Investigating the resolution ability of the HC-SRO4 ultrasonic sensor

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Abstract. An Arduino microcontroller has been used for many projects since its first presentation in 2005. This integrated chip used with a variety of sensors to construct many attractive projects and circuits. In this paper, we aim to investigate the resolution ability of one of the famous sensors attached to the Arduino which is called the ultrasonic HC-SR04 sensor. This sensor basically, is made from a transmitter and receiver that work in the sonar range of frequencies. It is used to indicate the distance of objects similar to the Radar principle. By experimental results another feature could be added to the data sheet of this sensor, named as distance resolution. By applying a reasonable shape and dimension for the target objects at a distance of 11 cm, the experimental results show that this sensor has resolution ability configured in the range of 7 cm displacement between two adjacent objects. Furthermore, the paper suggests increasing the sensor aperture to increase such ability for certain application that used the sensor for discrimination between adjacent objects.

1. Introduction
For more than 10 years, the word Arduino is frequently written in the search window for many internet search engines. Arduino is an open-source electronics board build from adaptive, flexible hardware, simple-to-learn software. Since its first creation in Ivrea Italy from a Master student, it attracts a huge interest for deferent sciences and even arts [1]. Its first release was in 2005 as a serial Arduino type then in May 15 2008 the second version as Arduino Nano was produced while the Arduino Uno has been available in September 24 2010 [2]. From that time till nowadays a plenty of smart, funny, useful projects had been presented. This paper using Arduino Uno as the main board for its purpose, Simply Arduino Uno that is described in Figure 1, is an integrated board contains a microcontroller Atmega823P with all the specifications recorded in Table 1, [3].

![Arduino Uno R3](image_url)

Figure 1. Arduino Uno R3 (a) board (b) pinout configuration
With this easy to use board, a variety of sensors are attached to construct different project applications [4-10]. The new generation of smart equipments that is mainly controlled by an integrated system of microcontroller and set of sensors will be the backbone of new smart cities [11-14].

Table 1. Arduino Uno specifications

| Component           | Specification |
|---------------------|---------------|
| Microcontroller     | ATmega328P    |
| Output voltage      | 5 V           |
| Input Voltage (recommended) | 7-12V       |
| Input Voltage (limits) 6-20V | 6-20V         |
| Digital I/O Pins    | 14 (of which 6 provide PWM output) |
| Analog Input Pins   | 6             |
| DC Current per I/O Pin | 40 mA         |
| DC Current for 3.3V Pin | 50 mA        |
| Flash Memory        | 32 KB         |
| SRAM                | 1 KB          |
| EEPROM              | 1 KB          |
| Clock speed         | 16 MHz        |

Among these applicable sensors, the ultrasonic HC-SR04 has played a significant participation in radar-like projects. In [15] the ultrasonic sensor was used to measure the distance in an intelligent system designed for obstacle avoidance. Shrenika R M et al [16] implemented a controlled system for monitoring the water level in a tank. The ultrasonic sensor is utilized as a component to measure the water depth which is fed to an Arduino to control a water pump according the water level in the tank. An array of ultrasonic sensors is used in a closed room to provide an assist for a person fall warning [17]. The proposed design with the aid of ultrasonic sensors succeeds in indicating the fall occurrence with 92% of all tested cases. In this paper, we aim to investigate the ability of the ultrasonic sensor to distinguish between two adjacent objects. This ability is a definition for the angle resolution parameter in radar-like radiations. In [18], similar idea for our work is presented to implement an ultrasonic radar. This research does not investigate the angular resolution of the main element in the radar which is the ultrasonic sensor.

The rest of the paper is organized as follows: in section 2, the theory and specification of the ultrasonic sensor is presented. Section 3 will be dedicated for system implementation, while the experimental circuit and results are listed in section 4. The overall conclusion is recorded in section 5.

2. Ultrasonic sensor specifications

This sensor operates as a transmitter-receiver system for ultrasound waves. Figure 2, illustrates the pin configuration of this sensor module with the Arduino board. The power pins represented by the VCC and GND which are attached to the 5 V and GND pins respectively on power pins of Arduino. The other
two pins are the trig and the echo which are used to trigger the transmitter to generate 8 ultrasonic pulses and receive the reflected echo from an object within the detected range. For the calculation of the distance of any object, let an object located at 10 cm away from the sensor, it is well-known that the speed of the sound is 340 m/s and to make the calculation more convenient for the case of experimental circuits, the speed is considered as 0.034 cm/µs. so, in order to measure the distance (D), we need to count the elapsed time (t) of wave travelling towards the object and return back, then use it as in equation (1).

\[ D = \frac{(t \times 0.034)}{2} \]

3. System model implementation

In this section, we aim to simulate the ability of the ultrasonic sensor to maintain angular resolution. From the radar point of view, the angular resolution is defined by the antenna beamwidth denoted by the −3 dB angle \( \theta \) or the half-power (−3 dB) points. The half-power points of the antenna radiation pattern are classified as the limits of the antenna beam-width for specifying the angular resolution to resolve two identical targets at the same distance.

As shown in Figure 3, the ultrasonic sensor is attached to servo motor. The servo motor has three wire connections, two of them for power and the rest for signal controlling its motion. The trig and echo pins for the ultrasonic sensor are attached to the I/O digital pins 3,4 respectively while the control wire for the servo motor is attached to pin 5.
4. Experimental results and analysis

The main contribution of this paper is the experimental investigation of the angular resolution for the ultrasonic sensor. The data sheet of such sensor defines the sensitivity as the minimum detectable signal can be accurately read by the sensor while this paper investigates its ability to distinguish between two adjacent objects. By using the circuitry shown in Figure 3, first we upload the code required for identifying the connected sensor and the servo to the Arduino board and determine the distance calculations and limiting the servo angle to be from $(0−60)^\circ$. In addition, to make the results more reliable we set a condition for the distance calculations as:

$$D > 20 \text{ cm} \rightarrow D = 0$$  \hspace{1cm} (2)

First, we test the ultrasonic sensor with single object at a distance of $(D = 11 \text{ cm})$ to construct its echo for such situation. Then we start to investigate the distance resolution by using two objects with the same dimensions as shown in Figure 4.

![Two separated objects](image)

**Figure 4.** resolution test for the ultrasonic sensor

The distance between the objects is switched into three values ($D = 3, 5, 7$). Then the results from the serial port screen from the Arduino IDE is copied and gives the shown Matlab graphs shown in Figures 5-8. Figure 5, illustrates that the echo for one object, it’s clear that the echo from the object spreads for almost all the coverage angle and the space founds in angle between $(10−15)$ does not indicates the presence for another object.

![Graph](image)

**Figure 5.** echo signal for one object at $D = 11$
Starting using two objects, Figure 6 is dedicated for two objects at the same distance but with spacing for \((d = 3 \text{ cm})\). The echo signal still indicates one object presence and give an echo almost similar to that of Figure 5. Even when increasing the distance between the two objects for \((d = 5 \text{ cm})\), the echo signal in Figure 7 doesn’t clarify the spacing in the echo as two objects, however the echo signal starts its presence actually at the correct angle of the first object rather than starts from angle \((0)\). The distinguishing of objects appears clearer in Figure 8, that give two bursts of bars with other peaks of less bars. It is not sharply separating echoes for Figure 8, but definitely the echo signal indicates different bars distribution on the graph. All in all, we think that the ultrasonic sensor doesn’t give us a clear distinguishing between adjacent objects that can rely on it. The main reason for that, return to the radar basics that define the angular resolution as a distance between two targets:

\[
D_A \geq 2R \cdot \sin\left(\frac{\theta}{2}\right)
\]  

Where, \(D_A\) represent the angular resolution as a function of distance and \(R\) is the slant range and \(\theta\) is the antenna beamwidth. The antenna beamwidth is given by:

\[
\theta = k \cdot \frac{\lambda}{D}
\]

Where \(D\) denotes the transmitter aperture dimension and \(\lambda\) represents the applied frequency which is round \((40 \text{ KHz})\). As a solution for such resolution limitation, it has been experimentally approved that increasing the diameter of the transmitter aperture will in turn insures better angular resolution.

![Figure 6. echo signal for two objects at \(D = 11, d = 3 \text{ cm}\)](image-url)

![Figure 7. echo signal for two objects at \(D = 11, d = 5 \text{ cm}\)](image-url)
Conclusion
The open source applications of Arduino motivate the designers for more attractive projects. This paper presents a performance investigation for one of most practical sensors which is the ultrasonic sensor. This sensor is mainly dedicated for distance estimating in a way similar to the radar distance measuring principle. We had investigated the distance resolution for this sensor which means that its ability to distinguish between two adjacent objects. The experimental results approved that this sensor has distance resolution ability within 7 cm between two adjacent objects. This poor resolution comes from its small radiating aperture. The paper conclude that this ability can be modified by increasing the diameter of the sensor aperture.

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