Voice-Controlled Smart Assistive Device for Visually Impaired Individuals

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Abstract—**This paper presents the modeling, implementation and testing of an experimental microcontroller (MCU) based smart assistive system which can be used by the visually impaired or blind people. This device includes haptic and audio feedback options from which the user can select. A Smart Phone can be used to control the device using predefined voice commands and Bluetooth connectivity. The device is portable and the purpose of its usage is to warn the user when objects are present on the walking path so collision can be avoided. Distance measurements, between the user and possible obstacles, are performed using ultrasonic echolocation and the data provided by the ultrasonic sensor is processed by a microcontroller, which also handles the feedback part. The hardware design, software architecture and mechanical design of the enclosure as well as the breadboard prototyping are covered in this material. Experimental results performed in different functionality scenarios demonstrate that the proposed system can be successfully used to fulfill its purpose.**

Keywords—Visually Impaired People; Assistive Device; Ultrasonic Echolocation; Voice Control; Mobile Devices

I. INTRODUCTION

According to the World Health Organization (WHO), there are roughly 39 million blind individuals in the world. Yet another 246 million are visually impaired to the degree that they have difficulties in reading and interpreting signs or printed material [1]. In Romania, approximately 120000 people are registered as officially blind [2].

Accessibility to the surroundings is important for all individuals, but access does not include only physical mobility, such as making a voyage between two predefined points by a selected transportation type, but also being able to recognize decision points in the neighboring environment, such as obstacles and signs. Accessibility therefore involves the ability to interpret, recognize and understand the arrangement of features in the environment as well as being able to find the way independently [3].

In past years, several electronic aid devices, called electronic travel aids (ETA), were introduced as a substitute for the white cane. Different implementation approaches combine various types of sensors, cameras or feedback channels. They all aim to improve the mobility of visually impaired individuals.

One such example can be found in [4] where a wearable navigation device is presented. A 2D vibrator array attached to the user's chest is linked to a portable computer (Tyflos) and provides tactile feedback based on the images captured by two miniature cameras. Another example of device with haptic feedback is described in [5]. The authors started with the supposition that the user is aware of the cane inclination and hence of the obstacle place. The two ultrasonic sensors are placed on a short cane and the user can detect the obstacle position (left, center or right) by moving the cane left to right and vice versa while walking in the environment. One of the most used ways to determine the distance and direction of an object is by means of ultrasound reflections – commonly called ultrasonic echolocation. The same principle was exploited in [6]. The authors developed a portable device that features a rechargeable polymer lithium battery, a potentiometer to adjust the range and sensitivity, an ultrasonic sensor and a MCU.

Alongside mobility, visually impaired individuals deserve an enhanced access to some sort of information that for other individuals is straightforwardly reachable (such as books or newspapers). The standard writing system used by blind and visually impaired people is the Braille alphabet. A solution to convert digitally stored text into Braille using solenoids is presented in [7] where a secure digital (SD) card is used to store text files. The characters are converted one by one on a display unit in Braille format using six solenoids to represent the letter in a format effortlessly interpretable by the user. .

Another key aspect of accessibility for visually impaired individuals is magnification. A solution for this is provided in [8] where Google Glasses are used to help low-vision Smartphone users by magnifying screenshots of the display that are sent in real time via Bluetooth. Up to 7 frames per second (FPS) can be transferred by the system at 8x magnification, which is adequate for tasks where the content does not vary at fast rates.

There are three main categories of direction-finding systems: i) vision enhancement (the input from a sensor or camera is processed and displayed on a visual display), ii) vision replacement (the information is displayed directly on the visual cortex of the human brain or the optic nerve) and iii) vision substitution (similar to the first category but the output is non-visual: acoustic, tactile or a combination of the two). The

978-1-5090-3748-3/16/$31.00 ©2016 IEEE

proposed navigation device belongs to the last class of navigation systems; the output can be either acoustic or tactile depending on user's selection.

We used the HC-SR04 ultrasonic rangefinder which can provide 2 to 400 cm non-contact distance measurements with an accuracy of up to 3 mm. [9]. The information provided by the rangefinder is processed by the ATmega 328 MCU which can be found on the Arduino board. It can trigger the acoustic or tactile feedback according to the voice command received via Bluetooth from a Smartphone. The Bluetooth connection is ensured by the Serial Port Protocol (SPP) Bluetooth module HC-05.

The remaining part of this paper is structured as follows: Section 2 presents a general idea of the investigational setup, including the hardware and software architectures, mechanical design of the case and the printed circuit board design as well as breadboard prototyping. Section 3 reveals pertinent experimental results and discusses accuracy characteristics. The author's conclusions and forthcoming developments are mentioned in the closing section.

II. EXPERIMENTAL SETUP

A. Hardware and Software Components

The block schematic of the proposed system is presented in Fig. 1. The measurements performed by the ultrasonic rangefinder are processed by the Arduino's MCU which is permanently checking if there is any voice command available in order to trigger the desired feedback method. The voice commands are transformed in strings using Google's Voice Recognition module for Android and are sent via Bluetooth to the device. The user can choose to use both feedback modes at the same time or stop any feedback signal.

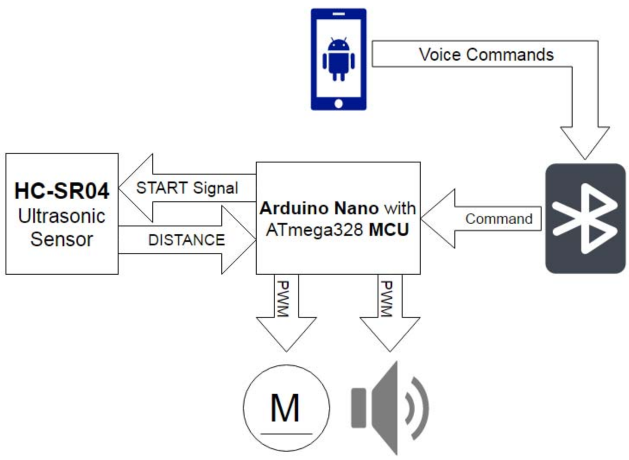

Fig. 1.Schematic of the experimental Assistive Device.

The proposed system is operated by the Arduino's ATmega 328 RISC microcontroller which is responsible for measurements processing, feedback and user interface interaction. In order to start the measurement procedures, the HC-SR04 needs a trigger input of 10 µs. Once the trigger signal is sent by the MCU, the rangefinder outputs on its transmitting terminal a cycle of 8 bursts at 40 kHz and waits for the reflected signal to return to its receiving terminal. Relation (1) is used to compute the distance to an object based on the delay of the reflected signal:

$$D = t/k, \tag{1}$$

where D is the distance to the object, t is the delay time expressed in μs and the constant k is provided by the manufacturer in the datasheet. For calculations of D in cm, k = 58.

The ultrasonic sensor range was software-limited at 20 to 200 cm. The upper side limit was set to 200 cm in order to comply with indoor usage and the lower side limit was set to the distance between the sensor and the fingertips so that the feedback stops once the user touches an object. The sensor cannot measure the distance to an object that: i) is more than 200 cm away, ii) is too small to reflect an adequate sound level and iii) has the reflective surface at a shallow angle so the sound will not reflect back to the receiver module.

For communicating with the Smartphone we have used the Serial Port Protocol Bluetooth module HC-05 which was designed for transparent wireless communication [10]. You can connect to the HC-05 module using a special designed Android application that incorporates the Voice Recognition module from Google. Once you have a connection between the device and the Smartphone you can send voice commands to the gadget. For this purpose we have 4 predefined commands: "Audio On", "Audio Off", "Vibration On" and "Vibration Off". A detailed diagram of the Bluetooth connection principle is shown in Fig. 2.

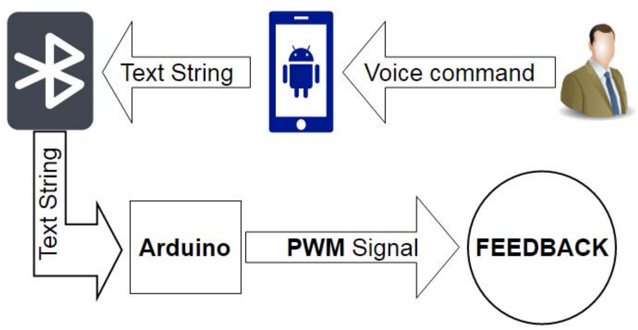

Fig. 2. Voice commands over Bluetooth implementation principle.

The device can provide both acoustic and tactile feedback to inform the user if there is an obstacle in his walking path. The strength of the acoustic or tactile signal is adjustable, depending on the distance. The MCU outputs a Pulse Width Modulated (PWM) signal at one of its I/O pins and the duty cycle is directly responsible for the intensity of the feedback signal.

The voice command "Audio On" is used to start the audio feedback mode. The MCU starts sending PWM signals to pin 16 which drives the speaker through a NPN transistor. The audio mode remains active until the command "Audio Off" is sent by the user. Correspondingly, the vibration motor can be selected as feedback method using the command "Vibration On" and it can be stopped using "Vibration Off".

The device is powered by a lithium-ion battery that can provide an output voltage of 3.7 V. This voltage is raised by the high efficiency POLOLU-2115 step-up converter [11] at nominal 5 V - which is the supply voltage for the MCU. A charging solution for the battery is also provided using the TP4056 module. The charging module uses the LTC5056 chip with thermal feedback from Linear Technologies to provide a constant 4.2 V charging voltage and can be supplied with 5 V at 1 A from any charger with mini USB type B connector [12]. In Fig. 3 we present the breadboard prototyping of the project.

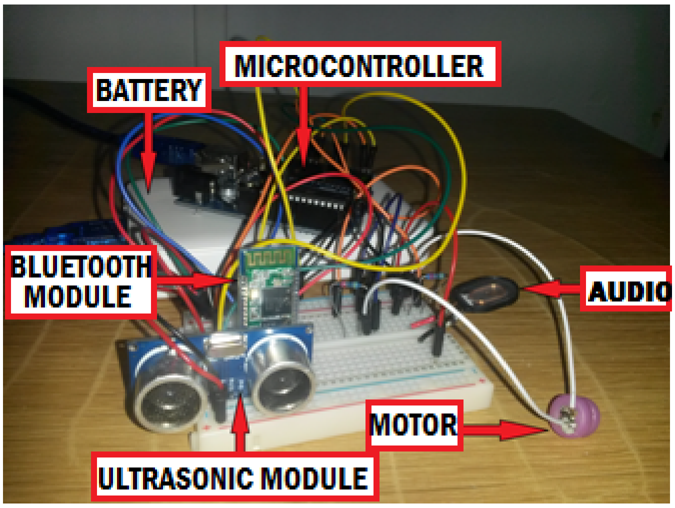

Fig.3. Experimental setup in the laboratory.

This system corresponds with the schematics presented in Fig. 1. An Arduino board was used as an alternative to the stand alone MCU and the battery pack used to power the prototype can deliver 5 V.

In order to transform the functional prototype into a wearable device an enclosure and a custom printed circuit board (PCB) were designed. The first version of the PCB is a double sided one which has a cutout for the battery installation and was designed using Zuken's CR-5000 advanced PCB design software. The dimensions of the PCB are presented on the left side of Fig. 4, while on the right side the actual PCB is presented (top side view).

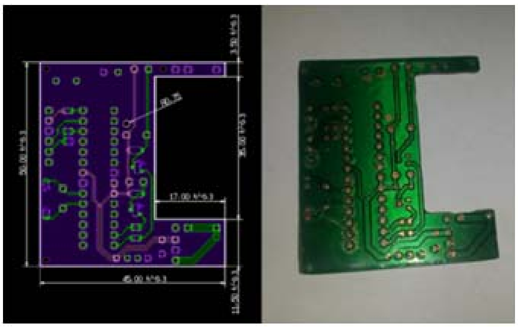

Fig. 4. System PCB: design details (left) and top side view (right).

At the time of the submission of the present material, an improved version of the PCB is being developed. The PCB and the enclosure will be redesigned in order to minimize the size the final product.

The enclosure of the device was designed in Creo and 3D printed and has the following dimensions: a length of 60 mm, a width of 49 mm and 29 mm in height. It has a leather band attached and can be wrist mounted.

In the back side of the case two hinges are designed such that the PCB, the battery, the ultrasonic rangefinder, the battery charger module and the Bluetooth module are easily accessible. Preferably, the whole component should have a uniform thickness - the nominal wall thickness. This was not possible for this design but variations were kept to a minimum. Most of the walls of the enclosure are 2 mm thick, but there are areas with 4 mm made to be used as mechanical support for the PCB. The thinnest part of the enclosure has 1 mm and it is located on the bottom side. In Fig. 5 we present a side view of the enclosure 3D design.

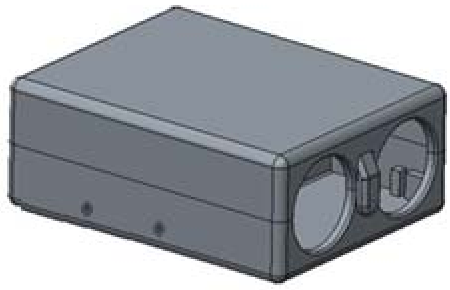

Fig. 5.Side view of the enclosure 3D model.

B. System Functionality Features

Since the device has been designed as an educational project, the authors have followed system design rules reported in [13]. Fig. 6 presents the first version of the assembled device which is fully portable and powered by a rechargeable battery. The main advantage of this device is the mounting location, allowing the user to have both hands free. It is also extremely easy for the user to scan the entire surrounding environment by moving his hand in dissimilar positions. The user is always aware of the position of his hand reported to his body and can easily identify the direction of the obstacle.

Before starting navigating unaccompanied it is recommended for the visually impaired individual to be guided in front of a barrier by someone else in order to get used with the intensity of the audio and tactile signals according to the distance to the obstacle. The intensity of the feedback signal increases inversely proportional with the distance to an object.

Fig. 6. Prototype version of the assembled device.

The assembled device has a weight of only 200 g. Once the preferred feedback mode is selected the phone can be placed in the pocket. The Bluetooth connection remains active and the user can actively change the working mode using voice commands. If a 1 Amp charger is used, the charging time for the battery (from 2% shutdown threshold to fully charged) is about 45 minutes.

III. Experimental Results

For the presented device we have focused our tests on the accuracy of the measurements and the ability of visually impaired individuals to keep away from obstacles in a controlled environment. We verified if the feedback modes can work all together and calibrated the intensity of the feedback signals such that they have the same magnitude in both modes. The device was tested in indoor conditions. It is not recommended to use it outdoor because it is not waterproof and the maximum detection range is limited to 200 cm. The tests were performed on 5 blindfolded individuals in various environmental situations. All the individuals were able to navigate in the environment and avoid the obstacles.

As an additional test, they were asked to find using ultrasonic echolocation a glass of water on a table, raise it and drink the water. The position of the glass was easily identified using a left to right swing of the arm.

The most accurate results were obtained with flat surfaces as obstacles at an angle of maximum 30˚ from horizontal. Surfaces with irregular shapes can reflect the signals in the vicinity of the ultrasonic sensor and the results of the measurement can be erroneous. This shortcoming can be suppressed by moving the hand both in the horizontal and vertical planes.

The mobile device application is compatible with any Android Smartphone and the Bluetooth is by design enabled once you open the application. Once the Bluetooth connection is established, the mobile application can be naturally used – it has no more than one button that must be pressed every time the user decides to send a new command to the MCU.

IV. Conclusions and Future Development

This paper presents the prototype version of a smart assistive system which can be used by the visually impaired or blind people. The proposed device is a guiding mechanism that helps avoid collisions with obstacles present on the walking path. This work has been inspired from existing systems which are used by visually impaired and blind individuals on a daily basis. Inclusion of a Smartphone capable of sending Bluetooth commands to the device offers a great base for further progress.

In future designs some new sensors will be included (for pulse and inclination measurements). In this way, any medical emergency can be monitored. The exact location of the user can be provided using the GPS function of the mobile phone. The tilt sensor can be used to start or stop the ultrasonic echolocation depending on the hand position. When the ultrasonic sensor is facing down the user's hand is not used for navigation and for battery saving reasons the device can go in standby mode.

We will also focus on minimizing the dimensions of this device and development of new functions. As a first assignment, we will redesign the PCB and the enclosure and we estimate that we can reduce the length of the device by 2 cm. The height and width of the device are currently limited by the dimensions of the ultrasonic sensor.

Acknowledgment

The authors are grateful for the support provided by Alfa Test S.R.L, www.alfatest.ro.

References

[1] World Health Organization (WHO), http://www.who.int/mediacentre/factsheets/fs282/en/, last accessed on 06.07.2016.

[2] European Blind Union (EBU), http://www.euroblind.org/media/employment/thm-overview-version-3-final-rev-RF_Romanian-translation.doc, last accessed on 02.07.2016

[3] W. Barfield and T. Caudell, "Fundamentals of Wearable Computers - and Augmented Reality," Lawrence Erlbaum Associates, Mahwah, New Jersy, 2001, pp. 429-431.

[4] D. Dakopoulos, S. K. Boddhu, and N. Bourbakis, "A 2D Vibration Array as an Assistive Device for Visually Impaired," IEEE 7th International Symposium on BioInformatics and BioEngineering, Boston, USA, October 2007, pp. 930-937.

[5] B. Ando, S. Baglio, V. Marletta, and A. Valastro, "A Haptic Solution to Assist Visually Impaired in Mobility Tasks," IEEE Transactions On Human-machine Systems, Vol. 45, No. 5, pp. 641 – 646, October 2015.

[6] L.H. Villamizar, M. Gualdron, F. Gonzalez, J. Aceros, and C.V. Rizzo-Sierra, "A necklace sonar with adjustable scope range for assisting the visually impaired," 35th Annual International Conference of the IEEE EMBS, Osaka, Japan, 3 - 7 July 2013, pp. 1450 – 1453.

[7] A. Kulkarni, and K. Bhurchandi, "Low Cost E-Book Reading Device for Blind People," Computing Communication Control and Automation International Conference (ICCUBEA), Pune, Maharashtra, India, February 2015, pp. 2-3.

[8] S. Pundlik, H. Yi H, R. Liu, E. Peli, and G. Luo, "Magnifying Smartphone Screen using Google Glass for Low-Vision Users," IEEE

Transactions on Neural Systems and Rehabilitation Engineering TNSRE-2015-00191, pp. 1 – 10, March 2016.

[9] Datasheet from Micropik, micropik.com, last accessed on 02.07.2016.

[10] Datasheet from RoboShop, roboshop.com, last accessed on 28.06.2016.

[11] Datasheet from Pololu, https://www.pololu.com/product/2115, last accessed on 02.07.2015

[12] Datasheet from Linear Technology, http://www.linear.com/products/step- up_(boost)_regulators, last accessed on 05.07.2016

[13] S. Nanu, "Educationalaspects incontrolsystemdesigntechnology," Scientific and Technical Bulletin, Series: Electrotechnics, Electronics, Automatic Control and Computer Science UAV Arad, Vol. 4, No 1, pp. 584-589, 2007.