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 design 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 watch accuracy and a prototype demonstrated functionality. Manufacturing the watch mechanism out of brass will reduce friction between moving parts. A driving mechanism must also be incorporated in order to produce a fully functioning watch.

1 Introduction

The Braille language is the universally accepted form of written communication for individuals who are visually impaired. 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].

There are two types of watch products currently on the market for the visually impaired: 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 touches the actual hands to identify the time. For this reason, these watches can be difficult to read and the hands of these watches are fragile. Various concept Braille watches have been developed, such as the Haptica Braille Watch [3]. However, there is no published mechanism and it is not currently marketed.

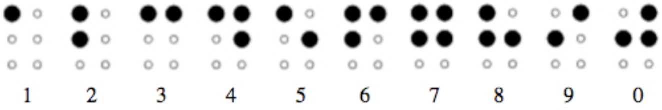


Fig. 1 Braille numbers 0-9 only use top four dots

A functional Braille watch will provide visually impaired individuals an accurate, a discrete and a user-friendly way to read time. A Braille watch prototype was created that utilizes a pin, disk and gear mechanism to display the time using standard Braille spacing. The design has been modified to ease mass-production, and a motor has been identified for use within the watch. This design is the first to prove that it is possible to create a functional Braille watch, which can be used to improve the daily life of visually impaired individuals.

2 Braille Watch Design

The watch design consists of three distinct design features: the Braille pins, the disks and the gears. When integrated together, these components create a functional Braille watch. The iteration described here displays 12-

hour time in hours and minutes with an AM/PM indicator, although other iterations are possible.

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, (minutes and hours), and each number consists of four Braille dots, a total of sixteen pins is needed to display all numbers. An additional 17th pin is used to indicate AM or PM to the user. The pins are positioned with standard Braille spacing and are stabilized to permit vertical movement and inhibit lateral movement.

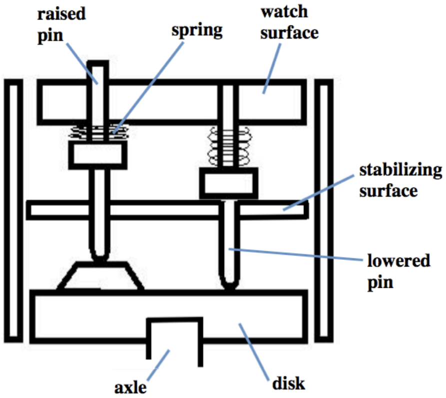


Fig. 2 A side view of the disk demonstrates how a raised disk surface can push a pin above the surface of the watch, while the watch casing and springs stabilize the pins

2.2 Disks. The disks are patterned with the appropriate raised and lowered surfaces (Fig. 3). Above each disk, four pins are positioned over three concentric tracks of surfaces, with two diagonal pins positioned over the same track. By rotating the disk about a fixed axis, the pins are raised and lowered in a numerical sequence. Fig. 4 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, 0-5, Disk 3 displays numbers 1-9, 0-2, and Disk 4 displays numbers 0-1, 0-1, 0-1, 0-1, 0-1, 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.

2.3 Gears. The gears and disks are combined into one component so that each moves synchronously with the other. The gear system was designed to incrementally rotate each disk at the required time and to keep each disk stationary between times. 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 (Fig. 5). The single-tooth gear interacts with the small teeth in sequential order, thus

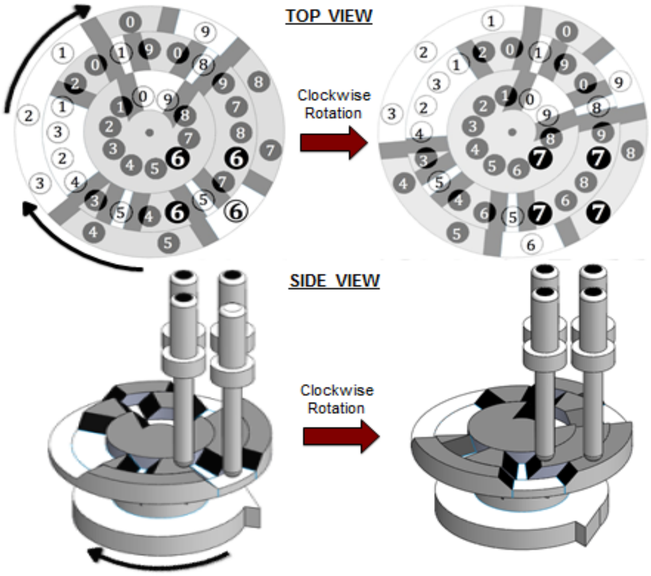


Fig. 3: Each disk has a variety of raised and lowered surfaces. As a disk rotates clockwise, different combinations of pins are raised and lowered and the user will detect a different number

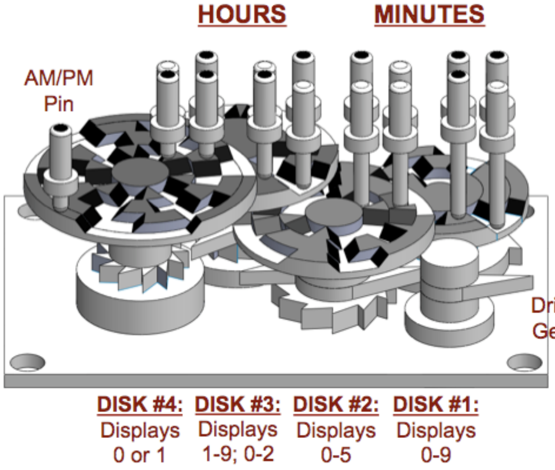


Fig. 4 Each disk corresponds to a different digit required to display the time. Standard Braille spacing between the Braille characters was achieved by overlapping the disks

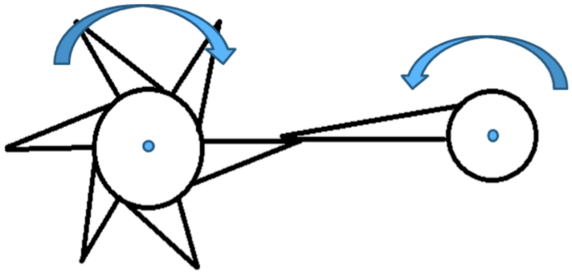


Fig. 5 A full rotation of the one-tooth gear on the right corresponds with a partial rotation of the multi-tooth gear on the left

causing the incremental and progressive rotation of the multi-tooth gear.

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. 4). 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. 4, 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. 4 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. 6). As can be seen in Fig. 4, 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. 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).

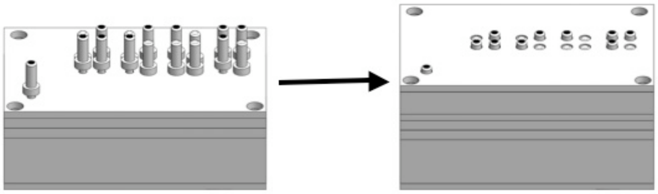


Fig. 6 Middle and top casing components support pins within a separate compartment

3 Design Fabrication

Current prototypes of the design have been manufactured using a 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. 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) contains "steps". These "steps" create significant friction as the pins slide along the surface of the disks. Additionally, the epoxy parts are 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. By dividing the disk and gear component into layers, molding and casting provides a precise, durable and inexpensive method for manufacturing the Braille watch.

3.1 Design Alterations. In earlier prototypes, 3D printing was used to manufacture the gears and corresponding disk as a single component. In order to ease the molding process, the gears and disks were broken into layers (Fig 7). Each layer contains a square-shaped hole through its axis, which a square-axle fits through, holding together and aligning each layer in the correct orientation. Master copies of the layered-parts and axles were then manufactured and used to make the molds.

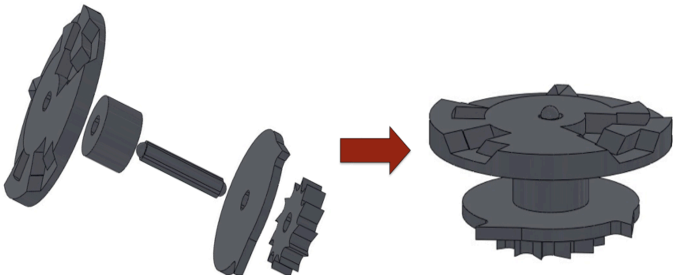


Fig. 7 Re-designing the custom gear and disk component into multiple parts allows for easier mass-production

3.2 Master Copy Fabrication. Computer numerical controlled (CNC) milling was used to manufacture the master copies of the disks. 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 cut any desired part with an accuracy of up to 10 μm [5]. Due to its low cost, durability and CNC mill-compatibility, aluminum provided the best material option for manufacturing the disk master copies. The final parts were durable and, unlike the rapid-prototyped disks, contained no “steps”.

CNC milling also provides the best option for fabricating master copies of the gears and axles. While this was not pursued due to a limited budget, CNC milling would be the optimal manufacturing approach in the future.

3.3 Molding and Casting. For prototyping purposes, a silicon based mold provides the best option due to its ability to withstand temperatures up to 340°C [6]. The molding process started by securing the master copies of the disks and gears to the base of a petri dish, which was subsequently filled with the silicone molding material. The petri dish was then placed into a vacuum chamber with a pressure of 15 mmHg where it was allowed to sit for 16 hours. After removing the molds, the gears and disks were casted using a urethane resin and six different lead- and tin-based metal alloys [7]. Of the metal alloys tested, the two alloys with the highest melting point, 147°C and 176°C, were found to provide the most accurate cast. While not as durable as the metal casts, the urethane casts were easier to work with and provided a smoother finish.

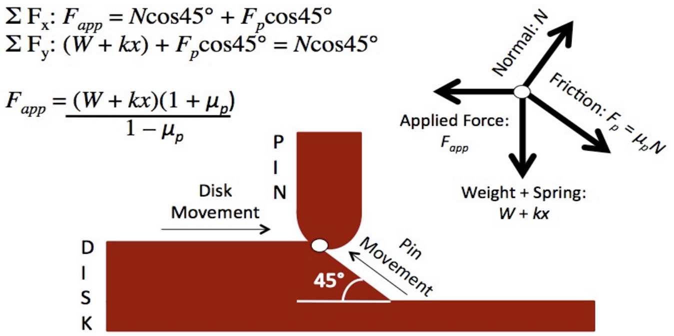
Ideally, in a mass-manufacturing setting, the parts will be spin-casted from brass using cast-iron molds. Brass provides durability, and its self-lubricating properties will lower friction within the watch. While the entire molding process comes with a high initial cost, parts can be inexpensively manufactured after these primary costs are incurred. With brass currently selling for $5.75 per kilogram [8], material costs would be $0.06 for the entire watch.

4 Force Analysis and Motor Implementation

To have a completely functional prototype, a motor or other operating mechanism must be incorporated into the current design. In order to successfully operate the watch, this driving mechanism must meet several requirements. First, it must approximately fit within the current footprint of the design. While there is some flexibility in this criterion, the driving mechanism should not increase the watch dimensions past reasonable wristwatch size. Next, the mechanism must be able to function on a long-lasting DC power source. A device that requires frequent battery changes is undesirable since it increases inconvenience for the user and escalates long-term maintenance costs. Finally, the driving mechanism must be able to overcome the maximum torque (τ_{max}) that occurs at the drive gear. This value was determined through a detailed force analysis of the watch.

4.1 Force Calculations. In order to determine the maximum torque required by a driving mechanism, a worst-case scenario was identified and modeled for the force analysis. This situation modeled all pins at the peak of the transition surfaces and all gears as interacting. While this never actually occurs since all 17 pins are never raised simultaneously, if the operating mechanism could overcome this modeled force, then it could overcome the actual maximum internal force.

When completing the force calculations, there were two main forces to consider: the force the pins and springs exert on the disk surfaces, and the friction between the bottommost gears and the surface of the bottom casing. The pins were modeled at the cusp of the transition surfaces since the pins exert a maximum force on the disks in this position (Fig. 8). The primary forces resisting the rotation of the disk are due to the compression of the springs and the weight of the pins. The force required to move the pins along the disk surface was solved for (F_{app}). The friction between the gears and casing were a function of the coefficient of friction, the surface area of the base of the gear, and the sum of the forces pushing down on the casing. After the pin and gear forces were calculated, each was translated into a torque measurement (Fig. 9). These calculations were then used to model the forces that occur between neighboring interacting gears. Fig. 10 demonstrates how the gear of Disk 1 must exert a torque



$$\Sigma F_x: F_{app} = N\cos 45° + F_p \cos 45°$$

$$\Sigma F_y: (W + kx) + F_p \cos 45° = N\cos 45°$$

$$F_{app} = \frac{(W + kx)(1 + \mu_p)}{1 - \mu_p}$$

Fig 8 The pins were modeled at the cusp of the transition surfaces; using a force diagram, the force the pin applies to the disk surface (F_{app}) was solved for

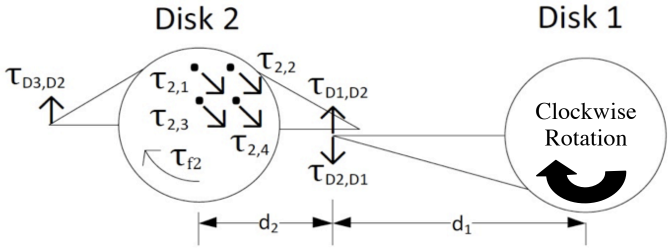
$$\tau_{Disk\#,Pin\#} = \frac{\rho_{pin} V_{pin} g + kx}{1 - \mu_p} (1 + \mu_p)(d)$$

ρ_{pin} = density of the pin (constant across all disks)
V_{pin} = volume of the pin (varies with given disk)
k = spring constant of springs holding pins in place
x = compression distance of spring
μ_p = friction between pin and disk
d = distance of pin from center of disk (varies with disk and pin)

$$\tau_{f,Disk\#} = \mu_c \frac{2}{3} \frac{r_{out}^3 - r_{inner}^3}{r_{out}^2 - r_{inner}^2} \left(n\left(\rho_{pin} V_{pin} g + kx\right) + \rho_{gear} V_{gear} g \right)$$

r_{out}= outer radius of base of gear shaft for given disk
r_{inner}= inner radius of base of gear shaft for given disk
n = number of pins for the given disk

Fig. 9 The forces from the pins (top) and base of the gears (bottom) result in a torque exerted on the corresponding disk as it rotates



$$\boxed{\tau_{D1onD2} = \left(\tau_{2,1} + \tau_{2,2} + \tau_{2,3} + \tau_{2,4} + \tau_{f2} + \tau_{D3onD2}\right)}$$

$$\boxed{\tau_{D2onD1} = \frac{\left(\tau_{2,1} + \tau_{2,2} + \tau_{2,3} + \tau_{2,4} + \tau_{f2} + \tau_{D3onD2}\right)}{d_2}(d_1)}$$

Fig 10 By modeling the torque each gear exerts on its neighboring gear, the maximum force required at the drive gear can be determined

on the gear of Disk 2 large enough to overcome all the opposing torques (τ_{D1onD2}). Consequently, Newton's Third Law states that the gear of Disk 2 exerts an equal force on the gear of Disk 1, resulting in a resisting torque on the gear of Disk 1 (τ_{D2onD1}). Applying this relationship between all gears of the system yields the maximum torque required at the drive gear, $\tau_{max} = 3.6\text{x}10^{-3}$N. Although a motor has not yet been implemented, this torque calculation falls within the capability of several micromotors with sizes smaller than the footprint of the watch [9].

5 Future Work

Implementation of a motor within the design will result in a fully functioning Braille watch, at which point 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. This design is easy to read, discrete and reliable. In the future, a motor will be integrated into the design, and the watch will be mass-produced using a cast and mold approach. Having an animated model verifies the efficacy and accuracy of the design and will help solicit a company to commercially market the watch. This innovative prototype demonstrates that it is possible to create a Braille watch that is silent and easy to read, thus, improving the quality of life of visually impaired individuals.

Acknowledgement

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