Vibrotactile Glove Guidance for Semi-Autonomous Wheelchair Operations

H. Uchiyama
hajime@uga.edu

M. A. Covington
mc@uga.edu

W. D. Potter
potter@uga.edu

Artificial Intelligence Center
The University of Georgia
Athens, GA 30602-7415

ABSTRACT

This paper describes the use of a tactile display, the Vibratactile Glove, which provides a wheelchair user who has severe visual impairment with essential information to operate a powered wheelchair, such as directions and spatial representation. In the absence of visual information, the user receives a series of vibration signals that indicate obstacles or desired directions in the environment. The vibration signals are conducted to the operator's skin through a 3-by-3 array of vibrating elements (also known as vibrotactor). The vibrotactor array is placed inside of a glove so as to face the back side of the hand. Using the vibrotactor array, sequences of aligned stimuli indicating directional guidance (vertical, horizontal, and diagonal) and points of stimuli indicating obstacles (vibration of any of eight periphery tactors) are generated. The haptic sensitivity of stimuli localization is reinforced by signal repetition with short inter-stimuli period. The preliminary results reveal the positive potential of the Vibrotactile Glove as an effective and robust tactile display that can convey essential information of wheelchair operation to a user with severe visual impairment.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Assistive Technology

Keywords

Semi-autonomous Wheelchair, Tactile Display, Vibrotactile Glove

1. INTRODUCTION

Studies have shown that all disabled individuals, regardless of their age, benefit substantially from access to independent mobility, including electrically powered wheelchairs [3, 11, 15]. Independent mobility increases vocational or educational opportunities, reduces dependence on caregivers, and promotes a feeling of self-reliance and self-esteem. Unfortunately, some individuals are unable to independently operate a powered wheelchair due to their impairments of motor, sensory, perceptual, or a combination of these. In the aim of assisting individuals with multiple disabilities, a number of studies have been conducted in the field of assistive technology which combine robotics and artificial intelligence to develop autonomous wheelchair control [9, 16, 2, 10, 8].

These autonomous wheelchairs are equipped with a computer and various types of sensors, and address specific problems such as: obstacle avoidance, local environment mapping, and route navigation. With autonomous control, the system probes the environment, detects an obstacle, plans a navigation route, makes decisions, and actually controls the wheelchair, which leaves the user totally dependent upon the equipment.

While some users may be comfortable with the autonomous wheelchair transportation system, others want to be more involved with the process. It is essential for them to feel as if, or actually, they are in control, while being responsible for both the decision-making and motion of everyday transportation activities rather than being a passenger.

A semi-autonomous (SA) wheelchair is an electric powered wheelchair containing perceptual and navigational capabilities, which provides just as much assistance as the user really needs. In order to develop an appropriate SA wheelchair system, the type of assistance must be determined based on the user's physical conditions. We have chosen a typical SA wheelchair user who is wheelchair-bound with severe visual impairment, but is tactilely and audibly competent with fine motor control of the upper extremities. The SA wheelchair autonomously acquires sensory inputs from the environment, processes them, and provides navigational information transformed to fit the user's available sensory resources, such as audible or tactile perception.

Communication between the user and SA wheelchair via a versatile and robust man-machine interface plays an important role to achieve successful transportation activities. For those who have visionary impairment, only limited ways to communicate are available, either in auditory or tactile. Auditory communication, such as voice navigation or warning beepers, may seem to be the easiest or most appropriate way to acquire the information from computers. However, making noise might be socially inappropriate on certain occasions. Also, hearing the contents of the auditory information may be disturbed by the background noise of an environment. Furthermore, additional sound sources are undesirable with respect to preserving the user's resource of attention since people with severe visual impairment extensively use their own auditory sensory system to collect the environmental information.

Human tactile perception is robust and suitable for multimodal sensing[4]. Some researchers have defined a tactual display as a device which presents information to the individual by stimulating the perceptual nerves of the skin[7]. While people with blindness already use their haptic sensory system (e.g. using a cane), the somatic sensory system at another cutenous area is still largely available. Since the user passively receives most information, an effective form of tactual information should comprise vibrations (*vibrotactile signals*).

The communication between the user and SA wheelchair should consist of various kinds of vibrotactile signals conveying information via human tactile perception. Previous work evaluating a variety of tactile feedback systems has shown substantial potential of these kinds of communications [5, 7, 13, 12, 14, 17]. For example, some researchers have derived several benefits by studying the cutaneous sensory saltation in order to develop a haptic interface[12]. The sensory saltation may provide directional information that requires an otherwise highly intuitive grasp. It can be established by relatively simple hardware configurations, such as an array of tactors, and can be perceived on many body sites, such as the fingertip and the back[1].

Our goal is to develop a useful vibrotactile display which is to be used in part of the SA wheelchair system. In this paper, we design some selected vibration patterns in order to evaluate the potential of our vibrotactile display, facilitating translation from visuospatial to vibrotactile information.

2. DESIGN

In our design, we conclude that the vibrotactile display should reasonably be located at the hand because we have defined that our users can operate the SA wheelchair with little or no problems using their hand. The fingertip, by contrast, would not be a convenient place for using a vibrotactile display because many individuals with severe visual impairment already use their hands to control a joystick, hold a cane, and read Braille signs by their fingertips. Further, a display mounted on the back seat would not be ideal because the users would frequently need to adjust themselves to put their back against the seat.

Although the palm side of the hand is much more sensitive in tactile perception than the back side of the hand, the volar flexion during the joystick operations makes it difficult to design a robust vibrotactile display which guarantees consistent pressure of a vibrotactor to the skin. On the other hand, the back side of the hand maintains its flatness better during the joystick operation. Therefore, we chose the back side of the hand as a locus of the vibrotactor.

Since our purpose is to convey translated visuospatial information to the user, an array of vibrotactors should obviously be employed rather than a single vibrotactor. The choice of an appropriate size of array depends upon the area of the

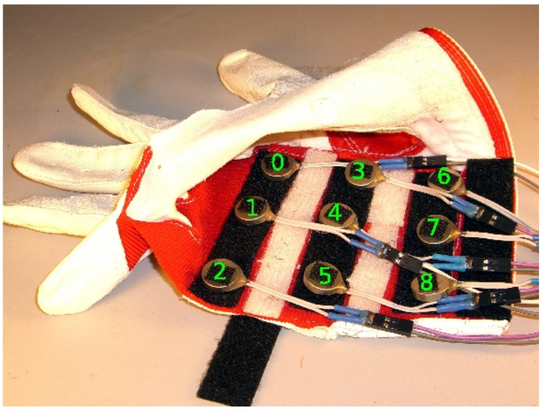

Figure 1: The layout of the vibrotactor array on the back side of the glove.

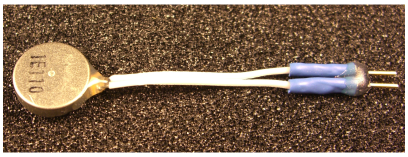

Figure 2: The vibrotactor consisting of a vibrating disk motor and connector pin.

locus, the size of each vibrotactor, and the tactile sensitivity of the corresponding cutaneous area.

Naturally, a suitable form of carrying the vibrotactile display is a glove (*Vibrotactile Glove*). The Vibrotactile Glove consists of the vibrotactile array inside the glove so as to face the back side of the hand and a motor-array controller, which generates and sends signals to the vibrotactors.

2.1 Vibrotactile Array

The vibrotactile array consists of vibrotactors aligned in a three-by-three arrangement with nearly equal inter-tactor spacing (Figure 1). The space varies from one to one-half inch according to the size of the user's hand. We used an ordinary baseball glove and cut it on the little-finger side to make it easier to install the vibrotactor array. Each vibrotactor is attached inside of the glove by Velcro®and contains a miniature vibrating electric disk motor attached with a connector pin (Figure 2). The vibrating motor is thin, lightweight, and characterized by an off-centered weight causing lateral vibration when the specified voltage (3 V) is applied. It is also fully self-contained in a housing shell, thus no moving parts are visible.

2.2 Motor-array Controller

The motor-array controller is a single-board computer that was built to control an array of vibrating disk motors. The controller receives input from a PC by a serial port and executes predefined patterns of vibration in an array of up to 16 motors. The vibration patterns are defined in an assembly-language program.

The prototype of the motor-array controller is shown in Figure 3. The CPU is an Atmel AT89C55, a flash-memory

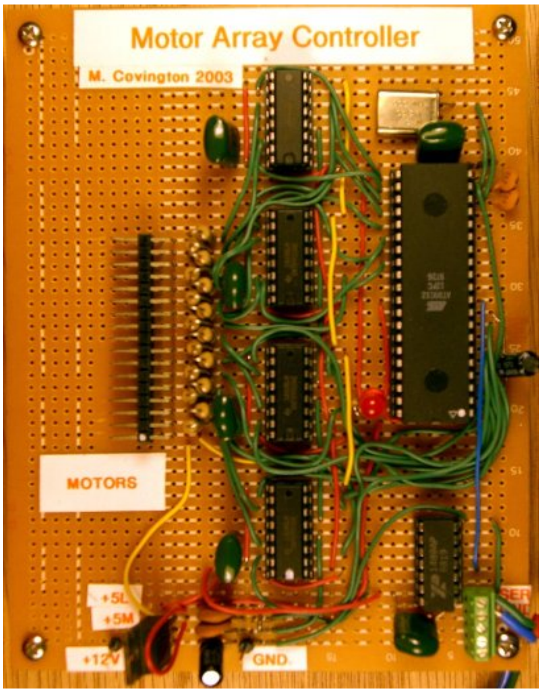

Figure 3: The prototype of the motor-array controller.

derivative of the Intel 8051 (MCS/51) with the same instruction set. Serial input is received through an MC1489A or equivalent RS-232 line receiver. Two of the CPU's output ports (P0 and P1) are coupled to the motors through SN754410 motor control ICs.

2.3 Vibrotactile Signal Patterns

All the necessary information to operate the SA wheelchair must be symbolized as a set of signals, so that the system is able to transmit the signals to the vibrotactile display to generate vibrotactile signal patterns. The vibrotactile signal patterns for the SA wheelchair operation are categorized into three groups: warning signal, spatial representation, and directional guidance.

Warning Signal When an emergency situation occurs in which the SA wheelchair determines that it is too dangerous to drive the wheelchair or finds any sort of system malfunctioning, the warning signal is invoked, and the user must stop the wheelchair movement.

Spatial Representation The spatial representation is translated from visuospatial information to help the user to "sense" the orientation and distance of an obstacle.

Directional Guidance The directional guidances are designed to navigate the wheelchair user in the desired direction (e.g. "go-forward," "turn-left," and so forth).

The vibrotactile display consists of nine vibrating motors. A vibrating motor generates an individual pulse and its characteristic is determined by controlling the duration of pulses and the interpulse interval. A sequential pulse consists of

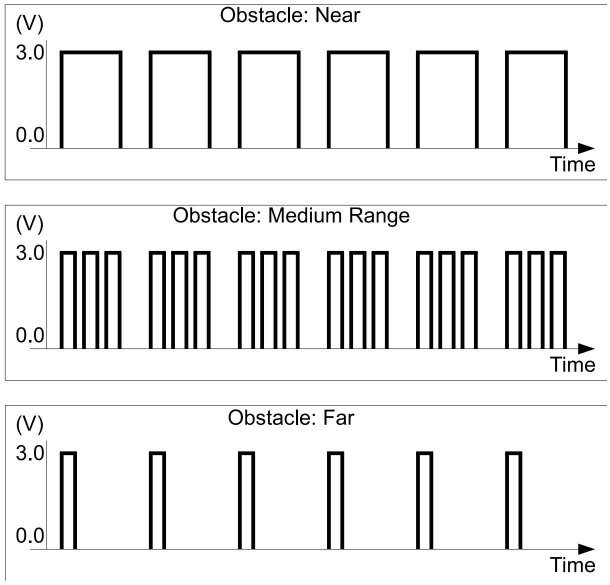

Figure 4: A pulse pattern of notifying an obstacle (top: obstacle is near, mid: obstacle is in medium range, bottom: obstcle is far.)

a sequence of individual pulses generated by more than one vibrating motors that indicate the desired direction.

2.3.1 *Warning Signal*

The warning message does not need to contain any visuospatial information, thus, we designed all vibrotactors to repeat a long duration pulse simultaneously.

2.3.2 *Spatial Representation*

The orientation and distance of an obstacle need to be discretely mapped into the vibrotactile display due to its limited spatial resolution. The orientation of an object was mapped into the locus of the corresponding peripheral vibrotactors, each of which represents approximately 45 degrees of the surrounding area of the chair. The degree of distance was set into three levels: "near" is the range from the chair to approximately 0.6 m; "medium," 0.6 to approximately 2 m; and "far," 2 m to the maximum length of the ranging sensor.

The magnitude of each level is implemented by the density of the vibration pulse. Repetition of a single short vibration pulse represents the "far" range; three short pulses, the "medium" range; and a long pulse, the "near" range (Figure 4).

Simultaneously displaying multiple obstacles is possible; however, the more obstacles displayed, the more confusing the information is. In our design, we set the limitation of the maximum number of the obstacles to two, shown in the vibrotactile display at a time.

2.3.3 *Directional Guidance*

The directional guidance is designed to generate successively activating vibrotactors with a short interstimuli period. The

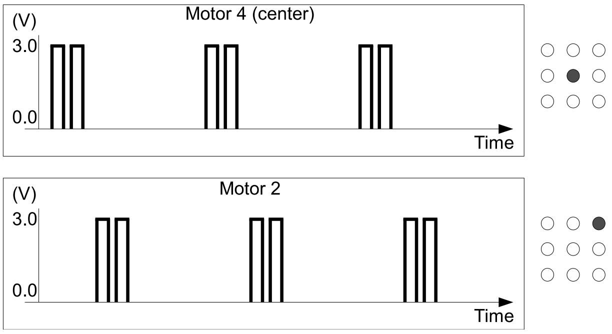

Figure 5: An example of the pulse pattern to indicate direction ("north-east"). The dark circle in the array represents the activated tactor.

center vibrotactor is first invoked with two short pulses followed by another two short pulses in the desired direction. We set the number of short pulses to two in order to avoid confusion with spatial representation.

Figure 5 shows a sample pattern of the direction "go-forward-right" (or "north-east") by using two tactors: tactor 4 and tactor 2, in sequence. Applying the carefully chosen inter-stimuli intervals between the tactors (20 to 200 ms[6]), the user would feel on their hand a single sensation in the disignated direction rahter than two separate stimuli.

3. CURRENT STATUS

Currently we are in the process of implementing this vibrotactile display in combination with another part of the project (developing the SA wheelchair system). The experimental field test of the wheelchair operation using the Vibrotactile Glove will begin this spring.

4. REFERENCES

[1] R. W. Cholewiak and A. A. Collins. The generation of vibrotactile patterns on a linear array: Influences of body site, space, and time. *Perception & Psychophysics*, 62(6):1220–1235, 2000.

[2] J. D. Crisman and M. E. Cleary. Progress on the deictically controlled wheelchair. In V. O. Mittal, H. A. Yanco, J. M. Aronis, and R. C. Simpson, editors, *Assistive Technology and Artificial Intelligence*, volume 1458 of *Lecture Notes in Computer Science*, pages 137–149. Springer, 1998.

[3] J. Douglass and M. Ryan. A pre-school severely disabled boy and his powered wheelchair: A case study. *Child Care, Health Development*, 13:303–309, 1987.

[4] J. B. V. Erp and H. A. V. Veen. Vibrotactile in-vehicle navigation system. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(Issues 4-5):247–256, July-September 2004.

[5] F. A. Geldard. *Sensory Saltation: Metastability in the Perceptual World*. Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1975.

[6] F. A. Geldard. The mutability of time and space on the skin. *Journal of the Acoustical Society of America*, 77:233–237, 1985.

[7] F. Gemperle, N. Ota, and D. P. Siewiorek. Design of a wearable tactile display. In *Fifth International Symposium on Wearable Computers (ISWC '01)*, pages 5–12. IEEE Computer Society, 2001.

[8] T. Gomi and A. Griffith. Developing intelligent wheelchairs for the handicapped. In V. O. Mittal, H. A. Yanco, J. M. Aronis, and R. C. Simpson, editors, *Assistive Technology and Artificial Intelligence, Applications in Robotics, User Interfaces and Natural Language Processing*, volume 1458 of *Lecture Notes in Computer Science*, pages 150–178, New York, 1998. Springer.

[9] S. P. Levine, D. A. Bell, L. A. Jaros, R. C. Simpson, Y. Koren, S. Member, and J. Borenstein. The NavChair assistive wheelchair navigation system. *IEEE Transactions on Rehabilitation Engineering*, 7:443–451, June 21 1999.

[10] D. P. Miller. Assistive robotics: An overview. In V. O. Mittal, H. A. Yanco, J. M. Aronis, and R. C. Simpson, editors, *Assistive Technology and Artificial Intelligence*, volume 1458 of *Lecture Notes in Computer Science*, pages 126–136. Springer, 1998.

[11] K. Paulsson and M. Christoffersen. To develop "on track": severely multi-handicapped children with developmental delay can drive electric wheelchairs with loop-tape steering. In *Karolinska Institute, Stockholm, Sweden*, 1991.

[12] H. Tan, A. Lim, and R. Traylor. A psychophysical study of sensory saltation with an open response paradigm. In *Ninth (9th) International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, 2000.

[13] H. Z. Tan and A. Pentland. Tactual displays for wearable computing. In *The International Symposium on Wearable Computers*, pages 84–89, Jan. 20 1997.

[14] R. Traylor and H. Z. Tan. Development of a wearable haptic display for situation awareness in altered-gravity environment: Some initial findings. In *Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pages 159–164, 2002.

[15] G. Verburg, L. Balfour, E. Snell, and S. Naumann. Mobility training in the home and school environment for persons with developmental delay. In *Final Report to Ontario Mental Health Foundation and Ministry of Community and Social Services' Research and Program Evaluation Unit*, 1991.

[16] H. A. Yanco. Wheelesley: A robotic wheelchair system: Indoor navigation and user interface. *Lecture Notes in Computer Science*, 1458:256, 1998.

[17] J. S. Zelek, S. Bromley, D. Asmar, and D. Thompson. A haptic glove as a tactile-vision sensory substitution for wayfinding. *Journal of Visual Impairment & Blindness*, 97(10):1–24, oct 2003.