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A Survey of Ultrasonic Sensors and their Applications

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Abstract: The aim of this document is to provide detailed information on some of the readily available ultrasonic sensors. It also explains the working principle of the sensors and how they are implemented. Finally, we look at a few applications of these sensors along with a decision making guide. This document will help any reader wanting to learn about ultrasonic sensors and deciding which one suits their application's need.

Keywords: Ultrasonic sensors, Distance measurement, Obstacle detection, HC-SR04, HC-SR04P, US42V2, JSN-SR04T, US-100

I. INTRODUCTION

The primary use of an ultrasonic sensor is to measure distance. They achieve this using ultrasonic waves. Ultrasonic means having a frequency above the human ear's audibility limit of about 20,000 hertz [1]. Today various ultrasonic sensors are available cheaply, each different from the rest but all working on the same principle, explained in the next section. In later sections we will see the significance of distance measurement and how it can be transformed for other applications.

II. WORKING PRINCIPLE OF ULTRASONIC SENSORS

Ultrasonic distance measurement is carried out using ultrasonic sensors in the following way:

An ultrasonic transducer is triggered for a short amount of time, using the trigger pin by the microcontroller, which causes it to emit a pulse of sound. This pulse then travels in the media at the speed of sound.
Upon hitting an obstacle, this pulse is reflected and it either returns back, or takes another path [5].

Case I: The Pulse Returns back
The pulse that returns is picked up by the same or a different transducer (depending on the implementation). This transducer on receiving the pulse converts it into a logic signal for the microcontroller. The time between these trigger and echo events is calculated by the microcontroller. This time is also called time-of-flight [4]. The time thus calculated can be used to measure the distance, as the speed of sound is known for the media.

The formula for the above explanation is given by [2]:

$$Distance = \frac{Time \times Speed\ of\ Sound}{2}$$

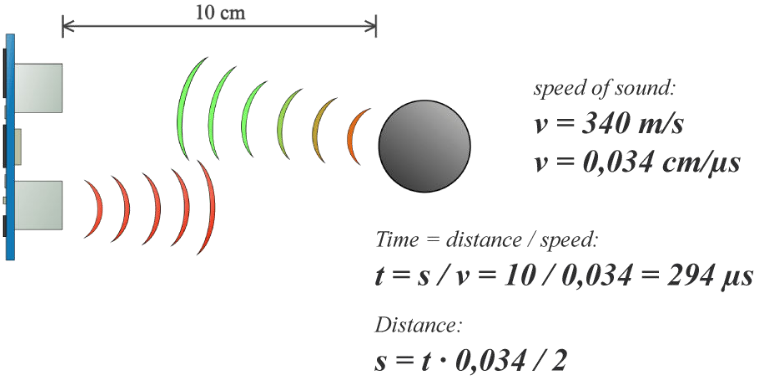

Fig. 1 An example illustrating ultrasonic distance measurement

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For Example, the Speed of sound at sea level = **343 m/s** or **34300 cm/s** thus,

$$Distance = 17150 \times Time(unit\ cm)$$

An illustrative example can be seen in fig 1[3]. Here we see how the time it takes for the sound to travel 10 cm can be calculated, considering the speed of sound as 340m/s. Similarly, the distance can be calculated if the time is known.

Case II: The Pulse does not Return

In this case, the microcontroller waits for a specified amount of time and then continues the program execution. The time specified may depend on the maximum measuring distance of the microcontroller, for instance.

III. COMPONENTS OF THE ULTRASONIC SENSOR

An ultrasonic sensor is mainly composed of two parts:

A. Ultrasonic Transducer Module

It can be either two separate transducers, a speaker and a microphone on a common base, or a single device that performs both functions. Various transducers are designed to operate at various frequency ranges. The ones which we study here produce 40KHz frequency.

B. Driver Circuit

The driver circuit interfaces with the microcontroller. In general, most driver circuits have four pins namely:

1) VCC Pin: Power is provided to the sensor using this pin. The ultrasonic sensors that we will study, run on either 3.3 volts or 5 volts. The source of the power can be the microcontroller or external.

2) Ground Pin: Ground or GND is where the electrical level is at 0 Volts. It is typically available on the microcontroller marked as GND and this is where this pin should be connected.

3) Trigger Pin: A pulse of ultrasonic frequency can be triggered by applying a specific voltage to this pin for a short amount of time.

4) Echo Pin: The echo pin is set to HIGH right after sending the pulse and becomes LOW when the transducer receives the reflected sound. This change in state from HIGH to LOW is detected by the microcontroller.

IV. SOME COMMONLY AVAILABLE ULTRASONIC SENSORS

Here we look at some of the affordable and readily available ultrasonic sensors. They are:

A. HC-SR04

It is a very popular four pin module. The pins are namely Vcc, Trigger, Echo and Ground respectively (Fig. 2). It has two eye-like transducers, one of which functions as a transmitter and the other as a receiver. It needs +5v to function and has a theoretical measuring distance from 2cm to 400cm. It is the least expensive of all the sensors that we compare.

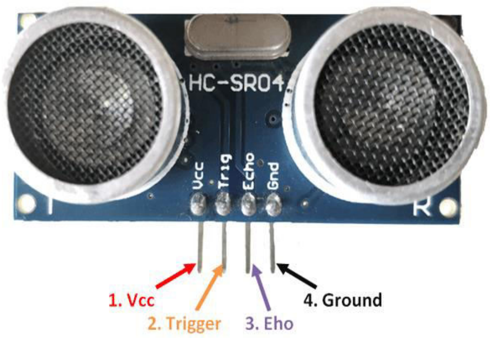

Fig. 2 The HC-SR04 with its pins labelled

To start the measurement, the trigger pin has to be made high for 10uS and then turned off. This action triggers an ultrasonic wave at frequency of 40KHz from the transmitter and the receiver will wait for the wave to return. The

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returning wave on being detected makes the Echo pin go LOW, which the microcontroller keeps track of and calculates the distance, as mentioned previously. Specifications of HC-SR04 are shown in Table 1.

Table I Specifications of HC-SR04 Sensor

Parameter	**Value**
Operating voltage	+5V DC
Theoretical Measuring Distance	2cm to 450cm
Practical Measuring Distance	2cm to 80cm
Accuracy	3mm
Measuring Angle	30 degree
Trigger Input Pulse Width	10uS

Applications of HC-SR04: Measuring distance, fuel volume, water tank level, obstacle avoidance systems etc.

B. HC-SR04P

The sensor is similar to HC-SR04, the only difference is that it has a wider voltage range of 3V to 5.5V DC. Theoretical measuring distance is reduced a little bit at 3V. This sensor is suitable for microcontrollers that can only provide 3.3V, like the Arduino Due or a Raspberry Pi.

TABLE II SPECIFICATIONS OF HC-SR04P SENSOR

Parameter	**Value**
Operating voltage	+3V-5.5V DC
Theoretical Measuring Distance	5V: 2cm - 450cm 3.3V: 2cm - 400cm
Practical Measuring Distance	2cm to <=80cm
Accuracy	3mm
Measuring Angle	30 degree
Trigger Input Pulse Width	10uS

Applications of HC-SR04P: Similar to HC-SR04, but with lower voltage requirements.

C. HY-SRF05

It is an upgrade to HC-SR04 in terms of precision i.e. 2mm instead of 3mm. It also has a slightly greater distance measuring range. It is fully compatible with HC-SR04 code. It is shown in Fig. 3.

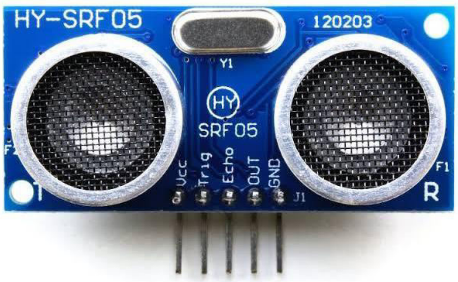

Fig. 3 The HY-SRF05 sensor (Notice the "OUT" pin)

It has an additional pin labelled "OUT", which can be used to connect to an oscilloscope to view pings [6].

Table III Specifications of HY-SRF05 Sensor

Parameter	**Value**
Operating voltage	+5V DC
Theoretical Measuring Distance	2cm - 450cm
Practical Measuring Distance	2cm to <=80cm
Accuracy	2mm
Measuring Angle	30 degree
Trigger Input Pulse Width	10uS

Applications of HY-SRF05: Distance measurement, Interference detection using the "OUT" pin etc.

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D. US-015

It is also a four-pin ultrasonic sensor. Its strength is its stability and accuracy. It gives out consistent readings as compared to the previously mentioned sensors. Its measuring angle is also slightly smaller than both the HC-SR04 and HY-SRF05. It is shown in Fig. 4.

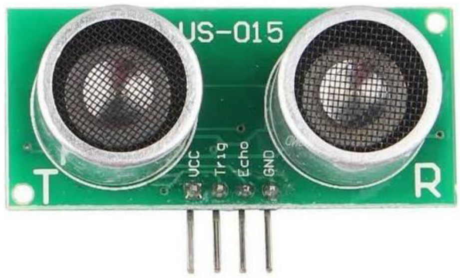

Fig. 4 The US-015 sensor

Table IV Specifications of US-015 Sensor

Parameter	**Value**
Operating voltage	+5V DC
Theoretical Measuring Distance	2cm - 400cm
Practical Measuring Distance	2cm to <=80cm
Accuracy	0.5mm
Measuring Angle	30 degree
Trigger Input Pulse Width	10uS

*Applications of US-015:*Due to its stability and consistency, it is better suited for robotics, autonomous driving systems and other projects that have similar requirements.

E. GY-US42

This sensor uses a single transducer instead of two. This conserves space and makes the module smaller. This sensor not only has trigger and echo, similar to HC-SR04, but also serial communication. It also has I2C communication which means that this module can be interfaced, using I2C bus, with various other I2C sensors such as the BMP280, a barometric pressure and altitude sensor. This is also the most expensive sensor that we study in this paper. It is shown in Fig. 5.

Fig. 5 The GY-US42 sensor

Table V Specifications of GY-US42 Sensor

Parameter	**Value**
Operating voltage	+3V-5V DC
Theoretical Measuring Distance	2cm - 720cm
Accuracy	1 cm
Trigger Input Pulse Width	10uS
Serial Communication	Yes
I2C Communication	Yes

Applications of GY-US42: This module is mainly used in drones and other such UAVs (Unmanned Aerial Vehicles). It is generally connected to flight controllers to identify the distance of the UAV from the ground. Other applications

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include horizontal distance measurement, obstacle avoidance, automatic control, traffic control, security, industrial control, artificial intelligence and research.

F. US-100

This sensor looks similar to the ones before, but it has an additional feature i.e. Serial Communication. This feature is enabled using the jumper (comes with the sensor) on the sensor's rear side. Removing the jumper makes the sensor behave as a regular ultrasonic sensor, with trigger and echo pins. With the jumper in place however, the microcontroller can communicate with the sensor using serial communication at 9600 baud [7]. This module also has a temperature sensor, which is used to get more accurate readings of the distance measured. This is because the temperature of the atmosphere, along with various factors [9], affects the speed of sound [8]. Fig 6 and Fig 7 given below, show the front view and the rear view of the US-100, respectively.

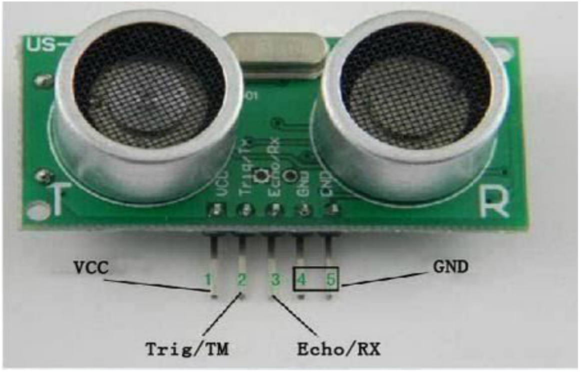

Fig. 6 The US-100 sensor (Front View)

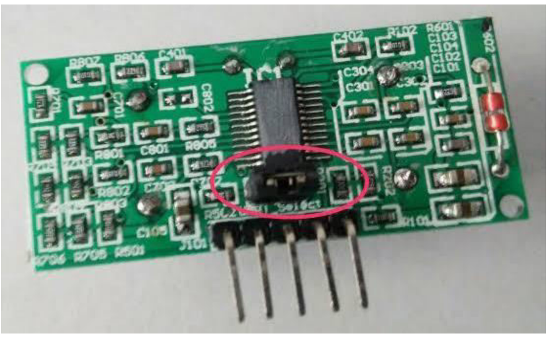

Fig. 7 The US-100 sensor (Rear View)

In the front view notice that pins Trig and Echo are also marked with Tx and Rx respectively. With the jumper engaged, these pins will be used in serial communication. The jumper can be seen in the rear view (circled in red).

Table VI Specifications of US-100 Sensor

Parameter	Value
Operating voltage	+5V DC
Theoretical Measuring Distance	2cm – 450cm
Practical Measuring Distance	2cm to <=80cm
Accuracy	1mm
Measuring Angle	30 degree
Trigger Input Pulse Width	10uS
Serial Communication	9600 baud
Temperature Compensation	Available in Serial Data Mode

Applications of US-100: This sensor can accommodate most of the requirements and replace the HC-SR04 in various applications. However, it costs about four times more, which is its downside. It can do all of the aforementioned tasks; thus, it has a huge scope. Temperature sensing and compensation are an added bonus. The microcontroller has less work to do due to this sensor's automatic measurement and serial communication abilities. This makes the implemented system more stable.

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G. JSN-SR04T

This is the only waterproof sensor that we come across. It has a single waterproof transducer, attached to a long wire which connects to the trigger circuit (Fig. 8). It uses the standard trigger-echo interface that we have seen so far. Its measuring angle is significantly more than the previous ones, quoted at about 75 degrees. Being waterproof, this is the only sensor suitable for an outdoor environment.

Fig. 8 The JSN-SR04T sensor

Table VII Specifications of JSN-SR04T Sensor

Parameter	**Value**
Operating voltage	+5V DC
Theoretical Measuring Distance	25cm – 450cm
Accuracy	2mm
Measuring Angle	75 degree
Trigger Input Pulse Width	10uS
Waterproof	Yes

*Applications of JSN-SR04T:*Considering the durability of this sensor, it can be used outdoors with confidence. Some of its major applications are parking sensors, underwater distance measurement, outdoor tank level measurement etc.

V. CONSIDERATION GUIDE

Let us outline the features that make any sensor stand out from the rest. This will help the reader in picking the right one for their projects.

A. *Cheapest:*HC-SR04 is the cheapest of them all.

B. *Most interfacing options:*GY-US42 has more interfacing options than the rest.

C. *Most Accurate and Stable:*US-015 is the most accurate, with a precision of 0.5mm.

D. *Most Durable:* JSN-SR04T

E. *Widest operating voltage range:* HC-SR04P

F. *The jack-of-all-trades:*The US-100 can be considered an all-rounder. It has decent accuracy, comes with an inbuilt temperature sensor and both trigger-echo as well as serial communication.

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VI. CONCLUSION

We have studied the basics of ultrasonic distance measurement and some of the popular ultrasonic sensors. We looked at their specifications and strengths. We hope this paper makes the selection and the decision-making process, when considering ultrasonic sensors, easier.

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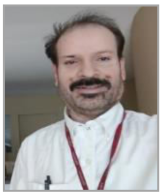
BIOGRAPHY

Vipul Kushwaha is an ME student and a developer. IoT, sensors and microcontrollers are his areas of interest. He is currently developing an IIoT project for the Indian Railways.



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