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OBSTACLE DETECTION SYSTEM FOR VISUALLY IMPAIRED PERSON

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Abstract*—Electronic travel aids are used for detect obstacles, identifying services, and, generally, obtaining useful information from the surroundings, thus enabling a secure and valuable development of the environment. A drawback is unnatural codification, which may direct to usability concerns. This paper introduces a haptic device aimed to provide the user with information on the existence of obstacles within the environment. The haptic interface is intended to reproduce the stimulus provided by a traditional white stick, without any contact with the atmosphere. A prototype, implemented through a short stick with an embed smart sensing approach and an active handle, is presented. Twenty-five blindfolded normally sight users participated to assess system production in detecting obstacles and properly conveying their position by the haptic line. With respect to detecting obstacles and their positions, the average values of the understanding in the case of left, center, and right placed obstacles are 0.735, 0.803, and 0.830, while the specificity values are 0.924, 0.835, and 0.827, correspondingly.

Index Terms—Electronic cane, haptic interface, mobility, ultrasonic sensors, visually impaired.

INTRODUCTION

Several solutions have been industrial to assist visually Simpaired users in the stage daily activities [1]–[7] and mobility tasks [8]–[25], by using different approaches to deliver the information to the user. Examples of systems adopted to translate environmental content into auditory and tactile are discussed in [17] and [18]. Mobility and navigation aids exploiting wireless or mobile technologies are available [19]–[23], also in the field of context-aware systems [24],[25]. Mobility aids should improve life quality and wellbeing of visually impaired people while providing self-confidence and autonomy. To this end, such assistance must exploit an efficient way to convey the information to the end user. Research dedicated to providing the user with haptic feedback to properly map the context include the capability to sense the environment through touch and kinesthesia, meaning the ability to perceive body position, movement and weight (by receptors located in muscles, tendons, and joints) [26]–[29]. As an example, in[16], an electronic device to be attached to a traditional white cane and aimed to alert users of low-hanging obstacles is presented. The system uses an ultrasonic range sensor and an eccentric mass motor to deliver information about detected obstacles by haptic alerts. Other haptic interfaces adopted for mobility and training tasks are described in [30]–[37]. approach aimed to provide the end user with information on the perceived environment, by a natural form of codification such as by vibrations produced on the cane handle mimicking the real sensation provided by the use of a traditional white cane are being developed. A solution to convert obstacle

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positions into a suitable stimulation of the hand palm was addressed in [38]. This study includes a long white cane with a matrix of strain gauges on the handle and recorded the palm C cross-interference between actuators installed in the cane handle, and the absence of a cane-floor interaction model allowing for the dynamic setting of the obstacle perception threshold. This paper presents a short cane with an embedded smart sensing strategy and an active handle. The haptic tool installed in the cane handle implements a codification strategy which is designed to convey to the user's palm a sensation similar to the one provided by a traditional white cane bumping against an obstacle. Thus, the main advantage of the proposed solution resides in the possibility to provide the user with this form of natural codification of the detected obstacle position, rather than an unnatural form of codification. This strategy supports avoiding the masking of natural echoes (the user must be always able to "visualize" the environment), improving user confidence in the device effectiveness and reducing training. Moreover, the proposed methodology enhances the visually impaired people's autonomy by avoiding inconvenient environmental interactions. To reinforce the choice of using a cane as the vector for detecting obstacle information, the white cane is the very first aid for visually impaired people. The white cane is able to provide the user with a lot of useful information about the surroundings. With respect to [38], this study offers new solutions for the smart processing unit and the haptic interface, avoiding cross-interference between the actuators. A new cane-floor interaction model supports implementation of an adaptive operation mode of the obstacle detection strategy.

DETECTION/STIMULATION PARADIGM

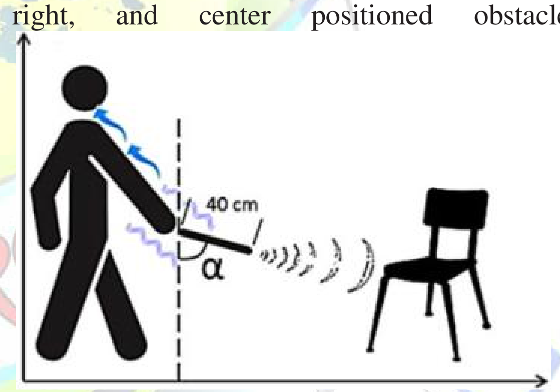
A schematization of the proposed approach is shown in **Fig. 1.** When the haptic cane detects an obstacle along the walking path of the visually impaired user, it will produce on the cane handle a vibration mimicking the real sensation provided by the use of a traditional white cane.

Although the stimulation produced on the hand palm by a white cane bumping into obstacles has been addressed in [38], results identified the need for a complex stimulating pattern. The achievement of such spur requires a complex actuator configuration, whose performance can be strongly compromised by the user's usage and capability to properly hold the cane. As a consequence, the possibility to

Provide the user with different stimuli for different vertical locations of the obstacle can be easily compromised by the way the user holds

The cane. On the basis of this consideration, a study of the stimulation produced on the hand palm by a white cane bumping into obstacles

was performed, by exploiting a implied matrix of sensors aimed to assess the effect of left, right, and center positioned obstacles,



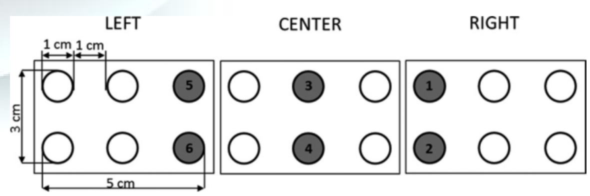


Fig. 2. Results of the characterization surveys oriented to estimate the relationship between obstacle locations and stimulated hand palm zones. Dark cells correspond to the stimulated zones of the palm. Results obtained are related

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to the right-hand side use of the device. Independently of their vertical position. The approach uses an array of strain gauges sensors installed on a standard white cane and covering the interface between the user hand palm and the cane handle .Fig. 2 shows the results where the central area of the hand palm has been represented (5 cm × 3cm). The maps in Fig. 2 are related to each obstacle position (left, center, and right) and have been created by observing the dynamic of the perceived stimuli in the six monitored areas (two left, two center, and two right) corresponding to the actuator position.
Successively, such dynamics have been filtered by a threshold algorithm and the areas characterized by a meaningful solicitation have been selected. Different solicitation zones have been observed for different obstacle positions. Here, the stimulating pattern in the haptic cane will be independent of the cane tilt. The main assumption is that the user is aware of the cane inclination and hence of the obstacle position along the vertical dimension. Blind people sense the position of an obstacle with respect to their body reference frame via proprioception under active exploration, i.e., they move the cane in the space and perceive the position of the cane through the position and orientation of their arm holding the cane. The solicitation maps in Fig. 2 are used to drive the actuators installed in the cane handle in order to reproduce on the user palm a sensation similar to the one produced by a white cane bumping into obstacles. The activation times for each set of actuators have been fixed on the basis of experiments performed with the instrumented white cane [38], during which the typical solicitation times, due to the cane interaction against obstacles, have been estimated. This study explores the possibility of providing the user with a tactile stimulus. Unless all necessary information can be measured in runtime, physically accurate tactile stimulation is impossible. This is one of the main reasons why the vast majority of tactile user interfaces use abstract yet intuitive and carefully designed tactile stimuli. Providing a dynamic-free tactile stimulus, which does not reproduce the dynamic of solicitations observed in the user hand palm, is a first proof of concept of the methodology proposed. A dedicated algorithm has been developed to implement the mapping between the information collected through the multisensor probe (obstacle position) and the set of actuators to be activated. The first task of the algorithm is to detect the obstacle position in the space in front of the user. Successively, a lookup table, implementing the correspondence maps in Fig. 2, is used to activate the actuators embedded in the cane handle. Actuators 1, 2 are actuated together, as well as 3, 4 and 5, 6. The overall effect produced by the paradigm will be the stimulation of the user palm zones, thus mimicking the real sensation provided by a traditional white cane bumping into a (detected) obstacle. To avoid false alarms in obstacle detection, due to the cane-floor interaction, an adaptive operation mode of the obstacle detection strategy has been implemented. Given the length of the developed haptic cane (40 cm, see Fig. 1), mimicking the operating range of a traditional white cane (120-cm length) means that the cane tilt a falls within [30°,90°] and the detection (minimum distance between the obstacle and the sensor head) has been fixed to 80 cm. distance D dist When the cane tilt a falls within [0°,10°], the information provided by the ultrasound distance sensors is ignored; when it falls in the range [10°,30°], the detection distance is defined as a function of a. The offset distance is the vertical position (a =0) between the cane and the floor, DOS. By fixing the constraints

$$Ddist|_{a=0^{\circ}} = D \quad (1)$$

$$Ddist|_{a=30} = 80cm \quad (2)$$

The following interpolation model estimates the detection distance as a function of the tilt α

$$Ddist = DOS + \alpha 80 - DOS/30 \quad (3)$$

A flow diagram of the Detection-Stimulation algorithm is in Fig. 3, where numbers in the circles on the right are the identifiers of the

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activated actuators **[see Fig. 4(c)].**

PROTOTYPE IMPLEMENTATION

This section describes the implementation of an instrumented con- tactless cane. As improved from [38], this new version of the haptic cane exploits new solutions for both the smart-processing unit and the haptic interface in order to avoid the cross-interference effects between the actuators. The adopted strategy to detect obstacles exploits two dual-element high-performance ultrasonic distance ranger modules, Devantech SRF08, installed on a short cane to estimate the obstacle's distance from the user, D (where i =1, 2 states for the ultrasound sensors). Each module employs two ultrasound transducers working at 40-kHz implementing the transmitter (Tx) and the receiver (Rx), respectively. The SRF08 has a configurable maximum range from 3 to 600 cm, uses an I2C interface, and features a typical current consumption of 15 mA. Two SRF08 devices are used for obstacle detection. The two modules assure the partial overlapping of the conical beam of the two ultrasound transmitters. The distances D, measured by the sensors, are then compared with the detection distance Di. If either measured distance is less than Ddist , the algorithm running on the microcontroller reveals the presence of an obstacle. Information on which module (left/right)

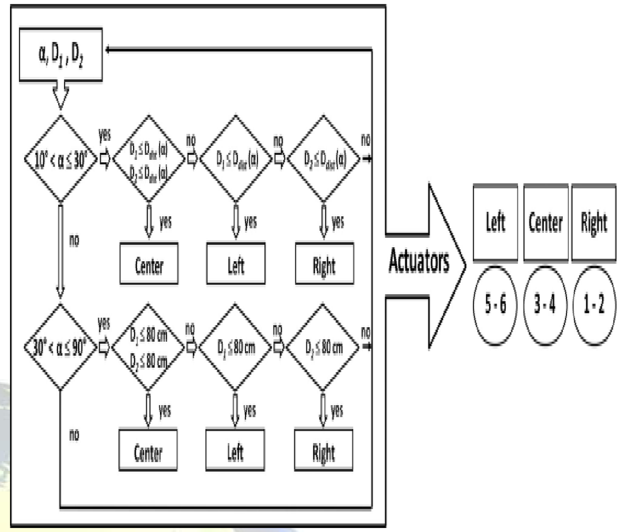

Fig. 3. Flow diagram of the algorithm used to determine the position of the obstacle on the user's path and the combination of actuators to be activated. D1 and D2 are the estimated obstacle distances from the two ultrasound sensors and a is the cane tilt.

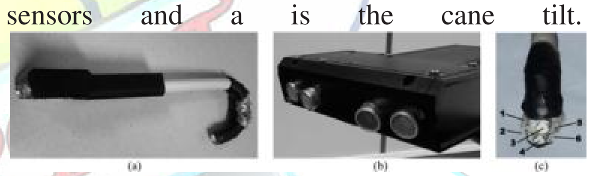

Fig. 4. (a) Contactless cane. (b) Ultrasound sensors. (c) Vibrating actuators installed on the cane handle.

Detects the obstacle is used to estimate the obstacle position: If both measured distances are less than D, then the obstacle is detected in center position. **Fig. 4** shows implemented contactless cane with theultrasound sensor head. Dist Unlike a traditional white cane, the sensing solution provides the user with awareness of the obstacle position (left, center, and right) without the need for sweeping the cane from left to right and vice versa. As mentioned, the threshold distance Ddist is evaluated in real time as a function of the haptic cane inclination a, in order to improve As mentioned, the threshold distance

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Ddist the difficulty detection dependability. For this purpose, an accelerometer ADXL335, a low power three-axis accelerometer with signal trained voltage outputs, is used. The device measures acceleration with a minimum full-scale range of ±3 g and presents a typical sensitivity of 300 mV/g on each axis while noise density is typically 150 µg/_Hz rms for the x- and y-axes and 300 µg/_Hz rms for the z-axis. The device can measure the static acceleration of gravity in tilt-sensing applications. In the new version of the prototype, a set of six flat vibrating actuators, Solarbotics VPM2, was installed on the stick hold. The adopted matrix configuration covers the contact interface between the cane handle and the palm [see Fig. 4(c)] with the aim of "imprinting" on the user palm a sensation similar to that provided by a conventional white cane bumping against obstacles. The disc-shaped actuators have a diameter of 1 cm and are placed on the cane handle to stimulate a restricted hand palm zone minimizing cross-interferences. The actuators are 1 cm apart. A passive rubber sheet, placed under and between the actuators, mitigates the propagation of vibrations along the cane handle. The prototype includes a soft cover improving the device handling, without compromising the actuator operation. Different from [38], the present version of the prototype employs three sets of actuators to codify obstacles in the left, center, and right positions independently on the vertical position of the obstacle. Devices 1 and 2 are actuated for an obstacle detected on the right, 3 and 4 for the center, and 5 and 6 for a left positioned obstacle [see Fig. 4(c)]. Data from the sensors are acquired and processed by a microcontroller unit. A Droids Multi interface Board equipped with a PIC18F2520 Microchip running at 40 MHz has been employed due to its versatility. The actuators are controlled by the digital ports of the microcontroller board. The sensor head and the processing node are battery operated. With respect to power consumption, the current budgets for each actuator and for the electronics are 90 and 100 mA, respectively. The operation time on battery depends on the activation rate of actuators (i.e., the number of obstacle detected). An operation up to5hhas been experimentally verified, by powering the device with a 9-V–1200mA/h, AA size, battery pack. A schematization of the electronics is in Fig. 5. Data provided by the multisensor architecture are transferred by a wireless communication procedure (IEEE 802.15.4) to a dedicated PC station. The wireless link is implemented through an X Bee-PRO module by Max Stream, Inc., which supports the Zig Bee communication protocol in the ISM 2.4-GHz frequency band. An X Bee-USB board connected to the PC station is used to receive and supply data to a Lab VIEW VI. The graphical user interface (GUI) (see Fig. 6) allows setting the communication protocol parameters and

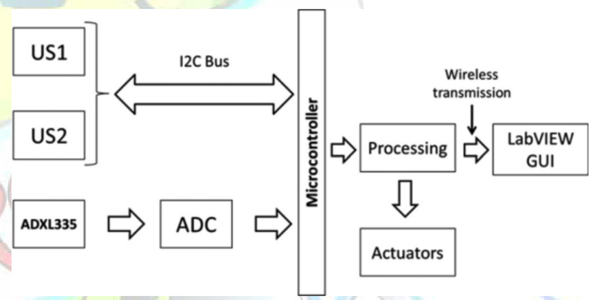

Fig. 5. Schematization of the electronic installed on the contactless haptic cane.

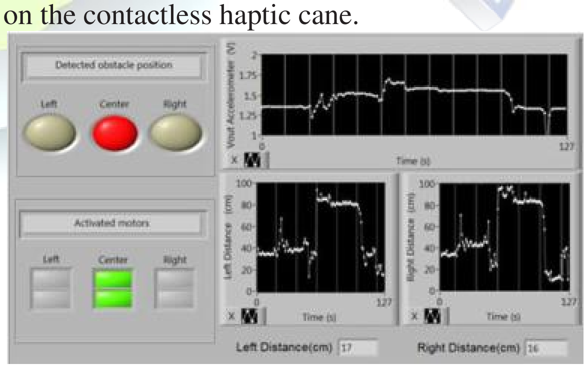

Fig. 6. Lab VIEW GUI with an obstacle in the center position

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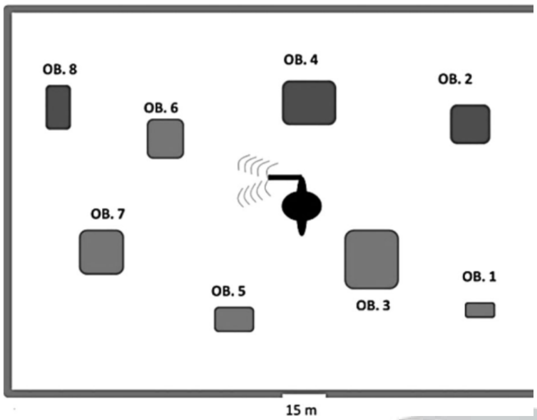

Fig 7. Typical scenario with several obstacles (OB)

Displaying the output signals from the ultrasonic transducers and the accelerometer. The GUI is used to monitor the distance of the detected obstacle, its position, and the vibrating actuators activated. The device responsiveness is constrained by the acquisition/processing cycle duration which, in the worst case, is 1 s. Such dynamics are well-matched with the users' needs and would not cooperation the performance of the proposed solution.

EXPERIMENTAL METHODS

The experiments aim to assess the system performance in a supervised mode. The environment shown in Fig. 6 was used to assess failures of the Ultra Sound system (obstacle missing) and other related events.

A.Participants

Twenty five right-handed users (four females) with normal vision participated. Their ages ranged between 24 and 41 years (mean 32.3 years; standard deviation (STD) 4.4 years). Their mean height was 174.7 cm (STD of 6.3 cm).

B. Scenario

The aim was to assess providing the user with the "right" haptic feeling about obstacles positioned on the right, left, and center positions with respect to his/her walking path. A scenario was arranged by randomly positioning eight obstacles in an area of 15 m × 6m(see Fig. 7). Obstacles had different dimensions ranging from 10 cm to less of1m. Fig. 7. Typical scenario with several obstacles (OB).

C. Procedure

The task was to perceive the sensation produced on the hand palm, by a cane bumping against right, left, or central obstacles. The participants were blindfolded and were asked to move inside an environment where obstacles have been randomly positioned. First participants were trained to feel the presence of obstacles by means of a traditional white cane. For the experimental trials, the participants were instructed that the stimulation patterns do not depend on the vertical position of the obstacles. They were told to use the features of the haptic cane to detect left and right positioned obstacles while maintaining the cane positioned along the walking direction and not to use sweeping movements. Missed objects and erroneous detections were not identified to the participants but were noted by the experimenters

.

D. Dependent Measures

Sensitivity R and specificity S in detecting left (L), center (C), and right (R) obstacles, are defined as

TABLE I

SENSITIVITY AND SPECIFICITY FOR OBJECTS ON THE LEFT,CENTER, AND RIGHT

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	RL	RC	RR	SL	SC	SR
Avg	0.735	0.803	0,830	0.924	0.835	0.827
S.D.	0.257	0.197	0,260	0.133	0.190	0.248

E. Experimental Design and Data Analysis

Each blindfolded participant was asked to move inside the environment starting from a random position until detecting ten obstacles. Each participant did one trial without having any knowledge about the obstacles position. Participants were asked to notify to the supervisor their perception of the obstacle position. Analyses of data to investigate statistical differences by position (left, center, right) have been conducted in terms of sensitivity R and specificity S
.

RESULTS

Table I presents the results for sensitivity and specificity with the new cane.

CONCLUSION

This paper has investigated using a short multisensor cane to assist the visually impaired with obstacle avoidance, by exploiting haptic information about the presence of obstacles. The goal is to reproduce stimuli similar to a traditional white cane without contacting the environment. This study demonstrates the possibility to convey environmental perception using a natural codification and avoiding artificial auditory or unnatural tactile codification. In addition, the sensing architecture allows for obstacle detection without the need for sweeping the cane in front from side to side.
The results obtained with blindfolded normally sighted users encourage further efforts to develop the proposed methodology. Future actions will be dedicated to optimize the active handle (also for left-handed users), and to include new sensors extending the system functionality in terms of environment perception and tilt estimation. In addition, testing with the visually impaired is necessary.

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