A 64-Solenoid, Four-Level Fingertip Search Display for the Blind

Sarah Frisken-Gibson, Paul Bach-Y-Rita, Willis J. Tompkins, and John J. Webster

Citation

Taking $z$ transforms and solving, we get the transfer function $H(z)$

$$H(z) = \frac{Y(z)}{X(z)} = \frac{(1 - \alpha)(z^2 - 2z \cos \omega T + 1)}{z^2 - (\alpha + (1 - \alpha)2 \cos \omega T)z + (1 - \alpha)}$$

where the substitution $N = \cos \omega T$ has been made.

We can see that $H(z)$ represents a linear, shift-invariant digital filter with unity gain at dc, zeros on the unit circle in the $z$ plane at $\pm \omega T$, and poles just behind the zeros. In other words, $H(z)$ represents a fixed notch filter at 60 Hz. Changing $\alpha$ simply changes the location of the poles and thus, the transient response of the filter.

As stated above, the analysis given here simplifies (6) by replacing $d \times \sin (f(nT + T))$ with $\alpha \times f(nT + T)$. Without this replacement, the original algorithm is only a close approximation to a linear time-invariant notch filter, slightly slower in convergence (transient response) and with some internally generated noise, its amount dependent on the size of $\alpha$.

The plotted signals shown in Fig. 2 of the paper are described as showing the learning and unlearning characteristics of the adaptation algorithm. The same plots are, of course, what would be obtained when observing the transient response of a fixed notch filter.

The result here can be compared to results presented in [2]. There, an adaptive notch filter is described; but when the reference signal is a deterministic pure sinusoid, the filter simplifies to a fixed time-invariant notch filter. In a sense, (1) generates the pure sinusoid, thereby giving similar results.

In summary, because the proposed algorithm uses an internally generated reference, the algorithm is not truly data adaptive. Its performance vis-a-vis any 60 Hz components in the signal or interference will be the same as that of a fixed notch filter, except that some additional internally generated noise will be introduced.

**REFERENCES**


---

**A 64-Solenoid, Four-Level Fingertip Search Display for the Blind**


**Abstract**—This paper describes the design and prototype model of a nonvibrating fingertip search display device. It was designed for use in experiments to determine the importance of fingertip exploration in tactile vision substitution. An $8 \times 8$ array of miniature dc solenoids mounted on 5 mm centers forms a raised two-dimensional display. With the aid of an IBM PC, it translates a visual image into a contour map of raised pins similar to transitory braille. The four possible pin heights of 0, 0.33, 0.67, and 1 mm represent discrete levels of image intensity. The user controls the location and resolution of the image sent from the IBM PC to the display by moving a mouse.

**INTRODUCTION**

In the 1960’s and early 1970’s, considerable effort was directed towards the goal of building a complete vision substitution system for the blind. The initial goal was to replace sight by supplying visual information to the blind user through an alternative sense such as hearing or touch. The initial system design assumed that a blind person would walk down the street with a miniature camera attached to a pair of glasses, thereby learning about the visual surroundings as the camera coded the visual data and supplied it through another sense.

In demonstrating the brain’s plasticity and its ability to adapt remaining senses (such as touch) to replace lost or damaged senses (such as vision or hearing), Bach-y-Rita showed the theoretical feasibility of vision substitution [1]. A number of systems have been developed and tested but few have ever been used beyond the laboratory [2]–[6]. High costs, large size, high-power demand, and the problem faced when trying to filter out some of the barrage of information present in real world situations have impeded the commercial realization of such devices.

**MOTIVATION**

The hypothesis that one can learn more by active exploration than by “passive touch” has existed for some time. Defining “active touch” as exploration of an object with the fingers and “passive touch” as having familiar visual forms pressed into the skin, Gibson [7] concludes that “the experience of active touching and looking are more nearly equivalent; they are more alike to introspection than those of passive touch and vision.”

In addition, since a blind person is already highly experienced with haptic exploration (exploration with the fingertips), a vision substitution system that could be haptically explored might be both more easily interpreted and more easily adapted to. These ideas indicated a need to study the value of haptic exploration in vision substitution and led to a suggestion of the need for a “raised 2-D display to be scanned with the fingers” [4]. With this suggestion in mind, we began the design and development of the haptic display device.

**REQUIREMENTS AND A REVIEW OF POSSIBLE SOLUTIONS**

Because we designed the haptic display device for experimental purposes, many of the inhibiting requirements that accompany sensory aid systems—such as portability, low power needs, and low cost—were not a primary concern. Instead, we concentrated on designing and building a device which was most suitable for doing research on the value of haptic exploration.

The following is a list of our initial design goals.

1) High spatial resolution: This required that the display elements be as closely spaced as possible and that the display be able to represent a large image with as much detail as possible.

2) Gray scale: Optimally, we wanted as many as 16 intensity levels represented. As a minimum, we required the device to have more than two levels (black/white).

3) IBM PC controlled: For flexibility, we wanted to control image processing, controlling signals, and timing as easily as possible so we chose to interface the device with a PC rather than using a dedicated microprocessor.

4) Fast response: We wanted to be able to change the image quickly as well as to represent a moving object. This required fast response of the display elements.

5) Nonvibrating: Almost all existing tactile sensory aids use vibrating stimulators. We had used vibratory tactile displays in pre-
vious projects and were interested in exploring the value of a non-vibrating display.

6) Comfort: The display had to be easily and comfortably scanned with the hand.

With our list of requirements, we considered as many ways of transmitting information haptically to the skin as we could imagine. These methods included electrotactile [1], [2], thermal, and mechanical—including pressurized fluid jets [8], [9], mechanical latches, and electromagnetic solenoids [1], [2]. Maure, formerly at the American Foundation for the Blind in New York, began work before his death on a two-level haptic display in which pins were mechanically latched into place. This work had not been completed when this paper was written. All the other methods involved vibration or pulsed stimulation as well as other properties that would not allow us to satisfy our requirements. Our choice was to use nonvibrating miniature dc solenoids.

**SYSTEM OUTLINE**

The haptic display device consists of an 8 × 8 array of miniature solenoids, controlling circuitry, and an IBM PC. The solenoids are spaced 5 mm apart giving total display dimensions of approximately 40 × 40 mm. Each solenoid has a special spring system which allows the head to take on four discrete levels at heights of approximately 0, 0.33, 0.67, and 1.0 mm above the zero level.

Each solenoid is supplied with the discrete levels of current needed for the four head positions via a simple current source. The control voltage is supplied to the 64 individual solenoid circuits in a raster scan fashion from a digital-to-analog converter controlled by the IBM PC and a sample-and-hold circuit holds this voltage steady between refreshes.

Fig. 1 shows a system diagram. A PC captures the image using a digital camera [10] or retrieves a previously stored image. It then sends the 8 × 8 portion to the display. To select the desired portion of the full image, the blind user moves a mouse (Microsoft) to “scan” the image. A square portion of the full image surrounding the mouse cursor is then processed and sent to the display.

**SOLENOIDS**

The display elements are miniature dc solenoids (Electromechanisms SP-18, 6 V) mounted in two layers to permit the close spacing of the display elements. Fig. 2(a) and (b) shows the spacing and layout of the two layers. The spacing between solenoid heads is 5 mm which gives row and column lengths of 35 mm.

A solenoid’s pushrod is forced upward to three different possible levels by dc currents of 80, 100, or 120 mA. This upward force opposes the downward force of a nonlinear two-spring system. The power consumption of the 64 solenoids is about 30 W when all solenoids are in the fully on position. Thus, a fan is necessary for cooling.

**SOFTWARE**

The software controlling the haptic display device sends an 8 × 8, four-level image to the display in a raster scan motion. In advance we determined the voltages required to drive each solenoid to the different desired levels. We then stored the corresponding values in a lookup table which is accessed whenever data are sent to the display.

The blind user “scans” the full image by moving a mouse about the table top. The use of the mouse follows the development of a time-division multiplexing device built in this laboratory that was designed to present the blind subject with more information than a small display can provide [11]. The software monitors the position of the mouse and selects a square portion of the image around the mouse cursor. The intensities of the pixels in this square portion are averaged over areas corresponding to the 8 × 8 display elements. Intensities are coded into four levels and this processed image is stored on the data array accessed by the software which sends data to the haptic display device. These data are updated whenever the mouse is moved. The scan path is recorded for studies of a user’s progress with the system and of important features in object recognition.

**DISCUSSION**

We completed a number of studies to test the achievement and perceptibility of the four heights. We found that four stable and equally spaced head heights were attainable using the spring device described above. In a test of head height repeatability, we found in tests of applying the four different current levels to a solenoid that the head heights had a standard deviation (SD) about their mean of less than 8 percent of their mean value (for example, at the head height of 0.33 mm, we measured an SD of 0.02 mm). As a preliminary test of perceptibility of the four head heights, we presented eight subjects with a sequence of 100 random heights. Each subject was given a 5 min training period before the test. Six subjects detected the head heights easily and quickly with less than three errors in 100. One subject had difficulty distinguishing the two lowest levels and made nine errors in 100 trials. One subject always detected the three different levels, but often shifted the level upward, mistaking level 0 for 1, level 1 for 2, etc. Both the subject and the experimenter agreed that his training session had been inadequate.

We tested one level of the 8 × 8 device (32 solenoids) and found that the software and the electronics worked satisfactorily, although we felt that some improvement in mouse tracking speed could be made. The problem lies in reading and storing graphics data from the screen and might be improved with the use of Assembly language. We assembled the two-level 8 × 8 device (64...
solenoids) and discovered several physical problems that we will improve upon in future models. Since the springs were individually cut by hand, there were variations in the two intermediate heights from solenoid to solenoid. A possible solution is custom made conical springs with length-dependent spring constants. Friction between the pushrods and the Plexiglas plate created a major physical problem, sometimes altering a solenoid’s response to the controlling current. Also the wires routed between the solenoid layers in some cases interfered with the upward motion of the pushrods. An aesthetic problem with the display is that it is quite noisy. When the solenoids move to the fully on position, they make an audible click that is distracting.

More details of design, software, and testing of the prototype model are available [11].

CONCLUSIONS

We were generally encouraged with the results of experiments with our prototype model. We feel that it satisfied the requirements we set out to achieve. We will use the knowledge gained from these experiments and from observed problems to complete the final design of the haptic display device.

REFERENCES


Angle Independent Ultrasonic Detection of Blood Flow

GREGG E. TRAHEY, JOHN W. ALLISON, AND OLAF T. VON RAMM

Abstract—We present a new technique for blood velocity imaging based on tracking the motion of the speckle pattern produced by blood. Unlike Doppler velocity determinations, these are angle independent. Initial in vivo experiments yield promising results.

Manuscript received June 24, 1987; revised August 14, 1987. This work was supported by the Whitaker Foundation and DHHS NIH Grant CA-37586 and DHHS NCI Research Grant CA-43334.

1These images were provided to us by Diasonics, Inc., whose assistance we gratefully acknowledge.

0018-9494/87/1400-0965$01.00 © 1987 IEEE