P-49.2: Rotating-Wheel Braille Display for Continuous Refreshable Braille

John Roberts
Information Technology Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA

Oliver Slattery and David Kardos
Information Technology Laboratory, NIST, Gaithersburg, Maryland, USA

E-mail: john.roberts@nist.gov, phone: 301-975-5683, http://www.itl.nist.gov/div895/isis/projects/Braille

Abstract
Refreshable Braille provides a critical path to display accessibility. High cost and reliability issues severely limit the market for existing Braille displays. A novel wheel-based design addresses reliability issues, and provides continuous Braille text with many-fold reduction in cost.

1. Introduction

The increasingly pervasive influence of information technology on daily life makes accessibility a higher priority than ever before. Millions of blind and visually impaired people in the US (and far higher numbers worldwide) need some form of non-visual access to information. Non-visual displays differ from visual displays, but some features and issues are strikingly similar to those of visual displays. Significant progress has been made with text-to-speech systems, but many users prefer the precision and the reading experience of touch-based Braille systems.

The widespread use of Braille displays has been limited primarily by cost and reliability issues. The cost to the user of a conventional 80-character Braille display is often $10000-15000 US, and maintenance costs can be around $500 per year. The primary cost and reliability factor is the large number of electromechanical actuators. Each 6- or 8-dot Braille cell requires six or eight actuators, with hundreds needed for the entire display. Smaller displays (e.g. 8-character) are available, but require the user to move a finger back and forth, raising issues of convenience and repetitive stress injuries.

Our objective in undertaking this project was to find a new approach to Braille display design that would significantly lower cost and improve reliability, and still provide a worthwhile reading experience approaching that of full-line (80-character) displays.

2. Origin of the Braille Project

In October, 1998, NIST hosted the first-ever general workshop on electronic books and electronic book reader devices, “Electronic Book ‘98”. This workshop and the activities of its participants led to the formation of the Open Electronic Book (OEB) Forum, and the development of the Version 1.0 OEB specification for electronic book file format. NIST has participated in the OEB Forum as a facilitator, providing an acting Chair, and conducting electronic book research to support the development of the standard.

At the workshop, there were calls for information accessibility – it was pointed out that with the book information available electronically, it is both feasible and important to include provisions for access using non-visual display. The primary non-visual display technologies are speech (synthesized speech, and in some cases recorded human speech) and touch-based Braille. Both have certain advantages: speech synthesizers are widely available, can be implemented in software, and require fairly minimal training for use, while Braille offers high precision (particularly useful for applications such as composition and computer programming), silent reading (for public use, teaching, speaker notes, and so on), and a fundamentally different reading experience from speech output that many users prefer. Despite the large price advantage of speech systems, there is strong interest in Braille displays, which have suffered a limited market presence primarily because of the high price (an 80-character Braille display, for example, can cost as much as $10000-15000, and even an 8-character display may cost as much as $1500-2000).

In response to calls for accessibility, and in support of electronic book standardization, NIST created the Accessibility for Electronic Books project. Speech-based systems are already readily available, with vigorous ongoing standardization activity, so it was decided to concentrate initial focus on finding a way to address the high cost of Braille displays, and to facilitate their use as an information interface. An analysis was therefore conducted of the characteristics and cost issues for existing Braille displays. A new Braille display technology developed, which is particularly well suited to portable applications such as electronic book readers, but which should also serve quite effectively in general purpose Braille display systems for desktop computers, Internet access, etc. The target in the development of this new technology was to reduce the cost of moving parts and drive electronics (not counting control electronics, packaging, and design of a consumer product) by a factor of ten or more.

3. Existing Braille Displays

Braille displays utilize electromechanical components rather than the light emitting or shuttering components of visual displays, but the basic function is the same – to convey information to the user. There are a number of Braille displays available on the market, from eight cells (characters) to eighty cells in length. The displays provide either six dots or eight dots per cell (originally Braille was always six dots per cell, but in some cases, particularly computer displays, eight dots are used). A common characteristic of the commercially available displays is that every dot of every cell is individually controlled by an actuator (solenoid actuators have been used, but piezoelectric actuators are now common), so, for example, an 80-cell, 8-dot display requires 640 actuators, plus the associated drive electronics for the actuators. The number of actuators is the primary cost factor in Braille displays. Displays with fewer cells (for example, the 8-cell displays) are available at lower cost, but the shorter line of text significantly reduces convenience.

4. The NIST Braille Reader

Since the primary cost factor of existing Braille displays is the large number of actuators, it was decided to address the cost issue by finding a way to greatly reduce the number of actuators needed, without the inconvenience of a short-line display. There have been attempts in the past to do this by creating a single-cell display, with the idea that the user would hold a finger over the single cell, and the dots would move up and down to produce a succession of characters, which the user would perceive and mentally reconstruct into text. Such devices have not been commercially successful, for two main reasons. First, the human sense of touch is most sensitive to the sensations produced by lateral motion (scanning) of the object being touched, thus the users could not readily feel the up-and-down motion of the dots in a single-cell display, without moving the reading finger side to side, which is tiring if it must be performed once per character. Second, Braille users mentally construct a geometric model of the layout of the Braille characters, and having all the characters apparently in the same place interferes with this mental process, much in the same way that sighted users have difficulty reading as text a succession of letters that appear in the same place on a visual display.

Another method that has been tested is to build a fingertip-sized array of pins with extremely close spacing (a millimeter or less, which is several times the density of Braille dots) and to control the up and down motion of this array of pins so that it creates the impression of a textured surface moving laterally under the fingertip. (This can be pictured as one of the “bed of nails” or “Pin Art” toys with hundreds of movable pins, with a hand laid against the pins on one side of the toy, receiving the tactile impression of an object that is moved across the other ends of the pins on the other side of the toy.) The virtual textured surface thus generated can contain the impression of moving Braille dots. Experiments with this design have been fairly successful, but unfortunately the need to concentrate the action of a large number of actuators (for example, a 1cm by 1cm display with 1mm pin spacing would require 100 actuators) has thus far prevented the development of a commercial product.

Our approach is to design a display for which only a few actuators need be in operation at any given instant, but which gives the user an impression of reading an infinitely long line of Braille text. This is done by putting the Braille text on a rotating wheel or disc. Instead of moving fingers over a motionless line of text, the user puts one or more fingers against the wheel, and the Braille text moves underneath the finger, producing a sensation of motion, providing sufficient stimulus for the sensors in the fingertips, and allowing the user to construct a mental model of the geometric layout of the text. The wheel or disc has a specified “reading area”, the arc of the circle where the user can touch the surface to read the Braille. The text on the wheel remains constant (relative to the body of the wheel) within the reading area, and is updated (“refreshed”) outside of this reading area. The impression the user receives is therefore that of a static line of text moving under the fingers.

5. The First Generation Prototype

In order to test the validity of the design concept, it was necessary to construct a working prototype. For our first-generation prototype, we chose a disc architecture – the Braille text is laid in a circle on the face of a rotating disc, somewhat like the sidewall stripe on an automobile tire. The display is designed for reading with just one finger, and twelve actuators (enough for two Braille cells) are required to drive the reading area. To hold the total number of actuators down to twelve, each pair of cells is coupled to the adjacent pairs of cells, so the Braille dots are raised or lowered in a repeating 2-cell pattern around the disc (Figure 1).

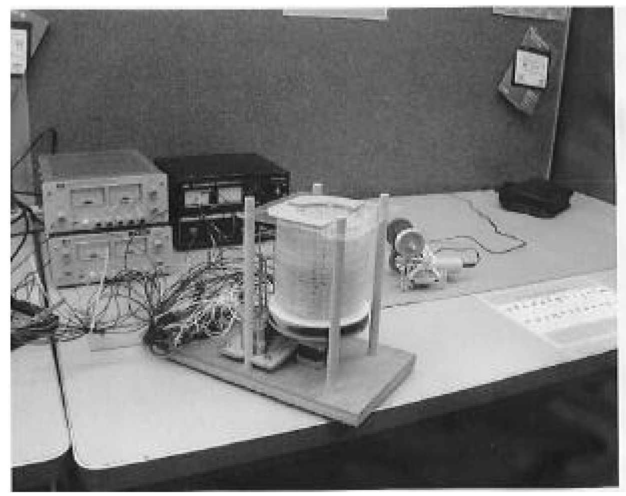

Figure 1. The First Generation Prototype

The display is connected to a computer, which is programmed to receive text (ASCII, word processor file format, or more recently Open Electronic Book specification format) and to drive the rotation of the disc and the motion of the Braille dots to produce Braille text. The speed of rotation of the wheel (and the associated speed of presentation of Braille text) can be adjusted by the user.

This first-generation device is a proof-of-concept prototype. It demonstrates that moving Braille text can be generated inexpensively (the parts cost for the display was about $200), and shows how a production device might operate, but the tolerances for the prototype (for example, the height and shape of the dots) and the limited speed of operation make actual use for reading difficult. In addition, operational controls for a blind user have not yet been implemented, and it is necessary for a sighted user to set the parameters through the control program’s graphical interface. Nevertheless, the prototype has been sufficiently operational to permit evaluation by a number of Braille users, to guide the further progress of the project.

6. Feedback from the User Community

Following the completion of the prototype, the project was announced at the Electronic Book '99 workshop in September, 1999 at NIST in Gaithersburg, Maryland, and on several accessibility electronic mailing lists. A number of Braille users have also visited the lab and an exhibition at the Maryland Technology Showcase in Baltimore, Maryland, and offered their analyses. The feedback following these announcements and demonstrations is being used to guide the course of research, and the development of a second-generation prototype.

All those who have offered comments have favored the concept of a high-performance, low-cost Braille display. There has also been considerable interest in the use of this technology in a portable device. Concerns have been primarily in the areas of readability and user controls.

Readability: While many users read Braille with one finger, many others prefer to use multiple (up to four) fingers, and mentally combine the sensations from all the fingers. Since the first prototype uses a repeating 2-cell pattern around the wheel, it can only be read with one finger. We have therefore decided to concentrate future efforts on devices that set the Braille dots at one point in the rotation of the wheel, providing an extended reading area for use with multiple fingers. Other users have pointed out that since Braille is traditionally provided in a static mode, reading moving text may be difficult or less preferable for many. We agree that static text will always have certain advantages, and it may require the lower price of the rotating wheel technology to persuade some users to make the effort to learn to read moving text. (In a simple demonstration with rotating fixed text, approximately half of experienced Braille users have been able to read the text immediately with no additional training - we consider this to be encouraging evidence that a high percentage of users can learn to read moving text on a production device.) We are also working on several ways to use this technology to produce static text, the simplest being the addition of a “Stop/Start mode”, in which the wheel rotates and writes enough text to fill the reading area, then stops while the user reads, then upon a signal from the user produces another segment of text. This mode may be applied immediately by new owners of production devices, while they are learning to read in continuous rotation mode.

User controls: The top priority among those who have commented is a means to control the speed of the wheel (and correspondingly the speed of presentation of text) on the fly. In other words, users want to be able to change speed even mid-word, for example to hurry past words that they have already guessed from context. Another high priority is the ability to re-read the previous few words, in the same way that users of linear Braille displays or sighted users of visual displays can go back and check a word. Others have expressed interest in electronic book features, such as sentence/paragraph/page forward/back navigation, search, dictionary, bookmark/annotation, and so on. An additional important feature is position information – the user should be able to press a button, vocalize a command, or some other stimulus, directing the display to stop presenting the text and let the user know which paragraph/page/chapter is currently being read. Many of the requested user control features require a context change (an interruption of the normal sequential presentation of text). Our approach at present is to signal a context change by blanking out all text displayed for a short period of time – the wheel continues to rotate but with no text displayed.

7. The Second-Generation Braille Reader

We are constructing a second-generation Braille reader prototype in order to address the issues raised by Braille users, permit realistic testing of the Braille reader features, and support the electronic book standardization effort.

7.1 Second Generation Design Approach

The new prototype is based on a rotating wheel, with the Braille text on the rim of the wheel like the tread on a tire. A small number of actuators (three actuators for 6-dot Braille, four actuators for 8-dot Braille) set the Braille dots at one point in the rotation of the wheel, and the text remains stable and readable over an extended reading area, allowing multiple-finger reading. To make this writing mode possible, and also to further lower cost of the Braille display, we have developed a new tactile display control technology called the “Passive Pin Displacement System”. This new approach utilizes fixed, unpowered devices that are moved relative to the Braille dots by the rotation of the wheel, for the control of the dots and their associated pins for most of the rotation of the wheel. Active control is used only at the point in rotation where the actuators set the reading positions of the pins.

To visualize the operation of the passive pin displacement system, picture a Braille pin in the shape of a simple flat-headed carpenter’s nail, except that the end that would be pointed on a nail is cut off flat, with rounded edges. This end, when raised a specified distance above the reading surface, forms a Braille dot. The “nail head” end of the pin is used to control the position of the pin, as it moves with respect to non-rotating structures mounted inside the wheel. The two primary passive structures are ramps, and a position retention device. The motion of a pin head against a solid ramp can force it to move to the extended position, with a Braille dot protruding from the reading surface. A different ramp design can force the pins to the recessed position – such a ramp must have a slot down the center to make room for the passage of the shaft of the pin, while the ramp contacts the inner face of the head of the pin. One type of ramp or the other is used at some point in the rotation of the wheel (outside the reading area) to force all the pins to a “default” position, before they encounter the actuators. The actuators shift the position of selected pins to the non-default position to create the Braille text. Immediately after the actuators is the position retention device. This may be generally described as a slotted track along which the heads of the pins move, with the slot wide enough to accommodate the shaft of the pins, such that for the extended pins, the head of the pin rides “on top” of the structure (toward the outer rim of the wheel), while for the retracted pins, the head of the pin is kept “underneath” the structure. The position retention device therefore holds each pin in the position that was set by the actuators. This device underlies the reading area of the wheel, and prevents the pressure of the reading fingers from pushing the Braille dots into the surface (Details in Figure 2, wheel structure in Figure 3).

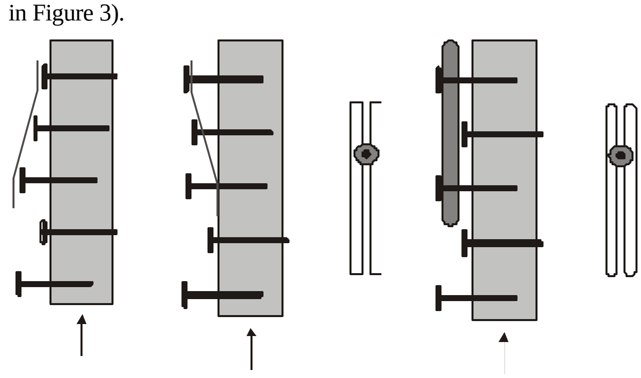

Figure 2. Ramps and Position Retention Device

The advantage of the passive pin displacement system is its extreme simplicity (thus low cost) and ruggedness of all of the mechanical components. Having only three or four actuators also greatly reduces the cost and complexity of the drive electronics. It is hoped that this design approach can lower costs for the mechanical parts and drive electronics of a Braille display to a few cents per pin. The wheel edge structure (Figure 3) also permits compact design - potentially, a portable reader package could be the size of a portable CD player.

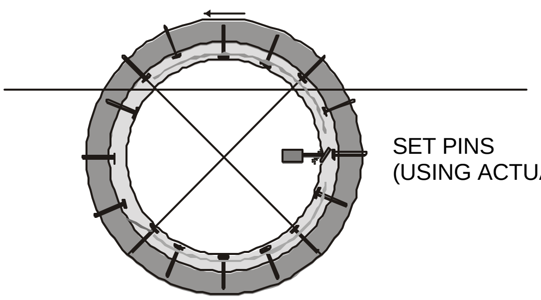

Figure 3. Wheel Architecture, with Passive Devices and Actuators

7.2 Design Issues

The chief design issues that have been identified thus far are:

- **Dimensional tolerances:** must be chosen to provide smooth operation, and regulation Braille text.
- **Preventing jams:** the passive position retention device must be shaped so that occasional pins that are not fully in the extended or retracted positions do not jam the device.
- **Component wear:** because the design includes mechanical motion, component materials and lubrication must be selected to minimize wear.
- **Actuator speed:** determines the maximum speed at which Braille may be displayed.

7.3 Extensions of the Design Approach

The technology developed for the rotating wheel Braille display can be applied to other touch-based display applications:

7.3.1 Line-oriented displays

The pins are mounted in a fixed, line-oriented display. The actuators and passive pin positioning devices are mounted in an assembly that moves underneath the bed of pins. The Braille text is written from one end of the line to the other in a scanning process, after which the user reads the line of text before refreshing the display to bring up the next line. Such a display is more complex and expensive than a wheel-based display, but should still be far less expensive than a conventional (one actuator per dot) line display, and it offers the advantage over the wheel approach of permitting the user to read full lines in static mode, the same as a conventional display.

7.3.2 Page (multiline) displays

Braille users who read printed Braille are accustomed to a multiline format, while the high cost of Braille cells has generally limited users of refreshable electronic Braille displays to a single line of text. If a passive pin displacement linear display is sufficiently economical, it may be practical to combine multiple lines of text into a page mode display (one writing head with three or four actuators per line). As an example, a 40-column, 15-line page display with 6-dot Braille would require 45 actuators using this design, versus 3600 actuators using a conventional design.

7.3.3 Graphic displays

Graphic displays, which depict two-dimensional images, with line drawings, textures, and possibly relief (multiple height) information, have been a long-term goal of the blind community. Graphic printers are available and highly valued – unfortunately they put a fixed output on paper or other media, and thus are of limited use in applications such as rapid scanning of many images, as would be done while “surfing the web”. As a long term goal, if dot pitch can be made sufficiently fine, and if issues such as feature roughness (analogous to the “jaggies” in a visual display) can be resolved, this technology may make refreshable tactile graphic displays practical.

8. Progress to Date

The technology used for the first generation prototype and that being used to develop the second generation prototype have been incorporated into a patent application. Research on the electronic book project is implementing Braille reader accessibility. The first-generation prototype is being used in the development of user controls and software, and development of the second-generation prototype is underway. NIST is looking for companies interested in using this technology to manufacture tactile displays – there have been several expressions of interest. NIST is also interested in the possibility of collaboration or other research opportunities.

9. Summary

Information accessibility is important for access to electronic media, and Braille is an important non-visual display method, which has been limited in use largely by the high cost of displays. We have developed a technology that can result in a massive reduction in the cost of manufactured Braille displays. Experiments to date have shown the basic validity of the design approach, and we are continuing research to further demonstrate the merits of this design, and increase the benefits it provides. Numerous comments from Braille users indicate that this design approach has high potential, and will serve an important purpose.

10. Acknowledgements

- Victor McCrary and the rest of ITL/NIST management for support of the Accessibility for Electronic Books project.
- The NIST Advanced Technology Program for its support of electronic book research.
- Fernando Podio, for suggesting a Braille electronic book.
- The many Braille users and members of accessibility organizations who have provided comments and advice.

11. References

[1] "Investigative Approaches to the Study of Braille Reading", Emerson Foulke, PhD, University of Louisville, Ky, Journal of Impairment and Blindness, American Foundation for the Blind, Vol. 73, No. 8, Oct. 1979, pp 298-308, http://www.braille.org/papers/invea/invea.html

[2] Handbook of Perception, Volume VIB, Feeling and Hurting, Ed. Edward C. Carterette and Morton P. Friedman, Department of Psychology, UCLA, Academic Press, 1978.

"The 400-Pin Tactile Stimulator Array", the JHU Somatosensory Labs http://www.med.jhu.edu/somlab/lab/research/methods/400pin

ISSN0000-0966X/00/3001-0000-$1.00+.00 © 2000 SID