A Wearable Device Supporting Multiple Touch- and Gesture-Based Languages for the Deaf-Blind

Nicholas Caporusso[1,2(✉)], Luigi Biasi[1,2], Giovanni Cinquepalmi[1,2], Gianpaolo Francesco Trotta[1], Antonio Brunetti[1], and Vitoantonio Bevilacqua[1]

[1] Department of Electrical and Information Engineering (DEI), Polytechnic University of Bari, Bari, Italy
ncaporusso@gmail.com
[2] INTACT srl, Bari, Italy

Abstract. Over 1.5 million people in the world who are completely deaf-blind use touch-based alphabets to communicate with others and to interact with the world. However, they rely on an assistant who plays the role of an interpreter in translating the world for them. Unfortunately, despite the research work realized in the last decade, on the market there are no assistive devices for providing people who suffer from severe multi-sensory impairments with technology for social inclusion. In this paper, we introduce dbGLOVE, a wearable device for supporting deaf-blind people in being completely independent in communicating with others and in interacting with the world. Our system was co-designed with users to be a natural interface and to accommodate for different already-existing touch- and gesture-based languages, such as Malossi and deaf-blind manual, in order to offer a unique device for connecting different communities with an affordable solution.

Keywords: Deaf-blindness · dbGLOVE · Malossi · Deaf-blind manual · Wearable devices

1 Introduction

People who are blind or deaf rely on sensory replacement to compensate for their People who are deaf-blind have a severe degree of combined visual and auditory impairments resulting in limited communication, access to information, and mobility. According to estimates, 1.5 million people are completely deaf-blind, worldwide. Moreover, different levels of blindness and deafness affect over 150 million people.

Deaf-blind individuals primarily use touch to communicate with others and to interact with the world. Touch cues can be utilized in basic (functional) communication. Also, advanced tactile signing techniques and tactile alphabets, such as, the deaf-blind manual, Lorm, or Malossi, are the preferred communication system in the communities of people who are deaf-blind: the hand becomes a typewriter for writing and reading messages using a specific tactile code.

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In the last decade, several devices successfully explored the possibility of incorporating touch-based languages into wearable technology in the form of gloves to help people who are deaf-blind interact with the world [1]. However, lack of attention to ergonomics leads either to demonstrators which cannot be manufactured or to prototypes having poor acceptability. As a result, there are no commercial devices which are market-viable products that can be utilized effectively by end users, and, thus, individuals who are deaf-blind still lack opportunities for being completely independent in communicating with others, interacting with the world, working, and being fully included in the society.

In this paper, we introduce dbGLOVE, a wearable interface for touch- and gesture-based interaction which is specifically designed for providing people suffering from multi-sensory conditions with support for bidirectional communication. dbGLOVE is designed to refine the work discussed in [2] to incorporate several already existing touch-based languages, so that people who are deaf-blind are not required to learn a new communication system, which is among the most complicated tasks for them.

We discuss the ergonomics of the device and its hardware architecture, consisting of a flexible pad which incorporates a total of 42 sensors and actuators (18 capacitive sensors, 5 flex sensors, 16 vibration actuators, and a 9-degrees-of-freedom Inertial Measurement Unit consisting of accelerometer, gyroscope, and magnetometer). Heterogeneous sensors accommodate for the different touch and motion cues utilized in functional communication and in tactile signing and alphabets, such as the deaf-blind manual, Malossi, or Lorm. As a result, the proposed device can be utilized by the people with multi-sensory impairments to input text and messages via touch. These, in turn, can be displayed on a screen so that the sighted can visualize them, they can be translated into speech with a Text-To-Speech (TTS) system, or they can be transmitted over the Internet to people who are co-located or remotely located. In addition to providing users with an input interface to PCs and smartphones, dbGLOVE incorporates actuators which enable simulating touch cues in the form of vibrations over the palm of the hand, so that the deaf-blind can use it as an output device, to receive feedback and to read messages.

Moreover, we describe the implementation of two tactile communication systems, that is, the deaf-blind manual and the Malossi alphabet, which are well adopted in the United Kingdom and in Italy, respectively. Involving users and experts in a participatory, co-design process led to their optimal adaptation on dbGLOVE.

Finally, we detail the experimental results of a preliminary study involving healthy individuals who received the device for the first time. The experiment focuses on both input and output features, to evaluate the viability of dbGLOVE as a bi-directional communication device. The majority of participants (72%) were able to use the device efficiently (80% performance), without any prior knowledge of any the languages. Consequently, from our findings, we can conclude that dbGLOVE can be utilized as a viable interaction tool for enabling communication in people with sensory and multi-sensory impairments, though further investigation involving deaf-blind individuals will be realized as part of our future work.

2 Related Work

In case of multisensory impairments, tactile alphabets are utilized as an alternative communication system. They rely on the concept of sensory substitution to replace the communication channels which are compromised (e.g., vision or hearing) with touch. Several touch- and gesture-based alphabets have been developed and they consist of different components, as described in [1], in the form of gesture, pressure, and touch cues. Specifically, the Malossi, Lorm, and deaf-blind are three alphabets that use the surface of the hand to represent letters using different types of tactile signing. In the Malossi alphabet, shown in Fig. 1, phalanxes are utilized to sign letters in the form of different pressure cues: different areas of the (left) hand can be pressed or pinched in sequence to write words on the palm of the deaf-blind individual as in a typewriter.

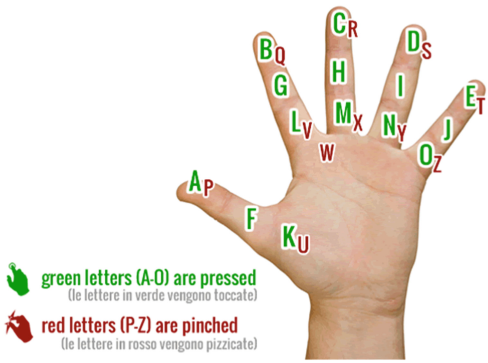

Fig. 1. The Malossi alphabet: letters from A to O are pressed, letters from P to Z are pinched.

The Malossi alphabet has a simple structure which is more suitable for implementation with respect to other languages, such as, Lorm, which were incorporated in wearable glove-like devices [3], recently. Moreover, it provides with a single interaction surface, that is, the palm of the hand, with several advantages with respect to or other communication systems relying on different areas, as described in [4, 5]. Furthermore, tactile languages based on pressure inherently support mobility [1], because they utilize a limited surface of the body and simple stimuli. This characteristic is very different from gesture-based alphabets, which would require complex robotic systems for producing output [7]. Furthermore, the layout defined by the language is very convenient, because the letters are located in areas having similar physiological structure [6], though they have different sensitivity and stimulation intensity. Also, the overall layout of the language is similar to other alphabets, such as the deaf-blind manual [7], which results in the opportunity of serving multiple communities and language niches with a single interface.

3 System Design and Architecture

In this Section, we describe the hardware and software architecture of the proposed system. It consists of a device structured in two components: the central unit and a replaceable pad. The former is responsible for acquiring input from the user (i.e., movement of the hand, touch cues over the surface of the pad, and the flexion/extension of the fingers), processing signals, and communicating with an external device (e.g., PC or smartphone) equipped with drivers and applications (Fig. 2).

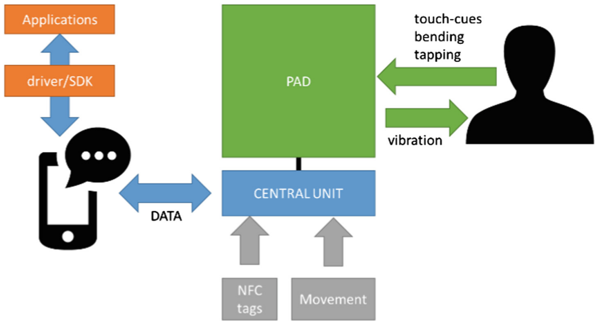

Fig. 2. Block-diagram of the architecture of the device.

3.1 Hardware Device

The hardware component of the system consists in a device that can be worn on the left or right hand. Several research papers presented interactive devices in the form of fabric gloves incorporating electronics. However, this introduces intensive mechanical stress over the components, in addition to increasing the complexity in manufacturing the device. Conversely, dbGLOVE utilizes a single surface consisting of a hand-shaped pad in which electronic components are incorporated in a polyurethane cast to ensure resistance to moisture. The shape of the device has been designed to map a statistical hand accommodating for 95% of the adult male population. However, different sizes can be realized to support children. Within the outer cast, there is a printed circuit board (PCB) realized with a mix of rigid and flexible material to ensure durability and resistance, to enable flexing and extending fingers, and to increase the ergonomic feeling of the device. The surface of the pad includes 18 one-wire capacitive sensors based on the architecture of the commercial MPR121 controller available from Freescale [8]. 15 sensors are conveniently placed over the phalanxes, to accommodate for the layout defined by the Malossi alphabet; 3 additional sensors are located on the top of the palm, to provide users with additional functions (e.g., menu, next, previous). A tactile texture modeled over the surface of the pad displays the corresponding representation of the letter in Braille, in order to facilitate users who are Braille-savvy and to increase Braille-literacy of people who know touch-based alphabets, only.

Moreover, the polyurethane coating increases impedance and, thus, acts as a shield for spurious signals which are known to be an issue for capacitive sensors.

Moreover, dbGLOVE includes 5 commercial flex sensors [9] which detect flexion/extension of the five fingers to support recognition of sign languages. This implementation is very different from other solutions: we placed flex sensors over the palm to reduce mechanical stress on the components and to avoid bending problems which affect the signal, as discussed in [1]. Flex sensors are incorporated within two protective layers which enable sliding within the cast, in order to reduce known issues related to mechanical stress on soldering pads on the proximal area of the sensors [1].

Finally, the back of the pad, which is in contact with the surface of the palm, includes 16 vibrotactile actuators in the form of precision button-style motors [10]. 15 motors are located over the phalanxes, in locations which correspond to capacitive sensors. One actuator is located over the palm to provide the user with feedback about menu functions. Two motor drivers accommodate for simultaneous vibration of up to two actuators. They are utilized for reproducing tactile sensations over the hand of the users by means of skin displacement at different intensity [5]. In particular, pulse wave modulation (PWM) is utilized to define diverse pressure cues (Fig. 3).

Fig. 3. Front and rear views of the pad of the device.

The pad is connected by means of an I2C bus to the central unit. By doing this, the pad can be easily replaced in case of damage, or for hygienic reasons. The central unit includes an Inertial Measurement Unit having 9 degrees of freedom (accelerometer, gyroscope, and magnetometer), the microcontroller, and a rechargeable LiPo battery which supports up to 10 h of continuous operation, in addition to status LEDs and power button. The device connects via Bluetooth Low Energy or USB with PCs and smartphones, in order to reduce pairing issues and ensure maximum durability. The firmware of the device includes signal processing algorithms and security protocols.

3.2 Software System

The software system was designed with the aim of providing users with the maximum degree of versatility with respect to connectivity and usage. To this end, the software component of the system consists of a main application which includes the driver, the system for configuring the settings of the device, and a UDP server for exposing data on the local network, as shown in Fig. 4. This architecture supports multiple applications based on a standard UDP client which receive pre-processed data from the device. Libraries available as Software Development Kits enable developing applications easily and leveraging signal processing functions which are part of the core application.

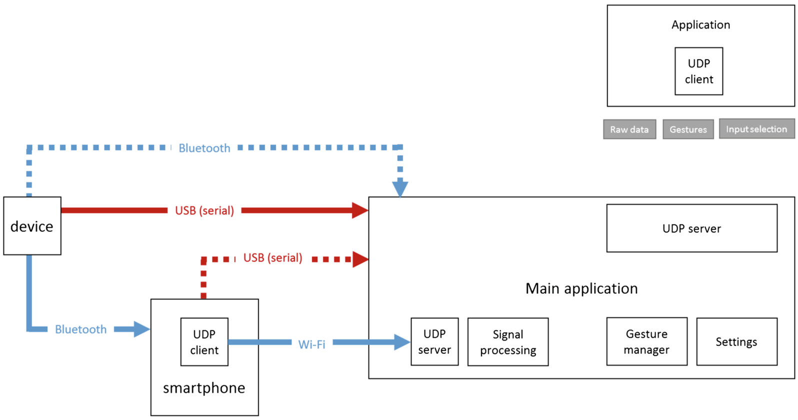

Fig. 4. Block-diagram overview of the software architecture of dbGLOVE.

4 Experimental Study

In this Section, we describe an experimental study in which we evaluated the efficacy of dbGLOVE as a bi-directional communication tool. To this end, we divided the study in two experimental tasks focusing on the output and on the input features of the device. We primarily considered the former, as producing output which can effectively be recognized by users is one of the main issues in the development of glove-like devices for the sensory and multisensory impaired [1]. Also, we specifically considered capacitive input, and we did not take into consideration flex sensors, because the purpose of this study was evaluating the simplest form of tactile alphabets, that is, touch-based languages consisting of pressure cues, such as, the Malossi alphabet and the deaf-blind manual.

A piece of stimulation software was realized ad hoc to implement the tasks of the experimental protocol. Figure 5 shows the interface of the application. It includes a panel for monitoring the data transmitted from the device, a shape showing the status of the sensors, and a control panel for activating motors at different intensities.

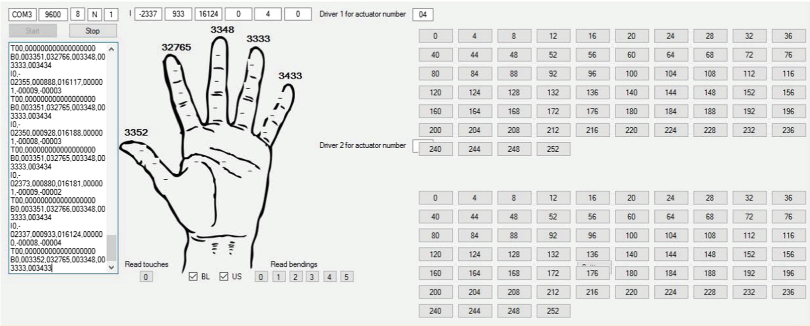

Fig. 5. Screenshot of the software utilized in the experimental study.

A total of 88 individuals were recruited for the experimental studies. We utilized two different groups of users for task 1 and 2, because our objective was to evaluate the input and output features separately. Participants had normal vision and hearing, and no prior knowledge of any tactile languages. Also, they had normal sense of touch, which was evaluated with on a simple assessment based on sensitivity to pressure. The majority of them were not familiar with deaf-blindness. We did not recruit any people with multisensory impairments because our objective was to preliminarily evaluate the effectiveness of the device, before involving individuals who are more delicate and prone to frustration.

The experiment was realized in noisy environments to reproduce the condition of real-life scenarios, though they were allowed to comfortably seat in front of a desk with the equipment. Subjects were provided with short briefing about deaf-blindness, and they were instructed about the tasks before starting the experiment. They had 5 min to get familiar with the device and explore it, before the beginning of the task.

In task 1, participants were delivered tactile stimulations at different intensities over the palm of the hand, and they were asked to identify the area in which the stimulation occurred. Specifically, trials involved 3 sets of stimulations each consisting of 5 pressure cues at different intensities, and on different sensitive areas. Both intensity and location were chosen randomly, ensuring that each trial included different intensities and areas, in order to deliver at least one stimulus for each sensitive area. Vibrations were delivered at intensities ranging from 1 to 251, representing no stimulus and maximum intensity, respectively: we defined 6 different intensity levels (i.e., 1, 51, 101, 151, and 251) to standardize the protocol. In each trial, motors were activated according to a specific pattern: intensity was increased by 50 in each stimulation, in the first trial; it was completely random in the second trial; in the third trial, intensity was descending. This was to identify the minimum and maximum sensitivity thresholds, and to evaluate individuals' touch sensitivity. 70 volunteers participated to the study. Individuals ranged from 16 to 65 in age (average 28 ± 12). A total of 1071 responses were recorded.

In task 2, participants were provided with an informative leaflet displaying the Malossi alphabet for 10 min before the beginning of the test. Then, they were presented with random letters on the display, and they had to touch the area of the device representing the letter. The objective of the test was to evaluate the effectiveness of the device in recognizing input from the user, in terms of sensitivity of the actuators, and thresholds for avoiding spurious signals. 18 individuals participated to the study. Their average age was 25 ± 7. In each trial, users were presented with 27 letters displayed at random. A total of 468 responses were recorded.

5 Results and Discussion

In the first task, we focused on evaluating the effectiveness of the device in representing output. Specifically our objective was three-fold: (1) obtaining the range (minimum and maximum) in terms of intensity for vibration to be recognized correctly; (2) studying the efficacy of dbGLOVE as an output device; and (3) identifying critical areas of the hand in terms of recognition of the stimulation.

763 correct answers were obtained out of 1071 responses, showing an accuracy of 71.24% in recognizing the area in which vibration occurred. However, as shown in Fig. 6, performance is strictly related to the location of phalanxes. Specifically, proximal and distal phalanxes show the highest similarity and very good performance ranging from 70.5% to 92.6%. Conversely, medial phalanxes have the worst results, showing an average accuracy of 49.28%. However, this is due to the lack of adherence of the pad to the phalanx, which can be compensated by introducing holders to be attached to medial phalanxes. Figure 6 shows high performance on lower intensity values because participants were able to correctly identify that either no vibration occurred, or it had very low intensity.

As regards to preferred intensity, values ranging from 100 to 250 produce the best results, though stronger pressure cues lead some decrease in performance due to the dispersion of stimuli over a larger surface, as shown in Fig. 7, which represents the distribution of individuals who identified vibration in areas which are close to the actual phalanx being stimulated. As a result, frequencies from 100 to 200 accommodate for individuals' different sensitivity, and maintain good accuracy levels.

By increasing adherence of the pad to the palm of the hand and, specifically, to medial phalanxes, we obtained +10% increase in performance, leading to 81.68% overall accuracy in recognizing output, in users who received vibrotactile stimulation

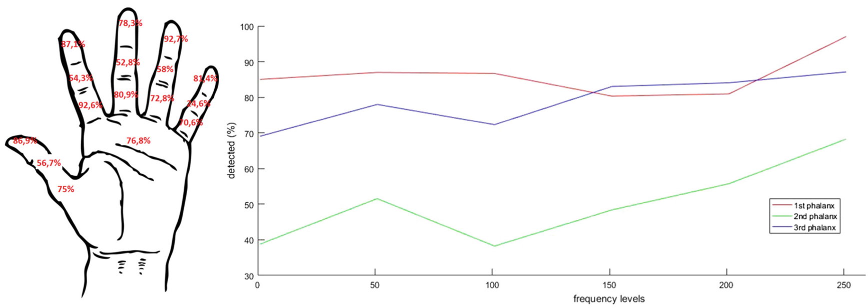

Fig. 6. Performance in recognizing output: data about individual areas and about intensity.

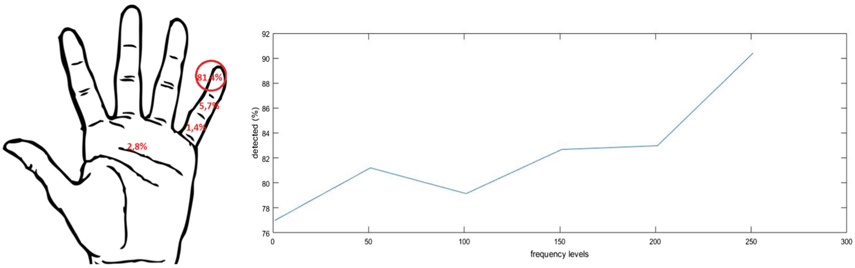

Fig. 7. Performance in recognizing output: higher intensities and dispersion effect.

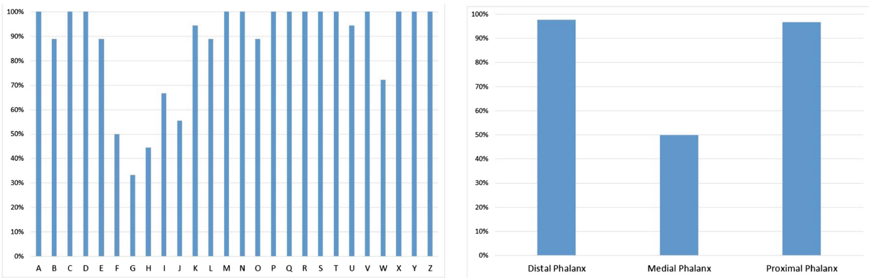

Fig. 8. Performance in task 2: difference in phalanxes.

for the first time. Indeed, by introducing some training, users will be able to get more familiar with the device and consequently, improve their performance.

In regard to task 2, which focused on the input features. Specifically, the objective of the study was two-fold, that is, (1) to evaluate the accuracy in detecting input, and the time spent by users to understand the communication system. We obtained 408 correct answers out of 468 responses, showing an accuracy of 87.17%. Figure 8 shows the accuracy for each letter: as in the previous task, the proximal and distal phalanxes have the best performance, with 97% and 98% accuracy, respectively. Conversely, the medial phalanx shows accuracy level of about 50%. This issue which will be investigated in our future work, could be caused by several factors, from sensitivity of the device to the nature itself of letters located on medial phalanxes.

6 Conclusion

In this paper, we introduced dbGLOVE, a wearable device for enabling blind and deaf-blind individuals to communicate with others and interact with the world by means of a natural interface that reproduces already-existing touch- and gesture-based alphabets adopted by different communities of people suffering from multisensory conditions.

We detailed the architecture of the system and specifically, the hardware and the software components, and we presented the results of an experimental study focused on the evaluation of the effectiveness of the device as a bi-directional interface for recognizing input and providing users with tactile output based on pressure cues over the surface of the palm of the hand.

Results from our study show that all the subjects were able to realize the experimental tasks. Moreover, by appropriately adjusting the ergonomics of the device, performance in correctly recognizing tactile stimulation is 81%, whereas the effectiveness of the input system is 87%. These results were achieved in individuals without any previous knowledge about the device and the communication system. Also, results were obtained in noisy environments to reproduce real-life scenarios.

Future work will include experiments involving individuals who actually have some degree of multisensory impairment to the visual and auditory channels, and who are proficient with touch- and gesture-based alphabets. Also, investigation will focus on the time required for learning the language, as touch-based systems are among the first forms of communication which are utilized for teaching languages to children who are deaf-blind born or to people who become deaf-blind. Finally, future work will include studies on the inter-dependency between languages, that is, learning Braille from Malossi and vice versa.

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