Development of a Portable Braille Display Using a Fast Prototyping Platform for Power Electronics

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Abstract

This paper presents the design of a horizontal rotating wheel Braille display, using the advantages of a fast prototyping platform for power electronics (FPP). The prototyping platform performs the control of four linear electromagnetic actuators, one DC-motor and can communicate via a serial link with a PC.

1 Introduction

In order to offer visually impaired people the same possibilities for computer use as sighted people, a tactile interface is necessary to replace the computer screen. The Braille alphabet, worldwide used by blind people, offers such a tactile representation of the regular alphabet and other characters needed in general. An example of the sentence ‘hello world’ is given in Figure 1.

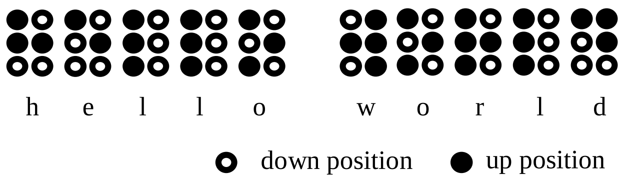

Figure 1: Example of the Braille alphabet

To recognize a relief pattern like Braille, the movement of the tactile sense with respect to the relief is indispensable [5, 15]. Refreshable linear Braille displays (Figure 2) have already been developed in the past. For reading, fingertips slide over the pins of the Braille cells, just as with ‘paper Braille’. Existing refreshable Braille displays consist of 20 to 80 Braille cells allowing one line of text to be shown at a time. They are generally large and expensive. Small displays only contain a single or a few Braille cells, with pins pushing up to the fingertips. However, they are not as successful as larger displays because the skin is more sensitive to lateral movement than to orthogonal pressure. The sensation of the lateral movement, however, can be achieved with a rotating ring concept.

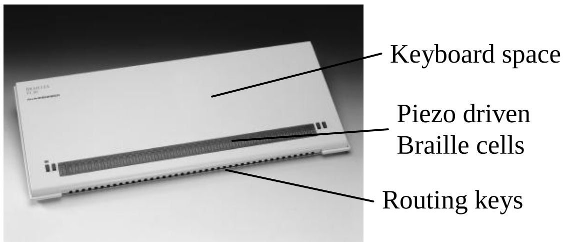

Figure 2: Commercial refreshable Braille display

2 Design concept

The concept of the rotating wheel has some advantages over existing Braille displays. Moreover it is less expensive, mainly due to the use of a smaller number of actuators. Also higher reading speeds can be achieved.

2.1 Rotating wheel concept

The frictional sensation of moving over a line of Braille characters without the need of a long and bulky linear display, is achieved with the rotating ring concept [6, 14]. The rotating wheel display consists of a stationary reading finger sliding over the dynamically located reading pins of a Braille cell on the rotating wheel. This wheel, on which 40 Braille cells are located, rotates inside a housing, driven by a permanent magnet DC motor (Figure 3). Only a single part of the ring can be ‘read’ in a window (‘3 character display’), the remaining part of the ring is covered by the housing. As the wheel rotates, a new cell enters the window in the housing. Just before this point, the reading pins have to be set: all pins take a predetermined position according to a particular letter of the Braille alphabet (Figure 1). Once a Braille cell is located in the window, pins should retain their position. After leaving the window, pins have to be reset.

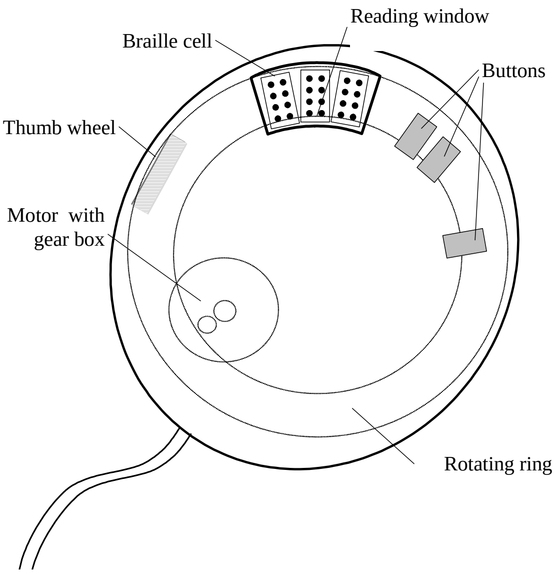

Figure 3: Design concept of a Braille mouse

The rotating ring concept also permits infinite text lines, and thus increased reading speed because the hand no longer has to return to the beginning of the line [12].

2.2 Reading pin positioning

To retain the pins in their position while appearing in the reading window, by preference energy consumption is avoided. Permanent magnets or mechanical systems can fulfill this requirement.
In regular Braille displays a holding force of 0,1 N is sufficient. This force could be generated with small permanent magnet rings connected to the reading pins (Figure 4). Electromagnetic simulations, verified with measurements on a prototype, showed holding forces of 0,1 N can be reached [13].

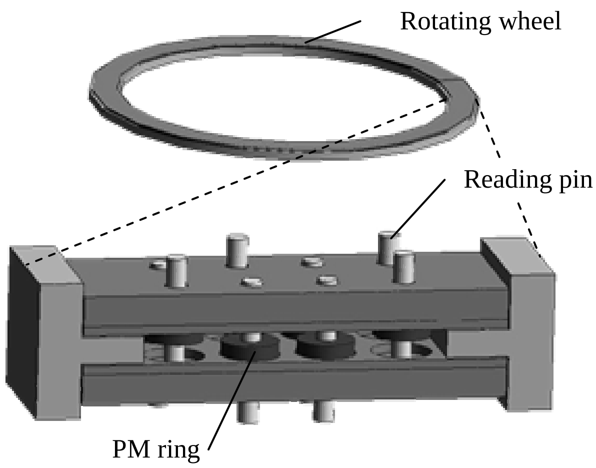

Figure 4: Permanent magnet ring holding concept

However when a reading finger slides over the reading pins, a force higher than 0,1 N can be exerted on the pins, accidentally resetting a pin. As the pins are not activated in the reading window any more, higher holding forces are required. A mechanical blocking rail system delivers enough holding force [12].

For bringing the Braille pins in their appropriate positions, only 4 actuators are necessary, compared to 640 actuators for a regular large linear display. Each of those 4 actuators controls a circle of the rotating wheel (Figure 3). All pins on a circle are activated successively by the same actuator.

Commercial Braille displays almost always use piezoelectric actuators. In this concept they can not be used because they are too slow. The time for activating a reading pin is calculated to be 4 ms [11]. Therefore, a special Braille setting actuator was developed. Different actuator concepts were compared [2], followed by simulations of electromagnetic actuators (Figure 5) [11].

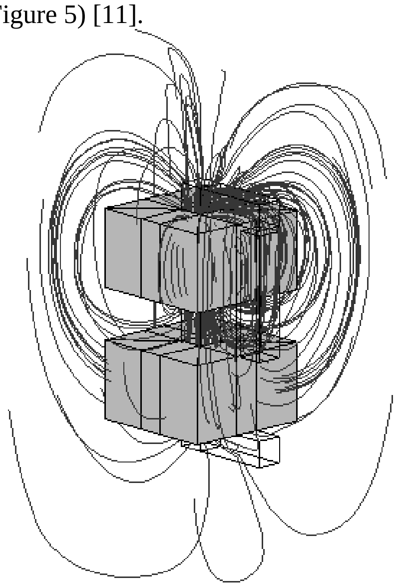

Figure 5: Flux lines in a 3D-model

As a result the 4-in-1 Braille setting actuator, being able to set 4 reading pins simultaneously, was developed [11]. This actuator combines 4 moving coils with one set of stationary permanent magnets (Figure 6). According to the Lorentz law, the forces generated are proportional to the applied coil current.

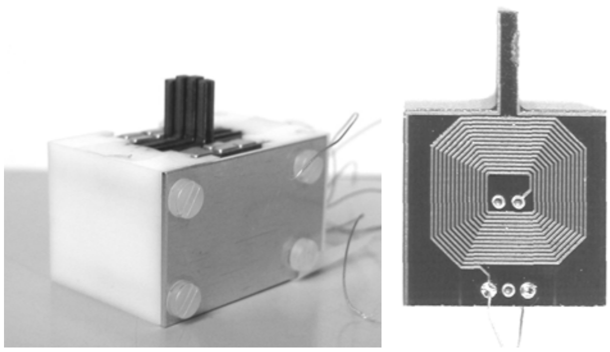

Figure 6: Prototype of the 4-in-1 actuator

Simulations indicated a current of 1 A generates more than sufficient force for the speed requirements. However, friction results in lower forces and thus in higher current demands (Figure 7).

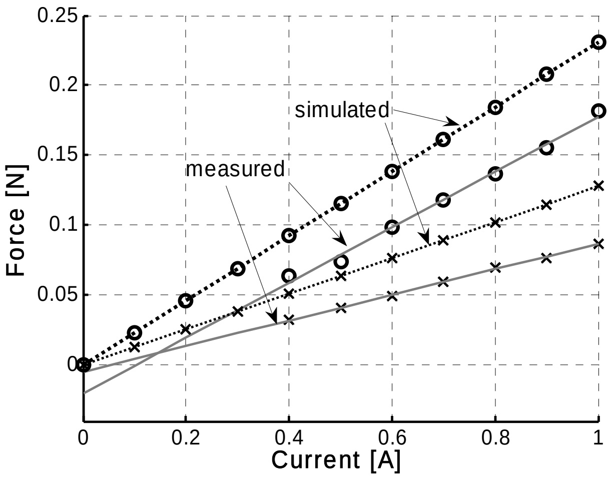

Figure 7: Simulated (dotted) and measured (full line) force as function of the current for 2 coils of the 4-in-1 actuator.

2.3 Motor

The maximum rotating speed of the ring has to be proportional to the maximum reading speed of the user. The maximum reading speed determined by tests, corresponds to 14.4 characters per second [7], which results in a rotation speed of 24 rpm. To allow this reading speed the ring of the Braille Mouse has to be driven at low rotational speed. A gearbox can be used, but is not necessary. The motor has to deliver a sufficient torque to accelerate or brake the ring, to compensate for friction losses and to counter the variable resistance of the finger during reading. For the prototype a permanent magnet DC motor is used (Table 1).

U_{nom}	6 V
P_{nom}	1.2 W
T_{max}	2.7mNm
n_{max}	10900 rpm

Table 1: Rating plate of RE13 [8]

3 Control scheme

This paragraph presents the requirements for the control unit of the Braille mouse. The main tasks of the control unit are a controller for the motor, based on the desired and actual speed, and a control algorithm for the 4-in-1 actuator.

3.1 Control unit

Inputs of the control unit are the Braille text that has to be represented, the desired reading speed and the actual position and speed of the rotating wheel, measured with optical encoders. Outputs are signals for the motor and the Braille setting actuator (Figure 8).

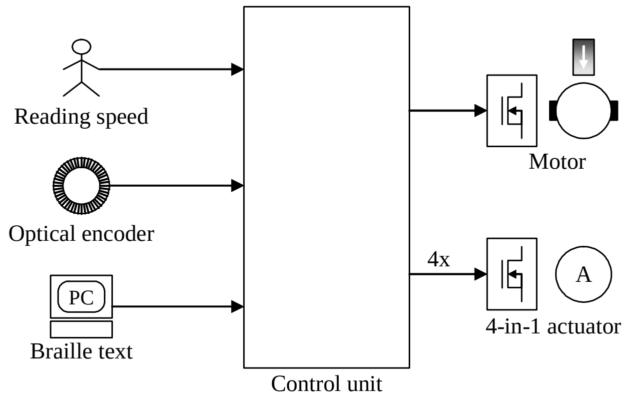

Figure 8: Block diagram of the Braille display control

The user indicates his desired reading speed with a thumb wheel mounted on the housing of the Braille display (Figure 3). An incremental encoder sends this signal to the control unit. The optical encoders on the rotating wheel give the actual position, direction of rotation and an initializing signal at the beginning of each Braille cell.

The control unit processes all inputs and calculates the setting control signals of the actuators and the control signal of the motor. There are 13 I/O signals (Table 2).

2	Serial port: communication with the pc
3	Position measurement
2	Desired speed
4	Setting actuator
2	Control of the motor

Table 2: I/O signals of the control unit

3.2 Motor drive

The first task of the control unit is the control of the motor. The thumb wheel mounted on the housing of the Braille display imposes the desired speed of the motor. The speed is controlled with a PI-controller (Figure 9) [3].

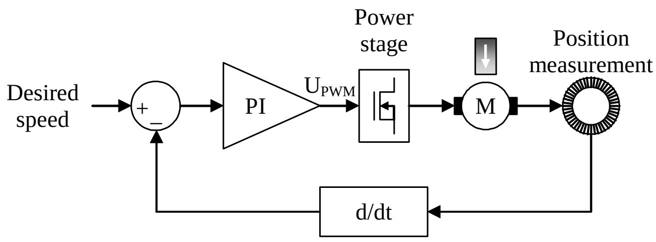

Figure 9: (PI)-controller for the motor

To prevent oscillations in the output of the control circuit, dither is added. Dither is a high frequency signal and is added to the driving signal U_{PWM}. This results in a smoother rotation at low reading speed [1].

3.3 Actuator

The Braille actuator has to set the appropriate Braille pins, depending of the actual rotating wheel position and the desired Braille character. However, because of the inertia of the actuator and Braille pins not only the actual rotating wheel position, but also the speed has to taken into account. As collisions of the reading pins with the mechanical rail system sometimes occurred, an extra routine was implemented. This routine performs a short reverse rotation of the wheel and restarts the setting of the Braille pin.

The force developed by the 4-in-1 actuator is proportional to the current I_A. As the desired force is not constant, so is the current (Figure 10). At time t_1 the coil has to move fast enough upwards, pushing the Braille pin above the mechanical blocking rail system. Subsequently the coil has to stay in that position with a limited holding force till the reading pin has moved into the blocking system. Finally the coil is pulled down at time t_4 in order to be ready at time t_6 for activating the next reading pin. As mentioned before, the times t_1-t_6 depend on the reading speed.

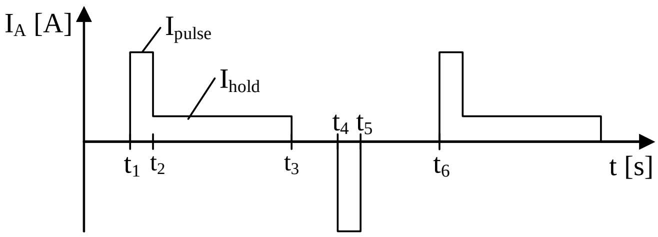

Figure 10: Desired actuator current as a function of time.

3.4 Reading

The text created by the Braille display has to correspond to the text appearing on the PC screen. Screen reader software [4] translates this text to Braille ASCII and sends it to the serial port of the PC. The control unit translates the ASCII code into Braille, using a look-up table.

4 Implementation on FPP

Although a microcontroller is well suited for the implementation of the control unit, a fast prototyping platform (FPP) was used during the development phase [16]. Due to the difficulty of modeling a practical system, hardware-in-the-loop testing systems are increasingly used. Those systems use reconfigurable controllers with the actual system to evaluate a controllers' algorithm performance.

This platform contains a modular inverter system, consisting of four identical push-pull IGBT output stages, used to drive the 4-in-1 actuator. In order to control the motor an extra power electronic stage is connected to the processing core. The L293 is an integrated circuit motor driver for control of the small motor.

The processing core of the FPP is a Texas Instruments (TI) 'C6711 DSK. A daughter card with an Altera EP1K100 FPGA provides the outputs to the drive circuits for both motor and actuator. The FPGA also decodes the high-speed serial digital data streams for output current and dc voltage measurement in the inverter. Moreover it processes the quadrature encoder pulse signals from the position sensors and provides a serial data link with the PC for the Braille text. During development, the FPP is connected to TI's Code composer Studio-software on PC for monitoring measurement and control signals and adapting program code on the fly, enabling short design-and-test cycles.

5 Results

5.1 Evaluation by blind users

An important difference between existing Braille displays and the new concept is the movement of the text. Normally fingertips slide over Braille characters, but in this concept the sensation of moving over a line of Braille characters is achieved by a lateral motion of the Braille characters. Moreover, the circular shape causes a small distortion of the Braille characters. The distortion is noticeable by blind users, but it is not annoying on one condition: the diameter of the disc may not be too small.

Studies have proven that the reading speed is restricted by bringing the reading hand back to the beginning of a new line [9]. This takes 10% to 20% of the total time to read a line. Thanks to the concept of the rotating wheel this movement is no longer necessary and higher reading speeds could be achieved. However, tests on this prototype showed that high reading speeds are not achievable because of the increased probability of collisions between pins and the mechanical rail system. The number of collisions measured by test in function of the reading speed showed that with the prototype speeds above 10 characters per second are not achievable (Table 3).

Speed [characters/s]	Number of collisions per rotation	Probability of collision [%]
2.7	0.60	1.51
4.5	0.32	0.79
5.5	0.33	0.82
7.3	1.05	2.62
8.2	1.43	3.57
9.1	1.94	4.86
10	2.67	6.67

Table 3: Number of collisions in function of the reading speed

The maximum reading speed is restricted by the setting speed of the pins. When a reading pin moves upwards too slowly, there can be a collision of the pin and the mechanical rail system. Reading tests, based on the MNREAD test [7] show those collisions are annoying, even though the control takes care of them in order to prevent wrong character representations.

5.2 Implementation on the microcontroller

A fast prototyping platform was used during the development phase, but also a microcontroller is well suited for the implementation of the control unit. A suitable microcontroller needs 13 I/O pins (Table 2).

An implementation of the program is possible on a microcontroller AT89C5131, an 8-bit flash microcontroller with full speed USB device. This microcontroller contains 5 PWM modules, so the PWM generation can be performed in background.

6 Conclusion

A tactile refreshable Braille display has been presented, which offers blind people a reasonably priced opportunity to interact with a computer. The control of the rotating wheel display is developed on a Fast Prototyping Platform, enabling an efficient design-and-test cycle. Problems solved are e.g. collisions of the pins with the mechanical rail system and speed-adaptive control of the 4-in-1 actuator.

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