Designing a Universal Keyboard Using Chording Gloves

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ABSTRACT

A universal input device for both text and Braille input was developed in a Glove-typed interface using all the joints of the four fingers and thumbs of both hands. The glove-typed device works as of now for input of Korean characters, numbers, and Braille characters using mode conversion. Considering the finger force and the fatigue from repeated finger motions, the input switch was made of conductible silicon ink, which is easy to apply to any type of surface, light, and enduring. The usability testing with (1) blind subjects showed the performance matching with a commercial Braille keypad, and (2) non-blind subjects for Korean characters showed comparable performance with cellular phone input keypads, but inferior to conventional keyboard. Subjects' performance showed that the chording gloves can input approximately 122 Braille characters per minute and 108 words per minute in Korean character. The chording gloves developed in our study is expected to be used with common computing devices such as PCs and PDAs, and can contribute to replacing the Braille-based note-takers with less expensive computing devices for blind users.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Ergonomics, Haptic I/O, Input devices and strategies.*

General Terms

Design, Experimentation, Human Factors.

Keywords

Chording gloves, device-independence, keyboard, keymap, universal access, usability.

1. INTRODUCTION

Keyboards have been used as an important input device to computers. The increase in use of small portable electronic products such as PDA, cellular phones, and other wearable computing devices requires some type of external input devices for convenient and error-free typing. Conventional keyboard does not meet the needs of portability for these small electronic devices, resulting in many alternatives in the form of flexible or folding keyboards and keypads.

For use of many small portable electronic products, chord keyboards have also been proposed as input devices [1-7]. A chord keyboard is a keyboard that takes simultaneous multiple key pressings at a time to form a character in the same way that a chord is made on a piano. In chord keyboards, the user presses multiple key combinations, mainly two-letter combinations, to enter an input instead of using one key for each character. Pressing combinations of keys in this way is called chording [4, 6]. Since chord keyboards require a small number of keys, they do not need large space, neither many keys of regular keyboards such as the QWERTY keyboard. For example, the Handkey Twiddler is a one-handed chord keyboard with only 12 keys for fingertips and a ring of control keys under the thumb, and the Microwriter with only 6 keys [1]. As a typical two-handed chord keyboard, most Braille writers have a keyboard of only six keys and a space bar for all the Braille characters. These keys can be pushed one at a time or together at the same time to form Braille symbols for visually impaired people.

Several types of glove-based devices recognizing hand gestures or contact gestures directly have been widely proposed as input devices to computers. These devices are well suited for use in a mobile environment because the gloves can be worn instead of held, are light-weighted, and take up little space for carrying. It is, however, difficult to recognize enough separate gestures to allow useful text input. Rosenberg and Slater [6, 7] proposed a glove-based input device called the chording glove to combine the portability of a contact glove with the benefits of a chord keyboard. In their chording glove, the keys of a chord keyboard were mounted on the fingers of a glove and the characters were associated with all the chords, following the ***keymap***. Their design of the keymap, however, for the chording glove for alphabetic text input left rooms for improvement according to the experimental results.

Pinch keyboard is a virtual keyboard using Pinch Gloves. It used lightweight gloves with conductive cloth on each fingertip that sense when two or more fingers are touching. Pinch keyboard used the same key layout with QWERTY keyboard, and some "inner" characters were selected by wrist rotating motion that could be detected by motion trackers attached on the gloves. Pinching is basically the motion of making a contact between the tip of thumb and a fingertip of the same hand. The "Thumbcode" is also a one-hand device-independent chording sign language

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with a glove-based input switches similar to the Pinch keyboard. "Finge Ring" is a chord keyboard that uses finger movements with rings instead of wearing gloves [2]. For extensive review on chord keyboards, see Noyes [4].

The possibility of chord keyboards to make a Braille codes as well as text input is important for universal access in that both blind and non-blind users can use the same type of keyboards and computing devices. With embedded voice output and a detachable dynamic Braille display module, blind users can have access to regular computers and notebooks and enjoy the computing power and communication capabilities without spending too much for Braille note-takers with limited capabilities. With portable chord keyboards, blind users can access to any type of public information terminals and save or retrieve data with Braille codes. Allowing chord input, keyboards can be universally usable regardless of users' visual capability. This paper proposes a portable chord keyboard in the form of gloves that can provide both blind and non-blind users with universal accessibility to computing devices.

2. SYSTEM STRUCTURE

2.1 Layout

A pair of universal chording gloves was proposed and developed by a research team at Sungkyunkwan University, Korea. Two-handed glove-based input seems ideal for Braille character input for its natural interface using thumb and the remaining fingers just like two-handed input by traditional six-key Braille typewriters. Since the thumb of each hand can easily touch the other fingers simultaneously, different combinations of finger selection can generate different chords for several Braille codes and also for other text characters and numeric input.

A finger motion to make input using the developed chording gloves is shown in Figure 1. An input can be made by contacts between the tip of thumb and character keys on the other fingertip or phalanges. Chording is possible by making contacts between the tip of thumb and two or more fingertips in parallel, i.e., simultaneously. Twelve character keys are placed on the fingertips as well as on all the phalanges of fingers on the palm side. The keys are made of conductible silicon ink applied to each part between the joints of the fingers with the rectangle of 1.5 cm by 1.3 cm.

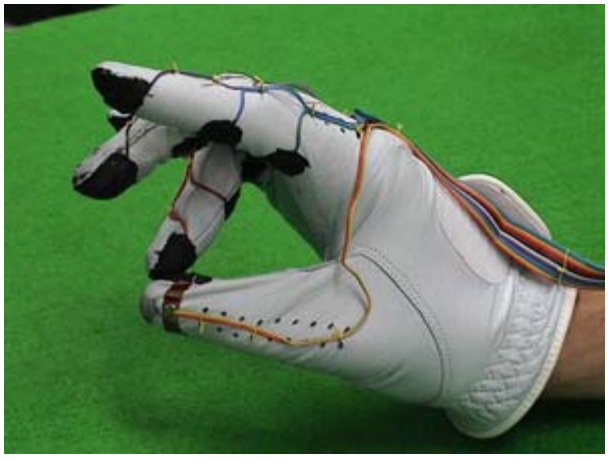

Figure 1. A finger motion for input using the chording glove

2.1.1 The Chord Keymap for Braille Input

A Braille input can be made according to a keymap developed as shown in Fig. 2. Actually the keymap used for Braille input is tailored after and follows the method as used on conventional Braille typewriter. Three keys, in particular, on the fingertips of the 2nd, 3rd, and 4th fingers of each glove correspond to three dots in a Braille code in the Braille keymap. The characters associated with all the chords in the chording gloves are designed in the same way with a Braille keyboard, which has been set as a standard for blind people's use of Braille system.

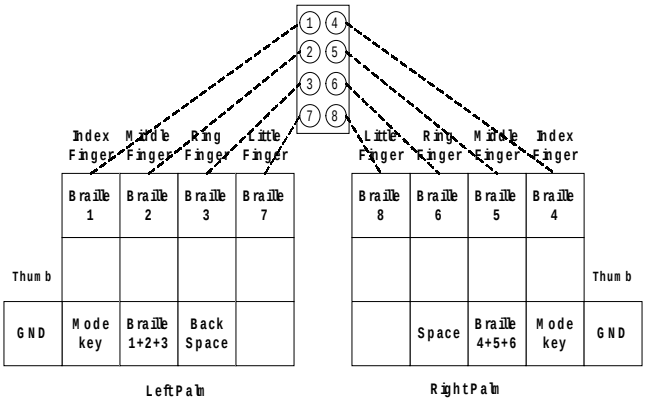

Figure 2. The chord keymap for Braille

2.1.2 The Chord Keymap for Korean and Numerics

A text input in Korean as well as numbers can be made according to a keymap developed as shown in Fig. 3. The keymap for Korean input, however, follows a different mapping scheme from conventional keyboards and uses chording for generating diphthongs and some consonants. As of now, no specific chord keymap has been developed for making alphabetical input other than that the keymap for English input would follow the arrangement of alphabet-finger mapping of the QWERTY keyboard.

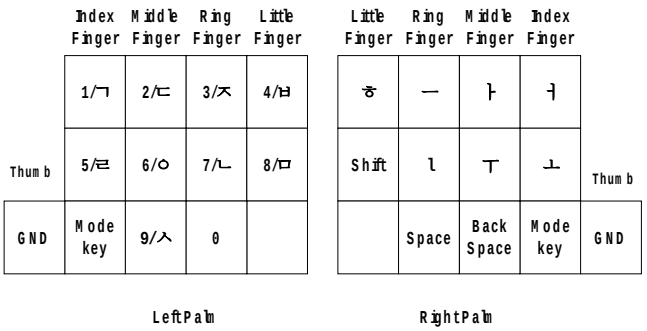

Figure 3. The chord keymap for Korean text and numerics

2.1.3 Combined Keymaps

These two keymaps are combined into one on a pair of gloves to make them universally usable. A mode key can change the input

mode among Korean, Numeric, and Braille. The keys on the bottom of right palm perform the functions of mode switch, space bar, backspace bar, and the carriage return, respectively, in all modes. A keymap for English alphabet to be combined into this universal keymap is now being developed for future use to make the gloves truly universal..

2.2 Controller

The 16F874 microprocessor is used for controlling and analyzing the signals from the chording gloves. The controller also works for functions of converting the signals to Braille or text codes and sending them to PC or PDA through a RS232C serial port or an IrDA wireless adapter. The controller works with a 9V battery.

The voltage outputs of chording gloves are sent to an embedded system that translates chord information into its corresponding Braille code, character, or number. The chord glove-based input device can be used in connection with commercial Braille-based notetakers such as BrailleLite, acting as a portable Braille keyboard, while it can make input to computers or PDAs directly as a universal keyboard. Blind users can get a feedback for what s/he typed by the chording gloves using only a voice output after making entry of each word.

2.3 Braille-to-Text Conversion Program

The chording gloves were originally proposed and developed for the purpose of providing a way for blind users to input and store texts directly to computers or small electronic devices such as PDAs. An obstacle for the blind users to use commercial products would be a lack of Braille-text conversion program for general applications embedded in the products such as text editors, address books, and notepads. A key to successful use of the chording gloves with PCs and PDAs may be seamless conversion of Braille-based input to text in any active application program. This conversion enables to create voice synthesis for the voice output of Braille input and to retrieve the stored information in any format for later uses.

A conversion program was developed to convert the Braille-based input from the chording gloves to text. A Braille code is translated to corresponding keyboard code in 'Hangul'(Korean) and the code is sent to active application program just like a keyboard input. Once the conversion program is installed on a PC or a PDA, it works seamlessly behind the screen and displays the converted text on the screen from the corresponding Braille input.

3. EXPERIMENTS

Experiments were performed using both the chording gloves and a Braille keypad for measuring the input speed and accuracy for Braille characters and Korean texts.

3.1 Experiment 1: Braille Entry Input

3.1.1 Subject

Ten blind subjects who just started to learn Braille characters participated in the study. All the subjects had no previous use of Braille-related devices such as Braille note-takers. The average age of the subjects was 28.2 years old.

3.1.2 Apparatus

Two types of Braille keyboard were used: the chording gloves and a conventional Braille keypad with 7 keys.

3.1.3 Procedure

Subjects were trained to use both devices to make a Braille input using short pre-defined sentences. The training sessions for a device consisted of 3 sessions each of which last for 3 hours. Therefore a total of 9 hours for each device was devoted to training for a subject. Subjects were asked to learn to make input with different sentences for each training session. A total of 18 hours was devoted for a subject to learn to input Braille codes using both devices.

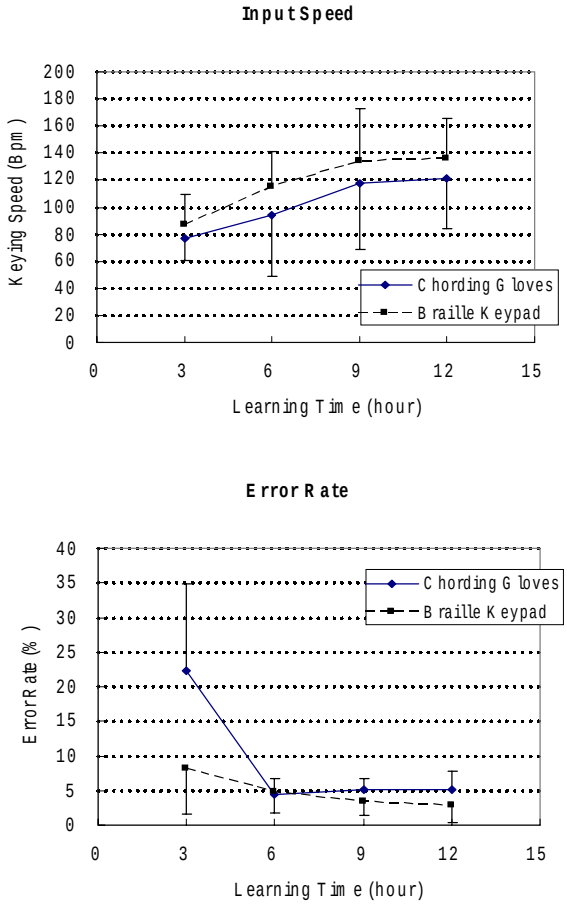

Figure 4. Performances for the chording gloves and Braille keypad, where the performances in the test session are shown at 12th hour.

Table 1. Result of Experiment 1

Device Type	Chording Gloves	Braille Keypad
Input Speed (Bpm)	121.5 ± 29.8	135.9 ± 37.0
Error Rate (%)	5.2 ± 2.7	2.8 ± 2.3

3.2 Experiment 2: Text Entry Input

3.2.1 Subject

Ten sighted college students participated in the second experiment. All the subjects had previous experiences in use of computer keyboard and a keypad of cellular phones manufactured in Korea for storing a short text messages. The average age of the subjects was 21.5 years old.

Upon completion of training sessions, a new sentence with 58 Braille characters was given. Input speed in terms of Bpm(Braille code per minute) and error rate were measured 10 times for each device with the same sentence. ResultsAverages in keying speed and error rate for trials at the last session for each device were calculated and shown in Table 1. No significant difference could be found between the chording gloves and Braille keypad in input speed ($p > 0.1$). However, a marginal difference could be found in error rate where the error rate of chording gloves is higher that that of keypad ($t = 2.14$, $p < 0.05$). The averages for input speed and error rate for each session, including training sessions, are shown in Figure 4. Averages for each training session is made for learning hours of 3, 6, and 9, and the test trials are presented at the 12th hour in the x-axis.

3.2.2 Apparatus

Three types of text entry devices were used: the chording gloves, a conventional QWERTY keyboard upon which Korean "Hangul" code is assigned, and a keypad of the most popular cellular phone models sold in Korea.

3.2.3 Learning

Subjects were trained to use the chording gloves to make a text input using short pre-defined sentences. The training sessions for a device consisted of 10 sessions each of which lasted for 4 hours over 10 days. A new sentence was used for each training session. Therefore a total of 40 hours was devoted to training for a subject. The learning effect of the chording gloves in terms of input speed and error rate is shown in Figure 5.

There were brief trainings for the other input devices since all the subjects were well familiar with the keyboard and keypads of their own cellular phones. Subjects were asked to learn to make input with different sentences for each training session.

3.2.4 Procedure

Upon completion of training sessions and when the subjects feel comfortable with each device, a new sentence was given. Text entry input speed in terms of wpm(words per minute) and error rate were measured 10 times for each device without practices with the same sentence. An average was calculated for each measure.

3.2.5 Results

The results of the second experiment are summarized in Table 2. There were significant differences in both input speed and error rate between the keyboard and the other input devices ($t = 64.04$, $p < 0.001$). No significant difference could be found between the chording gloves and the keypad of cellular phones in input speed ($p > 0.1$), but error rate was higher for the chording gloves ($t = 10.12$, $p < 0.01$) than the keypad of cellular phones.

For text entry input tasks, keyboard was by far better than other devices in performances, mainly due to subjects' long term exposure and experiences.

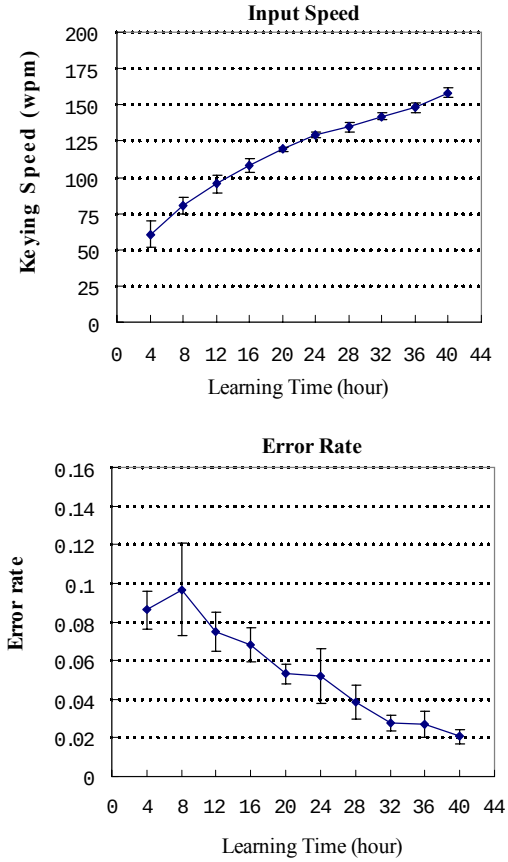

Figure 5. Learning effect of the chording gloves for text input in Korean

Table 2. Result of Experiment 2

Device Type	Chording Gloves	QWERTY Keyboard	C. Phone Keypad
Input Speed (wpm)	108.3 ± 23.5	388.0 ± 124.4	94.8 ± 26.4
Error Rate (%)	0.08 ± 0.06	0.01 ± 0.01	0.03 ± 0.01

4. USABILITY EVALUATION

Subjects' perceived ratings were measured for usability evaluation after the Braille and text entry experiments. Each subject rated for all the input devices they used for the experiments based upon the following four categories using 5-point scale. Subject was asked to rate 5 if s/he would think the device provides maximum usability in each category, while to rate 0 if not at all.

4.1 Portability

Subjects were asked to rate the portability of the devices based upon a 5 point scale, where 5 indicates the maximum portability. The portability of the chording gloves was rated 3.7 out of 5.0, compared to 3.4 for the keypad by blind subjects. Sighted subjects who participated in the Korean text entry input experiment rated the chording gloves 3.5, and the keyboard 3.0 for portability. Both groups of subject expected that the chording gloves' light weight

and non-rigid form could provide good portability. This is an important measure since the chording gloves can be further developed for a universal input device in ubiquitous computing environment.

4.2 Learnability

The learnability for both the chording gloves and keypad was rated 3.5 out of 5.0 by blind subjects, while sighted subjects rated both chording gloves and keyboard the same at 3.3. Since both uses basically the same keymap and finger combinations for generating Braille codes, there seemed to be no difference between the chording gloves and Braille keypad. As shown in Figure 4, blind subjects felt comfortable using both devices in just 9 hours of learning. Sighted subjects, however, seemed to take much longer to learn more complex text keymap. Figure 5 shows that there was room for improvement for more learning effect in input speed and accuracy even after 40 hours of training. The learnability for the chording gloves seemed to be rated higher than expected considering that the gloves required extensive learning to memorize the chords for generating certain texts.

4.3 Functionality

While the functionality for both the chording gloves and Braille keypad was rated 3.5 out of 5.0 by blind subjects, the functionality for the chording glove was rated 3.1 and keyboard was rated 3.4 by sighted subjects. Since chording glove has fewer keys and lot of chording was needed for extensive use of functions keys which are not visibly marked on the gloves, subjects seemed to be easily confused and thus thought that the functionality was not fully provided in the chording glove.

4.4 Overall Satisfaction

Overall satisfaction by the blind users were rated higher for Braille keypad than the chording gloves as the ratings were shown 3.9 vs. 3.7 out of 5.0. Familiarity must be an important factor to provide overall satisfaction to use, so that users seemed to be subjectively satisfied more with the familiar and conventional keypad input method than glove based method in Braille entry input tasks. Sighted subjects showed a little more overall satisfaction with the chording gloves than the QWERTY keyboard. Boredom in using the conventional keyboard seemed to contribute to the result based upon the interviews with selected participants.

Table 3. Perceived Ratings in Usability Evaluation

Usability Aspects	Braille Entry Input by Blind Users		Korean Text Entry Input by Sighted Users	
	Chording Gloves	Braille Keypad	Chording Gloves	QWERTY Keyboard
Portability	• 3.7	• 3.4	• 3.5	• 3.0
Learnability	• 3.5	• 3.5	• 3.3	• 3.3
Functionality	• 3.5	• 3.5	• 3.1	• 3.4
Overall Satisfaction	• 3.7	• 3.9	• 3.3	• 3.2

5. CONCLUSION

The chording gloves developed in our research for universal input to computing devices showed comparing performances and usability to conventional Braille keypad and text entry device in conventional keyboard. Since the chording gloves developed here use two hands to make inputs instead of one hand, it has some advantages over one hand chord keyboard. Its interface is much more natural for Braille input and it can be fast and error-free [3]. Using more keys in two hands than fewer keys in one hand would also reduce the memory burden of chording combinations. The chording gloves have clear size and space advantages over both a regular keyboard and a chord keyboard.

In order to develop a keymap for the chord keyboards, either a strong spatial correspondence to the visual shape of the typed character should be used or strong link to a well-built semantic knowledge base should be created [3, 6]. The keymap for our universal chording gloves resembles the grade 2 Braille in the Braille mode, which is quite simple and easy to learn because of its natural interface, and the conventioanl keyboard in text mode, which is conventional and used daily by sighted users.

Since the Braille-based chording gloves have many advantages such as fast typing, low error rate, and space saving, they can be one good input device to commercially available small electronic products for blind users. With appropriate output devices to be connected to the small electronic computing devices such as notebooks and PDAs, the chording gloves can support the blind users' work with the general computing devices instead of Braille-based note-takers. Furthermore, since the proposed chording gloves have the same keymap as in a traditional Braille keypad, they can be seamlessly used for congenitally blind users who are well acquainted with Braille codes as well as for acquired blind users who want to learn Braille in later years [9].

The chording gloves in the text mode have advantages in portability and fast learning. It is light, and can be carried easily, and takes less space than any other text entry device. Since we always use our fingers and hand in a daily life, to make codes in combination by touching the thumb and other fingers together can be easy to remember and natural to perform. Universal access to computing devices and information by both sighted and blind users can be achieved by sharing the same input device and seamless conversion between the Braille-based codes and texts. With the seamless Braille-to-text conversion program working for the chording gloves, our universal chording gloves may help both sighted and blind users to communicate and understand with each other even though sighted users see characters or numbers rather than touch and feel the Braille.

We can conclude that the chording gloves developed in this study can contribute to:

- Possibility of replacement of Braille-based note-takers with conventional and less expensive PDAs by blind users,
- Universal access to computing devices and information by both sighted and blind users, and
- Expansion of glove-typed input devices to the realm of wearable computers for anybody to store and retrieve information at anywhere, in any form, and with any method of coding techniques easily.

Currently, a one-hand chord glove is being developed for universal entry since at least one hand needs to be freed for touching the Braille display while making Braille input, or for other daily activities while holding to or accessing to small hand-held computing devices to provide better usability.

6. ACKNOWLEDGMENTS

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