

Designing of a Shooting System Using Ultrasonic Radar Sensor

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Abstract

In this study, a scanning system using ultrasonic distance sensor was designed and implemented in order to observe a specific area. When any object is detected in the scanned area, the laser beam is sent to target. The instantaneous angle of the sensor in the scanned area and the locations of the detected targets are obtained in real time in the MATLAB environment. In addition, a practical interface is designed for users. The necessary codes for the system are executed in the MPLAB IDE environment and embedded to microcontroller. Target objects are detected successfully in the scanned area despite of some hardware disadvantages.

Key words: Ultrasonic radar sensor, area scanning, shooting system, detection objects.

1. Introduction

Radar (Radio Detection and Ranging) is a device to detect the presence of the objects in the atmosphere using radio waves. Radar was designed to detect aircrafts just before World War II. Nowadays, radar is employed for detection of objects in many applications such as meteorological events, aviation and robotic systems. The basic principle of a radar operation is as follows: Radars create a radio frequency energy signals; they reach to the object; even though most of the signal energy is scattered, some will be reflected back toward the radar [1]. In this respect, the operation of radar is similar to the reverberation of the sound waves. By using the speed of the sound in the air, the distance between the radar and object can be calculated. Ultrasonic sensors can detect the objects by means of sound waves operation principle [2]. In robotic applications, problems such as mapping, object identification or obstacle detection can be solved by using ultrasonic sensors [3-5]. Similarly, it is well known that ultrasonic distance sensors are used in automatic parking systems [6].

In electric motor applications, precision positioning is as important as stable and continuous rotation. For this reason, stepper motors with low misfits that can act as steps have been developed. They are basically similar to brushless direct current motors, but step motors have also different features for precise positioning [7].

Stepping motors have many advantages over conventional DC motors. These are:

- They can be used according to open loop control.
- An error that may occur in positioning in one step does not affect the next step.
- They require less maintenance since there is no brush and collector in its construction.
- They can be numerically controlled.

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- Rotor speeds are proportional to the pulse frequency applied to their inputs.
- Rotor rotation angle is proportional to the number of pulses applied to the input.
- They can respond quickly to input signals such as stopping and changing direction situations.

Stepper motor control can be easily performed with microcontroller-based systems [8]. They offer a wider and more effective control advantage over the system, even though these systems have disadvantages such as programming effort and cost. Such systems that do not involve microcontrollers, the control of the stepper motors can still be achieved economically with the help of analogue IC (Integrated Circuit) elements [9].

In this study, a continuous scanning of semi-circular geometry area with a radius of 200 cm was performed by using an ultrasonic distance sensor. Besides a shooting system mechanism that can send laser beams to the coordinates of the objects detected in the scanned area is operated in real time in synchronize with the ultrasonic radar. In the operation of system, stepper motors have been employed for driving the mechanism.

The system was controlled based on a microcontroller. An LCD display showing instant distances of detected objects, a driver circuit for each stepper motor, and computer communication interface circuits on the control board is assembled with the system. In order to be able to see the instant positions of the detected objects and the angle of the sensor on the computer, a radar screen was designed in MATLAB GUI environment and real time communication with the radar system was provided. The electronic design, communication and interface screen design of the system were simulated in computer environment and all the components were physically realized and experimental setup was established. The image of the prototype is shown in Fig 1.



Figure 1. The image of the prototype.

2. Materials and Method

2.1. Area scanning system

Area scanning systems generally consist of a step motor and an ultrasonic distance sensor. HC-SR04 model ultrasonic distance sensor was used in the system. In Fig. 2, an image of the sensor is presented.



Figure 2. Ultrasonic distance sensor [10]

The ultrasonic distance sensor produces 40KHz sound wave as it gets at least $10\mu\text{s}$ pulse signal to its trigger input. Then, the sensor detects the reflected sounds by switching to the resting mode itself via the receiver on it. During sound generation and reception, the Echo (output) pin remains in logic 1 state and then becomes logic 0 state, proportional to the distance between the object and the sensor. The duration of the echo-pin state at logic 1 was measured and the round-trip distance of the sound wave can be calculated by knowing the speed of the sound in the air (340 m/s, in average). For a better visual understanding, bumping and reflection of sound wave is illustrated in Fig. 3.

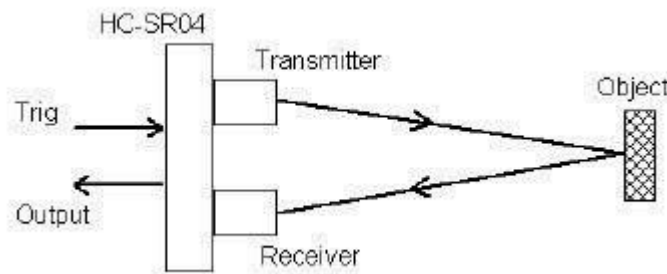


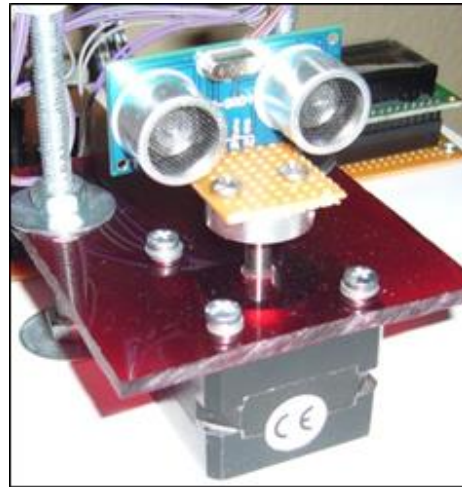
Figure 3. Operation of ultrasonic sensor

The sensing range of the ultrasonic sensor used in the system is maximum 400 cm according to the its datasheet [10]. However, the detection of distance in the developed system is limited to a maximum of 200 cm. In the designed area scanning system, the sensor is mounted on a stepper motor so that the sensor can continuously scan the area between 0° and 180° . A bipolar type step motor was employed for the motor activation. The stepper motor is basically composed of a rotor and a stator. The specifications of the stepper motors used in the system are given in Table 1. As seen from the table, the motor shaft performs a full turn in 200 steps. Thus, the angle of the motor shaft in one step is 1.8° .

Table 1. Step motor technical specifications

Specifications	Value
Operation voltage	7.2 V
Current per a phase	280 mA at 7.2 V
Number of steps per a tour	200 steps
Holding torque	0.65 kg.cm

The image of the area scanning system developed by assembling of the sensor and the stepper motor is given in Fig. 4.

**Figure 4.** Area scanning system

2.2.2. Design of shooting system

In addition to the radar system, a mechanism has also been designed to send a laser beam to the detected objects on the scanned area. In the designed shooting system, two bipolar stepper motors are used as bottom and top motors with the same technical characteristics to the stepper motors that are chosen for the area scanning system. The top motor is mounted to the shaft of the bottom motor. Thus, the motor at the top is made of capable to move in all directions at the y-axis (perpendicular to the floor).

To simulate the phenomenon that the target is shot, the laser marker is mounted on the shaft of the top motor in the horizontal position (parallel to floor). Thus, the laser marker has the ability to send beam to any point in the scanned area with two degrees of freedom system. The h height between the laser pointer and the sensor was fixed to 32 cm in the area scanning system.

When any object is detected within the scanned area, the coordinates of the object are determined and the necessary output signals are generated by the control card and transmitted to the shooting system. The laser pointer continues to move in both horizontal and vertical axes synchronously until the system will be able to send beam to the target coordinates detected by control cards. When the correct angle is reached, the laser marker is activated and the beam is sent onto the target. If

more than one object is detected in the area, the beam is sent to the target coordinates, starting from the first detected object. An image of the shooting system is shown in Fig. 5.

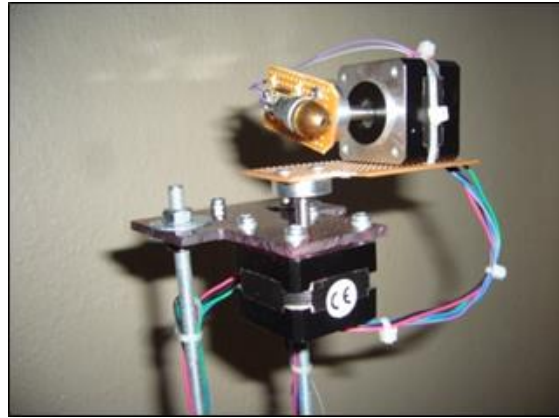


Figure 5. The shooting system

Figure 6 shows a principle diagram of the distance sensor, bottom and top motor, object, and laser marker to detect the angle that is required to reach the target. The distance between the distance sensor and the laser marker on the shooting system is expressed by h height and is set to 32 cm. The s distance indicates the distance measured between the distance sensor and the object. As shown in Figure 6, the laser beam must form a right angle to the target position. Eq. (1) gives the value of Q angle in the perpendicular triangle shown in Fig.6.

$$Q = \arctan\left(\frac{s}{h}\right) \quad (1)$$

The laser pointer is rotated by the upper step motor around z -axis until it reaches the calculated Q angle. The angle detection of the y -axis is found by using the value of the y -axis step motor shaft position when the ultrasonic sensor is detected an object in the shooting system. In the other words, the y -axis is the bottom step motor shaft position and the z -axis is the top step motor shaft position.

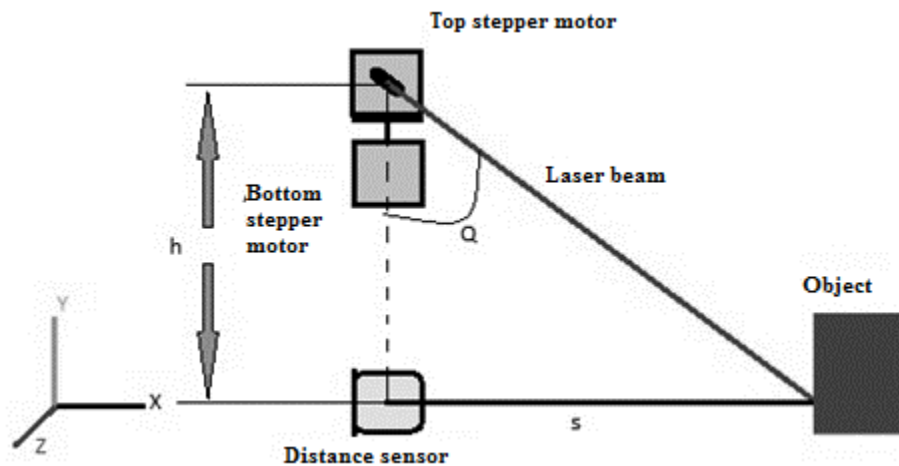


Figure 6. Angle determination of the shooting system.

2.2. Electronic system design

The electronic system is basically composed of two separate parts: the control system and the drive system. The ISIS Proteus/Ares simulation program was used in the development of open circuit drawing, simulation and printing circuit using for designing electronic circuits.

2.2.1. Control system

In the control system, 16F877A, an 8-bit microcontroller produced by Microchip company, and a crystal oscillator with an operation frequency of 20MHz were used as the oscillator. A 2×16 LCD screen was added to the control system to provide information about the current operating status of the entire system to the user. RS232 interface has been added to the circuit for communication with computer. The operating voltage of the entire system is considered to be + 5 V DC. There are three buttons on the circuit, namely, start, stop and reset buttons which can be accessed by the user easily. The simplified circuit diagram of the electronic circuit is given in Fig. 7.

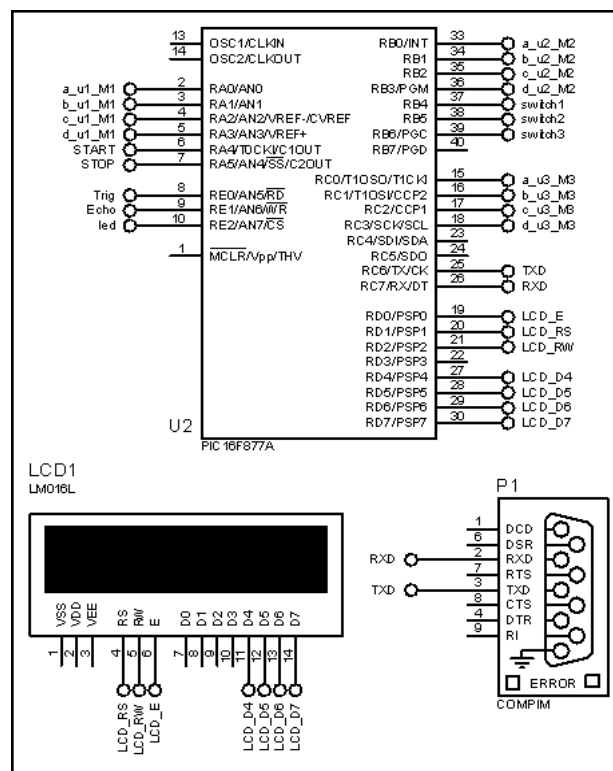


Figure 7. Electronic components of control system

2.2.2. Drive system of stepper motors

The L293D motor driver integration is used to drive the bipolar stepping motors in the area scanning and shooting system. The L293D motor drive integration allows two brushless DC motors

to run bidirectionally. Bipolar stepping motors can also be controlled by utilizing this feature of the drive integrator. Figure 8 shows the assembling scheme designed for a stepping motor.

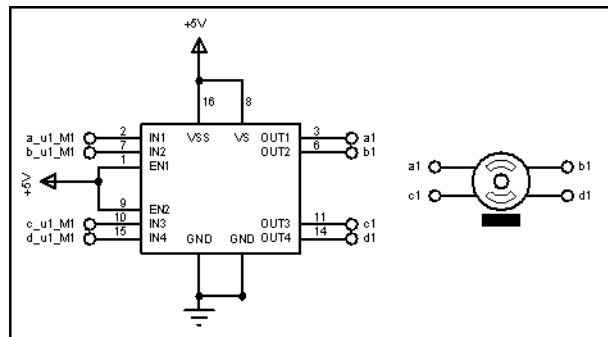


Figure 8. Bipolar stepper motor driving circuit

Motor control is provided by the IN1, IN2, IN3 and IN4 control terminals of integration. These control terminals are connected to the microcontroller and the control signals are generated via the microcontroller. Stepping motors can be driven in two different ways: full step and half step. The motor terminals and logic levels used in full step drive are given in Table 2.

Table 2. Full-step driving control table

Step	d	c	b	a
1	1	0	0	1
2	1	1	0	0
3	0	1	1	0
4	0	0	1	1

The stepping motors used in the system are controlled by half-step driving technique. Thus, when the full step accuracy is 1.8°, the half-step driving technique provides a 0.9° step angle and the resolutions of the motor-controlled area scanning and laser markers can be increased with smaller step ranges. Motor terminals and logic levels used in half step driving are given in Table 3.

Table 3. Half-step driving control table

Step	d	c	b	a
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1

2.2.3. Computer Interface Design

A radar screen simulator has been designed on the computer to inform the user for the location of the detected objects in real time and the direction of the ultrasonic distance sensor. Serial communication method is preferred for data transmission between computer and controller. The radar interface program is written in the Matlab environment using the C language. An example of the radar screen generated by the software is given in Fig. 9.

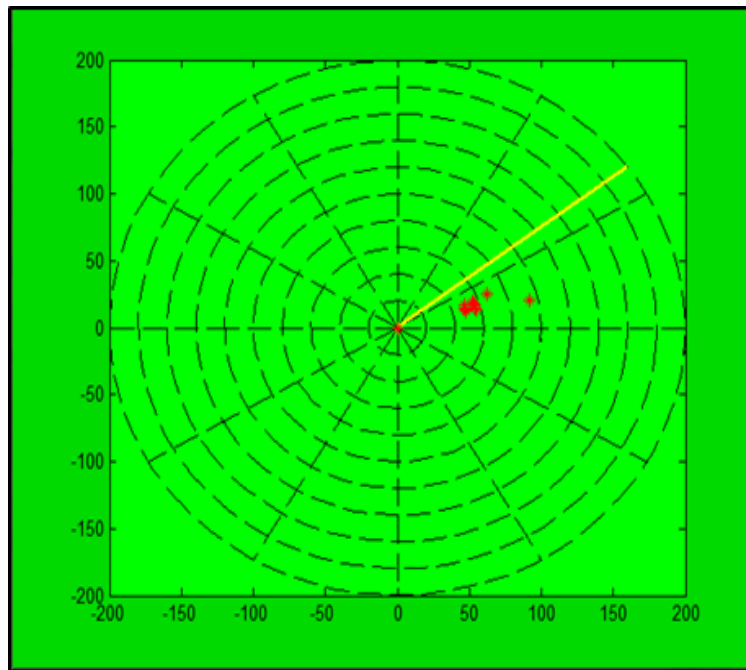


Figure 9. Interface screen of radar system

In the radar screen as shown in Fig. 9, the distance between the circles is 20 cm and the maximum detection distance is 200 cm. The red dots on the created screen show the position of the detected objects relative to the origin. The yellow line indicates the position of the ultrasonic distance sensor.

3. Experimental Results and Discussions

In this section, some problems and solutions are presented during the test of the system. Controlling bipolar stepper motors with half stepping technique increases the resolution of the system; but it also adversely makes the system operate slower. In the full-step drive technique, the stepper motor applies 4 states in turn, while in the half-step drive technique, 8 different states are applied and a certain amount of time must be waited after each step. Because of this, the half-stepping technique slows the engine speed a little, but it may contribute to high resolution which is needed for precise positioning.

Filtering in applications with ultrasonic distance sensor is very important. Because these sensors can be easily affected by noise. Therefore, this can lead to errors in measurements. Filtering has been done on the control software to minimize these errors in the study. For example, instead of

taking a single measurement, the distance was measured three times at each step of the motor and the averages of all measurements were taken. Although this filtering technique is a good way to minimize the error, the calculation cost is increased. Besides the necessity to wait 60 ms for sequential measurements make the scanning system slower.

The ultrasonic distance sensor performs the detection around 15° angle. For this reason, the laser pointer on the shooting system is not precisely positioned on the target in the prototype. In the control software, this error is decreased to a minimum level with necessary calculations. For this purpose, the difference between the position of the ultrasonic distance sensor when first detect the object and the output position of the ultrasonic distance sensor without determining the object was considered and the values divided into two to reach the middle point of the object and succeeded. Some of the future works are planned the increase the system performance. Firstly, artificial neural networks control algorithm is thought to perform the angle estimation according to the distance. Secondly, the positions of the objects in the three dimensional space can be determined by using advanced different distance sensors.

4. Conclusions

In this study, mechanical and electronic design of a basic radar system is realized. The distance range of the radar is designed as 200 cm radius. In order to increase positioning precision, half-step driving technique was used. After detection of objects, a laser-shaft mechanism with two degrees of freedom is designed with stepper motors. Thus the object in 200 cm radius is detected successfully. In addition, a useful interface for users is designed. Therefore, it is aimed to know whether there is object in the scanning area or not.

References

- [1] C. Wolff. Radartutorial home page
<<http://www.radartutorial.eu/01.basics/Radar%20Prensibi.tr.html>>, 05.03.2017
- [2] M.V. Paulet, A. Salceanu, O.M. Neacsu, "Ultrasonic Radar," International Conference and Exposition on Electrical and Power Engineering (EPE 2016), Iasi, Romania, s:551-554, 2016
- [3] A.M. Fathan, R.E. Saputra, A.N. Jati, "Mapping Algorithm Using Ultrasonic and Compass Sensor On Autonomous Mobile Robot," International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC), Bandung, Indonesia, s:86-90, 2016
- [4] A.R. Patkar, P.P. Tasgaonkar, "Object Recognition Using Horizontal Array of Ultrasonic Sensor," International Conference on Communication and Signal Processing, India, s: 983-986, 2016
- [5] B. Chu, "Mobile Robot Position Control Algorithm Based on Multiple Ultrasonic Distance Sensors," International Conference on Control, Automation and Systems (ICCAS), Busan, Korea, s:1238-1240, 2015
- [6] T.F. Wu, P.S. Tsai, N.T. Hu, J.Y. Chen, "Research and Implementation of Auto Parking System Based on Ultrasonic Sensors," IEEE International Conference on Advanced Materials for Science and Engineering (ICAMSE), Taiwan, s:643-645, 2016
- [7] S. Çicek, "CCS C ile Pic Programlama," Altaş Yayıncılık, 5.Baskı, 2010

- [8] W. Ruifeng, W. Zhe, W. Liying, "Stepper Motor Control Based on AT89S51 Microcontroller," International Conference on Intelligent Computation Technology and Automation, China, s:844-847, 2015
- [9] M.Y. Tarnini, "Fast and Cheap Stepper Motor Drive," International Conference on Renewable Energy Research and Applications, Italy, s:689-693, 2015.
- [10] HC-SR04 datasheet, <<http://cytron.com.my/p-sn-hc-sr04>>, 05.03.2017