# Measurement Analysis of HC-SR04 Ultrasonic Ranging Module

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***Abstract*—The objective of this report was to measure the reliability of the HC-SR04 Ranging Module through a series of tests where we measured 10 distances and compared it to its actual value. These results were then analysed through calculations to develop statements on the accuracy of the data and overall trends. The sensor proved to be fairly reliable however, to make greater estimations from the data it was realised that a larger sample of data needed to be taken.**

## I. Introduction

This Elegoo Ultrasonic Ranging Module is a device / sensor that possible to measure the distance to an object by using sound waves. It send out a sound wave with a specific frequency and listen the bounce back of the sound wave to measure the distance. The recorded elapse time between the generated sound wave and the bounce back of the sound wave makes this device to be able calculate the distance within the sensor and the object.

However, is the sensor could give a reliable data? In this experiment we are going to test the quality of the sensor by comparing the output eata from the sensor with the actual distance that we measure with a tape measurer to find the measurement error and precision from this device.

The way we conduct the experiment is by monitoring the distance from the measurement sensor with the actual distance. We create the circuit using Arduino Uno that are connected with the Elegoo modules and develop a code in Serial Monitor to show the measurement of the device. In this experiment, we create 10 sample data with a various distance from 5 cm to 50 cm and we test 3 times each from those data sample to find the mean data output from each sample.

It's a simple experiment yet there is still a challenge in doing it. One of the main problem is the sensor will give a different distance data (+1cm) when its side by side with the tape measurement. To cope with this issue, we need to find a way to keep a valid actual distance measurement without corrupting the data output from the sensor. Therefore, we use a sticky notes to points in certain distance level (5 cm to 50 cm) to make the sensor work effectively in giving the measurement data.

## II. Literature Review

### A. Ultrasonic Sensor

Ultrasonic sensor is a measuring device that utilize ultrasonic sound waves. It emits ultrasonic sound waves to the target object and transform the reflected sound into signal to measure the distance. Ultrasonic sensor itself has two main components: the transmitter and the receiver. The transmitter emits the sound using piezoelectric principal and the receiver will receive the sound that bounced of the target object.

Ultrasonic sensor measures the distance by calculating the time gap between the sound was emitted and then received by the receiver. It uses the physical principle of Doppler effect. The formula to calculate the measured distance can be expressed as

$$D = K \, x \, t \, x \, V$$

Where:

$K$ = constant close to 0.5, which depends on the sensor geometry [1]

$t$ = Time needed by the pulse to cover distance $D$

$V$ = Velocity of sound in air

### B. *Air Temperature Effect*

Previous study in ultrasonic distance measurement was done by Alessio Carullo and Marco Paris in 2001. The study was about transducer sensor on distance measurement which showed experimental standard deviation of the linearity with respect to the distance has been found to be of 0.3 mm [1]. Where velocity of sound in air is affected by temperature during distance measurement. The approximate formula to calculate the measured velocity of sound in air can be expressed as

$$V = 20.055\sqrt{T} \text{ [1]}$$

Where:

$T$ = Temperature measured during distance measurement.

A recent study on Arduino based ultrasonic sensor was performed by Biyyala Srijith, Chinnam Malathi Srilakshmi, and Vannada Swathi in 2021 and they have successfully identified several factors affecting distance measurement, for instance limitation on detection range (2 cm - 400 cm) and has good application due to its frequency which is more than human audible range (20 Hz - 20 kHz) [2]. For future applications, sensors accuracy should have been evaluated as details as possible. Therefore, this experiment focused on ultrasonic sensors HR-SR04, and this sensor is interfaced with the Arduino Uno board to measure even small distances accurately. The experiment results are evaluated based on sensors level of precision and errors that might occurred during measurement.

## III. OBJECTIVE

Sensor's performance is mainly defined by its accuracy and precision which are measured by collecting data of the measured value compared to the true value of measurement. This measurement error is then processed into an estimation that could be used to prevent or reduce the error from ruining the data. For this experiment, the aims are to determine the measurement error of the ultrasound sensor and to calculate the estimation from measurement. These can be achieved by setting up distance variables using an instrument that is relatively accurate and precise such as measuring tape, which is also defined as the true value for this experiment. The data will be taken and then processed by comparing it to the true value, thus the measurement error is received. Hypothetically the data will be less precise and accurate the further the distance.

## IV. METHODOLOGY

### A. *Distance Measurement Principles*

The transmitter begins a timer and emits 8 bursts of a 40 KHz directional ultrasonic wave when it is activated. The ultrasonic pulses go outward until they meet an object. The wave is then reflected towards the source at that location. When the wave was reflected, the ultrasonic receiver picked it up and the timer would stop. A 340 m/sec ultrasonic pulse moves through the atmosphere. The number of times the timer counts can be used to calculate the distance between the object and the transmitter. [3]

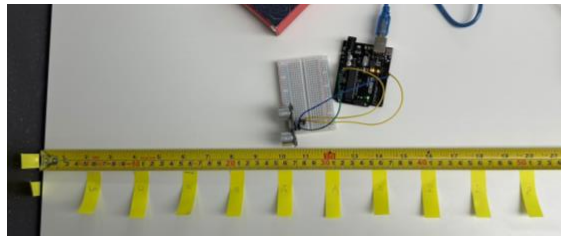

Fig. 1. Image of experimental setup

### B. *Experimental Protocol*

Equipment used: Elegoo Uno R3/Arduino Uno, Ultrasonic Ranging Module HC-SR04, Breadboard, Breadboard wires, Laptop/Desktop (can run Arduino), Measuring Tape, and Post-it-notes

#### 1) *Creating the circuit*

Create circuit using the following parts: Elegoo Uno R3 Board or Arduino Uno Board, Ultrasonic Ranging Module HC-SR04, breadboard and breadboard wires. Connect a wire from the 5V pin on the Arduino to the positive part of the long bus lines on the breadboard and connect a wire from the ground pin to the negative part of the long bus lines. Place the Ultrasonic sensor on the breadboard as shown in Fig. 1. Connect the ground pin on the sensor to the negative part of the long bus lines. Connect the vcc pin on the sensor to the positive part of the long bus lines. Connect the echo pin on the sensor to digital pin 10 on the Arduino board

#### 2) *Program the Arduino*

Go to the Appendix to find the code to program the circuit and copy and paste it into the IDE. Plug in the connector to Arduino to your laptop/desktop via the usb. Click upload and the circuit should start to work. Open the serial monitor by clicking the icon found in the top right corner

#### 3) *Conducting the experiment*

First gather the circuit you just created, measuring tape and post it notes. Find a flat surface facing a straight wall with no other objects in front of it. Open the measuring tape so you can clearly see up 50cm. At every 5cm place the post-it-notes down adjacent to tape as shown in Fig. 1. This is optional but you can place a post-it-note at the wall where its 0cm. Now take the tape measurer away. Measure values at each place you have put down a post-it-note 3 times and write it down in Table 1.

TABLE I. ELECTRICAL PARAMETERS OF SENSOR

| **Electrical Parameters** | **HC-SR04 Ultrasonic Module** |
|---|---|
| Operational Voltage | 5VDC |
| Operational Current | 15mA |
| Operating Frequency | 40KHz |

| | |
|---|---|
| Max. Range | 4m |
| Nearest Range | 2cm |
| Measuring Angle | 15 Degrees |
| Input Trigger Signal | 10us min. TTL pulse |
| Output Echo Signal | TTL level signal, proportional to distance |
| Board Dimensions | 1-13/16" X 13/16" X 5/8" |
| Board Connections | 4 X 0.1" Pitch Right Angle Header Pins |

TABLE II. MEASUREMENTS TO BE TAKEN

| | Measured distance (cm) | | |
|---|---|---|---|
| **Actual Distance (cm)** | **1st** | **2nd** | **3rd** |
| 5 | | | |
| 10 | | | |
| 15 | | | |
| 20 | | | |
| 25 | | | |
| 30 | | | |
| 35 | | | |
| 40 | | | |
| 45 | | | |
| 50 | | | |

## V. RESULTS AND DISCUSSION

The results of the measurement can be seen in the Table 3 below.

TABLE III. MEASUREMENT RESULTS

| | Measured distance (cm) | | |
|---|---|---|---|
| **Actual Distance (cm)** | **1st** | **2nd** | **3rd** |
| 5 | 5,00 | 4,90 | 5,00 |
| 10 | 10,78 | 10,88 | 10,80 |
| 15 | 15,67 | 15,69 | 15,67 |
| 20 | 20,25 | 20,26 | 20,16 |
| 25 | 24,84 | 24,85 | 24,73 |
| 30 | 30,31 | 30,41 | 30,36 |
| 35 | 34,58 | 34,17 | 34,20 |
| 40 | 38,93 | 38,83 | 38,91 |
| 45 | 43,78 | 43,88 | 44,12 |
| 50 | 48,47 | 48,57 | 48,86 |

Based on the result, the mean for each distance can be calculated using the formula

$$\overline{m} = \frac{1}{N}\sum_{i=1}^{N} Y_i$$

The variance of the measurement for each distance can be calculated by the formula stated below.

$$\sigma = \frac{1}{1-N}\sum_{i=1}^{N}(Y_i - \bar{Y})^2$$

The result of the calculation can be seen in Table 4. While it is possible to create a gaussian probability density function through the calculated mean and variance, it won't be accurate because the lack of data collected.

TABLE IV. MEAN AND VARIANCE CALCULATION

| | Measured distance (cm) | | | | |
|---|---|---|---|---|---|
| **Actual Distance (cm)** | **1st** | **2nd** | **3rd** | **Mean** | **Variance** |
| 5 | 5,00 | 4,90 | 5,00 | 4,97 | 0,00333 |
| 10 | 10,78 | 10,88 | 10,80 | 10,82 | 0,00280 |
| 15 | 15,67 | 15,69 | 15,67 | 15,68 | 0,00013 |
| 20 | 20,25 | 20,26 | 20,16 | 20,22 | 0,00303 |
| 25 | 24,84 | 24,85 | 24,73 | 24,81 | 0,00443 |
| 30 | 30,31 | 30,41 | 30,36 | 30,36 | 0,00250 |
| 35 | 34,58 | 34,17 | 34,20 | 34,32 | 0,05223 |
| 40 | 38,93 | 38,83 | 38,91 | 38,89 | 0,00280 |
| 45 | 43,78 | 43,88 | 44,12 | 43,93 | 0,03053 |
| 50 | 48,47 | 48,57 | 48,86 | 48,63 | 0,04103 |

The next step is to analyze the estimation model of the sensor. To do this, Least Square Line estimation method is used, which model is given by

$$Y = mX + a$$

Where:

$m$ = slope

$a$ = the intercept of the line

The slope can be calculated using the formula

$$m = \frac{\frac{1}{N}\sum_{i=1}^{N} X_i Y_i - \bar{X}\bar{Y}}{\frac{1}{N}\sum_{i=1}^{N} X_i^2 - \bar{X}^2}$$

Once the slope is calculated, the intercept of the line can be calculated using the formula

$$a = \frac{\sum_{i=1}^{N} \bar{Y}_i - m\sum_{i=1}^{N} X_i}{N}$$

After the slope and intercept of the line has been calculated, the regression linear model of the ultrasonic ranging module can be found as

$$Y = 0.9559X + 0.9738$$

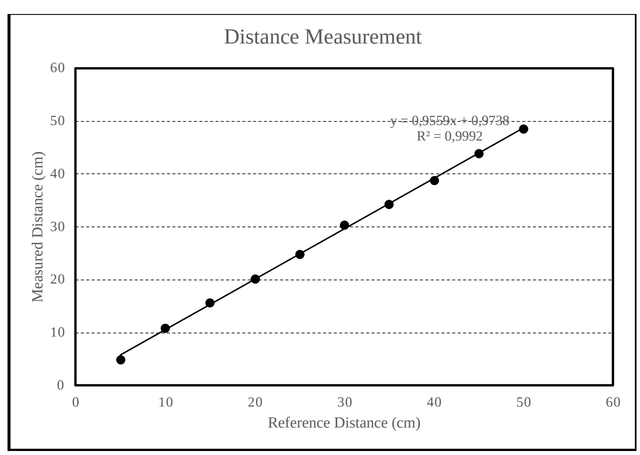


Fig. 2. Measurement and Line Estimation Result

Lastly, to determine the quality of estimate it is needed to calculate the R-Squared, which is also called as coefficient of determination. It is defined in the equation as

$$R^2 = 1 - \frac{SSE}{\sum_{I=1}^{N}(Y - \bar{Y}_i)^2}$$

It is found that the R-Squared is 0.9992. Since it is preferable to have the R-squared closer to 1, it is safe to say that the line estimation is accurate. Plot of the data and regression line can be found in Fig. 2, where it can also be seen that the line fit the data point. However, even though the line estimates well, it is still preferable to have more data point for more accurate estimation model.

## VI. Conclusion and Future Work

Despite our suggestions that more data should be gathered, the actual results show that the sensor is highly accurate. The exact conditions under which the experiment was carried out, however, would need to be repeated in order to obtain the same results because little or large items in the sensor's field of view can alter the measurement data. To elaborate on the need for more data, it is better to measure two distances rather than ten, and then repeat the process at least twenty times. This would eliminate the bias in our data and allow you to plot the results to a distribution curve.

For future work, the temperature aspect during ultrasonic measurements could be reviewed as it has effects on the velocity of sound. During controlled levels of temperature experiment, the ultrasonic distance measurement sensors accuracy provides references for future applications in different temperature environments. While doing this, more components can be added to the circuit, such as a heat sensor, and their outputs can be adjusted together with the ultrasonic sensor's output to produce readings that are more accurate.

## References


[1] Carullo and M. Parvis, “An ultrasonic sensor for distance measurement in automotive applications,” IEEE Sens. J., 2001.

[2] Biyyala Srijith, Chinnam Malathi Srilakshmi, and Vannada Swathi, “Arduino based Distance Measurement Sensor using Ultrasonic Sensor,” IIJRASET J., 2021.

[3] “HC-SR04 User Guide 1. Ultrasonic Distance Measurement Principles.” [Online]. Available: https://www.mpja.com/download/hc-sr04_ultrasonic_module_user_guidejohn.pdf

[4] C. W. De Silva, *Sensors and actuators : Engineering System Instrumentation*. Boca Raton: Taylor & Francis, CRC Press, 2015.