A User-Centered Approach to Artificial Sensory Substitution for Blind People Assistance

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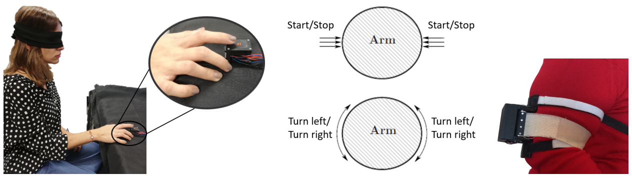
***Abstract*— Artificial sensory substitution plays a crucial role in different domains, including prosthetics, rehabilitation and assistive technologies. The sense of touch has historically represented the ideal candidate to convey information on the external environment, both contact-related and visual, when the natural action-perception loop is broken or not available. This is particularly true for blind people assistance, where touch elicitation has been used to make textual content easily accessible or to deliver informative cues for navigation. However, despite the significant technological advancements for what concerns both devices for touch-mediated access to alphanumeric stimuli, and technology-enabled haptic navigation supports, the majority of the proposed solutions has met with scarce acceptance in end users. Main reason for this, in our opinion, is the poor involvement of the blind people in the design process. In this work, we report on a user-centric approach for haptics-enabled systems for blind people assistance, whose engineering and validation have received significant inputs from visually impaired people. We present our approach applied to the the design of a single-cell refreshable Braille device and to the development of a wearable haptic system for indoor navigation. Finally, we propose novel solutions for navigation information touch-mediated delivery, whose implementation has been totally driven by the feedback collected from real end-users.**

I. INTRODUCTION

According to [1],*”Persons who become blind do not lose the capacity to see”*. This sentence well explains the concept of *Sensory Substitution* for blind people assistance, i.e. the possibility to deliver information commonly acquired through vision, relying on another channel, usually touch. Vision and touch are, indeed, highly intertwined for perception generation, synergistically working toward a multi-sensory representation [2]. In [3], it was also reported that a supramodal representation of objects exists in the ventral extrastriate pathway of sighted and congenitally blind individuals. Furthermore, the usage of the haptics channel to deliver vision-related information is preferable to the auditory one – which is usually augmented in blind people, whose elicitation could disturb posture and equilibrium control and severely affect social interactions [4]. For these reasons, a lot of effort has been devoted to develop haptic interfaces that mainly target navigation assistance – Electronic Travel Aids (ETAs) - which can surrogate spatial information on position and obstacle location and deliver it to the users via tactile sensory substitution [5]; and the accessibility of textual content through touch-related elicitation, commonly through refreshable Braille devices - whose raised dots change dynamically, enabling the representation of different texts with the same device [6]. Despite the significant technological advancements, the majority of these solutions have met with scarce acceptance in end users, due to the lack of intuitiveness and comfort of usage or because of the high costs. Main cause for this, in our opinio, can be ascribed to a non-perfect workflow design: the blind people have been minimally involved in the design and the validation phases of these prototypes. We propose a user-centered approach for the development of haptic interfaces for sensory substitution, presenting a single-cell refreshable Braille device *Readable* [7], and a wearable haptics-based navigation system for indoor guidance [4], see Fig. 1. We report on the developmental phases and novel solutions for navigation information touch-mediated delivery, which have been identified moving from the feedback collected from real end-users.



(a) (b) (c)

Fig. 1. A participant ”reading” through the *Readable* device (c) presented in [7] (a); Working modes of the wearable haptic device for the delivery of navigation cues in the system reported in [4] (b) and overview of the interface worn on the subject’s arm (c).

II. READABLE DEVICE

In [7], we presented *Readable* (see Fig. 1 (a)), a new electromagnetic refreshable single Braille cell. The system allows for the independent control of six dots and a spacing between the contact points comparable with the standard Braille coding. For more details please refer to [7]. The prototype was tested with eight blind people, who were expert Braille code readers. The evaluation phase was of paramount importance not only to show the capabilities of our system to correctly reproduce alphanumeric stimuli (no statistical differences in the recognition of the coded stimuli when the subjects used the *Readble* with respect to the interaction with traditional paper letters), but also to open to new application scenarios where our device could offer real benefits to real end-users, in every-day life. Indeed, blind participants evaluated

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the interface as intuitive, cost-aware, useful and well-accepted and identified the following areas where the usage of the *Readable* would be preferable with respect to the complete multi-cell Braille display or audio feedback: displaying the status of the household appliances; displaying the current floor of an elevator; integration in a cordless phone for a first call notification; showing the temperature measured via the thermometer; showing the light status on/off. This information will guide our future developments and a more in depth analysis of the applicability of *Readable* in every-day life.

III. WEARABLE HAPTICS FOR INDOOR NAVIGATION

In [4], we presented an indoor navigation system, which was composed of a RGB-D camera (to acquire the visual information on the environment and the obstacles), a processing unit - laptop (which used such information to implement obstacle avoidance strategies) and finally a wearable haptic interfaces (to deliver tangential stimuli to guide the user in an unknown environment). The development of the system was entirely driven by the requirements and the feedback provided by blind people. More details can be found in [4]. For the reasons above, the first step of our work was to interview four blind people to identify which features and functionalities a navigation system should ideally have. For the sake of space, we report only the main features related to the ideal interface, whose aim should be to intutively and effectively deliver the navigation information to the user: 1) *Haptic Information* Tactile stimulation was preferable to the auditory cues, as also reported also in [5]. 2) *Simplicity and intuitiveness of the delivered navigation commands* Clear and unequivocal instructions were evaluated as crucial for important communications. For instance, a clear and single strong pressure to indicate a change of direction (instead of constant stimulation) or obstacle detection are preferable. 4) *Wearable and hands-free system* The arm was considered as a good body location for haptic communication. We translated these requirements under a design point of view in the CUFF device (see Fig. 1 (b), (c)), a wearable haptic interface that consists of a belt attached to two motors that can rotate counterclockwise from a reference position (i.e. ”turn left” information), clockwise (”turn right”), or squeeze the users’ arm (single strong squeezing corresponding to ”stop” command; two light squeezing stimuli corresponding to ”go” instruction). The results of the experiments with blind people showed that our system could be an effective support during indoor navigation with the white cane, and a viable tool for training blind people to the usage of travel aids. However, after the delivery of turn right/left commands, the CUFF motors returned to the reference position. This sometimes caused a misleading perception in users. Furthermore, the sliding stimulus for implementing a turning command was always constant and set to the maximum; this enabled a more clear stimulus detection, but did not allow to graduate the information delivery based on the presence of obstacles. For these reasons, we decided to integrate vibrotactile information in the CUFF, to help to disambiguate these types of stimuli and provide a gradient in the stimulus delivery (to communicate a more or less intense turning action, and/or the location of the obstacles). The first step was the engineering of an elastic bend - see Fig. 2, with six cylindrical vibrating motors [8], positioned at a distance of 3.5 *mm* between each other [9]. The motors, powered with 3 V provided by the USB connection with the laptop, can vibrate at a frequency of 250 Hz, [10].

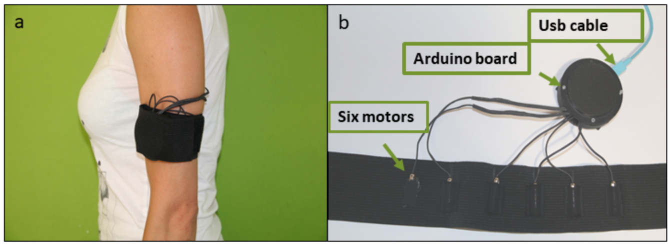

Fig. 2. On the top: The device worn by a participant. On the bottom: the six motors glued in the inner part of the bend

We asked four naive sighted, blindfolded volunteers (30.4 ± 3.2, 2 Female) to understand which was the amplitude of the stimulus (based on the number of the motors that were vibrating) and in which direction (left or right) they were vibrating. The different stimuli were the following, both starting from the right and the left of Fig. 2 b; 1) small stimulus amplitude (vibration of the first two motors); 2) mid stimulus amplitude (vibration of the first four motors); 3) large stimulus amplitude (vibration of all motors). We found that only one participant gave a wrong answer for the stimulus *”starting from right: mid stimulus amplitude”*. These results are encouraging, and push us to pursue the integration of the vibrotactile belt in the CUFF, whose design can be simplified to provide only squeezing stimuli, and its testing with blind users.

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