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DISTANCE MEASUREMENT DEVICE USING AN ULTRASONIC SENSOR

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Annotation

This article analyzes non-contact distance measurement technologies used in robotics and automated systems in the context of modern technological development. In particular, the working principle of ultrasonic sensors, their advantages, and a comparative analysis with other distance measurement methods (mechanical, optical, and laser) are presented. The affordability, accuracy, and independence from external lighting conditions of ultrasonic technology are justified as factors that increase its practical significance.

The article develops a model of a distance-measuring device based on an Arduino microcontroller and an HC-SR04 ultrasonic sensor. The propagation characteristics of ultrasonic waves, the processes of signal transmission and reception, and the mechanism of converting them into digital data are analyzed. The electronic circuit of the device is designed, a control program for the microcontroller is written, and the system is tested in practice.

As a result, it is determined that the developed device is capable of measuring distances from 2 cm to 400 cm with high accuracy. The proposed solution is significant due to its potential effective application in smart home systems and autonomous robotic devices.

Keywords

Ultrasonic sensor, HC-SR04, Arduino, distance measurement, microcontroller, ultrasonic waves, non-contact measurement, echo signal, automation, robotics

Introduction

In the era of modern technologies, robotics, automated systems, and intelligent control devices have become an integral part of human life. For the effective operation of these systems, sensors that obtain information from the external environment are of great importance. In particular, the issue of non-contact (without touching) distance measurement remains one of the most актуal problems in production, transport systems, and service sectors.

The technology of determining distance using ultrasonic sensors stands out from other types of sensors (such as optical or infrared) due to its affordability, accuracy, and independence from various lighting conditions (darkness or excessive brightness). Today, this technology is widely used in car parking systems, maintaining the distance of drones from the ground, and determining the position of products on industrial conveyor systems.

There are various methods of distance measurement: mechanical, optical, laser, and acoustic. The mechanical method requires direct contact with the measured object, which is often impossible (for example, when working with liquids or delicate objects). Although laser distance meters have high accuracy, they are expensive and require complex safety measures.

The acoustic (ultrasonic) method is derived from nature, particularly from the echolocation ability of bats and dolphins, and has long been the subject of scientific research. The creation of modern modules such as HC-SR04 has made this technology accessible and understandable even for ordinary users and students.

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The main goal of this independent work is to create a model of a device that accurately measures distance using an Arduino microcontroller and an ultrasonic sensor, as well as to analyze its working mechanism.

To achieve this goal, the following tasks were defined:

- To study the physical properties of ultrasonic waves and the laws of their propagation in air.
- To analyze the working algorithm of the HC-SR04 ultrasonic sensor.
- To develop the electronic circuit of the device and integrate the components.
- To write a special program code (sketch) for the microcontroller.
- To test the device in practice and evaluate the accuracy of the obtained results.

Object of study: Non-contact distance measurement systems and ultrasonic technologies.

Subject of study: The relationship between the signal transmission and reception time of the ultrasonic sensor and the process of converting this data into digital form.

At the end of this work, a device prototype capable of measuring distances from 2 cm to 400 cm with an accuracy of up to 3 mm will be developed. This project can serve as a core module in the future for creating smart home systems or autonomous moving robots.

- Sound physics: Dependence of sound speed on temperature (what is the speed at 20°C and how does it affect the measurement?).
- Comparative analysis of sensors: Create a table of advantages and disadvantages of ultrasonic sensors compared to infrared (IR) sensors.

Historical note: The discovery of ultrasound and its first use in radar systems.

2. General concept of the ultrasonic sensor

An ultrasonic sensor is an electronic device used to determine the distance to an object or to detect the presence of objects in the environment using ultrasonic waves. These sensors operate based on a physical phenomenon-the propagation and reflection of sound waves. Ultrasonic sensors are widely used in industry, robotics, automotive technologies, medicine, and automation systems.

Ultrasonic (ultrasound) waves are high-frequency sound waves that cannot be heard by the human ear. The human ear can typically hear sounds ranging from 20 Hz to 20 kHz. Sound waves above 20 kHz are called ultrasonic waves. Ultrasonic sensors generate sound waves in this range and use their propagation properties to determine distance.

The working principle of ultrasonic sensors is based on the propagation of sound waves in a medium at a certain speed and their reflection from obstacles. The ultrasonic signal sent by the sensor propagates through the medium and, when it encounters an object, reflects back. The receiving part of the sensor detects the returned signal and measures the time difference between the sent signal and the received signal. This time difference is used to determine the distance to the object.

In the process of determining distance, the speed of sound in the medium plays an important role. In air, the speed of sound is approximately 340 meters per second. Therefore, ultrasonic sensors use this physical value to calculate distance. The distance is calculated using the following formula:

Distance = (speed of sound × time) / 2

Here, time represents the round-trip time of the signal. The reason for dividing by two is that the sound wave travels to the object and then returns to the sensor.

Ultrasonic sensors usually consist of two main parts: a transmitting part and a receiving part. The transmitting part generates ultrasonic waves and sends them into the environment. The

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receiving part detects the reflected signal and converts it into an electrical signal. Then, a microcontroller or control system processes this signal and calculates the distance value.

In modern electronic systems, ultrasonic sensors are often used together with microcontrollers. For example, ultrasonic sensors can be used in various projects with platforms such as Arduino, Raspberry Pi, or other microcontrollers. This makes it easier to learn sensor technologies and to create various automated systems.

One of the important advantages of ultrasonic sensors is that they can operate in different environments. For example, they can work accurately even in low-light or dark conditions. This is because they use sound waves rather than light-based methods. Therefore, ultrasonic sensors are widely used in industry, robotics, and automotive systems.

In addition, ultrasonic sensors have a relatively simple structure, are easy to use, and are relatively inexpensive compared to other sensors. For this reason, they are also widely used in the field of education and serve as an important tool for students and researchers in creating various experiments and projects.

In conclusion, ultrasonic sensors occupy an important place in modern electronics and automation systems. They make it possible to determine the distance to an object using ultrasonic waves and are widely used in automating various technological processes. Therefore, studying the working principles and application possibilities of ultrasonic sensors is of great importance in the field of electronics and information technologies.

3. Working principle of the ultrasonic sensor

The working principle of ultrasonic sensors is based on the propagation of sound waves in a medium and their ability to return after hitting objects. This process belongs to the field of acoustics in physics, where it is possible to determine distance through the movement, reflection, and return time of sound waves. Ultrasonic sensors measure the distance to an object by using these physical laws.

Ultrasound refers to high-frequency sound waves that cannot be heard by the human ear. Typically, the human ear can hear sounds ranging from 20 Hz to 20 kHz. Sound waves above 20 kHz are called ultrasonic waves. Ultrasonic sensors generate sound waves in this range and transmit them into the environment.

During operation, an ultrasonic sensor performs several main stages. In the first stage, the sensor generates an ultrasonic signal and transmits it into the external environment. This signal is emitted using a special transmitting element. The signal propagates through the medium at a certain speed. If it encounters an object along its path, the sound wave reflects off the surface of that object and returns.

In the second stage, the receiving part of the sensor captures the signal reflected from the object. The received signal is converted into an electrical signal and transmitted to a microcontroller or control system. In this process, the time difference between the sent signal and the returned signal is determined.

The distance determination process is based precisely on this time difference. A sound wave travels through a medium at a certain speed. In air, the speed of sound is approximately 340 meters per second. The time taken for the signal to travel to the object and return is calculated, and this time is used to determine the distance.

The distance is calculated using the following formula:

$$\text{Distance} = (\text{speed of sound} \times \text{time}) / 2$$

In this formula, time represents the round-trip time of the signal. The reason for dividing by two is that the sound signal travels to the object and then returns to the sensor. If this calculation is not applied, the measured distance would be twice as large.

Ultrasonic sensors usually consist of two main parts: a transmitter and a receiver. The transmitting part generates ultrasonic signals and sends them into the environment. The receiving part captures the reflected signal. These two elements work together to determine the distance to the object.

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In modern ultrasonic sensors, this process is controlled by a microcontroller. The microcontroller manages the signal transmission process and processes the returned signal to calculate the distance value. The distance value can then be displayed on a screen or transmitted to other electronic systems.

The working principle of ultrasonic sensors is also similar to radar and sonar systems. For example, sonar technology is used to detect objects underwater. Ultrasonic sensors apply the same principle in an air environment.

Ultrasonic sensors are very convenient for distance measurement. They have a relatively simple structure and provide accurate results. In addition, they can operate in various environments. For example, they continue to function even in low-light conditions. Therefore, in some cases, they have advantages over optical sensors.

However, ultrasonic sensors also have some limitations. For example, soft surfaces or materials that absorb sound well may not fully reflect the signal. In addition, it may be difficult to detect very small objects. Strong environmental noise or temperature changes can also affect sensor performance.

Despite this, ultrasonic sensors are widely used in modern electronics and automation systems. They are applied in robotics, automotive parking systems, industrial automation, security systems, and various smart devices. Although the working principle of these sensors is simple, they are very useful and efficient technologies.

The working principle of ultrasonic sensors is based on the phenomenon of reflection of sound waves. The sensor sends an ultrasonic signal, which propagates through the medium, reaches an object, and reflects back to the sensor. The sensor measures the return time of the signal and calculates the distance to the object.

Ultrasound consists of sound waves with frequencies above 20 kHz, which cannot be heard by the human ear. Ultrasonic sensors use these high-frequency sounds.

The operation of the sensor is usually carried out in the following stages:

1-stage: Signal transmission.

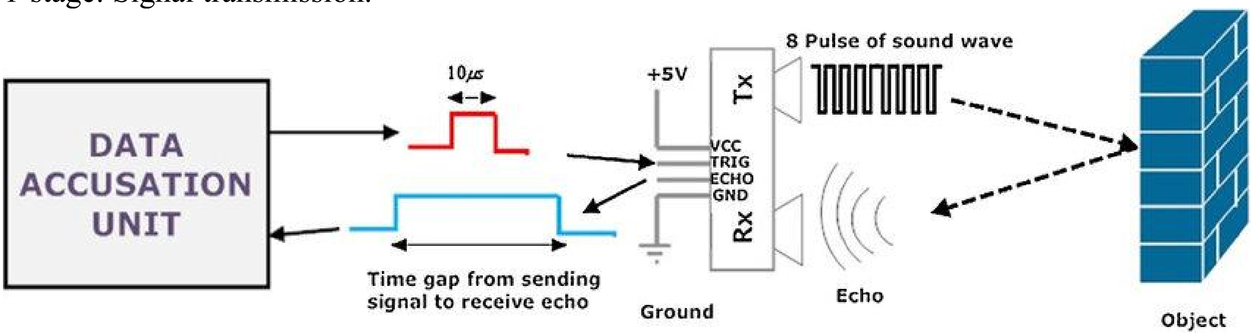

Figure 1. The transmitting (transmitter) part of the sensor generates an ultrasonic signal and sends it into the environment.

Stage 2: Signal propagation.

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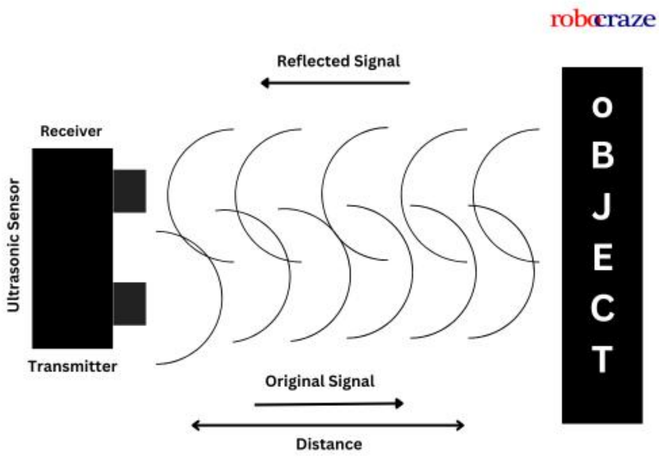

Figure 2. The ultrasonic wave travels in air at approximately 340 m/s.

Stage 3: Signal reflection.

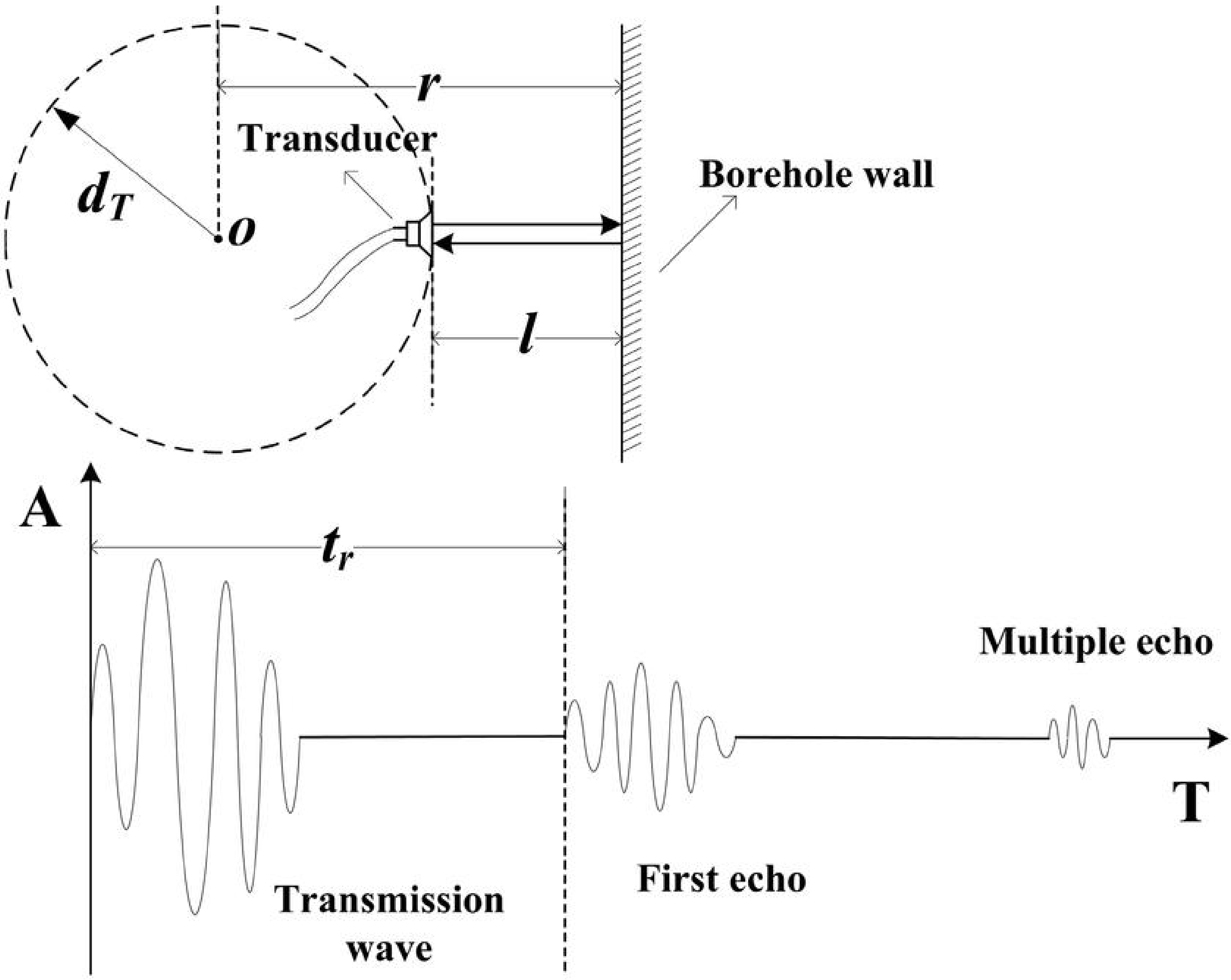

Figure 3. If there is an object in the path of the wave, the sound wave hits the surface of the object and reflects back.

Stage 4: Signal reception

The receiving (receiver) part of the sensor receives the returned signal.

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Stage 5: Distance calculation

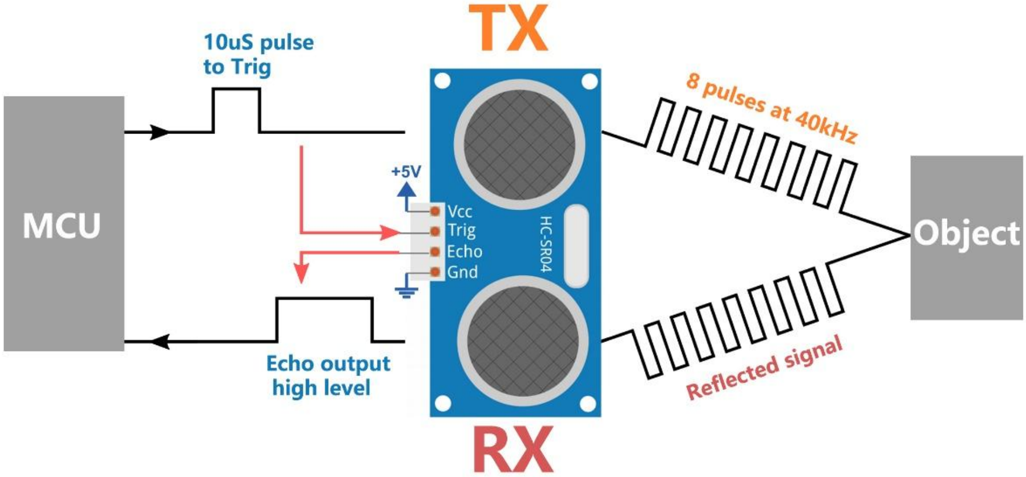

Figure 4. The time of the sent and returned signal is measured and the distance is calculated.

The distance is determined using the following formula:

Distance = (speed of sound × time) / 2

Here:

- speed of sound ≈ 340 m/s
- time – the round-trip time of the signal

The reason for dividing by two is that the signal travels to the object and then returns back to the sensor.

4. General information about the HC-SR04 sensor

The HC-SR04 ultrasonic sensor is an electronic module designed to measure distance using ultrasonic waves. This sensor is widely used in robotics, automated systems, smart devices, and Arduino-based projects. Despite its simple structure, the HC-SR04 sensor is capable of measuring the distance to an object with high accuracy.

The HC-SR04 sensor operates based on ultrasonic technology. The sensor sends an ultrasonic signal and receives the signal that is reflected back from the object. It measures the time taken for the signal to travel to the object and return, and calculates the distance based on this time. This process is controlled by a microcontroller. It is often used together with Arduino microcontrollers.

The measurement range of the HC-SR04 sensor is usually from 2 centimeters to 400 centimeters. The accuracy of the sensor can be approximately around 3 millimeters. Therefore, it works effectively even for detecting small distances.

An ultrasonic sensor usually consists of two main parts:

1. Transmitter

Generates the ultrasonic signal and sends it into the external environment.

2. Receiver

Receives the signal reflected from the object. One of the most popular ultrasonic sensors is the HC-SR04. This sensor is widely used in Arduino projects.

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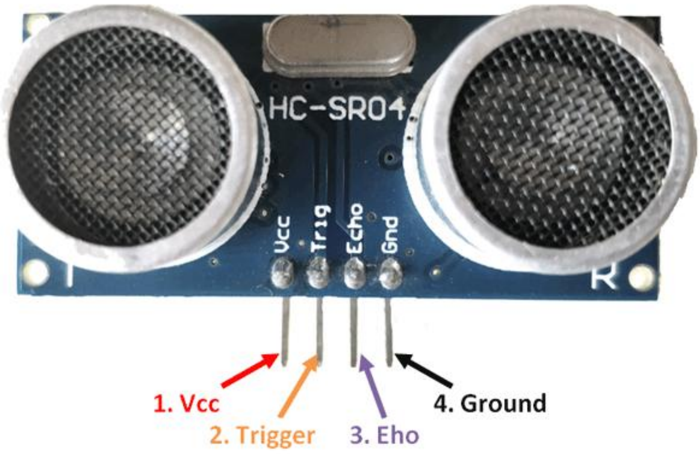

Figure 5. HC-SR04 ultrasonic sensor.

The sensor is connected through 4 pins:

Pin	Function
VCC	Power
GND	Ground
TRIG	Signal transmission
ECHO	Signal reception

5. Application areas of ultrasonic sensors

Ultrasonic sensors are one of the important electronic devices widely used in modern technologies. These sensors make it possible to determine the distance to an object using ultrasonic waves. Despite their simple working principle, they are effectively used in many fields. Ultrasonic sensors are widely applied in robotics, the automotive industry, industrial automation, security systems, and smart home technologies.

Application in robotics:

Robotics is one of the fields where ultrasonic sensors are most widely used. Robots use various sensors to detect the surrounding environment and avoid obstacles. An ultrasonic sensor determines the distance to the object in front of the robot.

For example, if there is a wall or another obstacle in front of the robot, the sensor detects the object and sends a signal to the robot's control system. As a result, the robot changes its direction or stops. This ensures the safe movement of the robot.

Application in the automotive industry

Ultrasonic sensors are also widely used in automotive technologies. In modern cars, parking systems operate using ultrasonic sensors. These sensors are installed at the front and rear of the vehicle.

During the parking process, sensors determine the distance to surrounding objects. If the car gets too close to an obstacle, the system warns the driver through an audio signal or display. This makes the parking process much safer and more convenient.

Application in industrial automation

Ultrasonic sensors also play an important role in industrial production processes. In factories and plants, it is necessary to detect distances and objects in order to automate various processes.

For example, ultrasonic sensors are used in conveyor systems to control the position and movement of products. In addition, these sensors are widely used to determine liquid levels, measure the height of materials, and create automatic control systems.

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Application in security systems

Ultrasonic sensors are also used in security systems. For example, in motion detection systems or alarm devices, ultrasonic sensors detect changes in the environment.

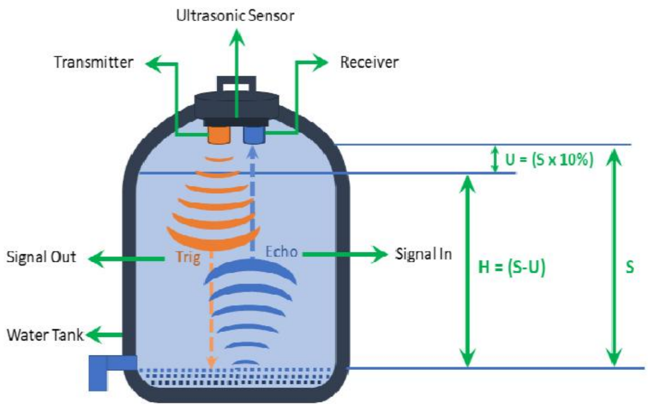
If the sensor detects movement in front of it or a change in distance, the system gives a signal. This is very important for ensuring security.

Application in smart home systems

In recent years, smart home technologies have been developing rapidly. In these systems, ultrasonic sensors are used to control various automatic devices.For example:

- automatic doors
- automatic lights
- water level monitoring systems
- smart robot vacuum cleaners

These sensors detect objects in the environment and ensure the automatic operation of devices.



Application in the medical field

Ultrasonic technologies are also used in the medical field. For example, the ultrasound diagnostic (USG) method is used to examine internal organs in the human body. This method operates using ultrasonic waves and is very important for assessing human health.

6. Practical part

In this practical work, a system was developed to determine the distance to an object using an HC-SR04 ultrasonic sensor and to visually display the result using LED indicators. The device provides a clear understanding of the distance by turning on the LED lamps sequentially as the object approaches.

Purpose of the work:

- To study the working principle of the ultrasonic sensor
- To implement distance measurement using Arduino
- To control LED indicators based on distance
- To develop skills in creating a practical electronic system

Required equipment:

- Arduino Uno
- HC-SR04 ultrasonic sensor
- Breadboard
- 3 LEDs

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- 3 resistors of 220 Ohm
- Connecting wires

Working principle of the device:

The working principle of this device is based on the propagation and reflection properties of ultrasonic waves. The HC-SR04 ultrasonic sensor is controlled by Arduino, and first emits a high-frequency ultrasonic signal through the Trig pin. This signal propagates through the air, reaches the object in front of it, and reflects back. The returned signal is received through the Echo pin.

The Arduino microcontroller measures the time between sending and receiving the signal. Based on this time value, the distance is calculated. During the calculation, the speed of sound in air (approximately 340 m/s) is taken into account, and the result is converted into centimeters.

The calculated distance value is compared with predefined thresholds in the program. If the object is far away, the LED indicators remain off. As the object gets closer, the LEDs turn on sequentially, visually showing the decrease in distance to the user.

Thus, the device determines the distance in real time and presents the result in a simple and understandable form.

The distance is calculated using the following formula:

$$\text{Distance} = \text{time} \times 0.01723$$

Here, the speed of sound is taken into account.

Arduino processes the time obtained from the sensor and calculates the distance in centimeters. Based on the calculated value, the LEDs turn on in a specific order.

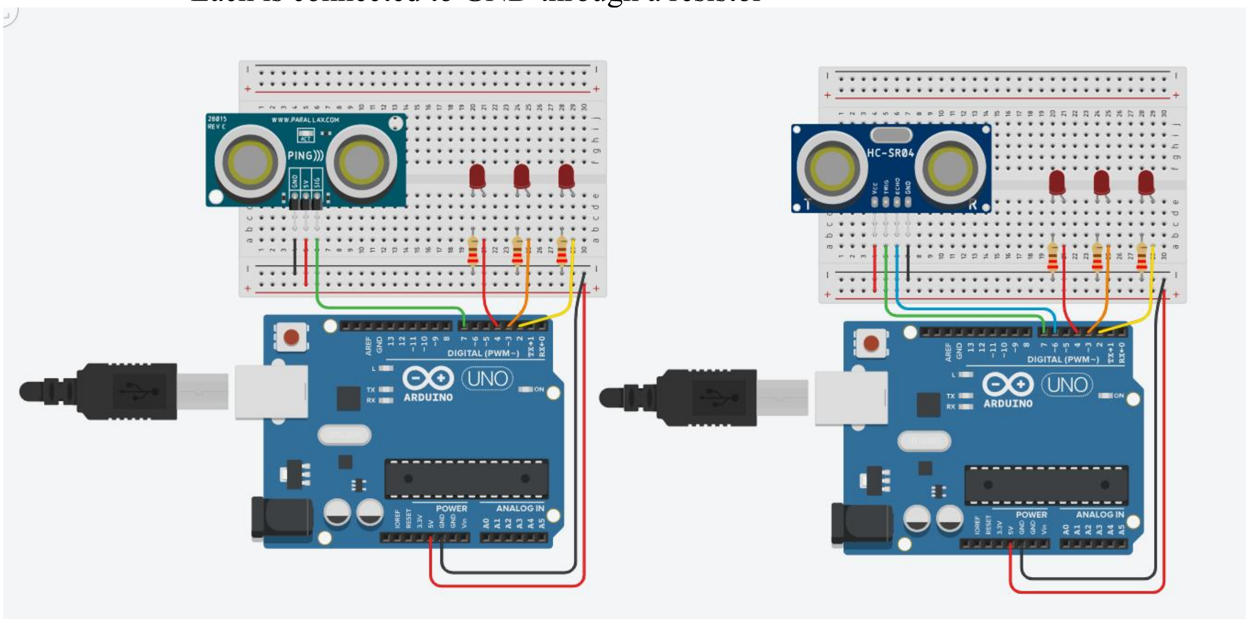
Connection diagram

Ultrasonic sensor:

- VCC → 5V
- GND → GND
- Trig → 7-pin
- Echo → 6-pin

LEDs:

- 1-LED → 2-pin
- 2-LED → 3-pin
- 3-LED → 4-pin
- Each is connected to GND through a resistor



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Kod

```
int distanceThreshold = 0;
int cm = 0;
int inches = 0;

long readUltrasonicDistance(int triggerPin, int echoPin)
{
  pinMode(triggerPin, OUTPUT);  // Clear the trigger
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
  // Sets the trigger pin to HIGH state for 10 microseconds
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);
  pinMode(echoPin, INPUT);
  // Reads the echo pin, and returns the sound wave travel time in microseconds
  return pulseIn(echoPin, HIGH);
}
void setup()
{
  Serial.begin(9600);
  pinMode(2, OUTPUT);
  pinMode(3, OUTPUT);
  pinMode(4, OUTPUT);
}
void loop()
{
  // set threshold distance to activate LEDs
  distanceThreshold = 350;
  // measure the ping time in cm
  cm = 0.01723 * readUltrasonicDistance(7, 6);
  // convert to inches by dividing by 2.54
  inches = (cm / 2.54);
  Serial.print(cm);
  Serial.print("cm, ");
  Serial.print(inches);
  Serial.println("in");
  if (cm > distanceThreshold) {
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
  if (cm <= distanceThreshold && cm > distanceThreshold - 100) {
    digitalWrite(2, HIGH);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
```

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```
  if (cm <= distanceThreshold - 100 && cm > distanceThreshold - 250) {
    digitalWrite(2, HIGH);
    digitalWrite(3, HIGH);
    digitalWrite(4, LOW);
  }
  if (cm <= distanceThreshold - 250 && cm > distanceThreshold - 350) {
    digitalWrite(2, HIGH);
    digitalWrite(3, HIGH);
    digitalWrite(4, HIGH);
  }
  if (cm <= distanceThreshold - 350) {
    digitalWrite(2, HIGH);
    digitalWrite(3, HIGH);
    digitalWrite(4, HIGH);
  }
  delay(100); // Wait for 100 millisecond(s)
}
```

Description of the working process

This program is written to determine the distance to an object using an ultrasonic sensor and to display the result through LED indicators.

When the program starts, the Arduino system is initialized and the pins connected to the LEDs are set to output (OUTPUT) mode. After that, the process of measuring distance using the ultrasonic sensor begins.

The sensor first sends a signal and then measures the time of the returned signal. Based on this time value, the distance is converted into centimeters. In addition, the distance is also calculated in inches and the results are displayed on the screen via the Serial Monitor.

In the program, the maximum distance limit is set to 350 cm. The calculated distance is checked against this limit.

If the object is located far away, all LED indicators remain off. As the object approaches, the LEDs turn on step by step. When the distance decreases slightly, only one LED turns on; when it gets closer, two LEDs turn on; and at the closest distance, all three LEDs turn on simultaneously.

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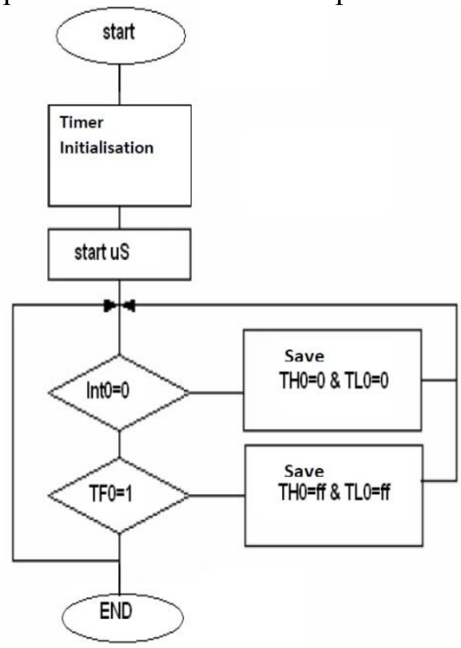
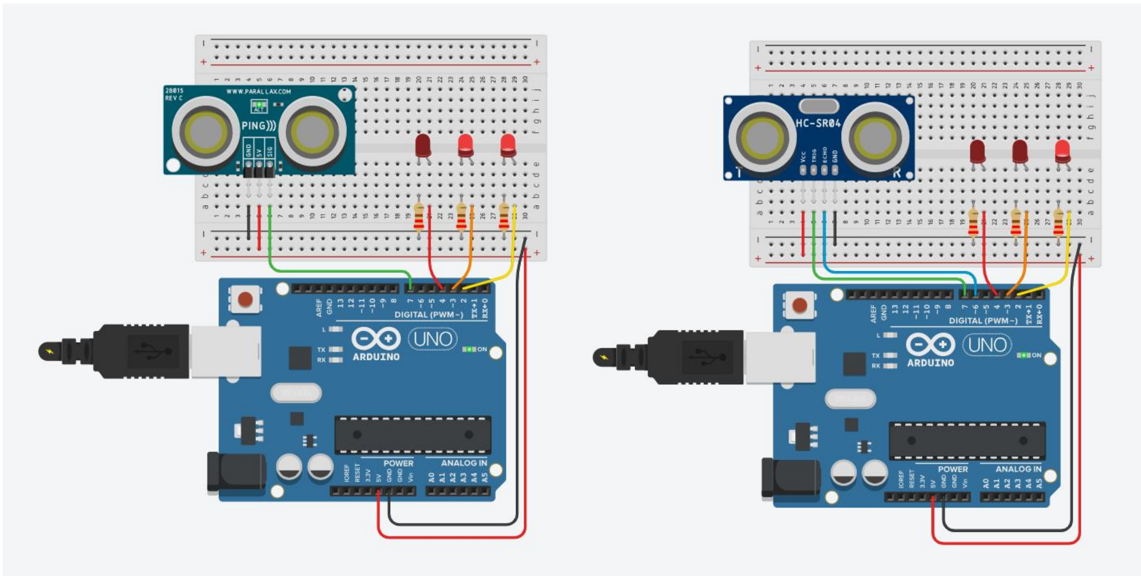
This system provides the user with quick and clear visual information about the distance and makes the operation of the device simple and easy to



understand.

Figure 7. The working algorithm of the device

Result:



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Experimental results:

Masofa	**Holat**	**LED**
> 350 cm	Far	Off
250–350 cm	Medium	1 LED
100–250 cm	Near	2 LED
< 100 cm	Vary close	3 LED

Application areas:

- Automotive parking systems
- Robotics

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- Security systems
- Smart home systems
- Obstacle detection devices

Conclusion

During this independent work, the working principle, structure, and application areas of a distance measurement device using an ultrasonic sensor were studied. In modern electronics and automation technologies, sensor devices play a very important role, as they are essential for monitoring, measuring, and controlling various processes. Ultrasonic sensors, in particular, are considered one of the most effective and widely used devices for distance measurement.

The working principle of ultrasonic sensors is based on the propagation of sound waves in a medium and their reflection from objects. The ultrasonic signal sent by the sensor travels through the medium, reaches the object, and reflects back. The sensor determines the time taken for the signal to travel to the object and return, and calculates the distance based on this time. This process is based on the laws of acoustics in physics, where the speed of sound in the medium plays an important role.

During the work, detailed information about the HC-SR04 ultrasonic sensor was also provided. This sensor stands out for its ease of use with microcontroller platforms such as Arduino and its ability to provide accurate measurement results. The HC-SR04 sensor is typically capable of measuring distances from 2 centimeters to 400 centimeters, with an accuracy of a few millimeters. Therefore, this sensor is widely used in robotics and automated systems.

In the practical part, a distance measurement device was created using the Arduino Uno microcontroller and the HC-SR04 ultrasonic sensor. The device was assembled using a breadboard, jumper wires, and LED indicators. The sensor was controlled through an Arduino program, and the distance to the object was calculated. During the experiment, the correct operation of the sensor was observed, and the distance values were clearly displayed in the Serial Monitor window. As the object approached the sensor, the distance value decreased, and as it moved away, the value increased.

Ultrasonic sensors are widely used in robotics, automotive parking systems, industrial automation, security systems, and smart home technologies. For example, in cars, parking sensors help the driver detect obstacles. In robots, ultrasonic sensors are a key component of obstacle avoidance systems. In industry, they are used to measure liquid levels and to control production processes.

In conclusion, ultrasonic sensors are one of the important devices in modern technologies. Although they have a simple structure, they operate very effectively and are used in various fields. Studying this technology is important for developing knowledge and skills in electronics, robotics, and automation. In the future, the use of ultrasonic sensors is expected to expand further and play a significant role in the development of new technological devices.

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