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Multichannel ultrasonic range finder for blind people navigation

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Abstract. The purpose of this paper is to present a multichannel ultrasonic range finder which was designed for the navigation system for blind people. A substantial number of consultations with blind people in the Blind People Centre in Krakow have shown that the navigation and obstacle detection with a help of a white stick only, is not sufficient enough to assure a high safety level. Electronic aids which are being designed for blind people should be mobile, comfortable and low-powered. That is why the MOBIAN© (a mobile safety system for the blind) project is being carried out by the authors to create a highly reliable safety navigation system for blind people. It could not only improve blind people quality of life but also their safety, especially when they are walking in unknown areas. As a part of this project, the multichannel ultrasonic range finder was designed, produced and tested. The tests have proven the device is capable of detecting objects from different directions in a range over 4 m. The device interface is easy to manage and can be controlled by almost any microcontroller or FPGA chip. The designed range finder is to be implemented in the electronic assistant project for blind people. Other systems, including the industrial ones, for instance, mobile robots or gates that count people entries, could benefit from this multichannel range finder. Usually, some low-cost ultrasonic range finders use two transducers for each channel (a transmitter and a receiver). The designed device employs only one transducer per channel which minimizes the end-device size and cost and at the same time provides with the main functionality. Novelty of this device is its multichannel design and the emplacement of the ultrasonic transducers, which can be used due to the application of the multichannel analog multiplexer. Thus, it is possible to detect obstacles, even the inclined ones, with higher reliability and increase the safety of blind people while walking. Also, this design and the transducers' placement allow to detect obstacles much quicker, when the blind user suddenly turns.

Key words: multichannel ultrasonic range finder, blind people navigation.

1. Introduction

Nowadays, almost every blind person uses some kind of a white stick. Due to the fact that blind person's remaining senses simply cannot compensate the lack of vision, a white stick has become an integral part of every blind person's life. In some special educational centers for visually impaired children, like the one in Krakow, children are being taught how to use a white stick to detect and avoid obstacles. Despite the fact that blind people are very skilled in using a white stick, this aid is not sufficient enough to assure a high safety level when a blind person is walking, especially in unknown areas. Many consultations with visually impaired people have showed that road imperfects, for instance, holes, bumps, etc., and also obstacles which occur on a level of a head are very dangerous and not so easy to detect only with a help of a white stick. That is why a mobile safety system for the blind is being carried out by the authors. Usually, visually impaired people are able to detect obstacles which occur from their waist to the ground, only with a help of a white stick. However, some obstacles require remote distance measurements due to the fact that a close encounter with the obstacles could cause harm to the blind person.

2. Remote distance measurements

One of the most accurate and fast distance measurement techniques in a macro scale employs an infrared (short distances) [1] or a laser beam (long distances) [2]. These techniques can be used for either measuring the distance from the blind person to a single point or creating a 2D or 3D distance map of the surroundings [3]. The authors developed a 3D distance map scanner based on the Hokuyo laser range finder, a servomechanism and a computational unit. With help of this scanner an object detection and recognition can be improved. A sample 3D scan of a room with its corresponding photo are presented in Fig. 1.

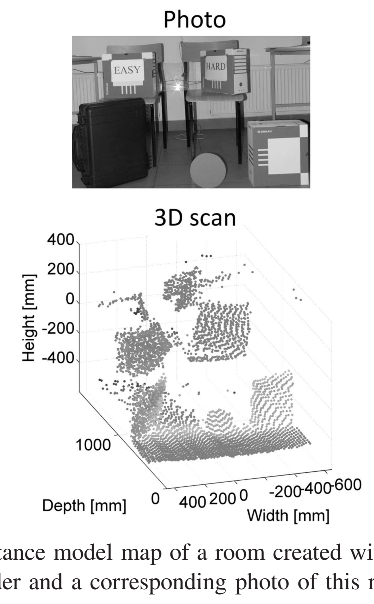

Fig. 1. 3D distance model map of a room created with a laser range finder and a corresponding photo of this room

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Laser range finders due to their physical restrictions have problems detecting glass surfaces. Furthermore, laser range finders consume too much power to be employed for a whole day performance in the battery-supplied mobile systems which are used by people. That is why the amount of time for which the 3D laser scanner is to be turned on should be reasonable. Therefore, an ultrasound range finder has also been implemented. Having both the laser and the ultrasound range finder makes it possible to achieve the desired safety level in navigation systems for blind people.

This paper presents a multichannel ultrasonic range finder. Thanks to a simple-to-manage-by- any-microcontroller interface this ultrasound driver can be used not only in blind people navigation systems but also as a replacement in some mobile robots surrounding perception systems [4] and low-cost industry distance measurement systems [5], etc.

3. Device design

Conducting the survey among blind people regarding navigation safety, the recurring problem is that in many cases, especially in urban areas, blind people suffer a head drama caused by a number of obstacles, i.e. post office boxes, signboards, road signs, etc. Blind people often said, they could really use an electronic device to help them to detect and avoid those obstacles. The authors carry out the design that is able to detect even small objects which are usually located above the waistline, thus very hard to detect with only a white stick. The device has to operate while the user is moving with approximate speed of 2–5 km/h and is able to detect mentioned obstacles at least a few steps ahead to give enough time for the user to react, which in practice means 2–4 m. There are no devices like that, suitable for blind people.

Ultrasonic range finders that provide a high reliability in detecting objects at the expense of a high accuracy (which is not so crucial for blind people navigation systems) usually compute distance with help of a time-of-flight [6].

Most of the available ultrasound range finders differentiate between ultrasonic receivers and transmitters [7]. In other words one channel for the distance measurement requires both a transmitter and a receiver to be a separate transducer. This forces the application of twice the number of transducers than there are ultrasound distance measurement directions. This paper presents the multichannel ultrasonic distance range finder which employs only one transducer for each channel. This helps to reduce the device size which is crucial in mobile systems.

The perfect ultrasound solution for the blind people navigation system would be the one in which ultrasound waves were sent in every direction to create a full 3D distance model. However, it is very hard to implement such volume of ultrasonic transducers in regard to the mobility, size and batteries limited energy capacity of the devices for blind people. In this paper a six channel driver is presented. A complete substitution of a white stick could lead to situations in which blind people – used to white sticks – feel insecure. That is why the six transducers check for obstacles in front of and on both sides of a blind person, who still can sense obstacles with a white stick which occur from the waist to the ground level. This transducers layout is presented in Fig. 2. This layout makes it possible to detect dangerous obstacles with a high reliability and on the other hand, the low volume of ultrasound transducers allows the device to be small, mobile and comfortable to be carried with. A simple block diagram of the multichannel ultrasonic range finder is presented in Fig. 3. Ultrasonic transducers are piezoelectric elements.

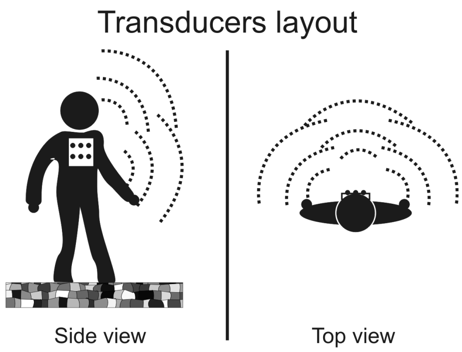

Fig. 2. Transducers layout and ultrasound waves directions in the device

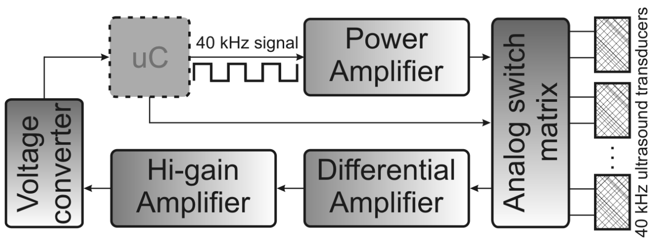

Fig. 3. Block diagram of the multichannel ultrasonic range finder front-end

They are often excited by a 40 kHz square wave [8]. The measureable distance depends on the amplitude of this wave. Therefore, the microcontroller generates the 40 kHz square wave which is amplified to obtain a greater distance. In this way the designed driver can be used by many different microcontroller families. The transmitter and receiver circuits are isolated by analog switches. This allows it to use only one transducer in each channel. The other advantage of this solution is that receivers circuits are protected from the high-voltage square waves. If the wave from the transmitter encounters some object, it is reflected. The voltage amplitude of the returning wave after transformation in one of the transducers is low. The signal from the wave is distorted due to the wave interference which occur during the reflection. To detect the returning wave a two stage amplifier was applied. For the first stage a differential amplifier was used. This helps overcome the distortion problem. Since the ultrasonic driver is to be controller by the wide range of silicon devices, an output voltage conversion block was applied.

The input and output interface of the ultrasonic range finder was designed to be used by almost every microcontroller available despite its peripherals and computational power. A switching flexibility allows signals to be multiplexed among receivers. One is able to transmit signal from a particular transducer and to receive the reflected wave on the other transducers. This is helpful for detecting objects which surfaces are inclined to the direction of the wave.

Various algorithms for the obstacle detection can be easily implemented, for instance, detecting a single obstacle, multiple obstacles situated in one line, an inclined surface detection, etc. [9]. If only a microcontroller has enough free pins, a second ultrasonic driver can be implemented, providing some extra channels for measurements.

For testing purposes, the time-of-flight sensing algorithm was implemented. Assuming that ultrasonic wave speed in the air is 344 m/s (room temperature), the time which passes between sending and sensing received wave determines distance divided by two, between piezoelectric sensor and the nearest obstacle.

4. Tests and results

Every piezoelectric transducer is excited by a signal from a microcontroller. This signal gets amplified to achieve a greater maximum distance. Once the control signal becomes constant, the transmitter should be disabled and the receiver should be enabled to monitor if the sent wave has returned. To better deal with oscillations after the transducer is no longer being excited, the load resistor was added to each transducer. To protect the receiver circuits from the high voltage of the weakening transducer signal and of course to avoid false measurements (a high level signal could be interpreted as a wave reflected from some obstacle which is situated in a very close proximity to the transducer), the signal from the transducer should be directed to the receiver only after the pin-voltage stabilizes. This delay determines the minimum distance that could be measured. By applying a resistor as close as possible between the transducer pins, the delay can be shortened. The difference between the delay in transducer with and without the resistor is shown in Fig. 4.

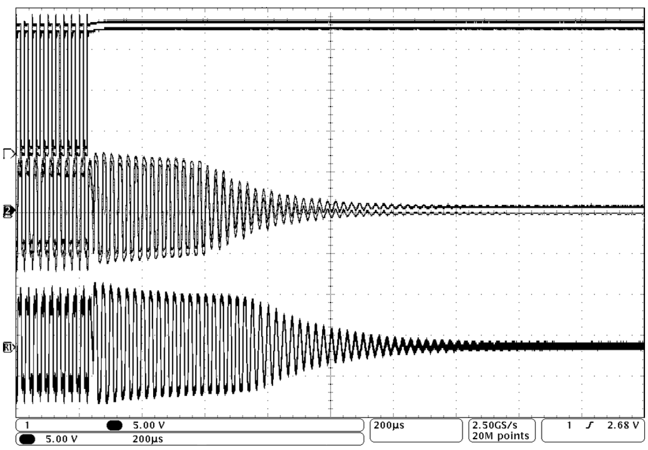

Fig. 4. Difference between transducers self-suppression times after the excitation signal stops generating square wave – the excitation signal (top), the signal from transducer without the extra load resistor (middle), the signal from transducer with the extra load resistor (bottom)

Tests have shown that the designed receiver circuit works properly. A flat surface obstacle was placed in approximately an 80 cm distance from the transducer. Distance measurements based on a time-of-flight parameter usually disregard a shape of the signal and detect only an amplitude above a certain value. That is why the amplifier is allowed to clip the output signal in order to increase the maximum distance. The applied output voltage conversion block adjusts the signal for the 0–3 V tolerance level microcontroller input pin. The final signal shape of the ultrasonic range finder output pin is presented in Fig. 5.

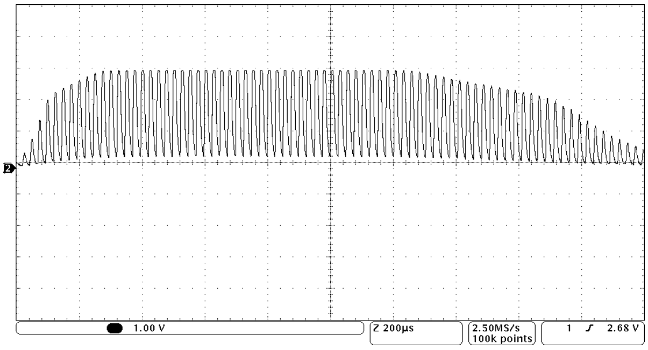

Fig. 5. The final signal shape on the ultrasonic range finder output pin after the amplification and the voltage conversion

In navigation systems for blind people, ultrasonic range finders generally notify about the nearest obstacle detected. This is sufficient enough because the blind person should be given a minimum but sufficient piece of information which assures safety and is not confusing. Nevertheless, the designed multichannel ultrasonic range finder can be used in other devices and not only in the blind people navigation systems. That is why the ultrasonic driver is able to detect more than one object on the way. A small object was added between the transducer and the flat surface obstacle to the previous test scenario. With help of some algorithms, the microcontroller is able to detect two obstacles on the way and to calculate their both distances from the transducer.

The ultrasonic driver was designed to detect obstacles in the range that lets blind people to be informed about the likely danger and gives them enough time to react properly. The maximum distance detection depends on how big the object surface is. For obstacles large enough to cause harm to a person, for instance, chairs, lamps, shelves, etc., this maximum distance is over 4 m. The maximum distance was tested in a room. Between the transducer and the wall, two flat surface objects were placed. The final signal shape on the ultrasonic range finder output pin is presented in Fig. 6.

The multichannel ultrasonic range finder presented in the paper was tested, with a help of blind people from the Blind People Centre in Krakow. The participants, after they were familiarized with the device, with a help of the range finder and vibration feedback, tried to avoid small and large obstacles, for instance walls, while moving towards them in normal walk speed. Afterwards, tests with 'the human obstacles' were conducted. In the first test, the blind users were walking toward 'the human obstacle' and in the second test 'the human obstacle' was moving toward the blind users. In all tests 7 out of 8 participants avoided all obstacles with a help of vibration interface, which is described in [11]. Blind users stated that by using that device and the vibration signal, they were able to 'feel the distance' and if the device was cheap enough and slightly miniaturized they would definitely use it as an electronic navigation assistant. Figure 7 presents the blind user trying to feel the distance from the wall.

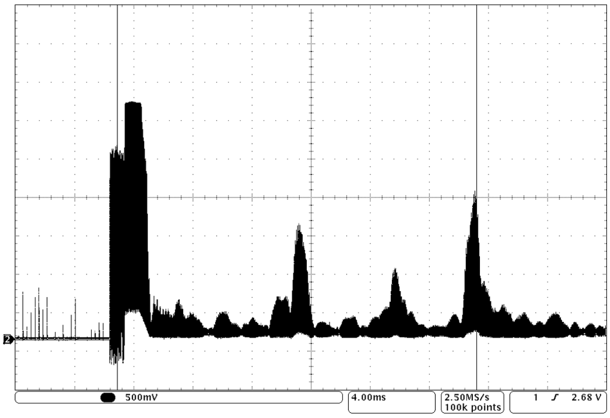

Fig. 6. The final signal shape on the ultrasonic range finder output pin in maximum rage test. Capabilities, features and also localization and detection accuracy of the piezoelectric transducers used in the design are presented in [10]

Fig. 7. Blind user's device test

5. Conclusions

The multichannel ultrasonic range finder is operational and presented in Fig. 8. It uses up to six transducers. Thanks to the scalability, some additional channels can be easily implemented. This ultrasonic driver was specially designed to be used in the electronic aid for blind people as a module to detect objects and measure the distance between the blind person and the obstacles. It uses only one transducer per channel to keep end-devices small and mobile. The driver interface can be controlled by almost every microcontroller or FPGA chip. Thanks to both the feature and the output voltage conversion block, the ultrasonic range finder can be used in other industrial applications, for instance, pedestrians or traffic monitoring systems [12] as the additional subsystem unit.

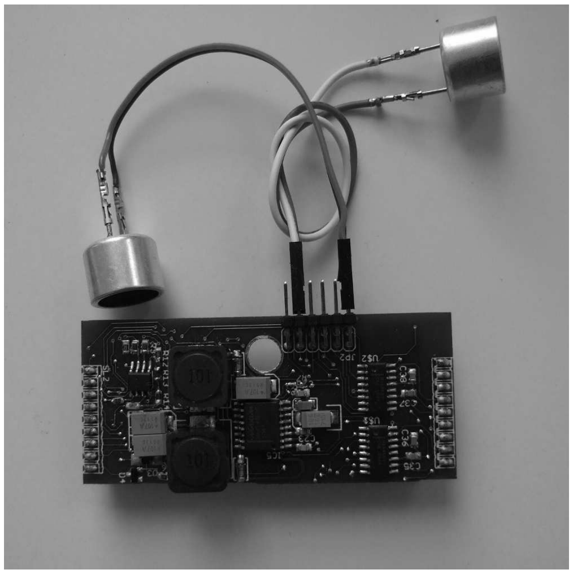

Fig. 8. Six channel ultrasonic range finder for various applications

Tests have proved that the driver works properly. The maximum and minimum distances which can be measured by the driver are sufficient enough to detect and inform in time about obstacles. The ultrasonic range finder is capable of detecting more than one obstacle at once. This functionality can be easily done by implementing special algorithms into the microcontroller.

The presented design does not possess the resolution of the LRF presented in Fig. 1. However, it is able to operate and detect obstacles in real-time – the presented LRF needs tens of seconds to do a full 3D scan. Furthermore, LRFs need hundreds mA to operate, not to mention the energy required by some MCU to process all the data from LRF. The presented multichannel ultrasonic range finder consumes less than a tenth of power which the LRF application requires to run and this feature makes the presented design suitable for mobile electronic devices for blind people.

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