VibroCap: A Mobility Supporting Hat For Blind

Koray Gürkan, Aydın Akan

Istanbul University, Department of Electrical and Electronics Engineering, 34320 Avcılar-Istanbul/Turkey
{kgurkan, akan}@istanbul.edu.tr

Abstract

In this paper, we present the VibroCap, a mobility aiding hat which is designed to detect obstacles and alert the visually impaired user. By using low cost PVDF (Polyvinylidene Fluoride) ultrasonic sensors, hat detects obstacles, which are located across the upper part of the human body and cannot normally be detected by white cane. Depending on the distance of the detected obstacle, visually impaired person is informed by three vibration motors placed on the forehead. The design stages and experimental results of the obstacle detection system are presented.

1. Introduction

White cane is the most frequently used mobility aid for the safe and independent movement of visually impaired people. However, white cane is unable to detect obstacles in upper part of the body. To ensure safety and higher independency sensation, several electronic mobility aids have been developed since 1960. In general, Blasch et al. [1] defined these mobility aids as "devices that transform information about the environment that would normally be relayed through vision into a form that can be conveyed through another sensory modality". These devices can be classified according to task of device; as electronic travel aids (ETA) for clear path and environmental information, and electronic orientation aids (EOA) for orientation and navigation.

Farmer and Smith [2] divide ETA devices into four categories. Type I devices (single output for object preview), provide clear-path information and considered a go-no-go system. These devices include Pathsounder (1965), Mowat Sensor (1972), Polaron (1980), Miniguide (1998), Hand Guide (2003) and Iglasses (2011) [3-7].

Type II devices provide multiple or complex outputs that indicate clear-path information. These devices may be used in conjunction with or as a part of wheelchair or long cane. Type II devices include N-2000 Laser Cane (2000), Ultra-Cane (2004) [8, 9].

Type III devices provide environmental information in addition to object preview. A device in this category provides information about the characteristics of the objects detected. Sonic Torch (1964), Sonicguide (1984), K-Sonar (2005) devices are in this category [10, 11, 12].

Finally, Type IV mobility devices differ from Types I, II and III in that artificial intelligence is an additional component. In this category, Sonic Pathfinder (1984) and Voice (1998) are the most widely known devices [13, 14].

Despite the large number of ETA devices are developed, in the case of complexity and functionality, successful devices are numerous. Electronic travel aids should be considered in the following topics;

First, visually impaired never has to be given up the early habit of mobility. Therefore, in the presence of the device, white cane must be still available and can be used by the visually impaired. For designed ETA, to detect the obstacles in the upper part of the body must be main mission. Informing auditory feedback will mask environmental sound, also in noisy environments these tones cannot be picked up by visually impaired. Thus, auditory feedback is not practical. Feedback signals have to be non-complex and must include short and clear information. Also, device should not adversely affect the aesthetics of the person and must be ergonomic. The components of the device have to be cheap as this affect the total cost of mobility aid.

The design of VibroCap was planned by considering mentioned issues. Main task of the developed system is to detect obstacles, which are located in upper part of the human body and cannot be normally detected by white cane (Fig. 1). To maintain a wearable and comfortable device, all of the components used in the system are inserted in a snap-back hat. To enable flexible and light device, tailor-made low cost PVDF (Polyvinylidene Fluoride) ultrasonic sensors are used to detect obstacles. By using miniature vibration motors, tactile feedback is applied to forehead area of the blind, which is large enough, never used for a task and haptically sensitive.

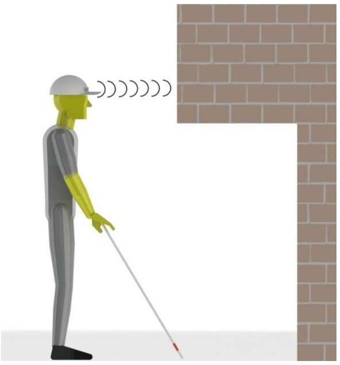


Fig. 1. VibroCap on action

2. The Developed System

Obstacle detection system includes two conical shaped PVDF based ultrasonic sensors, one for transmitting acoustic wave and another for receiving upcoming echo waves (Fig. 2). The design of the conical shaped PVDF sensor has explained in our early work [15] in detail, and is not mentioned any further. As the bandwidth of the sensor is wide enough, a frequency modulated (FM) acoustic chirp signal can be transmitted to air. Because of the acoustic impedance mismatch between air and obstacles, travelling acoustic wave reflects and reflected echo waves arrive to receiver sensor. Acoustic path of the scanning area can be changed by movement of the head so no beam-forming is necessary. To detect receiving echo with a high signal-to-noise ratio (SNR), pulse compression technique is used by matched filtering [15].

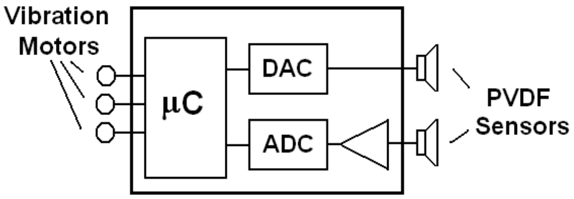


Fig. 2. Block diagram of VibroCap

A low cost 8-bit microcontroller (PIC18F452) and a high speed DAC (AD7524) produces a windowed linear chirp sine signal which has a decay from 20 kHz to 40 kHz with a duration of 0.5 ms. Amplitude of sine wave is 10 V and output sample rate of DAC is 500 kHz. Analog signal at the output of receiving sensor is amplified with a high bandwidth op-amp (AD843) and FET input op-amp (TL081). Total gain is 74 dB. Amplified analog signal is sampled with 204 kHz sample rate by 8-bit ADC (ADC0820).

Microcontroller board and vibration motors powered with a single 3.7 V 1000 mAh capacity Li-Po battery. To produce +/-15 V analog circuitry power supply, a step-up converter with a 100 kHz of switching frequency is included in microcontroller board.

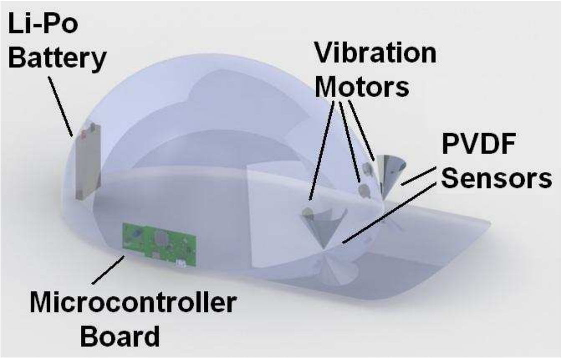


Fig. 3. Components of VibroCap.

2.1. Obstacle Detection and Haptic Feedback

After transmission of acoustic signal, arrival time of echo depends on the distance of obstacle. Velocity of acoustic signal in air is related with temperature and humidity; at 25°C it is approximately 345 m/s [15]. In case of detecting a long range obstacle, i.e. 3 meters, total time-of-flight takes 17.39 ms. If all of the obstacles in this range desired to be detected with high resolution, i.e. 1 mm, microcontroller must record ADC data continuously at least for 18 ms after producing chirp signal. However, high resolution is not necessary for obstacle detection, instead, because of high sample rate and lack of memory, after producing chirp signal, microcontroller starts receiving ADC data after a certain time delay. By this time delay, scanning range is extended without memory extension. Scanning range is divided into three distances which are 28-58 cm, 78-108 cm and 156-186 cm, respectively (Fig. 4). For each range, microcontroller waits longer after producing chirp wave with corresponding time delays 1.4 ms, 4.5 ms and 9 ms, respectively. However, blind zones occur, but no problem as visually impaired gets closer to obstacle.

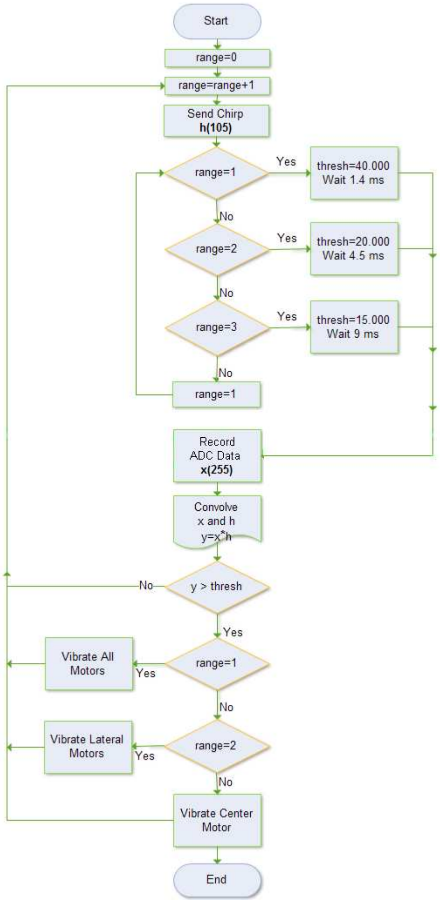


Fig. 4. Obstacle detection and feedback algorithm

To apply pulse compression technique, convolution of digitized echo signal which includes 255 samples, and original chirp signal with 105 samples, are obtained by microcontroller. Depending on the instant convolution result, microcontroller decides if an obstacle is detected, by comparing convolution result with an early known threshold levels, 40.000 for first range, 20.000 for second range and 15.000 for third range, respectively.

For each range step, different vibration motors vibrated by microcontroller, by means of an obstacle is detected. When distance of detected obstacle is in first range, all of the vibration motors vibrate. If distance is between 78 cm and 108 cm, laterally placed motors vibrate. Finally, if distance of detected obstacle is longer than 1.56 m, only one vibration motor at center vibrates.

3. Experiments

To maintain system performance, several experiments are performed. Convolution and haptic feedback algorithm are tested for different obstacle ranges.

Linear chirp sine signal produced by microcontroller is given in Fig. 5. Frequency of sine signal decays 20 kHz to 40 kHz in 500 µs and its amplitude is approximately 22.5 $V_{p\text{-}p}$.

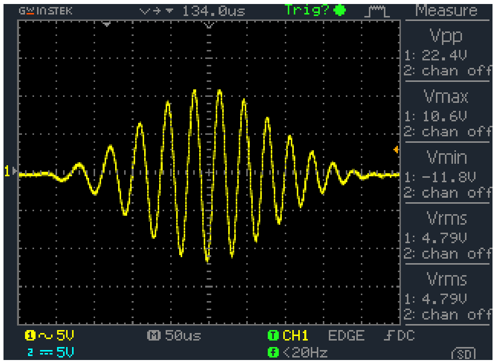


Fig. 5. Linear chirp sine signal produced by microcontroller

To test time delay between chirp signal and ADC recording start time, chirp signal and ADC control signals are displayed at the same time using a digital oscilloscope in accumulate mode. As given in Fig. 6, microcontroller waits longer after producing chirp wave with corresponding time delays 1.4 ms, 4.5 ms and 9 ms to change detection range.

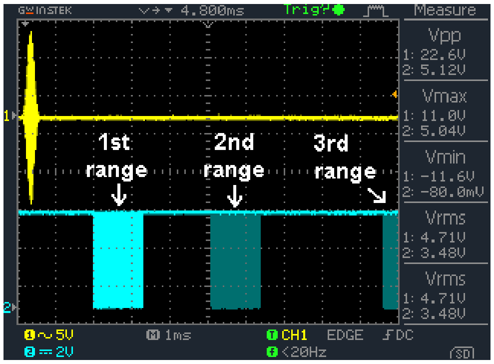
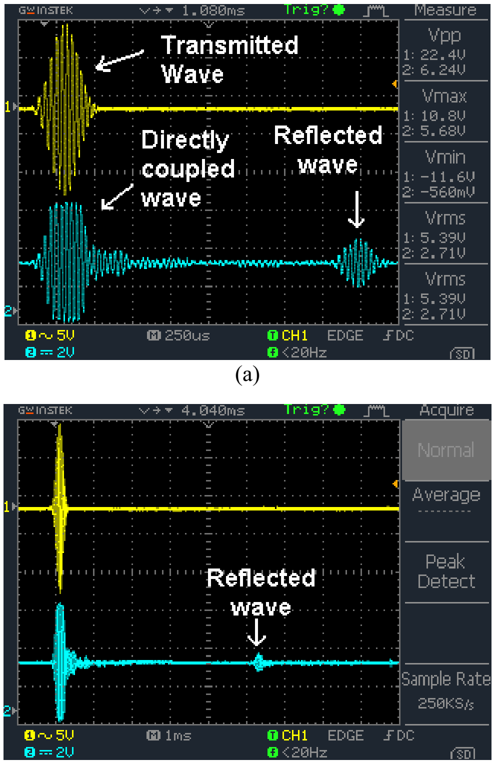


Fig. 6. Chirp and ADC control signals in accumulate mode

To measure variation of reflected wave with respect to distance and to test voltage amplifier block, several measurements are made by changing the distance of an aluminum plate which simulates an obstacle. In Fig. 7(a), transmitted and received signals are displayed for a distance of 33 cm. First echo is a result of acoustic signal which is directly coupled with receiving sensor without any reflection. Reflected wave amplitude is app. 2 $V_{p\text{-}p}$ and chirp signal envelope is still clear. Time of flight is approximately 1.75 ms. Since the gain of amplifier is 74 dB, reflected wave amplitude at the output of receiver sensor can be calculated as 400 $\mu V_{p\text{-}p}$.

When distance of obstacle is increased to 90 cm, reflected wave amplitude is decreased to 0.6 $V_{p\text{-}p}$ (Fig. 7(b)). It can clearly be said that SNR of echo signal has decreased to critical level to detect presence of an obstacle. For larger distances, amplitude of echo signal will be too low and obstacles cannot be detected with classical time domain amplitude threshold comparison method, thus, pulse compression technique is necessary.



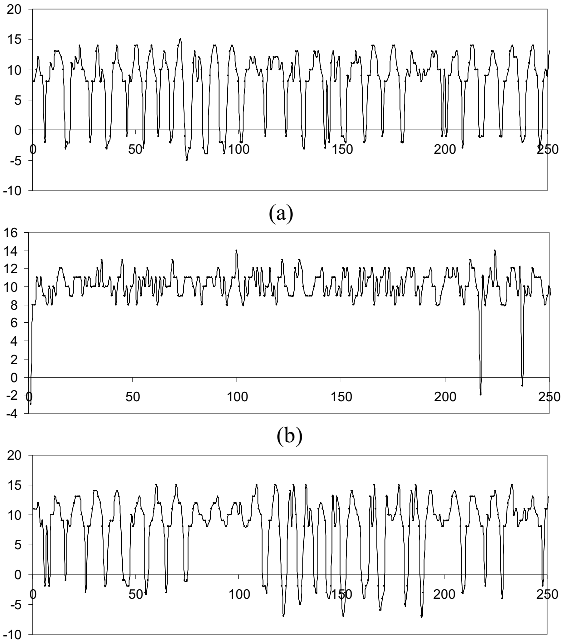
(a)

(b)

Fig. 7. Received signals for 33 cm (a) and 90 cm (b)

To check correctness of pulse compression process which is performed by microcontroller, 8-bit sampled data and 16-bit convolution result simultaneously transferred from microcontroller to a desktop PC via RS-232 interface. When obstacle distance is 172 cm, sampled ADC data for three range step and convolution results are given in Fig. 8 and Fig. 9, respectively. As can be seen from Fig. 8, it is impossible to detect presence of an obstacle, however, after pulse compression, convolution result in Fig 9(c) clearly shows that, there is an obstacle in 156-186 cm range, because convolution result exceeds threshold level (15.000) for this range. However, for other ranges, convolution results do not exceed threshold levels, 40.000 and 20.000, because of the absence of an obstacle in corresponding range.

Because an obstacle is detected in 156-186 cm, only vibration motor at center vibrates. For this case, gating signal produced by microcontroller is given in Fig. 10. All processes, generating chirp signal, scanning three ranges, recording ADC data and calculating convolution, takes approximately 4 seconds.

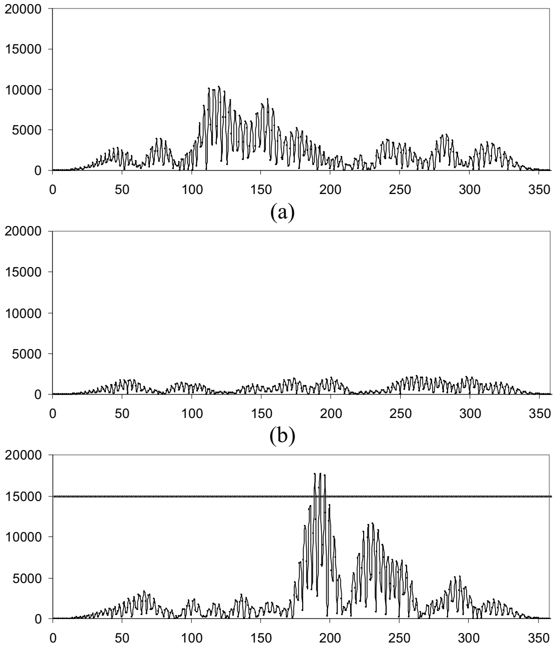


(a)

(b)

(c)

Fig. 8. ADC data sampled by microcontroller with ADC start time delay 1.4 ms (a), 4.5 ms (b) and 9 ms (c) when obstacle distance is 172 cm.



(a)

(b)

(c)

Fig. 9. Convolution of original chirp signal and ADC data given in Fig. 8

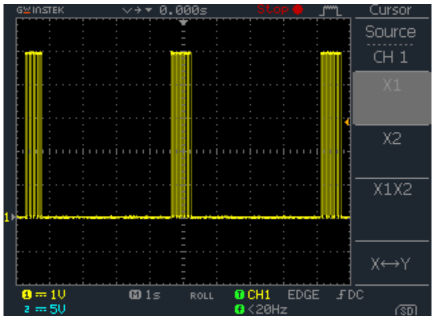


Fig. 10. Gating signals of vibration motor produced by microcontroller in presence of an obstacle.

6. Conclusions

The prototype of mobility aid, VibroCap, is successfully implemented. An effective range expander algorithm provides three range scanning intervals which are 28-58 cm, 78-108 cm and 156-186 cm, respectively. Pulse compression algorithm shown to provide clear obstacle detection even in long ranges. Three vibration motors are maintained to alert visually impaired without having to use hearing sense or the other hand. By this low cost device, it is possible to detect dangerous obstacles which are located in upper human body range and cannot normally be detected by white cane.

7. References

[1] Blasch, B.B., Long, R.G., Griffin-Shirley, N.J., "Results of a national survey of electronic travel aids", *J. of Visual Impairment & Blindness*, 83, 449-453, 1989.
[2] L. Farmer, D. Smith, "Foundations on orientation and mobility", AFB Press, New York, USA, 1997.
[3] L. Russell, "Travel path sounder", *Rotterdam Mobility Research Conf.*, New York, 1965.
[4] N. Pressey, "Mowat sensor", *Focus*, vol. 3, pp. 35-39, 1977.
[5] Nurion Industries, "*Polaron, electronic travel aid for the blind*" [online]. Available http://www.nurion.net
[6] G. Phillips (1998), "*The Miniguide ultrasonic mobility aid*", GDP Research, [online], http://www.gdp-research.com.au
[7] Ambutech Inc, (2011), "*iGlasses*", [online], http://ambutech.com/iglasses .
[8] Nurion Industries, (2000), "*Lasercane, electronic travel aid for the blind*" [online]. http://www.nurion.net/lasercane.htm
[9] Ultracane (2005), [online], www.soundforesight.co.uk .
[10] L. Kay, "An ultrasonic sensing probe as a mobility aid for the blind", *Ultrasonics*, Apr/June, 1964.
[11] L. Kay, "Acoustic coupling to the ears in binaural sensory aids", *J. of Blindness*, vol.77, pp.12-16, 1984.
[12] Bat 'K' Sonarcane (2005), [online],www.batforblind.co.nz.
[13] A. Heyes, "The Sonic Pathfinder: a new electronic travel aid", *J. of Blindness*, vol. 78, pp. 200-202, May, 1984.
[14] Meijer, P.B.L. "An experimental system for auditory image representations", *IEEE Transactions on Biomedical Engineering*, vol. 39, No. 2, pp. 112-121, 1992.
[15] Gürkan K., Akan A., "Design of a broadband semi-conical PVDF ultrasonic sensor for obstacle detection applications", *ELECO'2011*, Bursa-Turkey, 2011.