by using one's thumb to turn the roll of tape a few times. After returning the labeler to its horizontal position against a flat surface, a table or desk for example, users can begin typing. The keyboard is a combination of six buttons and a keyboard, similar to the one seen on the Perkins Brailler and on several other braille products (Humanware's BrailleNote, GWMicro's BrailleSense, and PacificVision's PACmate among them, although none of these prints labels). After typing, the tape will exit a slot on the left-hand side of the labeler, taking approximately three characters to do so (in other words, when a person types on the keyboard, the distance needed for the tape to travel between the embosser and the exit slot is three braille cells long). The user can therefore proofread what he or she has written shortly after typing it. Finally, the user would push a button on the back edge of the shell to cut the finished label, although this component was not fully integrated into the first prototype. The label is then ready to be placed on any object whenever the user decides to do so.

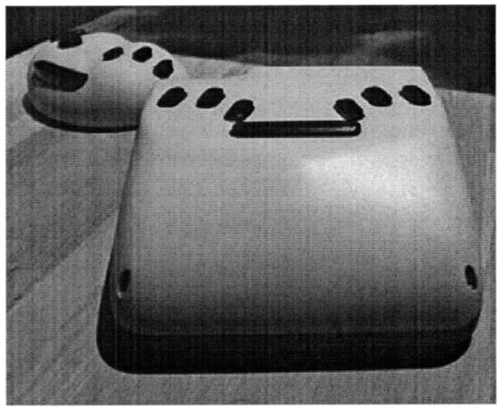

FIGURE 5: First prototype (in foreground. The item in the background was a model of a possible shape for the second prototype; it was a shell with no internal systems.)

3.2.1. Embossing module

The primary component of the labeler is the embosser; it is the mechanism of imprinting braille onto the label tape. Shown below in Figure 6, it has several critical features. The tape is advanced into a space between two horizontal surfaces, labeled as the "upper guide hole plate" and the "stamp plate" on the diagram. The stamp plate is a die; it has six through-holes arranged in the shape of a braille cell. The upper guide hole plate serves two purposes: first, it is the horizontal surface over which the tape slides and is held against the stamp plate. Secondly, it serves as the guide for the up-and-down motion of the pins that emboss the braille dots.

During the advancing of the tape, the tips of these pins remain just below the surface of the upper guide hole plate, to be raised only when the tape is embossed with a braille character. The pins are curved steel rods ending in a small rounded tip to emboss the tape. The curvature in these pins is a solution for the space constraint; a braille cell is very small, so the curve allows the bottom of the six pins to be farther apart than their tips, and therefore more easily controlled.

The motion of the six pins is controlled by three servo motors driving cam shafts. Each servo and cam shaft assembly controls two pins. Along the length of one cam shaft, there are two cams, at opposing angles to each other. When the servo rotates one way, it causes one cam to turn up while the other turns down. Above each cam is an embossing pin, so that when a cam is turned upwards, it leads the pin to emboss a dot. Thus, dots 1 and 4 in the braille cell are embossed by a single servo turning first one way, then the other. The use of one servo for each pair of braille dots allowed a significant reduction in size from a proposed design of one servo motor per braille dot.

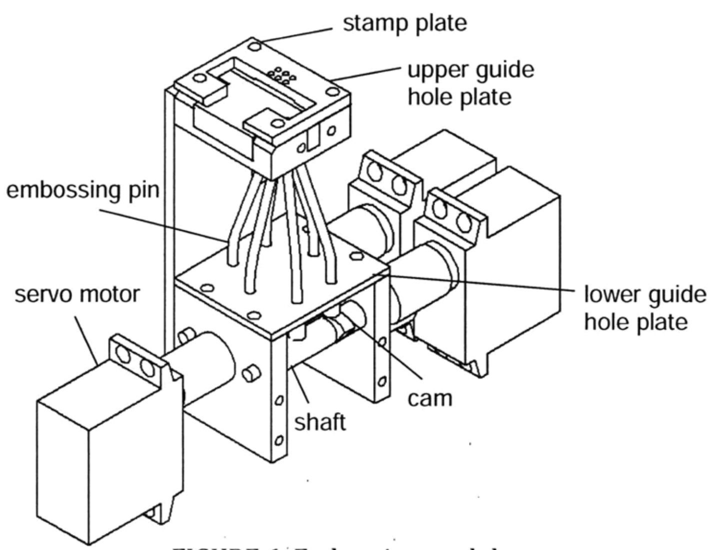

FIGURE 6: Embossing module

3.2.2. Keyboard

Although there was some suggestion of incorporating a standard QWERTY keyboard into the device, or of developing an alternate arrangement of the six braille keys, customer feedback on the earliest sketch models strongly suggested that people preferred the familiarity of the six-button keyboard as popularized by the Perkins Brailler. In this keyboard arrangement, each button maps to a dot of the braille cell, as detailed in Figure 7.

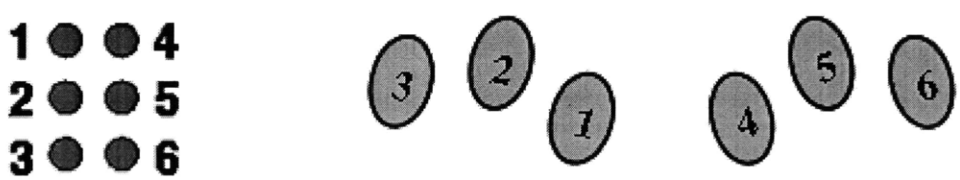

FIGURE 7: Key-to-dot mapping of the keyboard. An approximate arrangement of the keys is shown on the right, while the standard braille cell is on the left.

To type a character, the user presses down at one time on all the buttons required for the desired braille symbol. Each button is placed above a flexible rubber dome with a carbon center, which electrically closes a switch when it comes into contact with the PCB underneath it. These switches then control the motion of the servos in the embossing module.

3.2.3. Cutting mechanism

There were two goals to achieve when cutting the tape at the end of a label. First, the tape had to be cut, and as close as possible to the last character printed. Secondly, a method for making the adhesive backing on the tape easier to peel was necessary. In the first prototype, this mechanism consisted of two blades, one of which was rigidly attached to the button and which would therefore cut through the tape. The second was not rigidly attached to the button, but rather attached to the cutting blade with a small piece of compliant material between them, as seen in Figure 8.

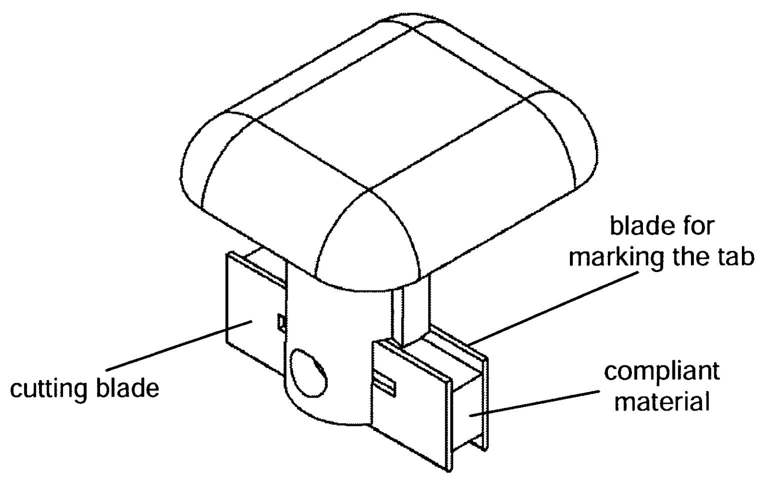

FIGURE 8: Attempted cutting mechanism for the first prototype

This allowed the second blade to move up slightly as the button was pressed down on the tape, releasing some pressure and merely cutting through the plastic portion of the tape, leaving the adhesive backing intact. When re-designing the cutting mechanism for the second prototype, this functioning component had to be considered and incorporated. This redesign was necessary because it was discovered that the force required to push the button through the tape was too large to be practical; this will be examined in greater detail in Section 5.1.

Identification of problems through user feedback

3.3. Focus groups

Due to time constraints, the first prototype had not been tested in its completed form by potential users in the fall of 2008. Before work could begin on the second prototype, the first step was to gather feedback on the first one. Having established contacts at the Perkins School for the Blind over the course of the first few months of prototyping, we returned to have a group of people give advice on the completed first prototype during February of 2009.

The team and prototype were invited to the annual conference of the California Transcribers and Educators of the Visually Handicapped (CTEVH; this organization was recently renamed CTEVBVI: the California Transcribers and Educators of the Blind and Visually Impaired) in mid-March of 2009. During the two days of the conference, feedback was gathered from blind people, both adults and children. Meanwhile, opinions were recorded from another target group for the labeler: the caregivers, teachers, and family members of blind individuals. During these meetings, the format of the feedback session was left deliberately unstructured. Ideally, the goal was to observe users interacting with the product without the need for significant instruction past a quick introduction of the device (and, for blind people, some verbal direction for finding the various components of the labeler). They were then asked to comment generally on what they liked, what they did not, and what they would like to see in a second prototype, or, eventually, a completed product.

3.4. Positive aspects of the first prototype

The aspect of the device that was most appreciated by testers of our device was the quality of the braille typed on the labeler. Respondents went as far as to call printed braille "gorgeous" (Judy Dixon, author of *Label It!*), or even "the sharpest Braille I've ever seen" (Mike May, of the Sendero Group, a company that develops blind-accessible GPS software). Of the several dozens of people who tested the labeler, not one had a negative comment about the typed braille. This suggested that the embosser, the primary component of the device, was performing adequately and any modifications on this part would be made on the basis of increasing manufacturability or power efficiency.

3.5. Issues with the first prototype

The groups of people who tested the first prototype were quite analytical in their approach to the labeler, and certainly not hesitant to give comments on aspects they would have liked to see improved. The shape of the first prototype was an issue that had been foreseen, especially given that the first prototype was made to be functional first rather than aesthetically (or ergonomically) pleasing, due to time constraints. The shape was deemed too box-like, it was too large, and it was too heavy. The flat bottom panel made people unwilling to pick it up from a flat, stationary surface such as a table, while people would rather have had a labeler they could hang around their necks and carry with them. Meanwhile, they did want to keep a certain amount of space in front of the keyboard to rest the palms of their hands.

The keyboard itself was another source of difficulty. From observations and photographs of several people's hands resting on the keyboard, it was possible to notice that the majority of users held their fingers curved over the keys, rather than flattening their palm. This provided information for positioning the spacebar key relative to the typing keys in the next prototype. People further identified that they would like the typing keys to be more concave, closer together, and for the spacebar to be wider. The cutting mechanism was not functional on the first prototype; therefore, the need for an improved method of cutting the tape was an obvious and anticipated problem. However, it was through speaking with the focus group at the Perkins School that the idea was developed for a sliding cutting mechanism, rather than one that would require the user to push a button towards him or herself. In the second prototype, these various changes were effected, along with changes based on improving the manufacturability of several components.

4. Resolution of problems for the second prototype

Two main considerations were made when modifying the design for the second prototype. The feedback from user testing of the first prototype was of significant concern, but there was also a focus on attempting to improve the manufacturability of some of the components inside the device. These changes resulted in a fully functional second prototype, shown in Figure 9.

FIGURE 9: Second prototype

4.1. Cutting mechanism

The cutting mechanism was one of the remaining non-functional parts of the first prototype. Although a working cutting mechanism prototype had been built to stand independently of the assembled device, the force required to cut through the thick plastic of the tape remained considerably too high to be reasonably expected to be incorporated as part of a portable device. This became more problematic when one considered that although the cutting mechanism prototype allowed the user to push on the button downwards into the table, when added to the labeler prototype the button would be oriented differently. The button would be positioned on the back surface of the device, requiring the user to push with a significant force towards him or herself, while simultaneously steadying the labeler and preventing it from being pushed towards the person.

The cutting mechanism was returned to the brainstorming stage. Several different methods were considered and abandoned for several reasons, either by analyzing the idea more closely on paper or by building quick cardboard prototypes. The idea of cutting the tape by having a blade approach it at an angle was explored particularly strongly, especially given that it is the principle seen in a pair of scissors. However, these systems mostly require a slot to exist underneath the tape, into which to slide the blade as it cuts down through the tape. Slots like these hinder the proper advancing of the tape; as a fresh piece would move forward, the edge of the piece of tape would catch on the slot and curl down into it. An alternative would have been to reverse the position of the blade, keeping it inside the slot flush with the surface while the tape is advancing, and moving it upwards out of the slot to cut the tape. However, the functioning flexible-blade system of the first prototype was ideally to be conserved for the peeling of the adhesive backing. It would have been difficult to properly position a separate "tab-marking" blade with this system. Furthermore, the tape would have to be held down by an extra component, as the blade moving upwards would take the tape with it rather than slice through it if the tape was not held in position.

The method of choice became a system based upon circular blades, which rolled across the tape to cut it. This achieved the necessary condition of cutting at an angle to reduce required user-applied force, without requiring extra slots which would interfere with the movement of the tape through the labeler. Shown in Figure 10, this assembly can still create the tab to help peel the

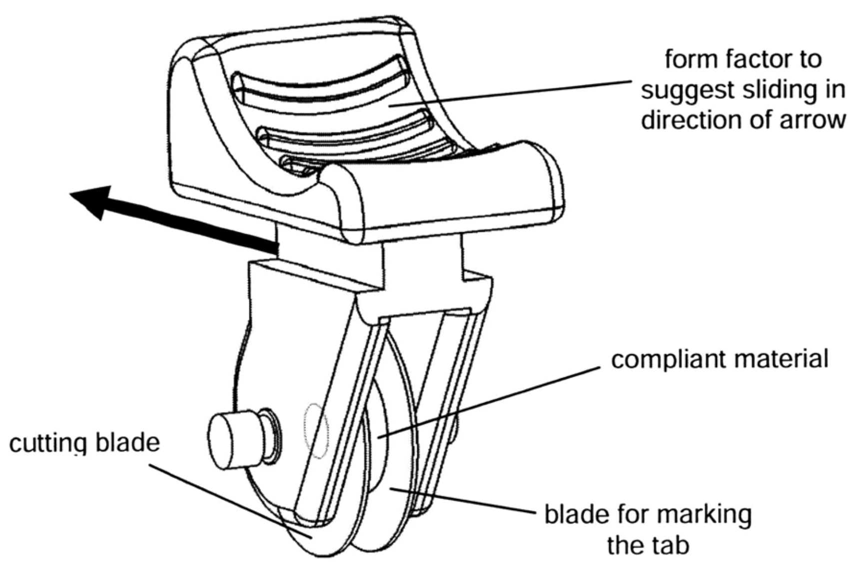

FIGURE 10: Cutting mechanism

backing from the label tape. The blade on the left cuts through the tape; it is held firmly onto the axle, which is itself allowed to rotate in the button so that the blades can roll. Meanwhile, the axle is turned down to a smaller diameter at the level of the rightmost blade. This blade is held to the assembly by the compliant material between itself and the cutting blade, and is kept vertical by being constrained between the compliant material and the edge of the button. Because the shaft is turned down at that point, the compliant blade can move up and down with some freedom so that it merely cuts the plastic of the tape, leaving a tab in place for ease of peeling as shown in Figure 11.

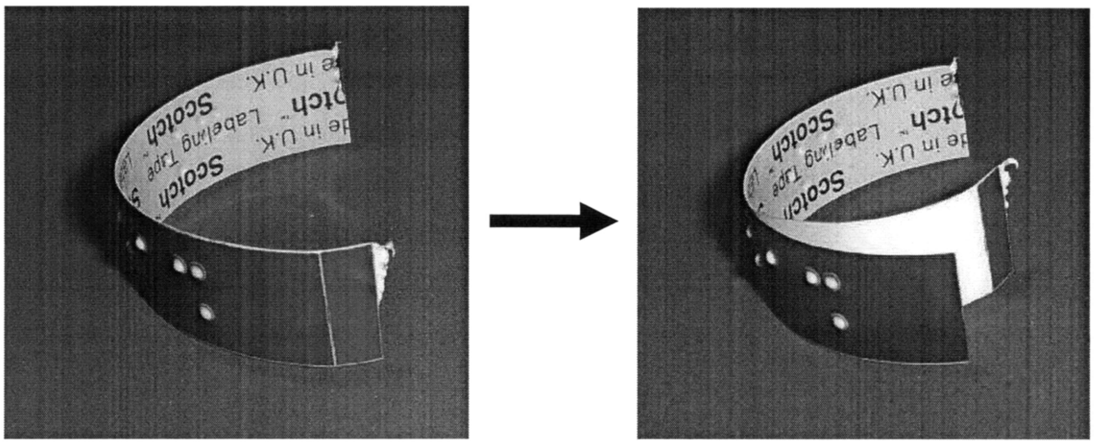

FIGURE 11: Peeling the label backing by means of a tab

The final component of this new cutting mechanism was the design of the button. Because the blades were no longer being pressed down against the tape, but instead rolled and dragged across it, the motion required from the user was quite different. Instead of pushing a button towards himself or herself, the user would slide a button down towards the table. In keeping with the idea that form should follow function, the new button was designed with a curved shape, bulged forward near the bottom and concave in the upper section. This was done to suggest that a person rest the tip of their finger in the concavity and push down against the protruding bulge, cutting across the tape. The button was spring-loaded both for the practical purpose of restoring the button to its starting position, and to provide the user with a satisfying click when the button had reached the end of its travel. Finally, the shell of the labeler was modified slightly to accommodate the sliding vertical motion of the cutting button, but this addition was made in keeping with the form factor of the shell, maintaining many of the same curves and fillets and completing the re-integration of the cutting mechanism into the assembled device.

4.2. Keyboard

In this labeler, the primary means of interaction between the user and the device is through the keyboard. It was therefore of prime importance to make it as intuitive, comfortable, and reliable as possible. In the first prototype, the first issue identified was that the spacebar was often sticky, and that if not pressed directly at its halfway point, it would not close the switch in the PCB below. The tape would thus not advance. Repeated testing suggested this to be due to the length of the key – a spacebar is far more likely to jam when depressed than the shorter typing keys, because even a small angle offset from the horizontal translates to a larger deviation in the position of each end of the key. This was resolved by adding a small metal bar that ran along the bottom of the spacebar key and was held on the inside of the keyboard guide, as shown in Figure 12. The slot in the keyboard guide allows the metal bar to move horizontally when the spacebar is pressed, while preventing the spacebar from being depressed unevenly. The addition of this bar to the key was done to the first prototype in preparation for the user feedback sessions and reduced the number of errors in spacing to zero over the course of the two-day test period.

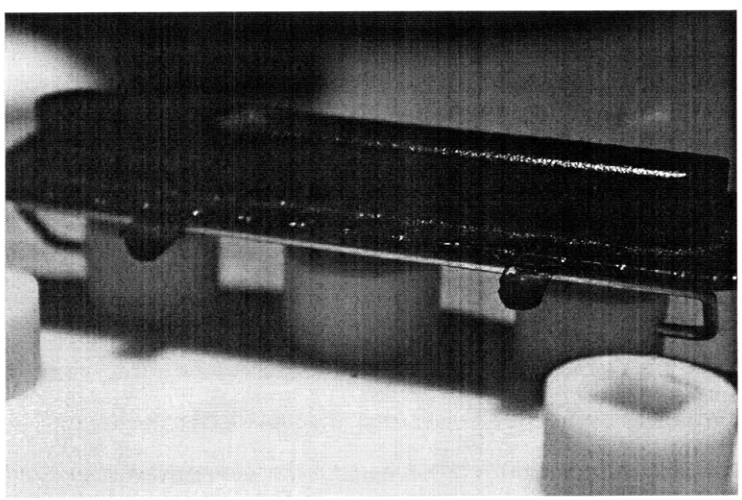

FIGURE 12: Solution to spacebar irregularities

The shape and position of the typing keys had been identified as problem areas by the test users of the first prototype. The concavity of the keys was increased to be made more comfortable, as shown in Figure 13. The three keys on each side were also moved closer together and re-positioned with relation to the spacebar key. These new locations were found on the basis of a comparison to computer QWERTY keyboards, after having noted that many users placed their fingers on the first prototyped curled onto the keys as one would do on such a keyboard.

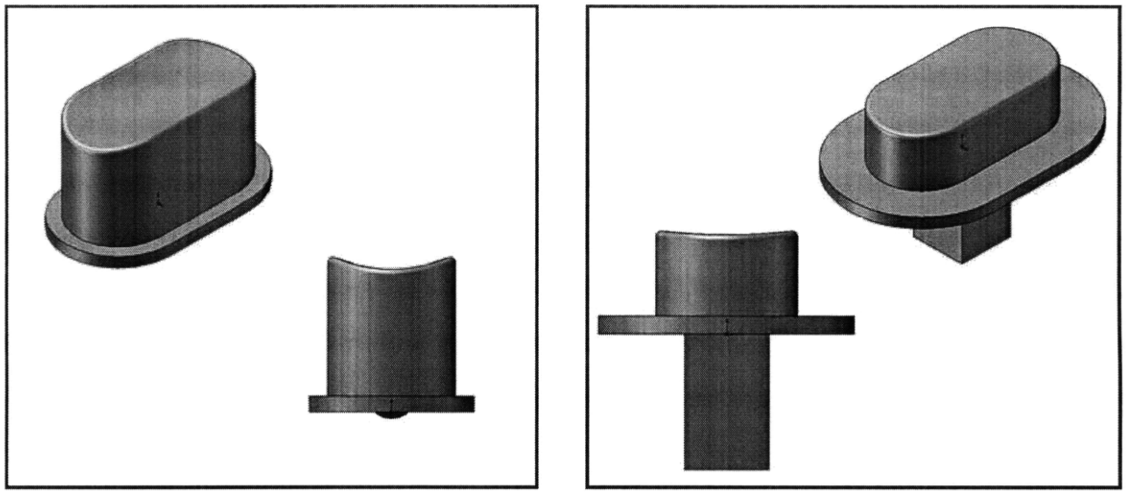

FIGURE 13: Change in key shape on the second prototype (left) compared to the first prototype (right)

4.3. Design of the shell

After the keyboard, the other means of interaction between the user and the labeler is through the shape of the shell. Furthermore, while in the first prototype the shell was merely a means of containing the inner components, during the development of the second prototype efforts were made to consider the shell as a component itself, and to integrate it with the modules inside.

Several areas of curvature were added to the second prototype, in contrast with the box-like shape of the first prototype. On the upper surface of the shell, the area where the user would rest his or her hands was given two bulges similar in size and shape to the convex surface of a computer mouse. This was in response to user comments of wanting a resting space for the edges of their palm when typing. The front and sides of the device were rounded to be made more aesthetically pleasing and more comfortable to handle. The bottom of the shell was redesigned significantly. The bottom of the first prototype was a 0.5" sheet of ABS plastic, which was heavy, very flat, and which served both as a bottom to the device and as a mounting plate for the various components inside. In the second prototype, the bottom of the shell had two flat edges on either side of a curved concave surface, as seen in Figure 14. The flat sections would allow the labeler to rest on a table, while the curved surface was designed to rest on the user's leg when sitting, or stomach or waist while standing.

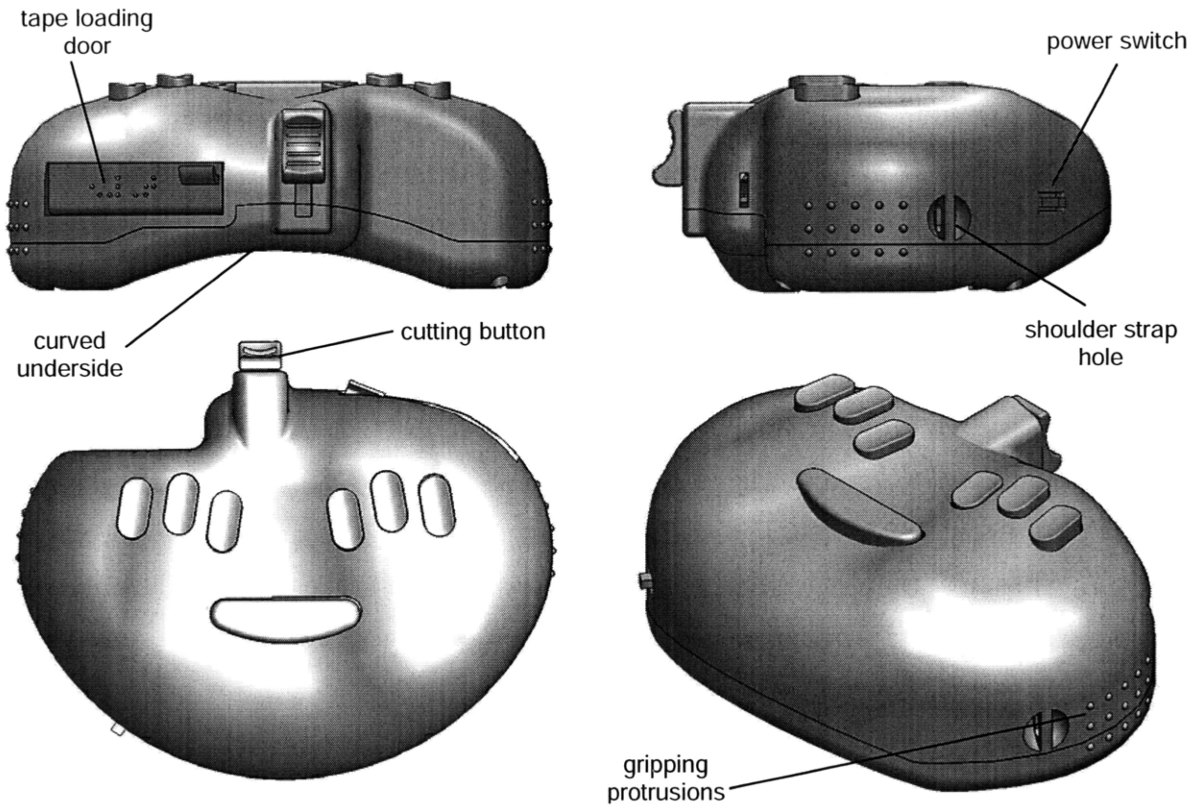

FIGURE 14: Model view of the shell of the labeler

Several modifications were made to improve the accessibility. The addition of holes for a shoulder strap was intended to make the labeler more portable; the holes were designed to fit the ends of standard camera straps. After received feedback that the first prototype difficult to grasp and remove from a table, several raised dots were added to each side of the shell in the second prototype. These dots added texture which could be used to grip the otherwise smooth plastic of the shell. Finally, the on-off switch on the first prototype had been located on the underside of the labeler, which was inconvenient as the user had to lift the prototype to access it, or would forget about its existence altogether and leave the device on. Instead, the second prototype included a switch on the left side of the front of the shell. The user would pass his or her hand over this area before or after typing, both helping blind individuals to locate the switch and ensuring that it was not forgotten.

4.4. Size and weight reduction

A reduction in the size and weight of the labeler was desired. The removal of the 0.5" ABS plate used as a bottom shell and as a mounting plate on the first prototype was the primary weight reduction method, as the remaining components were nearly all essential. The new prototype, at 2 lbs, thus had a weight that was reduced by 33% from the first one. The reduction in the size of the device was mostly due to significant condensing of the electronic components. Instead of a large (4"x5") FPGA board, which was used on the first prototype, the second prototype used an Arduino chip, which is significantly smaller at 1.5"x0.5". Moreover, the reduction of extraneous parts was a means of reducing weight and size. As such, an extra plate between the PCB and keys to guide the keys and protect the PCB was removed in favor of incorporating button guides directly into the shell. The final footprint of the second prototype was a rounded shape contained within a 8.5"x5.5" rectangle, and it was 3" tall between its lowest and highest points, although there was additional height reduction in the middle section due to the form-fitting curve.

More size reduction would still be possible under the current design; the front section of the labeler is empty. However, customer feedback having identified a preference for having a surface on which to rest the heel of the palm of the hand, this space was left unfilled to fulfill this comfort requirement.

4.5. Improved manufacturability

During the development of the first prototype, the primary goal was to create a labeler that was functional and that printed high quality braille. In several cases, the manufacturability of several components was not given enough attention. In the second prototype, every bolt used was a standard 4-40, to reduce the potential for lost bolts and to reduce the number of different parts in the device. As further reduction of total part number, more attempts were made to incorporate components directly into the shell. Openings for the battery holders and the switch were left directly in the shell instead of being added separately. The keys in the keyboard needed guides to ensure that their motion was purely vertical and that they did not fall into or out of the device. In the first prototype, they were held in place by a raised plate that had openings for each of the buttons and was screwed directly into the PCB. In the second prototype, this was replaced by downwards extruded guiding holes that were part of the upper shell, as shown in Figure 15.

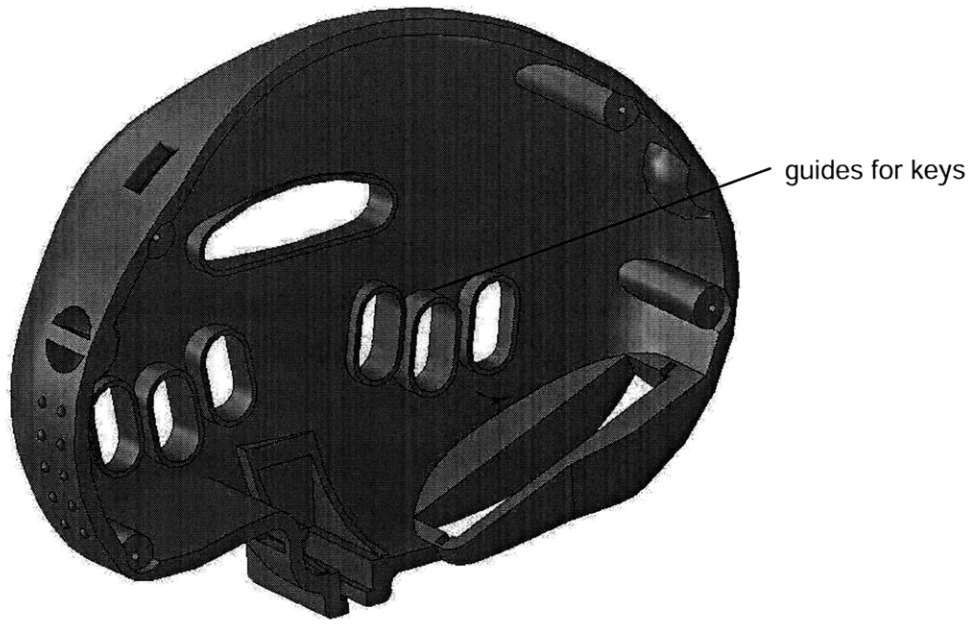

FIGURE 15: Demonstrating the incorporation of the keyboard into the shell

The first prototype made a significant use of 3D printing as a prototyping method. This was true of the second prototype as well; however, it was decided that in the second prototype, only the parts that would eventually be injection-molded in production, and therefore could not be made by their standard manufacturing method at the prototyping stage for cost issues, should be 3D printed. In the first prototype, the cams and camshafts in the embossing module had been 3D printed at a very high resolution to achieve the proper angle of separation between the two cams. As the cams interact with the steel pins in the embosser, injection molded plastic would not have been the manufacturing method used to mass-produce these cams. Therefore, an alternate method was developed. The two cams were designed using SolidWorks, and they were positioned at the desired angle to each other. One-eighth inch square holes were then added to the two sketches, such that the square holes in the two cams would be in line when the cams were at the desired angle. This would allow square stock, such as standard keystock, to be used as the axle and lock the cams in their proper position, as shown in Figure 16. The cams were then cut from 1/8" aluminum on the waterjet. A preliminary concern was the tolerances required on the square holes. Tests of six hole sizes were run to determine the ideal dimension that would allow the cams to slide onto the keystock, without being so loose as to rattle on the shaft. The keystock was turned down on each end both to be more easily connected to the servo motors, and to rotate more freely in the support sections on either side.

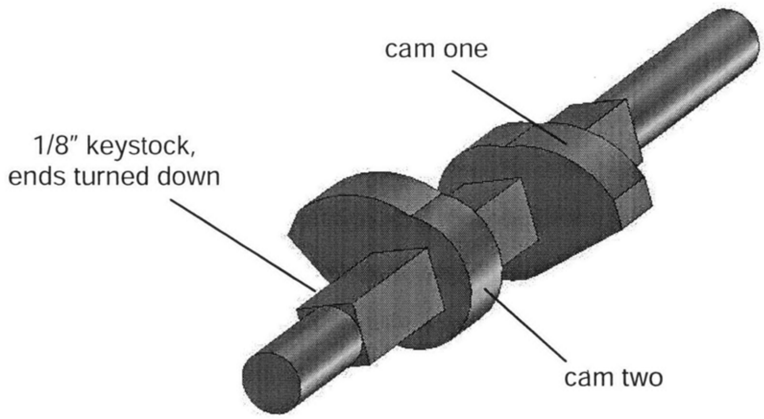

FIGURE 16: Camshaft assembly

5. Conclusions and future work

The goal of this thesis was to develop a working prototype for an electromechanical braille labeler that would improve upon the prototype developed in the fall of 2008. This began with an identification of the outstanding issues by having the prototype tested by blind and visually impaired people, who would be the target market for this product. These problems were addressed in the design stage of the second prototype, and finally a new prototype was built. This prototype has solved many of the concerns raised by reviewers of the first, and the next step is to bring this device to a stage at which it can be manufactured.

5.1. Long-term goals

This project has already achieved a measure of recognition, both at MIT and outside of it, for its potential to reach production. In May of 2009, this labeler won one of the MIT IDEAS awards, as well as the top award for a team-based undergraduate project at the DeFlorez Competition. The prize money from these contests will go towards the next steps of the process; namely, the patenting of the intellectual property, and the development of a beta prototype in preparation for full production.

It is expected that this work will happen in conjunction with a manufacturing company familiar with producing braille-related devices. Several such companies, both locally and throughout the United States, have expressed interest in continuing the project. Not only would these organizations have access to large-scale manufacturing facilities that do not exist on a college campus, but they would also have an initial access to the target market thanks to the brand recognition of products they have already released.

5.2. Ideas for expanded functionality

In considering what changes might be done to this labeler, there are two areas of focus. The first concerns the changes that would happen at the beta prototyping level. The second is a consideration of the aspects that could be expanded in future production runs.

For the beta prototype, the manufacturing processes would be quite different. The shell would be injection molded, and the plates around the embosser might be made of a single bent sheet of metal rather than several small pieces. The prototype, once complete, would be taken through extensive life cycle testing to verify the durability of the various components.

After a successful beta prototype, several additional features could be added. Some of these have come from direct comments from users who tested the first prototype. A common suggestion was to include transcription software and a USB port in the labeler, so that a person could connect the labeler to a computer and print directly from there. Additional software could read a label aloud after a person had typed it, to let the user know if he or she made an error before the printing was complete. Ultimately however, the first goal is to select a company that will manufacture this device.

Appendix

Braille Alphabet

⠁	A	⠅	K	⠥	U
⠃	B	⠇	L	⠧	V
⠉	C	⠍	M	⠺	W
⠙	D	⠝	N	⠭	X
⠑	E	⠕	O	⠽	Y
⠋	F	⠏	P	⠵	Z
⠛	G	⠟	Q		
⠓	H	⠗	R		
⠊	I	⠎	S		
⠚	J	⠞	T		

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Notes

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