Development of a Braille Watch for Use by Blind or Low Vision Individuals

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Worldwide, the Braille system provides 284 million blind individuals with a way to read and write [1], yet no device exists that allows these individuals to read the time in Braille. In order to tell time, the blind currently rely on either talking or tactile watches. However, talking watches are disruptive, while tactile watches are difficult to read and fragile. In order to improve on currently marketed products, a Braille watch prototype that allows blind individuals to read the time in standard Braille was created. The prototype was developed using the Viper si2 SLA rapid prototyping machine and utilizes four disks which each rotate beneath a set of four pins. The surface of each disk is divided into three rings: outer, middle, and inner, each of which contains raised and lowered surfaces cut into the face of the disk. As the disks rotate via a gear mechanism interconnecting the four disks, the pins are raised and lowered to display the desired numbers. An animation of the final design verified proper watch function as well as design accuracy. The design still needs to be manufactured using a more reliable and precise method, increasing the durability and reducing friction between moving parts in the final prototype. A driving mechanism must also be incorporated in order to produce a fully functioning watch. Additional future work includes performing functional testing on the completed prototype as well as searching for a company to aide in the development, mass production and marketing of the Braille watch.

1 Background

The Braille language is the universally accepted form of written communication for individuals who are blind and have low vision. It utilizes a system of dots arrayed in a three row by two-column grid. Raised dots are then located in any of the six positions, displaying different letters, numbers and symbols based on the configuration. As is shown in Fig. 1, the numbers 0-9 only use the top four positions of the three by two grid. In order for this method of communication to be accurate and precise, universal specifications have been developed. Each dot must have a base diameter of 1.44 millimeters (0.057 in.) while being 0.48 millimeters (0.019 in.) in height. Within each individual grid, the dots must be at least 2.34 millimeters (0.092 in.) apart, measured center-to-center, and each individual character should be a minimum of 6.22 millimeters (0.245 in.) away from the neighboring character [2].

1.1 Currently Used Devices. There are two types of watch products currently on the market for the blind: talking watches and tactile watches. Talking watches function by verbally relaying the time to the user whenever the user presses a button. This method is effective in communicating the time; however, it can be disruptive and draws attention to the user. Tactile watches, on the other hand, are silent. They function much like traditional analog watches, except the user must touch the face of the watch to feel where the hands are located. There are raised markings on the watch that indicate the positions of the numbers; however, there is no standard format for these markings, which vary from product to product. For this reason, these watches can be difficult to read and come with a learning curve when first used. Also, the hands of these watches are exposed to the user and, therefore, can be easily broken, damaged or bumped to display the incorrect time. In addition to the currently available products, there are several Braille watch concepts online, such as the Haptica Braille Watch created by David Chavez in 2008 [3]. However, these watches are purely ideas and no functioning Braille watch prototype has been created for any of these designs.

1.2 Design Problem Statement. In order to determine the time, the blind currently depend on talking or tactile watches. However, talking watches are disruptive, while tactile watches are difficult to read and fragile. Developing a watch that displays the time using the standard Braille number system would allow blind individuals to discretely, accurately and independently check the time. This device should be fabricated using durable and precise parts, have a self-contained power supply, use standard Braille spacing and be the size of a standard wristwatch.

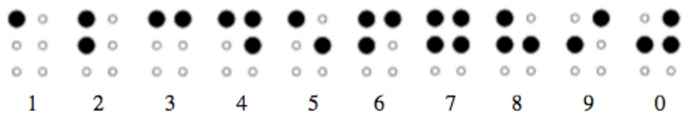

Fig. 1 Braille numbers 0-9 only use top four dots

2 Braille Watch Design

The following Braille watch was designed to display 12-hour time with an additional feature for AM/PM indication. Only hours and minutes are displayed with this design, although it could be altered to display seconds as well. The watch design consists of 3 distinct design features: the Braille pins, the disks and the gears. When integrated together, these components create a functional Braille watch.

2.1 Braille Pins. Each pin within the Braille watch design represents a specific Braille dot. By resting on either raised or recessed surfaces, these pins can rise above or remain flush with the watch surface respectively (Fig. 2). Since a total of four numbers are required to display the time, two for the hours and two for the minutes, and each number consists of four Braille dots, a total of sixteen pins is needed to display all numbers. Additionally, a 17^{th} pin is used to indicate AM or PM to the user. If the 17^{th} pin is raised, this indicates PM, while a lowered pin represents AM.

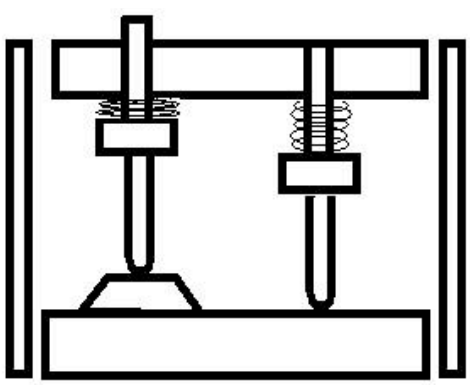

Fig. 2 The raised surface on the disk pushes the Braille pin to the surface of the watch

2.2 Disks. Each individual disk is patterned with a variety of raised and lowered surfaces (Fig. 3). Above each disk, four pins oriented with standard Braille spacing are stabilized to inhibit lateral movement but permit vertical movement. Allowing the pins to rest on the disk surface (Fig. 2), the pins are positioned over three concentric tracks of raised and lowered surfaces, with two diagonal pins positioned over the same track (Fig. 4). If a pin is on a raised surface, it will be pushed slightly above the watch plane, and if not, the top of the pin will remain flush with the surface of the watch. By fixing the position of the pins so that each pin is only able to move in a vertical direction, different combinations of pins can be raised and lowered by rotating the disk about a fixed axis. In this manner, different numbers can be formed. Fig. 5 shows how each disk corresponds to one of the four digits necessary to display time. Disk 1 and 2 are used to display the minutes, while Disk 3 and 4 are used to display the hours. Accordingly, each disk surface is unique since each disk must display a different set of numbers: Disk 1 displays numbers 0-9, Disk 2 displays numbers 0-5, Disk 3 displays numbers 1-9 and 0-2, and Disk 4 displays numbers 0-1. As was previously mentioned, since the watch displays 12-hour time, Disk 4 must contain a fourth track of raised and lowered surfaces in order to account for the AM/PM pin.

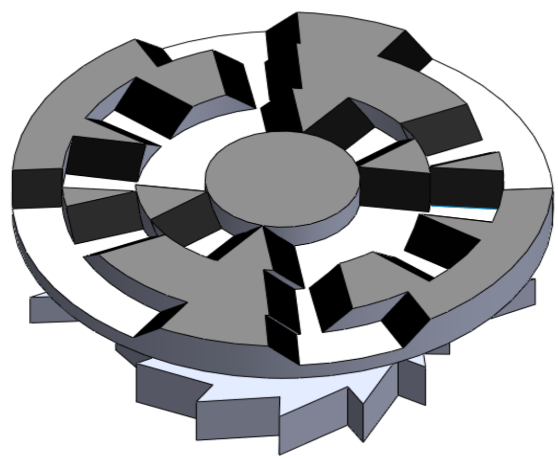

Fig. 3 Each disk has a variety of raised and lowered surfaces

2.3 Gears. A gear system was required to facilitate appropriate movement of each disk. Since the disks must be in a fix position in order for each number to be accurately displayed, this gear system needed to provide incremental rotation, such as that seen in a mechanical odometer, rather than a slow constant motion like that witnessed in an analogue clock. Fig. 6 demonstrates how this was done. By having a longer one-tooth gear interact with a shorter multi-tooth gear, a complete rotation of the one-tooth gear corresponds with a partial rotation of the multi-tooth gear. As the single-tooth gear continues

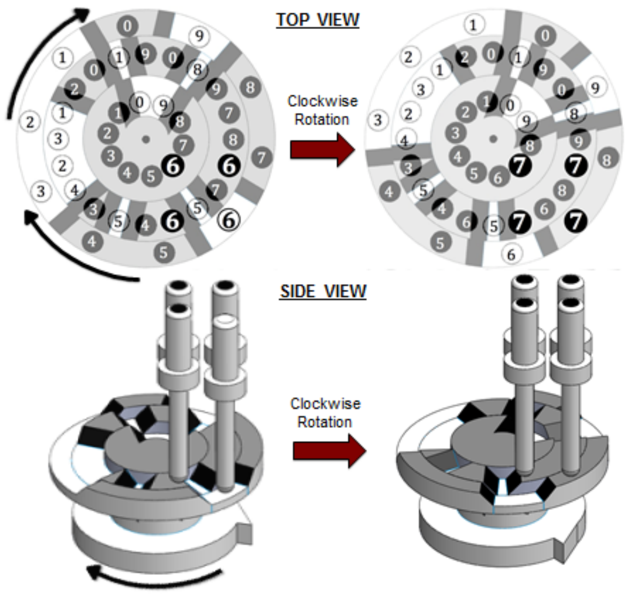

Fig. 4 As a disk rotates clockwise, different combinations of pins are raised and lowered and the user will detect a different number

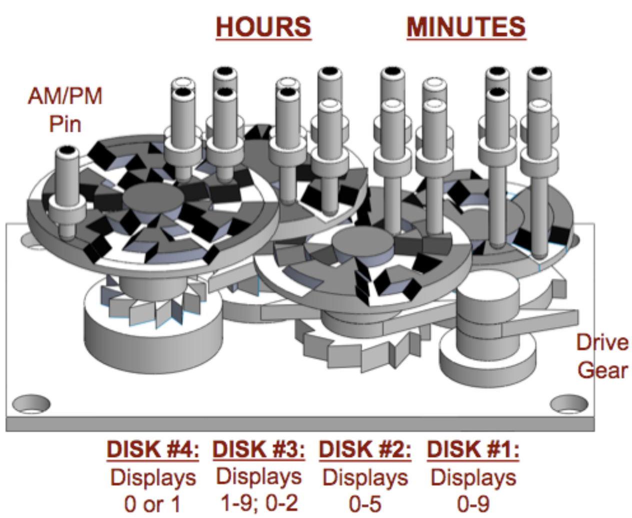

Fig. 5 Each disk corresponds to a different digit required to display the time.

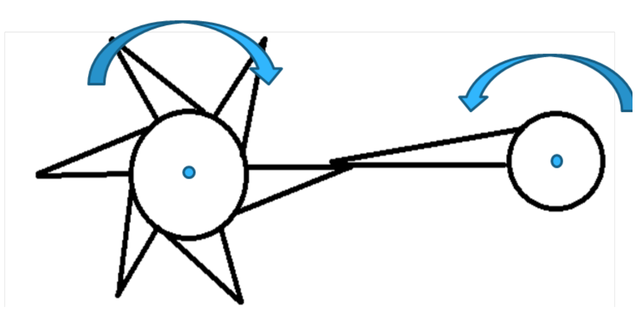

Fig. 6 A full rotation of the one-tooth gear on the right corresponds with a partial rotation of the multi-tooth gear on the left

to rotate, it will interact with the small teeth in sequential order and cause incremental rotation of this gear. By attaching the disks to the gears (Fig. 5), the intermittent motion of the gear translates to partial rotation of the disk, thus allowing the disk to display the appropriate number.

In order to create a functional watch, a driving mechanism, such as a motor, must be incorporated into the design. However, a constantly rotating motor could not be applied at Gear 1 since this would prevent Disk 1 from moving incrementally as is needed. Thus, an additional drive gear was added to the design (Fig. 7). This gear does not interact with any pins, but solely serves to rotate Gear 1. By moving at 1 RPM, the drive gear has the capability to control the entire watch. As can be seen in Fig. 7, the drive gear communicates with Gear 1, which interacts with Gear 2, which then rotates Gear 3, which, ultimately, controls Gear 4. Each gear corresponds to the disk with the same number.

2.4 Complete Assembly. While standard Braille spacing was achieved within each Braille character by properly spacing the Braille pins over each disk, standard Braille spacing between the Braille characters was also critical. This was achieved by overlapping the disks and then by placing the pins over different sections of each disk. Fig. 8 demonstrates how the pins were placed over the top right region of Disk 2 and Disk 4 and over the bottom right region of Disk 1 and Disk 3. This postitioning allowed Standard Braille spacing to be achieved.

Aided by the casing design, the assembly of the prototype is straightforward. First, the integrated gear and disk parts are placed on the corresponding axel in the bottom part of the casing. Although no driving mechanism has been implemented yet, once a motor is integrated into the watch, the drive gear will be incorporated into the design by being fixed around the axel of the motor. Once all the disks and the drive gear are in place, the middle portion of the casing is placed on top of the disks, enclosing the disks and gears between the bottom and middle portion of the casing. The pins are then appropriately placed in the holes located on top of the middle portion of the casing (Fig. 9). As can be seen in Fig. 5, the bottom of each pin is a different length and is designed based on the disk the pin interacts with; the distance between the disk surface and the top of the middle casing vary due to overlapping of the disks (Fig. 8). Once the pins are positioned in the middle portion of the casing, springs are mounted on the circular platform portion of the each pin. To finalize the assembly, the top portion of the casing is appropriately placed over the pins and the three sections of the casing are screwed together. Not including a motor, the final dimensions of the Braille watch design are 35.636 x 23.393 x 17.805 mm. (length x width x height).

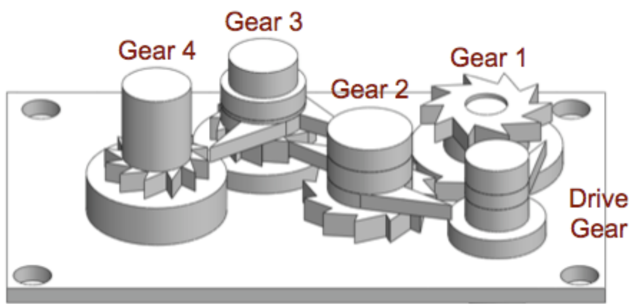

Fig. 7 1 RPM of the drive gear will control the motion of the entire watch

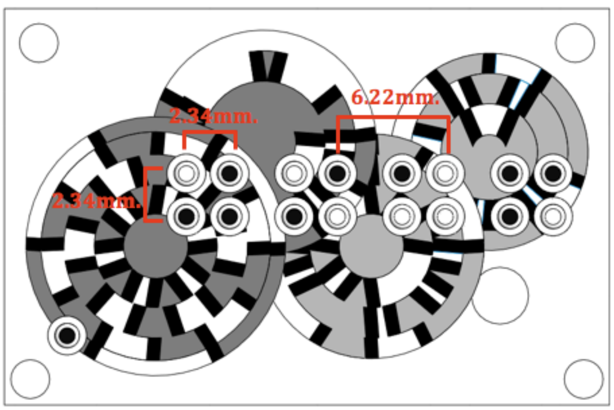

Fig. 8 Standard Braille spacing between the Braille characters was achieved by overlapping the disks

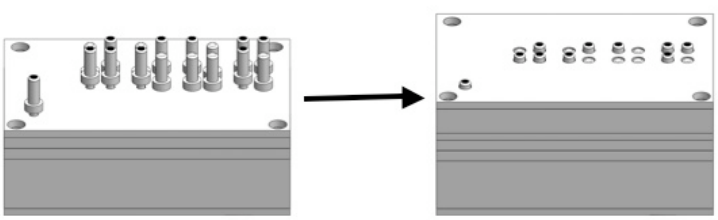

Fig. 9 Middle and top casing components support pins within a separate compartment

3 Design Fabrication

Current prototypes of the design have been manufactured using the Viper si2 SLA printer, a rapid prototyping machine capable of ~0.051 mm. precision [4]. While this approach has helped create a visual model of the Braille watch, there are many limitations to using this fabrication modality for the Braille watch. First, since the rapid prototyping machine prints parts in layers, the transition surfaces on the disks (the sloped surface between the lowered and raised portions) contained significant "steps". These "steps" create significant friction between the base of the pins and the surface of the disks. Additionally, the plastic polymer the printer uses to produce the parts is fragile, which leads to subsequent degradation and chipping of the gears. For these reasons, alternative manufacturing methods are needed to produce a durable and precise Braille watch. The disks and gears, specifically, provide the greatest challenge in the manufacturing process.

3.1 Disk Fabrication. Computer numerical controlled milling, or CNC milling, is likely the best candidate for disk fabrication. This process utilizes a rotating cutter head, similar to a drill bit, which is controlled by a computer program. Using computer-aided design (CAD) software, the CNC mill can be programmed to cutout any desired part with an accuracy of up to 10 µm [5]. Since the disks need to be made out of a durable material, aluminum, steel or stainless steel are the most likely material options. The University of Wisconsin Physical Sciences Lab (UW-PSL) is currently determining a quote for the cost of disk fabrication using CNC milling. Given that the price is within budget, the UW-PSL will likely fabricate the disks for the final prototype.

3.2 Gear Fabrication. In order to accurately manufacture the gears, the processes of photolithography and soft lithography were examined. Photolithography involves the process of shining UV light to transfer 2D geometrical shapes from a photomask to a substrate containing a photoresist chemical. The first step in photolithography involves the spin coating of the photoresist onto a Silicon base until the desired thickness is reached. Because the photoresist is the same height across the entire Silicon base, every part derived from this photoresist will also be the same height. Derived from CAD drawings printed onto a transparent sheet, the photomask is analogous to a camera negative when held between the photoresist and the UV light source. It is either colored black or left clear, with the UV light penetrating the clear areas and curing the substrate beneath it. The UV light serves to initiate cross-linking in the areas of the photoresist that it hits, curing it for the next stage of the process. This cured substrate is then washed away in a chemical bath, leaving only the areas that were blacked out on the photomask still intact on the photoresist. This final photoresist copy, now termed the "master", is carried over into the process of soft lithography.

The process of soft lithography involves an elastomeric material, such as PDMS, and a photoresist "master" created via photolithography. PDMS is poured over the photoresist "master" and subjected to two baking stages to cure it. After the second bake, the PDMS is solidified into a rubber like material that can be peeled off of the original photomask "master", resulting in a negative of the desired part. A variety of materials can then be poured into this mold in order to produce the final gears.

The main concern that arises from the photolithograpy/ soft lithography process lies in choosing the correct materials. Any material chosen to pour into the mold to make the gears must have a melting point lower than that of the mold, otherwise the molten material will cause the mold to melt. Since PDMS is used in nearly 98% of all soft lithography processes, it is the top choice for substrate material. However, with a melting point of around 200^{o} C, it eliminates the potential use of any type of metal as a gear material; thus, it is likely that acrylonitrile butadiene styrene (ABS) plastic will be used. While not as durable as metal, ABS plastic should be strong enough to withstand the gear forces, and with a curing temperature of 105^{o} C, it is useable with the PDMS substrate [6].

Since only one photomask can be used per "master" produced using photolithography, the gears must be fabricated in layers. In order to obtain correct alignment between gear layers, two small adjacent holes will be designed into each gear (Fig. 10). These two holes extend from top to bottom of the entire gear so that, when stacked and aligned properly, a pin can be dropped through the gear layer holes, aligning the gears to match the calculated gear orientations.

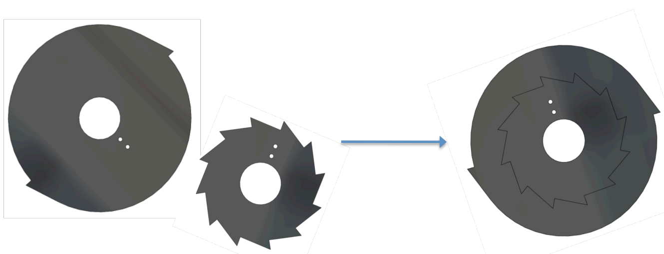

Fig. 10 During fabrication, gear layers are properly oriented by aligning layers corresponding to the holes extending through each layer

3.3 Long-Term Fabrication. Many of the fabrication methods discussed in this section are most applicable to the production of a single prototype. The approach for mass-production of the Braille watch, however, would likely use a different manufacturing process. Such an approach is injection molding. Injection molding involves the process of injecting a molten thermoplastic into a premade, negative mold of the desired part. Once the molten material has been injected into the mold, the mold is compressed by means of a clamping unit. Although a fairly simply process, the start-up cost is very high due to the cost of production of the negative mold. However, after the mold is manufactured, the only major cost is for materials, resulting in a much lower cost per unit over time when compared to other manufacturing methods [7]. For this reason, injection molding is the first choice for long-term mass production goals, but due to the high start-up costs, other methods are more suitable for simply producing a functional prototype.

4 Motor Implementation and Calculations

There currently is no motor incorporated within the Braille watch prototype. Implementation of a motor is critical to the production of a fully functional design. In order to successfully operate the watch, the motor must meet several requirements. First, the motor must be able to overcome the maximum internal force of the watch. Second, the motor must fit within the current footprint of the design. While there is some leniency in this criterion, the motor should not increase the watch dimensions past reasonable wristwatch size. Finally, the motor must be able to function on a long-lasting DC power source. A motor that requires frequent battery changes is undesirable since it increases inconvenience for the user and escalates long-term maintenance costs.

4.1 Force Calculations. When completing the force calculations, several design features had to be considered. There are four main friction forces functioning within the watch: the frictional force between the surfaces of the bottom of the gears and the bottom casing, the frictional force between interacting gears, the frictional force between the axels and the gears and the frictional force between the tips of the pins and surface of the disks. Other forces that must be considered are the work required to raise a pin from a lowered surface to a raised surface, the force of the springs pushing raised pins into the surface of the disks, and the weight of the entire pin, disk, and gear systems. It is critical to determine the maximum internal force that occurs at the drive gear since the chosen rotating mechanism must be able to overcome this force. Upon completion of force calculations, a motor can be chosen and power consumption estimates can be made. These predictions will be valuable in evaluating the competitiveness of the Braille watch against the talking and tactile watches currently on the market.

5 Future Work

Several steps are still required to produce a fully functional prototype. First, the watch must be manufactured out of durable materials using a more precise method than the rapid prototyping currently used. Ideally CNC milling will be used to fabricate the disks out of metal, while photolithography and soft lithography will be used to manufacture the gears out of ABS. Additionally, force calculations must be completed in order to complete the motor specifications for the design. Only then can a motor be chosen and implemented within the watch.

Once a fully functional product has been manufactured, product testing will need to be conducted.

While a recently created SolidWorks® animation of the watch verified that the design accurately displays all times as expected, this test should be repeated for the prototype to verify accuracy of the assembled watch. Another round of testing should measure the accumulation of any undesired debris (e.g., dirt, dust, etc.) on and within the various parts and compartments. In addition any wear that occurs at the gears, pins and the surface of the disks should be assessed to ensure that the product remains reliable over time. Battery life for the design will need to be determined as well.

Finally, the final product should be marketed. A patent application was recently filed at the United States Patent and Trademark Office for the Braille watch mechanism, and various companies that may have interest in a Braille watch product have been identified. Additionally, the market size is larger than previously believed. Not only could a Braille watch be helpful to individuals who are blind and have low vision, it could have applications for the military and elderly as well. This increased applicability should make the Braille watch even more appealing to companies and the general public. Ultimately, gaining the interest of a company will lead to the mass production and distribution of Braille watches worldwide.

6 Conclusion

A Braille watch was successfully created using a rotating disk, gear and pin mechanism. The final prototype met all major design specifications, with the exception of having a self-contained power supply and rotating mechanism. In the future, a motor will be integrated into the watch, and the final prototype will be fabricated using CNC milling and photolithography/soft lithography. Having verified the effectiveness and accuracy of the design using an animated model, hopefully a company willing to commercially market the watch can be found. This innovative prototype demonstrates that it is possible to create a Braille watch that is silent and easy to read, thus, improving the daily life of blind individuals.

Acknowledgement

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