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Realization of a radar system based Arduino

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Abstract

Abstract

Radar technology is widely used for object detection, distance estimation, tracking, and environmental monitoring. With the development of low-cost embedded systems, ultrasonic radar-inspired solutions have become increasingly popular in educational and practical applications.

This thesis presents the design and implementation of a low-cost ultrasonic radar system for real-time object detection and visualization. The system is based on an Arduino microcontroller, an HC-SR04 ultrasonic sensor, and a servomotor used for angular scanning. By rotating the sensor over a predefined angular range, the system acquires distance measurements at different spatial positions, simulating radar-like behavior. The data are transmitted to a computer and visualized in real time using the Processing environment.

To improve measurement reliability, a median filtering technique is applied to reduce noise, remove outliers, and suppress invalid echoes caused by sensor limitations and environmental disturbances. This significantly enhances signal stability and measurement consistency.

Experimental results show that the system successfully detects objects in real time and provides clear spatial visualization. The integration of embedded hardware, visualization tools, and signal processing ensures a stable, low-cost, and efficient sensing platform suitable for educational use and practical applications such as proximity detection and vehicle blind-spot monitoring.

The proposed approach demonstrates high effectiveness in improving measurement quality under noisy conditions. It ensures reliable detection even in the presence of environmental disturbances and sensor limitations. Moreover, the system maintains consistent performance across different scanning angles, confirming its robustness and practical usability.

Keywords: Ultrasonic radar, Arduino, HC-SR04 sensor, servomotor, object detection, realtime visualization, median filtering, signal processing, embedded systems.

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List of abbreviations

Radar	Radio Detection and Ranging
IDE	Arduino Integrated Development Environment
LCD	Liquid Crystal Display
CW	Continuous-Wave
FMCW	Frequency-Modulated Continuous-Wave
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
MPR	Medium Power Radar
LED	Light Emitting Diode
HC-SR04	Ultrasonic distance sensor module
VCC	Voltage Common Collector
GND	Ground reference terminal of the electronic circuit
DC	Direct Current
I2C LCD1602	16×2 I2C Liquid Crystal Display
SSD1306	SSD1306 controller
OLED	Organic Light Emitting Diode

General introduction



General Introduction

Radar (Radio Detection and Ranging) is an electromagnetic sensing technology designed to detect objects and determine their range, position, and velocity. Since its early development, radar has evolved into a fundamental tool in modern sensing systems. It operates by transmitting electromagnetic or acoustic waves toward a target and analyzing the reflected signals, known as echoes. By measuring the time delay between transmission and reception, radar systems estimate target distance, while antenna orientation provides directional information, and Doppler shifts enable velocity estimation.

Beyond its historical development and theoretical principles, radar technology has become widely used in both civilian and military applications, including air traffic control, meteorology, automotive systems, surveillance, and space exploration. Its ability to operate under adverse environmental conditions such as darkness, fog, or cloud cover makes it a highly reliable sensing solution.

In parallel with this evolution, the rise of open-source hardware platforms, particularly Arduino, has significantly transformed the development of embedded systems. Arduino provides an accessible and flexible environment for rapid prototyping, enabling researchers and students to design and implement practical sensing systems efficiently. Combined with low-cost sensors such as the HC-SR04 ultrasonic module, it becomes possible to build radar-like detection systems suitable for educational and experimental purposes.

This work focuses on the design and implementation of an ultrasonic radar detection system based on Arduino. The system integrates hardware components such as a servomotor for angular scanning and an ultrasonic sensor for distance measurement, alongside software tools including the Arduino IDE for control and Processing for real-time visualization. Furthermore, signal processing techniques, particularly median filtering, are introduced to improve measurement reliability by reducing noise and eliminating invalid echoes.

This project aims to develop a complete, low-cost, radar-inspired system capable of realtime object detection and visualization, while also demonstrating the effectiveness of simple signal processing techniques in enhancing overall sensing performance. The proposed system is designed to simulate radar-like scanning behavior using ultrasonic sensing, enabling continuous monitoring of the surrounding environment and providing spatial information about detected objects in real time. By integrating both hardware and software components, the system seeks to achieve a reliable and efficient embedded solution suitable for practical experimental and educational use.

The intended application of this system is primarily focused on vehicle blind-spot monitoring, particularly for trucks and heavy vehicles operating under highway conditions. 1

These types of vehicles are characterized by large blind zones that significantly reduce driver visibility and increase the risk of accidents during lane changes, overtaking, and maneuvering in dense traffic environments. By providing additional real-time spatial awareness, the proposed system aims to contribute to improved situational awareness for drivers and to enhance overall road safety, potentially reducing the frequency of collision-related incidents.

In addition to its technical development, the project also considers its potential for realworld deployment and commercialization. The detailed economic analysis, market positioning, and potential industrial applications of the system are further developed in the business plan annex, which complements the technical work presented in this thesis.

This thesis is organized into three main chapters. The first chapter presents the theoretical background of radar systems, including their historical development, fundamental operating principles, and principal applications. The second chapter introduces the hardware and software tools used in the implementation of the system, such as the Arduino platform, ultrasonic sensor, servomotor, and visualization environment. The third chapter focuses on the practical implementation of the proposed system, including hardware integration, software development, and the application of median filtering techniques for noise reduction and performance enhancement.

Chapter I

Overview of radar systems and principle



I.1 Introduction

Radar (Radio Detection and Ranging) is an electromagnetic sensing system designed to detect objects and measure their range, position, and velocity. The term “RADAR” was officially coined in November 1940 by U.S. Navy Lieutenant Commander Samuel M. Tucker and F. R. Furth, and it was internationally adopted by the Allied powers in 1943 [1]. Radar operates by transmitting electromagnetic waves toward a target and analyzing the reflected signals, known as radar echoes [2]. In most systems, the transmitter and receiver are co-located, forming a monostatic configuration [2], [3]. By measuring the time delay of the returned signal, the system determines the target’s distance; the antenna orientation provides its direction; and the Doppler-induced frequency shift reveals the target’s velocity [2], [3]. Under appropriate conditions, radar can also measure altitude, course, and other target characteristics [4]. One of radar’s key advantages is that its electromagnetic signals are largely unaffected by darkness and can penetrate fog, clouds, or other obscuring conditions, allowing detection of objects invisible to the naked eye [2], [4].

Modern radar systems can extract a wide range of information from a target’s echo, but determining the range via time delay remains one of the most fundamental and important functions [2]. Radar technology is widely applied across many domains, including meteorology for weather and storm monitoring, air traffic control for aircraft tracking, road traffic surveillance, military detection and tracking systems, and space applications such as satellite navigation and planetary exploration [1], [5]. The following sections present the main types of radar systems along with their fundamental operating principles.

I.2 Historical development of radar

The development of radar technology finds its roots in the early use of radioelectricity, which was primarily dedicated to telecommunications and radionavigation. As early as 1900, scientists such as Nikola Tesla suggested that electromagnetic waves could be used not only for communication but also for detecting distant objects and tracking their movement [1]. This idea marked one of the earliest conceptual steps toward modern radar systems.

A significant breakthrough came in 1904 when Christian Hülsmeyer introduced the *Télémobiloskop*, the first practical device capable of detecting metallic objects at a distance [2]. His system used a spark-gap transmitter to emit electromagnetic waves, which were reflected back when they encountered objects such as ships, aircraft, or other conductive targets. These reflected signals were then captured by receiving antennas, allowing detection without any cooperation from the target. This innovation represented one of the earliest practical

demonstrations of non-cooperative object detection using electromagnetic wave reflection. However, due to its relatively short detection range, limited to about 3 km, the system did not achieve widespread adoption at the time.

Radar technology truly began to take shape during the 1930s, a period marked by increasing global tensions and the urgent need for reliable early-warning systems. Several countries, including the United States, Great Britain, Germany, and France, simultaneously invested in radar research and development [3]. Among the key contributors was Robert Watson-Watt, who played a decisive role in transforming radar from a theoretical concept into a practical and operational system. By developing radar systems operating at decametric wavelengths, he demonstrated that it was possible to achieve long-range detection with sufficient power and reliability [4]. This progress led to the establishment of one of the first operational radar networks in 1935, when the British Air Ministry deployed a series of Radio Direction Finding (RDF) stations along the coast of England. This network, later known as *Chain Home*, became fully operational by 1939 and significantly enhanced Britain's air defense capabilities [5]. It proved particularly effective during the Battle of Britain, where it enabled early detection of incoming aircraft and provided critical time for defensive response.

Following World War II, radar technology experienced rapid advancements, largely driven by developments in microwave engineering. The introduction of high-frequency components, such as the cavity magnetron, allowed radar systems to operate in the gigahertz range, improving both resolution and accuracy [6]. As a result, radar systems became more compact, efficient, and capable of distinguishing between closely spaced targets.

Today, radar is no longer limited to military applications. It has become an essential technology in many civilian fields, including air traffic control, maritime navigation, weather monitoring, and road safety systems [7]. More recently, radar has also found applications in healthcare, particularly for non-contact monitoring of vital signs. Furthermore, advances in digital signal processing and artificial intelligence have significantly enhanced radar performance, enabling better noise reduction, target detection, and classification in complex environments [8]. Despite these technological evolutions, the fundamental principle of radar remains unchanged: the transmission of electromagnetic waves and the analysis of their reflections to detect and characterize objects.

I.3 Radar components

Radar (RAdio Detection And Ranging), a term introduced by the United States Navy, is an active sensing system that operates by transmitting radio-frequency electromagnetic waves and processing the echoes reflected from objects within the observation space. These objects

may include natural or artificial scatterers such as terrain features, atmospheric phenomena, airborne objects, or other obstacles present within the radar coverage area.

The principal capability of radar lies in its accurate determination of target location through the comparison of transmitted and received signals, enabling the estimation of parameters such as range and direction. Radar systems provide reliable operation under a wide range of environmental conditions, including low visibility and adverse weather, and are effective during both daytime and nighttime.

Figure I.1 illustrates a monostatic radar configuration, in which a single antenna is used for both transmission and reception. The transmitter generates an electromagnetic waveform that is radiated into the propagation medium by the antenna. When this wave interacts with an object, a portion of the incident energy is scattered, with part of it returning toward the radar. The backscattered signal is then captured by the same antenna and forwarded to the receiver for subsequent processing.



Figure I.1: Reflection of the transmitted wave from a target.

Explanation:

Speed: the propagation speed of the wave ($c \approx 3 \times 10^8$ m/s for electromagnetic waves)

Time (Δt): the round-trip delay between the transmitted pulse (T_1) and the received echo (T_R)

$\Delta t = T_R - T_1$: the time elapsed between transmission and reception

Division by 2: accounts for the wave traveling the distance twice — once toward the target and once back to the radar

1) Transmitter

The transmitter generates an electromagnetic wave in the radio-frequency range, intended to be radiated by the antenna. Radar frequency bands are defined according to standards established by the Institute of Electrical and Electronics Engineers [2]. In addition, the center frequency of

the signal and its bandwidth are subject to regulations imposed by the International Telecommunication Union. However, no specific constraints are placed on the waveform shape, provided that its spectral occupancy remains within the authorized frequency limits. **2)**

Duplexer

The duplexer enables the use of a single antenna for both transmission and reception by routing the transmitted signal to the antenna and directing the received signal to the receiver. It is a three-port device whose isolation is a critical parameter, as it protects the reception chain, designed to process low-amplitude signals, from the high-power transmitted signal. **3) Antenna**

The antenna is responsible for radiating the electromagnetic signal in a specified direction. Except for electronically scanned antennas, it is typically mechanically rotated to provide 360° coverage of the surveillance area. The antenna beamwidth in azimuth determines the angular resolution, which is directly related to the ability to distinguish between closely spaced targets. For a given antenna size, the angular resolution is inversely proportional to the operating frequency [3]. Consequently, for the same resolution, an antenna operating in the X-band is smaller than one operating in the S-band. Radar antennas are commonly implemented as slotted waveguide structures or as planar arrays of patch elements.

The antenna polarization corresponds to that of the electric field it radiates or preferentially receives, typically within its main lobe. In maritime environments, horizontal polarization is generally preferred over vertical polarization due to its reduced sensitivity to sea clutter [4]. Furthermore, when the radar system employs a slotted antenna, it can be modeled as an array of secondary radiating sources. As the antenna size increases, the time required to excite these secondary sources also increases [5]. For instance, a minimum pulse duration of approximately 85 ns is required for an antenna with a length of 6 meters. **4) Target**

A target is characterized by its effective size within the operating frequency range of the transmitted wave, commonly referred to as the radar cross section (RCS). For small targets, whose dimensions are on the order of the wavelength of the transmitted signal, the RCS is proportional to the wavelength [6]. Consequently, radar systems exhibit improved detection capability for small targets when operating at higher frequencies.

5) Receiver

The receiver amplifies the captured signal in order to distinguish target echoes from noise in terms of amplitude. It is typically preceded by a limiter, whose function is to protect the subsequent stages of the reception chain from high-power interference signals that may be incident on the antenna.

Since noise is the primary factor limiting a radar system's detection capability, particular attention is given to minimizing the noise introduced by the receiver chain. In radio-frequency

systems, the overall noise figure of the receiver is largely dominated by the first amplification stage; consequently, a low-noise amplifier (LNA) is generally placed at the front end of the receiver [6]. The receiver chain also performs frequency and amplitude conditioning of the signal to optimize the dynamic range of the analog-to-digital converter (ADC).

6) Radar Display

Several display modes are used to visualize the echo signal received by the antenna, commonly referred to as radar video.

The A-scan mode represents the amplitude of the received signal as a function of time or, equivalently, the propagation distance of the wave. This mode focuses on a single pulse, emphasizing the intensity of the received echo, and is particularly useful for calibrating the receiver according to the received power level.

The B-scan mode represents range as a function of the pulse number. It is especially useful for rotating antennas, as it enables the visualization of echoes over a complete scan. The strength of the received echo is typically represented using a color scale.

The most widely used mode is the PPI (Plan Position Indicator), which corresponds to a B-scan displayed in polar coordinates. The radar video is mapped according to the angular position of the antenna, making this representation the closest to an aerial view of the observed scene. Figure 2 illustrates an example of a radar image displayed in PPI mode. The radar image is typically shown using intensity variations (e.g., shades of green), detected targets are highlighted (e.g., by circles), and vessel information from the Automatic Identification System (AIS) may be represented by specific symbols (e.g., triangles). A land mask can also be applied to exclude non-relevant areas from processing, thereby reducing computational load.

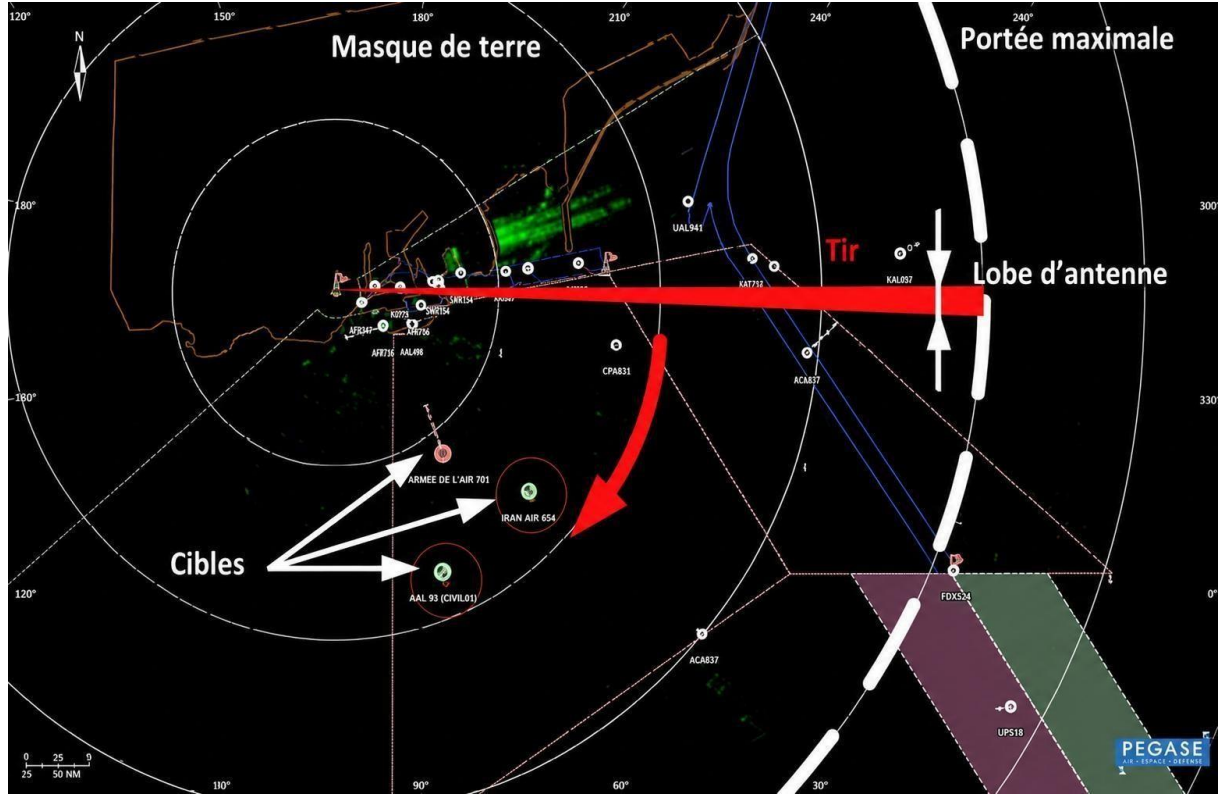


Figure I.2: Plan Position Indicator (PPI).

I.4 Principle of radar measurement

The processing applied to the received signal enables the extraction of several parameters related to the target. The time delay Δt , corresponding to the round-trip propagation time of the electromagnetic wave traveling at the speed of light c , allows the determination of the distance R between the radar and the target according to the following relation [7]:

$$R = \frac{c\Delta t}{2} \quad (\text{I.1})$$

Where:

R is the range to the target, $c \approx 3 \times 10^8$ m/s is the speed of light in free space,

Δt is the measured round-trip time of the radar pulse.

This fundamental principle forms the basis of all radar distance measurements. By accurately measuring the time delay, the radar can determine the position of objects without requiring any cooperation from the target. Further signal processing, such as amplitude analysis, Doppler filtering, or pulse compression, can provide additional information on target velocity, size, and material properties.

By considering the angular position of the antenna at the time of reception, it is possible to determine the target's coordinates and map them onto a chart or display. The echo power

provides information about the target's size, characterized by its radar cross section (RCS). A larger reflective surface results in a higher returned power [6].

For moving targets, the phase difference between the transmitted wave and the received echo is not constant. When a wave is transmitted toward a moving target, the reflected wave experiences a shift in frequency, known as the Doppler effect. A pulsed radar emits waves of duration τ at a pulse repetition frequency (PRF) f_r . By accumulating multiple echoes from the same target, the phase shift between successive pulses can be used to measure the Doppler frequency f_D [8]:

$$f_D = \frac{2v}{\lambda} \cos\theta \quad (\text{I.2})$$

where:

v is the radial velocity of the target relative to the radar, λ is the wavelength of the transmitted signal, θ is the angle between the radar line-of-sight and the target's velocity vector.

This principle allows the radar not only to determine the position of a moving target but also to estimate its radial velocity, which is essential for tracking and classification applications.

$$\Delta\phi = 2\pi f_D T_r \quad (\text{I.3})$$

The Doppler frequency is related to the radial velocity v_r of the target and the wavelength λ of the transmitted signal by:

$$f_D = \frac{2v_r}{\lambda} \quad (\text{I.4})$$

The resulting phase shift is therefore directly proportional to the radial velocity of the target:

$$\Delta\phi = \frac{2\pi v_r T_r}{\lambda} \quad (\text{I.5})$$

In terms of detection, the main challenge is to distinguish a target from noise in the received echo. Clutter represents unwanted echoes that interfere with the useful signal. Surface clutter arises from reflections off vegetation, terrain, or the sea, whereas volume clutter includes reflections from clouds, rain, or birds. Various studies focus on identifying these phenomena in order to separate useful echoes from clutter. Spectral analysis of the received signal is particularly useful for visualizing and mitigating clutter effects [9].

I.5 Classification of radar systems depending on technology

Radar systems can be categorized based on the technology and signal processing methods they employ. These technological differences determine the radar's performance characteristics, such as range resolution, target detection capability, and operational flexibility. The key classifications include:

1) Imaging radar / Non-Imaging radar

Radar systems can be broadly categorized into **imaging radar** and **non-imaging radar** based on how the received information is processed.

- **Imaging radar:** Imaging radar techniques aim to generate map-like representations or images of the target area from the received signals. These systems are used for applications such as weather radar, which visualizes precipitation and storm patterns, and military air surveillance radar, which provides detailed situational awareness of aerial environments [8], [9].
- **Non-Imaging radar:** Non-imaging radar systems provide measurement results as numerical values rather than images. Examples include radar altimeters, speed measurement devices, and secondary radar applications such as immobilizer systems in modern automobiles. These systems focus on specific target parameters like distance, speed, or altitude without generating detailed images [8], [10].

2) Primary and Secondary radar

- **Primary radar:** Primary radar systems emit high-frequency signals that are reflected by targets. Unlike secondary radar, primary radar relies solely on the echoes of its transmitted signal to detect and locate objects. The received echo signals are processed to determine target position, distance, and other basic parameters [8], [11].
- **Secondary radar:** Secondary radar requires the target (e.g., aircraft) to be equipped with a transponder. The radar interrogator sends a coded signal, which the transponder actively responds to with its own encoded reply. This response allows secondary radar to determine not only the range but also additional information such as altitude, identification, or system status, offering significantly more data than primary radar [9], [11].

3) Pulsed and Continuous-Wave (CW) radar

- **Pulsed radar:** Pulsed radar transmits short, high-power bursts of electromagnetic energy, followed by intervals during which echoes are received. By measuring the time

delay of the returned pulse and the antenna's pointing direction, pulsed radar determines the target's range, bearing, and sometimes altitude. Pulsed radars are widely used in air traffic control and long-range surveillance [10], [12].

- **Continuous-Wave (CW) Radar:** CW radar continuously transmits a signal, while the echo is received and processed simultaneously. Unlike pulsed radar, CW radar cannot measure absolute range directly unless modulation techniques are applied. CW radar can operate in monostatic or bistatic configurations, and in passive radar setups, signals from existing transmitters (e.g., television stations) are exploited to locate targets [12], [13].
- **Unmodulated CW radar:** These systems transmit a constant amplitude and frequency signal, specialized for speed measurements via the Doppler effect. They cannot measure distance and are commonly used as speed enforcement devices [12].
- **Frequency-Modulated Continuous-Wave (FMCW) radar:** FMCW radar modulates the transmitted signal in frequency or phase, allowing continuous measurement of distance or altitude based on signal delay or phase code analysis. The key advantage of FMCW systems is that they provide continuous target information without the need for separate reception intervals [12].
- **Intrapulse modulated radar:** Intrapulse modulated radars transmit longer pulses at lower power, with modulation within the pulse to allow pulse compression. This enables accurate range measurement even within the pulse duration, combining features of pulsed and FMCW radar [13].
- **Bistatic radar:** Bistatic radar systems separate the transmitter and receiver by a significant distance. This configuration can provide stealth advantages, reduce vulnerability to jamming, and offer unique measurement capabilities compared to monostatic radar [12], [13].
- **Ultrasonic radar:** operate using high-frequency sound waves rather than radio waves. These radars typically work in the 20 kHz to 1 MHz range, which is well above the threshold of human hearing and within the ultrasonic spectrum. The system transmits a pulse of sound, which reflects off nearby objects, and the distance to the target is calculated from the time-of-flight of the echo and the known speed of sound in air. Although ultrasonic radars are limited to short-range applications, from a few centimeters up to several meters, they offer high precision and rapid response in real time. Their performance is largely independent of lighting conditions, making them particularly suitable for applications in darkness or environments with poor visibility.

Ultrasonic radars are commonly employed in automotive parking sensors, obstacle detection in robotics, drone altitude measurements, and industrial level sensing. Compared to electromagnetic radars, ultrasonic systems have much shorter range but can measure small-scale objects with high accuracy. They are a low-cost and low-power alternative where short-distance sensing is sufficient, complementing traditional radar systems that operate in HF through W bands [14].

I.6 Radar waves and frequency bands

The electromagnetic wave spectrum extends up to frequencies on the order of 10^{24} Hz. This very wide frequency band is divided into “sub-bands” to account for the different physical properties of the waves it contains. The division into sub-bands was originally made according to “historical” criteria, and later adjusted to comply with an international nomenclature (at least in the Western context), which is now also considered somewhat outdated. Nevertheless, the traditional designation of sub-bands is still commonly used in the literature on the subject.[7] In summary, we will consider the following values:

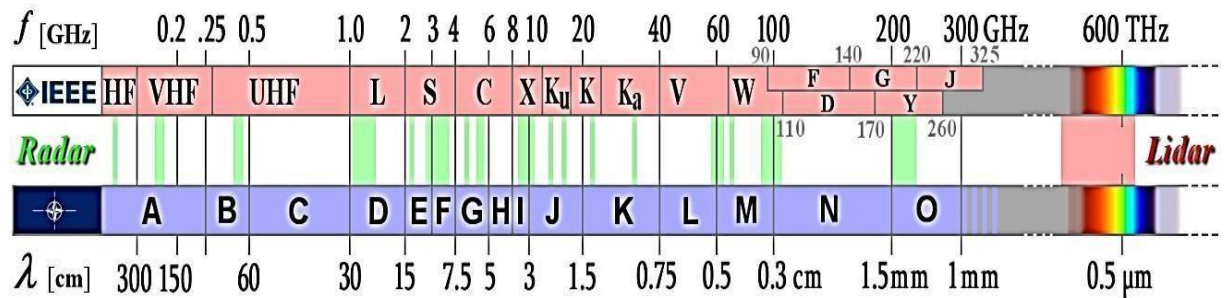


Figure I.3: Waves and frequency bands.

Unless the exact frequency is known, it is not always easy to translate an old designation into the new system while maintaining a reasonable level of precision. Often, manufacturer documents still cite the “old” designations (the line of German designations in the previous figure). Therefore, radars can operate over a wide frequency range. The higher the radar frequency, the more it is affected by weather conditions such as rain or clouds. However, higher frequencies also improve the precision of the radar equipment transmitting them. [2]

The following diagram shows, for example equipment, the sub-bands that are used.

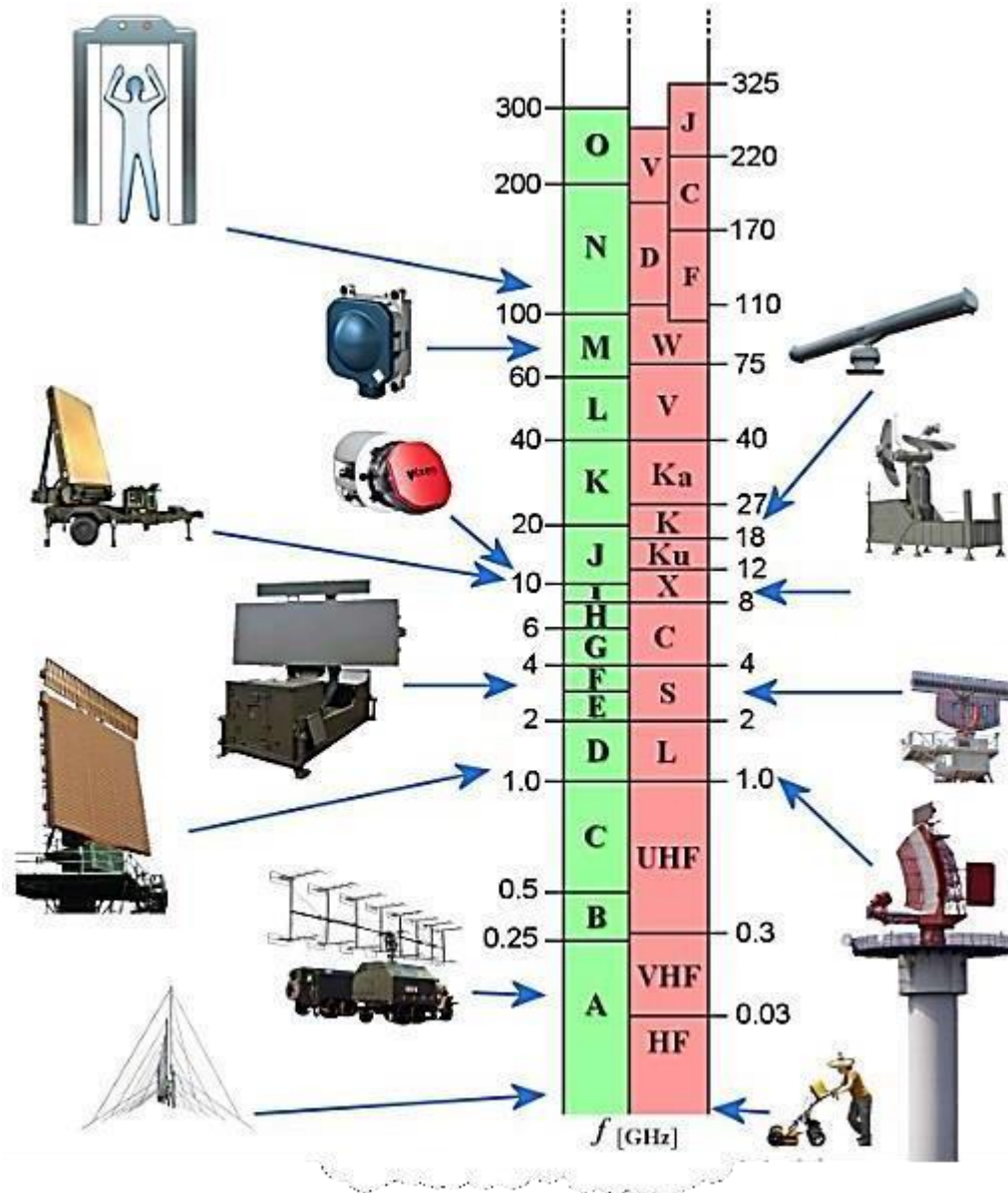


Figure I.4: Radar frequency sub-bands and their operational characteristics.

- Bands A and B (HF and VHF radars):** These frequencies are below 300 MHz and have been in use for a very long time. They represented the cutting edge of radio technology at the outbreak of World War II. Today, they are primarily used in very longrange surveillance radars, such as over-the-horizon radars. It is easier to achieve very high power at these low frequencies, their attenuation in the atmosphere is lower, and they propagate via the ground effect. However, their precision is lower than that of higher frequencies, and they require enormous antennas to obtain a beam capable of providing suitable azimuth and angle measurements. These frequencies are also used in telecommunications, which limits the ranges and bandwidths available for radar use.

They have gained renewed interest with the advent of stealth aircraft, as their shapes have less impact on lower-frequency waves. [7]

- **Band C (UHF Radars):** Frequencies from 300 MHz to 1 GHz are used for detecting and tracking satellites, as well as ballistic missiles on long trajectories. These radars therefore serve as long-range surveillance and fire-control acquisition systems (e.g., the MEADS medium-range air defense system). Some wind profilers also use these wavelengths, which are minimally affected by clouds and precipitation, to measure three-dimensional wind patterns above their site. Modern ultra-wideband radar technology operates across frequencies from Band A to Band C. These radars emit pulses across the entire range simultaneously, making them suitable for groundpenetrating radar applications, such as archaeological exploration. [2]
- **Band D (L-Band Radars):** Frequencies from 1 to 2 GHz are preferred for radars with ranges up to 400 km (250 nautical miles). These radars can transmit high-power pulses with large bandwidths and use pulse compression. Due to the curvature of the Earth, the maximum detection range is limited at low altitudes, and targets near the ground quickly fall below the radar horizon. In air traffic management, long-range radars for air corridors operate at these frequencies, often in tandem with wide monopulse secondary radar antennas that rotate more slowly than shorter-range radars. In the classical nomenclature, L-band can be remembered as “Large antenna, Long range”. [7]
- **Bands E and F (S-Band Radars):** The atmospheric attenuation in Bands E and F is higher than in Band D, though not excessive. Radars using these frequencies require greater transmission power to achieve an equivalent range. For example, the Medium Power Radar (MPR) uses a 20 MW pulse. Precipitation begins to noticeably affect these frequencies, which is why they are widely used in meteorological radars, particularly in tropical and subtropical regions. In the S-band, attenuation is relatively low even in heavy rainfall, allowing detection beyond the first storms, unlike higher-frequency meteorological radars used in northern latitudes. Airport surveillance radars operating in this band typically have detection ranges within 100 km (50–60 nautical miles), whereas weather radars such as the U.S. WSR–88D can reach over 250 km. [1]
- **Band G (C-Band Radars):** These frequencies are used by mobile battlefield radars for air surveillance and short- to medium-range missile fire control. Resolution for a given

antenna size is proportional to frequency, so this band provides good resolution with smaller, easily transportable antennas. C-band radars are also used in northern regions, such as Canada and northern Europe, because antenna and transmitter costs are much lower. Precipitation can cause attenuation at these frequencies; intense storms can partially or completely block the radar's view. This can be mitigated with a denser radar network with overlapping coverage areas. [2]

- **Bands I and J (X- and Ku-Band Radars):** Frequencies between 8 and 12 GHz require even smaller antennas, making them popular for systems needing lightweight radar equipment and limited range, as these waves are strongly attenuated by even light precipitation. Fighter, interceptor, and attack aircraft, which have limited space, extensively use these bands. Ground-guided missile systems also benefit from small antennas, enabling high mobility. These bands are also common in civilian and military maritime radars, allowing small, cost-effective antennas with good range and accuracy, usually employing waveguide slot or patch antennas protected by a radome. Synthetic aperture radars (SAR) for civilian and military mapping by aircraft or satellites also frequently operate in these frequencies. Some maritime patrol inverse SAR systems use them for atmospheric pollution measurements. [3]
- **Band K (K- and Ka-Band Radars):** As frequency increases, atmospheric absorption grows, causing radar beam attenuation, which limits both range and resolution. K-band radars are therefore restricted to very short-range, high-precision applications with very fast scanning rates. Surface radars use extremely short pulses of a few nanoseconds at these frequencies, enabling precise tracking of vehicles on airport tarmacs and runways, with resolution sufficient to identify vehicle shapes. [7]
- **Band V:** Attenuation becomes significant; even water vapor in the air can scatter the signal. The range of V-band radars is therefore very short, typically only a few meters, and they are limited to motion detection. [7]
- **Band W:** These frequencies exhibit two attenuation modes due to strong absorption by oxygen molecules (O_2). Around 75 GHz, attenuation is maximal, while at 96 GHz it is minimal. Recent automotive radars used for parking assistance, blind-spot coverage, and adaptive cruise control operate around 75–76 GHz [5]. Oxygen absorption protects these radars from interference by other frequencies. Laboratory equipment may operate

at 96–98 GHz for experiments with extremely high-frequency radar systems, approaching 100 GHz. .[5]

I.7 Conclusion

This chapter presented an overview of radar technology, including its historical development, main components, and fundamental operating principles. From the early contributions of Nikola Tesla and Christian Hülsmeyer to modern advanced systems, radar has evolved into a highly efficient sensing technology used for target detection, tracking, and measurement.

The chapter also explained how radar systems use transmitters, receivers, antennas, and signal processing techniques to determine target range, direction, and velocity through the analysis of reflected electromagnetic waves and Doppler effects. Advanced methods such as pulse compression and Doppler filtering improve detection accuracy and reduce noise under challenging environmental conditions.

Due to its reliability and versatility, radar technology is widely applied in military and civilian fields, including air traffic control, maritime navigation, meteorology, automotive safety, and healthcare. The concepts discussed in this chapter provide an essential foundation for understanding radar classifications, wave types, and frequency bands, which are important for the design and optimization of modern radar systems.

Chapter II

Main components of the ultrasonic radar system

II.1 Introduction

Over the past decade, the open-source hardware movement has gained worldwide momentum [15], with Arduino emerging as a central platform for applications ranging from everyday household devices to advanced scientific instruments. A diverse global community of students, hobbyists, and professionals has rallied around Arduino, collectively building an extensive repository of accessible knowledge. The proliferation of open-source hardware platforms lowers the learning curve, fosters innovation, and accelerates the translation of ideas into practical solutions for both novices and experts.

Before delving into the implementation details of the radar system, it is essential to introduce the tools employed in its design. This chapter provides an overview of the key software and hardware components, including the Arduino board for data processing, the HC-SR04 distance sensor, and other peripheral devices integral to the system's functionality.

II.2 Arduino boards

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board.

Arduino was born in the early 2000s at the Ivrea Interaction Design Institute in Italy [16], founded to provide students and designers with an easy-to-use, low-cost platform for rapid prototyping. The project originated from the need to simplify electronics education, making it accessible to people without formal training in programming or circuit design. Its initial goal was modest: create a board that could control sensors and actuators in a simple, intuitive way while keeping production costs low.

The name "Arduino" comes from Barone di Arduino, a historic figure from the region of Ivrea, reflecting the project's local roots. The first Arduino boards were designed as opensource hardware, encouraging users to study, modify, and share their designs. This philosophy of openness and collaboration quickly attracted a community of students, hobbyists, and makers, who began experimenting, sharing projects, and pushing the platform beyond its original educational purpose. The early success of Arduino demonstrated that accessible tools could empower creativity and innovation, laying the foundation for a global movement in opensource hardware.

II.2.1 Popular Arduino boards [17]

There are many varieties of Arduino boards on the market, there are a handful that are most commonly seen. The most commonly used Arduino boards by both engineers and hobbyists include: Arduino UNO, Arduino Nano, Arduino Due, Arduino Mega.

- **Arduino UNO:** The UNO is arguably the most popular Arduino. It is powered by an Atmega328 processor operating at 16MHz, includes 32KB of program memory, 1KB of EEPROM, 2KB of RAM, has 14 digital I/O, 6 analog inputs, and both 5V and 3.3V power rails.



Figure II.1: Arduino UNO board.

The Arduino UNO has a pin header arrangement that is rapidly becoming the industry standard for development boards, making it compatible with most development board shields on the market.

A power jack is included on the UNO, allowing it to be powered by an external wall wart. There is also a VIN option available for connecting the UNO to batteries.

The physical dimensions of the UNO (69mm x 54mm) make it a small development board that can easily fit into many projects and the four screw holes allow designers to securely fit them into place.

- **Arduino Nano:** The Arduino Nano is essentially an Arduino UNO shrunk into a very small profile, making it very convenient for tight spaces and projects that may need to reduce weight wherever possible. Like the UNO, the Nano is powered by an Atmega328 processor operating at 16MHz, includes 32KB of program memory, 1KB of EEPROM, 2KB of RAM, has 14 digital I/O, 6 analog inputs, and both 5V and 3.3V power rails.

(Note - Arduino Nano boards before V3.0 used the ATmega168 which essentially has half the specs.)

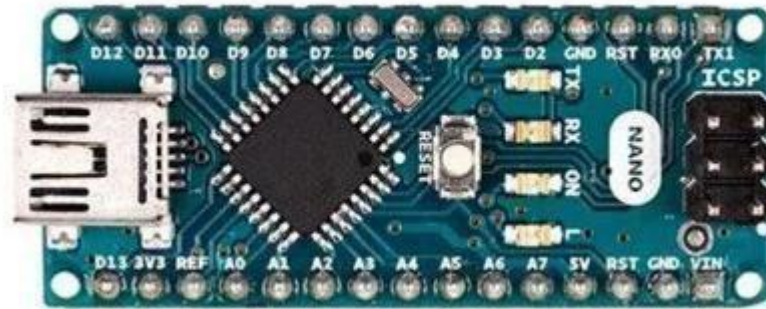


Figure II.2: Arduino Nano board.

The Nano, unlike the UNO, cannot connect to Arduino shields but it has pin headers which make it useful for breadboard prototyping or in PCBs with the use of a socket. Often, Arduino Nano boards are the cheapest Arduino board option available making them cost-effective for larger projects.

- **Arduino Due:** The Arduino Due is one of the larger boards and is also the first Arduino board to be powered by an ARM processor. While the UNO and Nano operate at 5V, the Due operates at 3.3V—this is important to note, because overvoltage will irreparably damage the board. Powered by an ATSAM3X8E Cortex-M3 running at 84MHz, the Due has 512KB of ROM and 96KB RAM, 54 digital I/O pins, 12 PWM channels, 12 analog inputs, and 2 analog outputs.

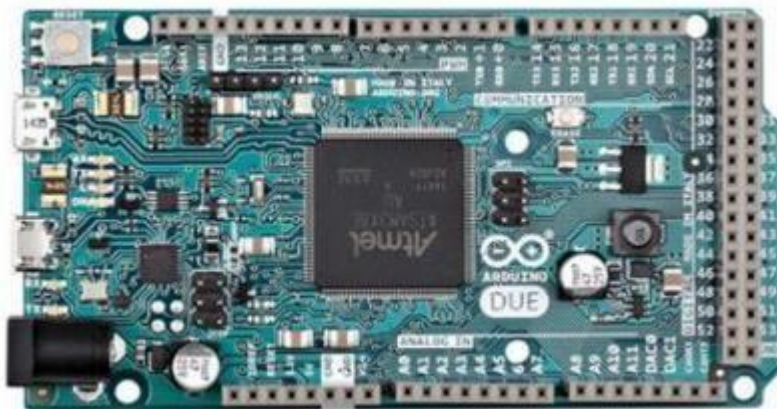


Figure II.3: Arduino Due board.

The Due does not have any on-board EEPROM and is one of the more expensive Arduino boards. While the Due has a large number of pin headers for connecting to the many digital I/O, it is also pin-compatible with standard Arduino shields. Software compatibility with the Due cannot be guaranteed.

- **Arduino Mega:** The Arduino Mega 2560 is somewhat similar to the Due in that it also has 54 I/O. However, instead of being powered by an ARM core, it instead uses an ATmega2560. The CPU is clocked at 16MHz and includes 256KB of ROM, 8KB of RAM, 4KB of EEPROM, and operates at 5V making it easy to use with most hobby friendly electronics.



Figure II.4: Arduino Mega board.

The Arduino Mega has 16 analog inputs, 15 PWM channels, a pinout similar to the Due, and is hardware compatible with Arduino shields. Like the Due, software compatibility with the Mega cannot always be guaranteed.

II.2.2 Arduino IDE

The Arduino IDE (Integrated Development Environment) is used to write the computer code and upload this code to the physical board. The Arduino IDE is very simple and this simplicity is probably one of the main reason Arduino became so popular. We can certainly state that being compatible with the Arduino IDE is now one of the main requirements for a new microcontroller board. Over the years, many useful features have been added to the Arduino IDE and you can now managed third-party libraries and boards from the IDE, and still keep the simplicity of programming the board. The Arduino software (IDE) is an open source software, which is used to programme the Arduino boards, and is an integrated development environment, devlopped by arduino.cc. Allow to write and upload code to Arduino boards. And it consiste of many libraries and a set of examples of mini projects. Arduino software (IDE) is compatible with different operating systems (Windows, Linux, Mac OS X), and supports the programming languages (C/C++). When you open the IDE for the first time, it creates a new

sketch named today's date. The programs in Arduino are called "sketches". The main window of the Arduino IDE is shown below in figure II.5.



Figure II.5: Arduino IDE first launch.

Code area is the largest white space where you write your sketch. The black area below is the output window where the IDE displays information about the compilation and downloading process, errors, and other things.

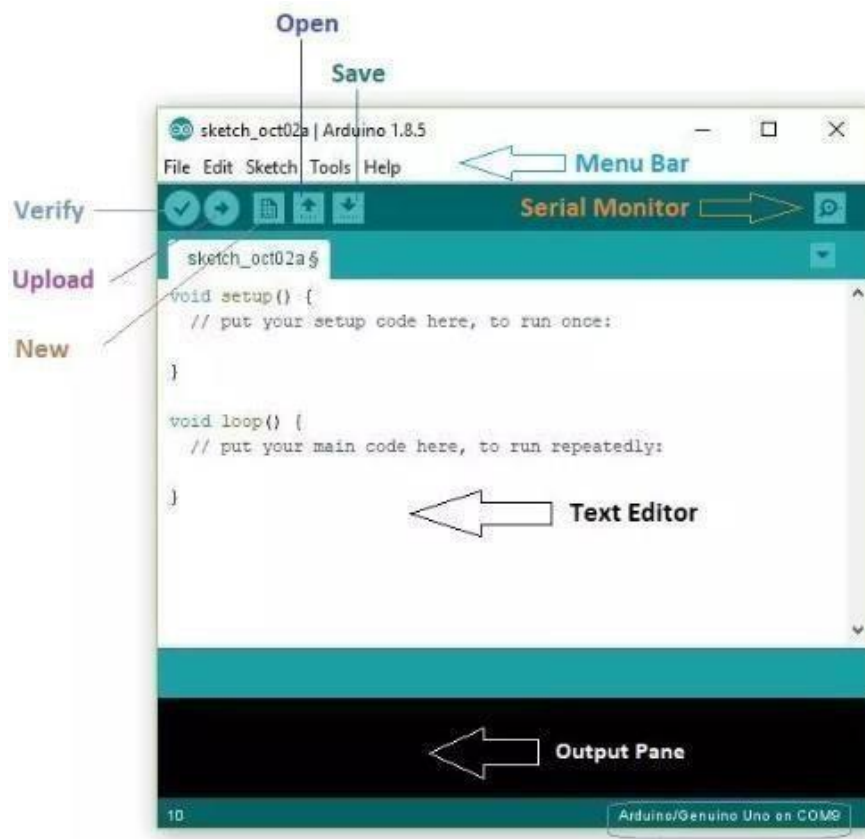


Figure II.6: Arduino IDE interface.

The IDE environment is mainly distributed into three section: Menu Bar, Text Editor and Output Pane. The Six buttons, of the toolbar menu, appearing under the Menu Bar are connected with the running program as follows.

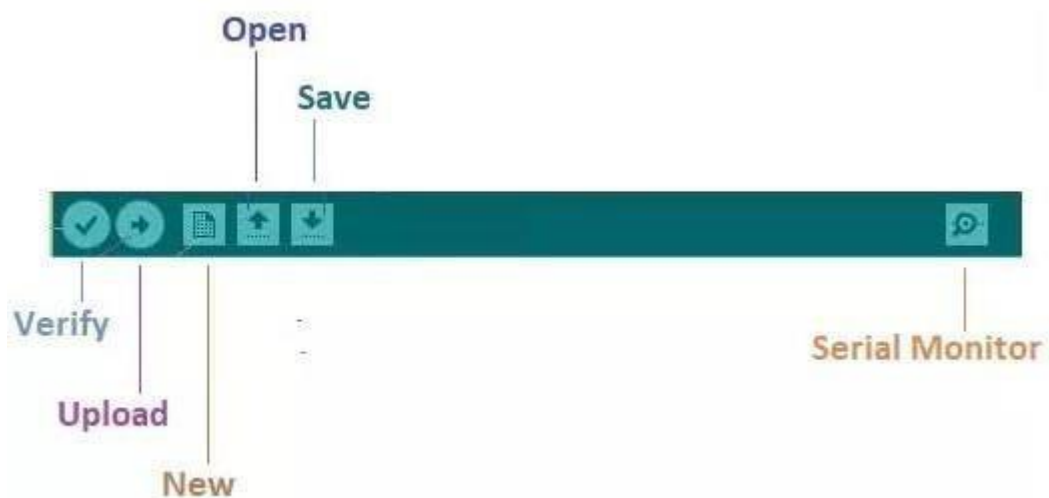


Figure II.7: Frequency used tools in programming Arduino board.

The toolbar menu in figure II.7, present the most important buttons in the Arduino software, because it contains the tools continuously used while programming the Arduino board. These tools are:

- 1) Verify: this button use to review the code, or make sure that is free from mistakes.
- 2) Upload: this button is use to upload the code on the Arduino board.
- 3) New: this button use to create new project, or sketch (sketch is the file of the code).
- 4) Open: is use when you want to open the sketch from sketchbook.
- 5) Save: save the current sketch in the sketchbook.
- 6) Serial monitor: showing the data which have been sent from Arduino.

II.3 HC-SR04 Ultrasonic Sensor

The HC-SR04 is an ultrasonic sensor module that is commonly used in electronics projects for measuring distances between the sensor and an object using sonar. They use sound waves whose frequency is greater than 20 KHz to measure the distance of an object. Ultrasonic sound is inaudible to humans.

The sensor has two main components: an ultrasonic transmitter and an ultrasonic receiver. The transmitter sends out a high-frequency sound wave, which bounces off an object and returns to the receiver. The time it takes for the sound wave to travel back to the receiver is used to calculate the distance between the sensor and the object (see figure II.8).

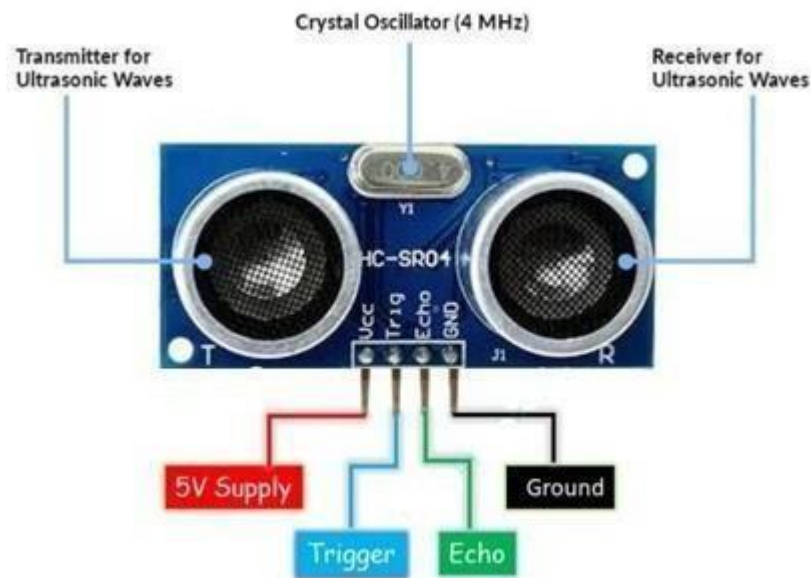


Figure II.8: Ultrasonic Sensor HC-SR04 [18].

The HC-SR04 sensor module typically consists of a small circuit board with two ultrasonic transducers (one for transmitting and one for receiving), a control IC, and a few other components.

- 1) VCC (PIN-1): It should be connected to 5V DC;
- 2) TRIG (PIN-2): It's an input to sensor. High pulse of $10\mu\text{s}$ is applied to this pin;
- 3) ECHO (PIN-3): It's an output of sensor. High pulse at this pin indicates time taken by sound wave to travel from transmitter to object and object to receiver. In above image left side is transmitting side and right side is receiving side;
- 4) GND (PIN-4): This pin should be connected to ground.

The HC-SR04 ultrasonic sensor works based on the principle of echolocation. The sensor sends out a high-frequency sound wave (typically 40 kHz) and measures the time it takes for the wave to bounce off an object and return to the sensor. This time can then be used to calculate the distance between the sensor and the object. Figure II.9 is a step-by-step explanation of how the HC-SR04 works:

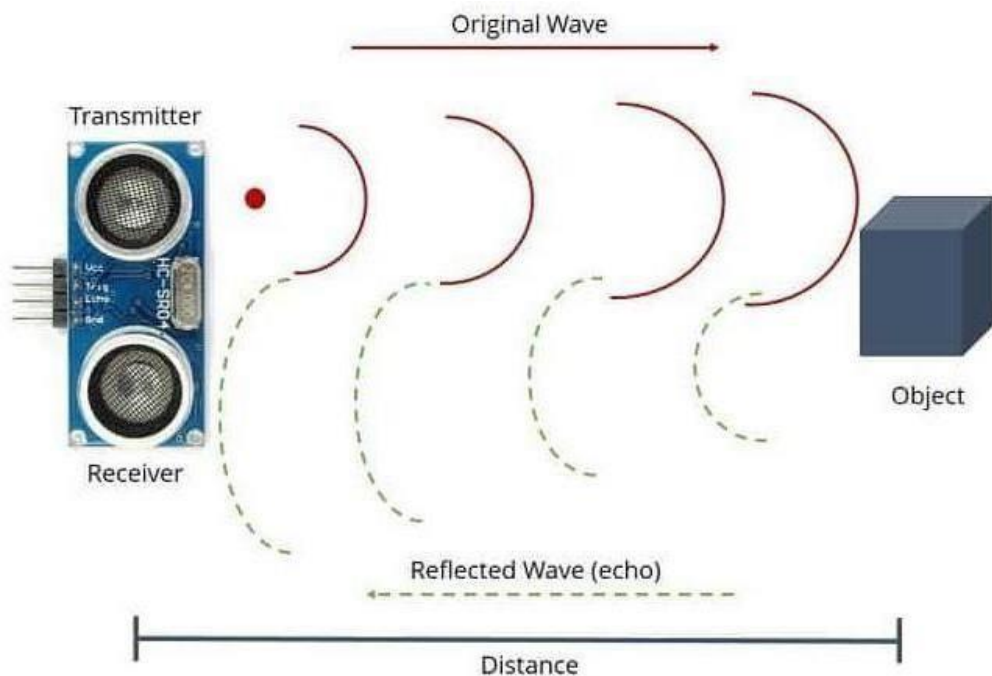


Figure II.9: Working of ultrasonic Sensor.

To calculate the actual distance between the sensor and the object we will use the formula $DISTANCE = (SPEED * ECHO\ TIME) / 2$ here at 20 degree Celsius the speed of sound is 343m/sec as the medium of transmission is air or we can also say: Sound speed and time given:

$$Sound\ speed = 343\ m/s = 0.0343\ cm/\mu s$$

$$distance = speed * time$$

$$Total\ distance = \frac{speed * time\ of\ hight\ (Echo)\ pulse}{2}$$

$$Total\ distance = \frac{343 * time\ of\ hight\ (Echo)\ pulse}{2}$$

We are dividing it by 2 because as we are traveling the same distance twice one is the original signal traveling towards the object and other one is the reflected signal traveling from the object. To start a measurement, and Triggering the sensor, a 10 μ s pulse is sent to the trigger pin of the sensor. This triggers the sensor to emit a burst of ultrasonic sound waves.

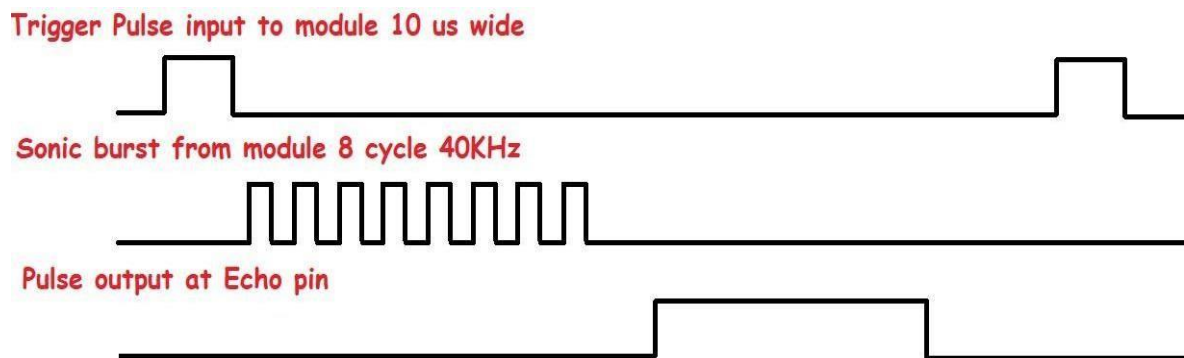


Figure II.10: Timing diagram of HC-SR04.

The ultrasonic sound waves travel through the air and bounce off from any objects in their path. The sensor waits for the sound waves to bounce back, and Sending the sound waves.

Here some applications of Ultrasonic Sensor:

- 1) Vehicle detection for car wash,

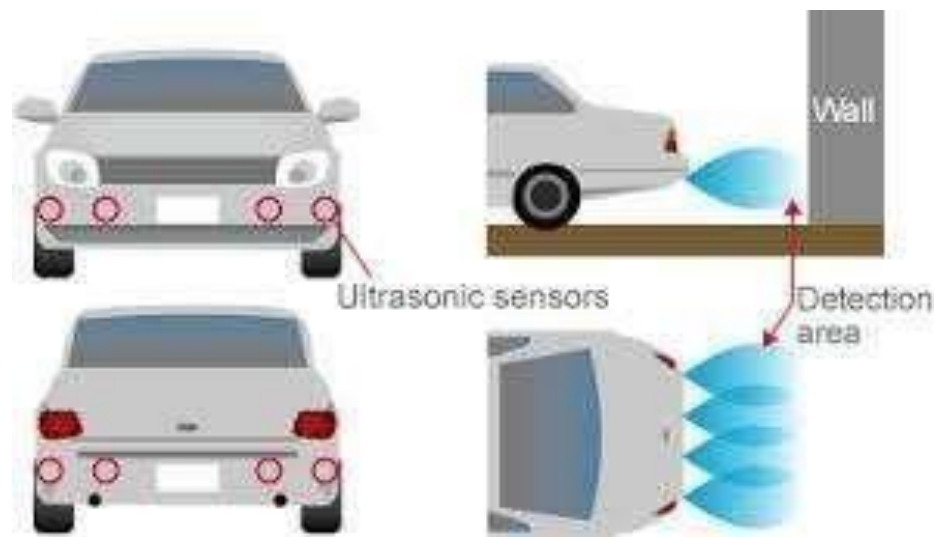


Figure II.11: Vehicle detection for car wash.

- 2) People detection such as counting,
- 3) Robotic sensing in drones,
- 4) Presence detection,
- 5) Tank level.

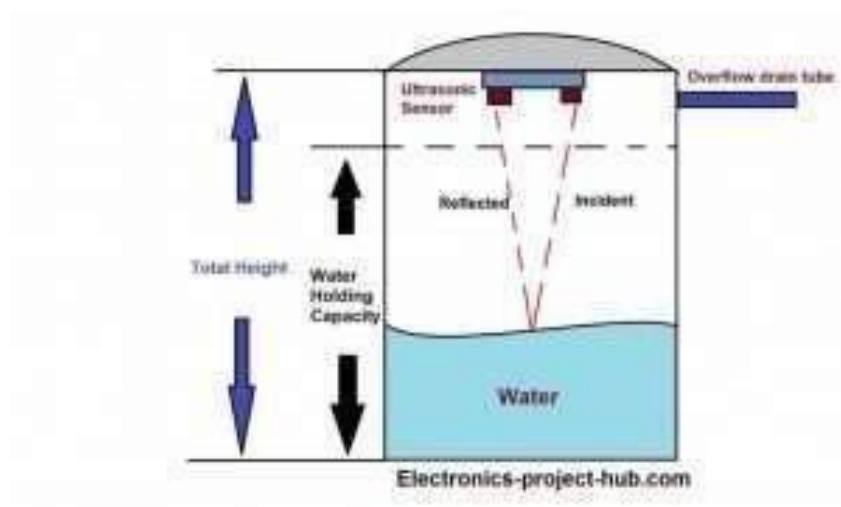


Figure II.12: Tank level.

Advantages of Ultrasonic Sensor:

- 1) Low cost,
- 2) Not affected by color or transparency of the object,
- 3) Not affected by the dust,
- 4) Greater accuracy,
- 5) Better sensing capability for all material types.

Limitations of Ultrasonic Sensor :

- 1) Very sensitive in different temperature and humidity as traveling speed varies accordingly,
- 2) Difficult to interpret readings from soft and curved objects,
- 3) Needs an media to send ultrasonic waves, 4) Have a limited range.

II.4 Servomotor

Servo motors are compact DC actuators capable of rotating to a specific angular position with high precision. They are widely used in applications such as robotic arms, steering systems, camera gimbals, and solar tracking mechanisms, where controlled angular motion is required. Servo motors typically have three wires: power, ground, and signal. The power wire is usually red and is connected to the 5V pin of the Arduino board, while the ground wire is typically black or brown and connected to the GND pin. The signal wire, usually yellow or orange, is connected to a PWM-capable digital pin on the microcontroller [19].



Figure II.13: Servomotor SG 90.

A servo motor is composed of several key internal components, including an outer casing, output shaft, gear train, potentiometer, DC motor, and an internal control circuit (embedded driver board). These components operate together to achieve accurate closed-loop position control.

The operating principle of the servo motor can be described as follows:

- 1) The microcontroller generates Pulse Width Modulation (PWM) signals and sends them to the servo motor through the signal wire. The internal control circuit interprets these signals as position references.
- 2) Based on the received command, the control circuit drives the internal DC motor, which activates the gear system. The gear reduction mechanism increases torque while reducing rotational speed, enabling precise and controlled movement of the output shaft.
- 3) The output shaft is mechanically coupled to a potentiometer, which acts as a position feedback sensor.
- 4) As the shaft rotates, the potentiometer also moves, producing a voltage signal proportional to the angular position. This feedback signal is continuously transmitted to the control circuit.
- 5) The control circuit compares the feedback signal with the target position derived from the PWM input and adjusts the motor's direction and speed accordingly until the desired position is reached. Once the target angle is achieved, the system stabilizes and maintains its position by continuously correcting any deviation.

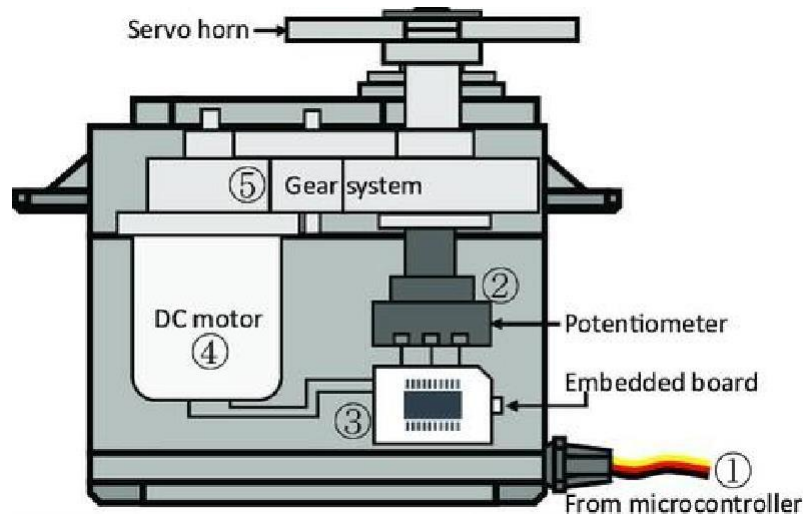


Figure II.14: Components of Servomotor SG 90.

The PWM control signal is a periodic square wave with a variable duty cycle. In servo applications, the control circuit measures the duration of the high pulse to determine the desired angular position.

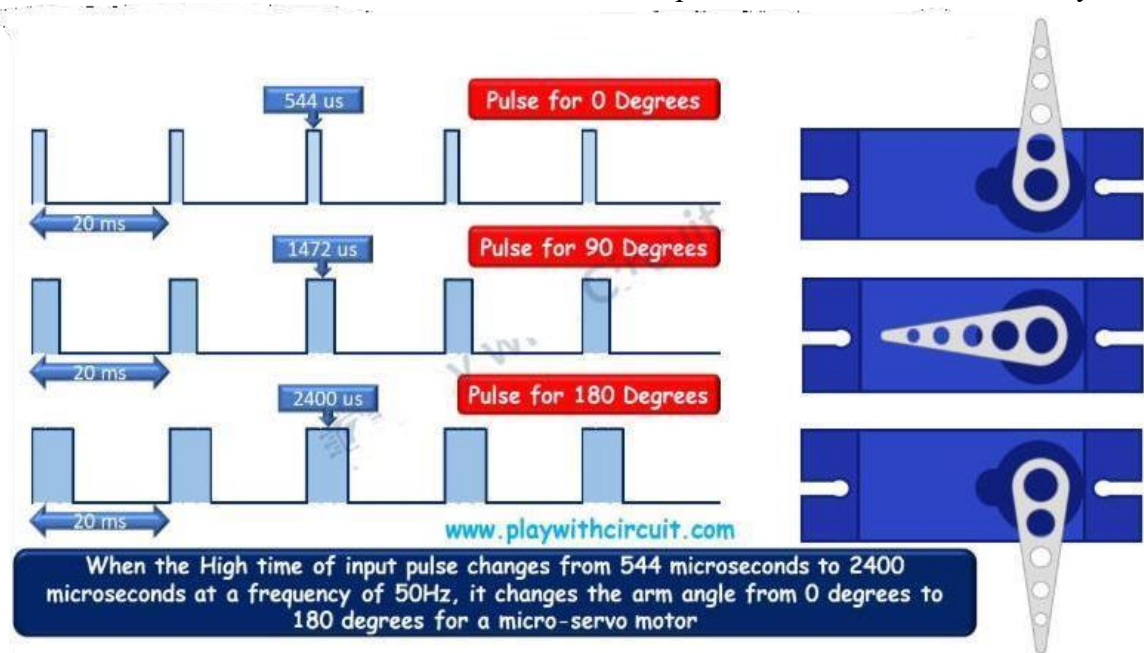


Figure II.15: Pulse width modulation of SG 90 servomotor.

The relationship between pulse width and the corresponding angular positions of the servo motor is illustrated in figure II.15. Typical values are as follows:

- A pulse duration of approximately 544 μs corresponds to 0° ,
- A pulse duration of approximately 1472 μs corresponds to 90° (neutral position),
- A pulse duration of approximately 2400 μs corresponds to 180° .

This pulse-width-based control mechanism allows the servo motor to accurately interpret input signals and achieve precise angular positioning, making it highly suitable for applications requiring reliable and repeatable motion control.

II.5 Display operating frequency

II.5.1 16×2 I2C Liquid Crystal Display (LCD)

An I2C LCD1602 is a device that can display text and characters on a 16x2 (16 columns and 2 rows) liquid crystal display (LCD) using the I2C protocol. You can use an I2C LCD1602 to show information from your Arduino projects, such as sensor readings, messages, menus,

etc. The I2C module has a built-in PCF8574 I2C chip that converts I2C serial data to parallel data for the LCD display.

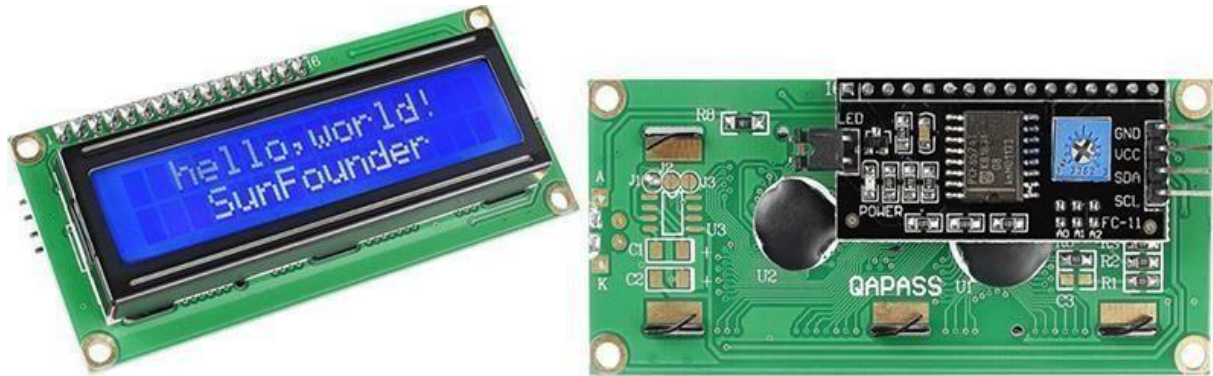


Figure II.16: I2C Liquid Crystal Display.

An I2C LCD1602 consists of a normal LCD1602 and an I2C module that is attached to the back of the LCD. The I2C module is a chip that can expand the I/O ports of the Arduino using the I2C protocol. The I2C protocol is a serial communication protocol that uses two wires: SDA (serial data) and SCL (serial clock). The I2C protocol allows multiple devices to communicate with each other using only two wires and unique addresses. The I2C module converts the signals from the Arduino into commands for the LCD. The LCD has 16x2 cells that can display characters or symbols. Each cell consists of 5x8 dots that can be turned on or off by applying voltage. The LCD can display different characters or symbols by turning on or off different combinations of dots.

Connecting the Arduino UNO to the I2C interface of the LCD requires only four connections. The connections include two for power and two for data. The chart below shows the connections needed.

- 1) VCC of LCD I2C: should be connected to +5V Arduino;
- 2) SDA of LCD I2C: should be connected to A4 Arduino;
- 3) SCL of LCD I2C: should be connected to A5 Arduino;
- 4) GND of LCD I2C: This pin should be connected to the GND of Arduino.

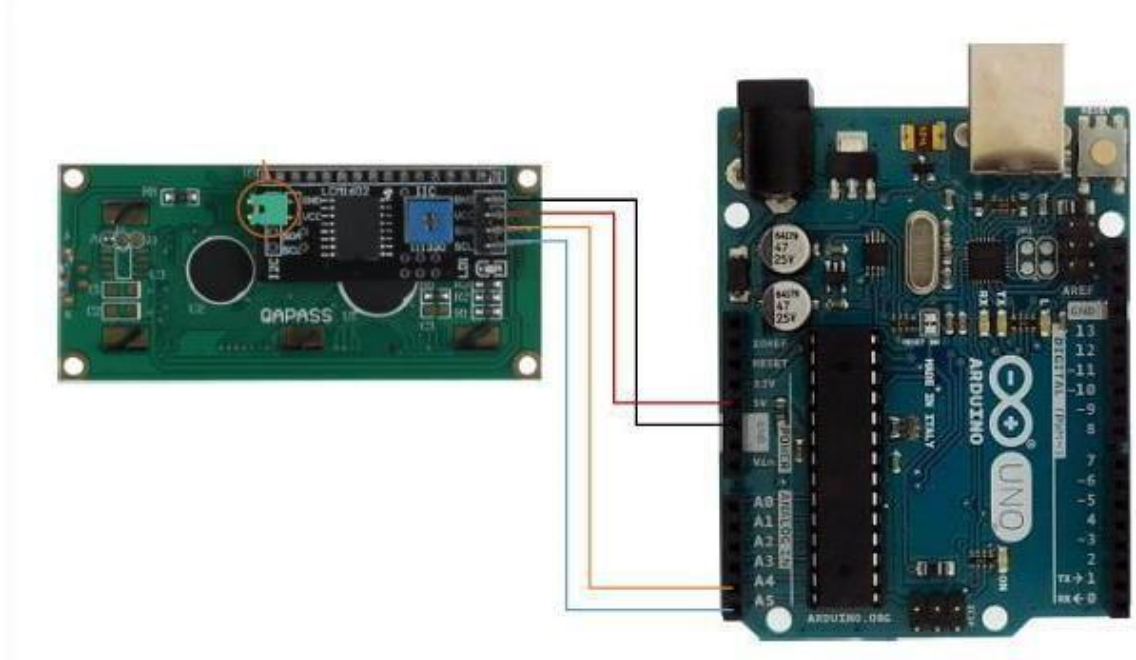


Figure II.17: Connecting I2C LCD1602 to Aeduino.

II.5.2 SSD1306 OLED display

The SSD1306 OLED display is a low-power graphical display module based on Organic Light-Emitting Diode (OLED) technology and controlled by the SSD1306 driver integrated circuit. It is commonly used in embedded systems due to its high contrast, wide viewing angle, and low energy consumption.

Unlike traditional LCDs, the OLED display does not require a backlight, as each pixel emits its own light. This allows it to achieve deep black levels, improved readability, and better performance in low-light conditions. The SSD1306 controller supports monochrome graphics and is capable of displaying both text and simple graphical elements with a typical resolution of 128×64 pixels.

The module is widely used in microcontroller-based applications such as Arduino systems because it communicates efficiently through serial protocols like I2C or SPI, requiring only a few connection pins. In this project, the SSD1306 OLED display is used to present realtime measurement data, enhancing system visualization and user interaction during radar operation.



Figure II.18: SSD1306 OLED display.

II.6 breadboard

A breadboard is a rectangular board with a grid of holes used to build and test circuits without soldering. Inside, it has metal strips that connect rows or columns of holes, allowing electronic components to be easily inserted and interconnected. Breadboards are reusable and come in various sizes. They usually have a central area for components and side rails for power distribution. Breadboards offer a non-permanent, reusable way to test circuit ideas. They're best for experimenting with layouts before committing to soldered or PCB-based designs.

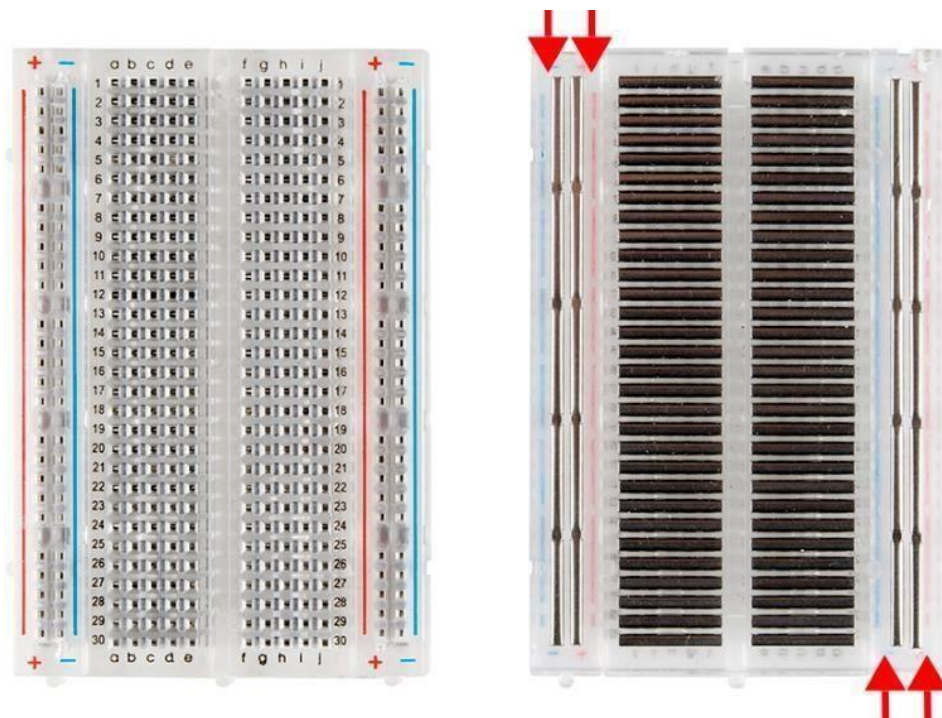
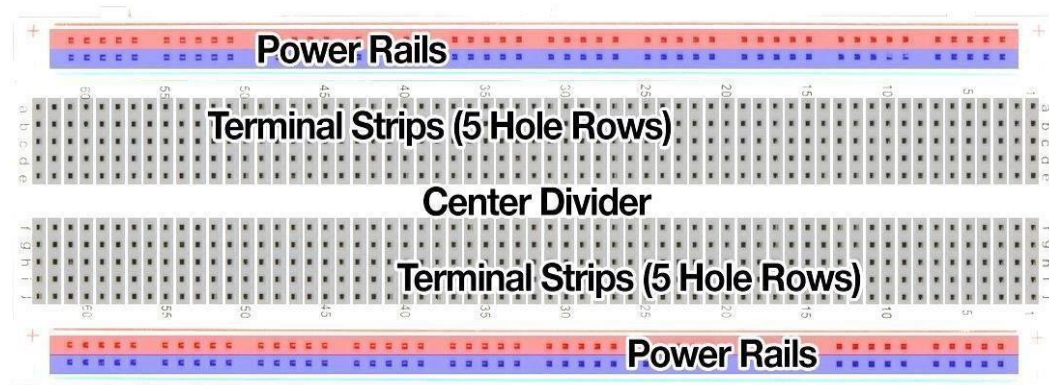


Figure II.19: Breadboard structure layout.

While it looks like just a piece of plastic with holes, there is a specific logic to how things are connected inside:

- **Terminal Strips (The Main Grid):** In the center area, holes are connected **horizontally** in rows (usually labeled A-E and F-J). If you plug a wire into A1 and another into B1, they are now electrically connected.
- **The Ravine (Center Notch):** The indentation running down the middle breaks the connection between the two sides. This is designed specifically so you can plug in Integrated Circuits (chips) without short-circuiting the pins on opposite sides.
- **Power Rails (The Sides):** The vertical columns on the outer edges (usually marked with red and blue lines) are connected **vertically**. These are used to provide a consistent source of power VCC and Ground GND to your entire project.

**Figure II.20:** Components of a breadboard.

II. 7 Resistors

Resistors are among the most commonly used passive components in electronic circuits and systems. Their primary function is to control and limit the flow of electric current, thereby maintaining desired voltage and current levels within a circuit. By doing so, resistors play a crucial role in protecting sensitive components and ensuring stable circuit operation. The operation of a resistor is governed by Ohm's Law, which states that the voltage across a resistor is directly proportional to the current flowing through it, provided the temperature remains constant. The proportionality constant is the resistance, measured in ohms (Ω), which is the standard unit of electrical resistance in the International System of Units (SI). The unit "ohm" is named after Georg Simon Ohm, a German physicist who formulated the fundamental

relationship between voltage, current, and resistance in electrical circuits. The symbol Ω is used to represent resistance in circuit diagrams and equations.

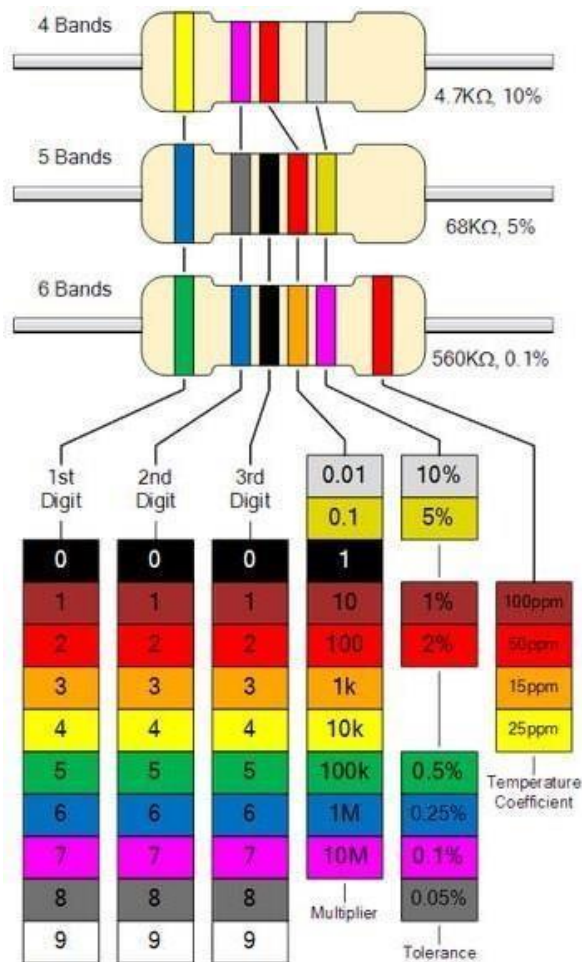


Figure II.21: Resistor color code system for determining resistance values.

Figure II.21 illustrates the resistor color code system used for identifying the resistance value and tolerance of resistors. This standardized coding method is widely applied in electronic components to allow quick and reliable determination of resistance without the need for direct measurement using instruments. The system is based on a series of colored bands printed on the body of the resistor, where each color represents a specific numerical value, multiplier, or tolerance level. By interpreting the sequence of these color bands, the resistance value can be easily determined, which is essential during circuit design, assembly, and troubleshooting. This method is particularly useful in practical applications where a large number of resistors with

different values are used, as it simplifies component identification and reduces the risk of errors during installation.

II.8 Buzzer

A buzzer is an electroacoustic transducer that converts an electrical signal into sound by generating vibrations through either a piezoelectric element or an electromagnetic coil. When powered, it produces sound waves by displacing the surrounding air, and is commonly used for alerts or audible signaling. There are two main types of buzzers:

- **Active Buzzer:** Generates a continuous sound when supplied with direct current (DC), as it contains an internal oscillator.
- **Passive Buzzer:** Requires an external alternating signal (typically a square wave) to operate, allowing control over the sound frequency.



Figure II.22: Passive buzzer.

II.9 Jumper Wires

Jumper wires are flexible wires used to link different points on a breadboard. They come in various lengths and types, such as male-to-male, male-to-female, and female-to-female.

Using color-coded wires helps identify signal, ground, and power lines more easily.

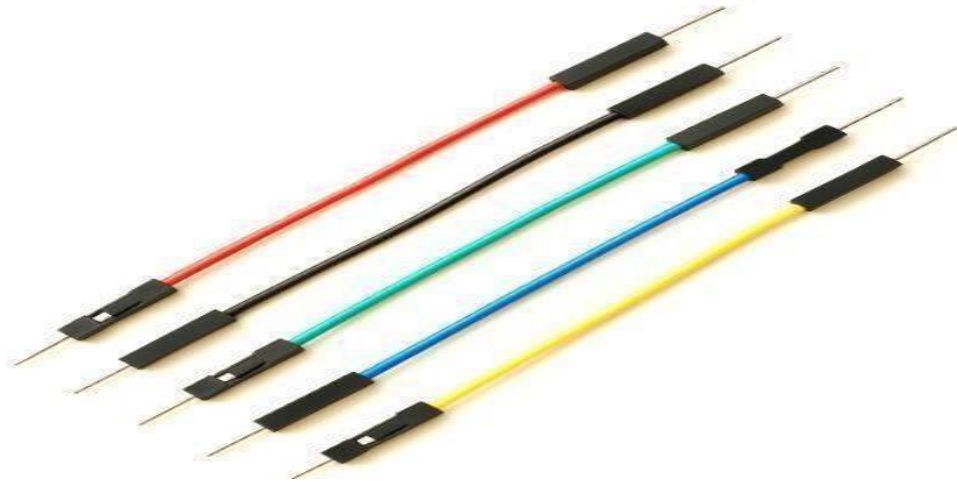


Figure II.23: Jumper Wires.

II.10 Conclusion

This chapter presented the essential tools and equipment used in the design and implementation of the ultrasonic radar system. It began by highlighting the importance of opensource hardware platforms, particularly Arduino, which has become a widely adopted solution for rapid prototyping and embedded system development.

The hardware components, including the Arduino microcontroller, HC-SR04 ultrasonic sensor, servo motor, LEDs, buzzer, and LCD display, were introduced and their roles within the system were clarified. In addition, the supporting software tools, such as the Arduino IDE and Processing environment, were identified as fundamental elements for programming, data processing, and real-time visualization.

Overall, this chapter provided a clear understanding of the technological foundation of the project. The combination of these hardware and software tools enables efficient data acquisition, processing, and graphical representation, forming the basis for the implementation of the ultrasonic radar system described in the following chapters.

Chapter III

Ultrasonic radar design and implementation



III.1 Introduction

In this chapter, the practical implementation of the proposed ultrasonic radar detection system is presented in detail. Following the theoretical study developed in the previous chapter, which introduced the operating principles and characteristics of the main hardware components, including the Arduino board, servomotor, ultrasonic sensor, LCD display, and OLED module, this chapter focuses on the realization and integration of these elements into a complete functional system. The developed system combines sensing, control, display, and visualization modules to perform real-time object detection and monitoring. The Arduino platform serves as the central processing and control unit, ensuring the coordination of all connected peripherals through programs developed using the Arduino Integrated Development Environment (IDE). In addition, the Processing environment is employed for graphical visualization and real-time representation of the acquired detection data, enabling the display of object position and distance during system operation and testing. To enhance the reliability of the measured data, a median filtering technique is applied to the acquired distance signals. This filtering stage is introduced to reduce impulsive noise, eliminate outliers such as invalid echoes, and suppress measurement artifacts caused by multipath reflections and sensor limitations. By replacing each sample with the median of neighboring values within a sliding window, the filter significantly improves the stability and consistency of the detected targets, ensuring a more accurate representation of the scanned environment. This chapter also describes the hardware assembly, software development, circuit implementation, and experimental setup adopted to validate the performance of the proposed ultrasonic radar system.

III.2 Experimental implementation of the ultrasonic radar

For the implementation of the proposed ultrasonic radar system, several hardware components were integrated to ensure real-time detection, processing, and visualization. The central control unit of the system is an Arduino microcontroller board, which manages all input and output operations and executes the embedded control algorithm. The sensing module is based on an HC-SR04 ultrasonic sensor, which is responsible for measuring the distance to surrounding objects using sound wave propagation. To enable angular scanning of the environment, the ultrasonic sensor is mounted on a servo motor, allowing controlled rotation over a defined angular range from 0° to 180° .

III.2.1 Electric circuit and hardware configuration

The electrical circuit of the proposed ultrasonic radar system is designed to ensure reliable interaction between the sensing, control, visualization, and alert modules. The complete configuration is centered around the Arduino board, which acts as the main control and processing unit responsible for coordinating data acquisition, signal processing, and peripheral control. To provide real-time monitoring and user interaction, the system integrates multiple output and visualization devices. A 16×2 I2C Liquid Crystal Display (LCD) is employed to display essential operational parameters such as the measured distance, scanning angle, and object detection status. In parallel, an SSD1306 OLED display is incorporated to generate a radar-style graphical interface that visually represents the sweeping motion of the ultrasonic sensor as well as the position of detected objects. This graphical representation improves the readability and interpretation of detection results during system operation. The system also includes an alert subsystem composed of two light-emitting diodes (LEDs) and a buzzer. The green LED indicates normal system operation and safe conditions, whereas the red LED and the buzzer are activated whenever an object is detected within a predefined safety threshold distance. This dual visual and auditory signaling mechanism enhances the responsiveness and effectiveness of the detection system. To ensure electrical protection and stable operation, 1 k Ω current-limiting resistors are connected in series with the LEDs. Figure III.1 presents the block diagram of the proposed ultrasonic radar system, illustrating the interconnection and interaction between the main hardware components, sensing unit, display modules, and the Arduino-based control unit.

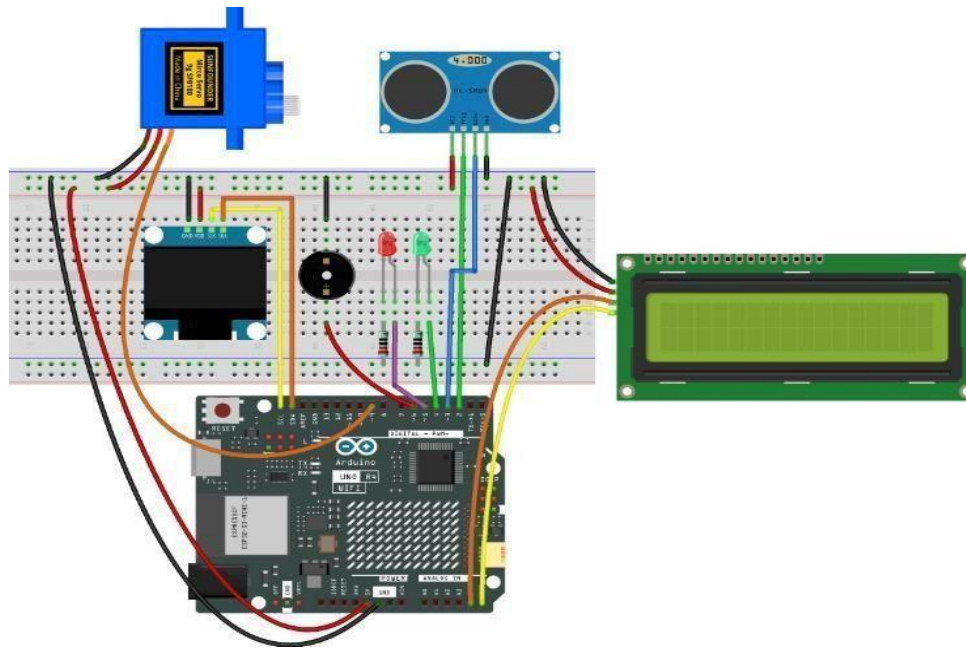
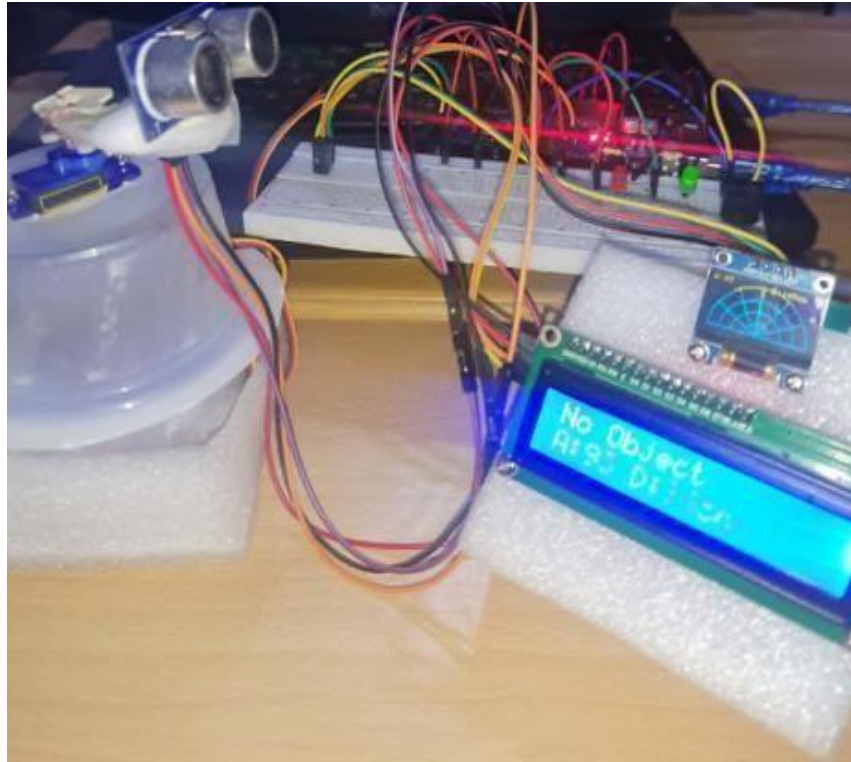


Figure III.1: Block diagram of the Arduino-based electrical circuit configuration.

Figure III.2 presents the realization of the ultrasonic radar circuit based on Arduino, illustrating the complete hardware implementation of the system. It shows the interconnection between the main components, including the ultrasonic sensor, servomotor, display units, and alert devices. This diagram provides a clear overview of the overall electrical circuit configuration and system architecture.

**Figure III.2:** Realization of the ultrasonic radar circuit based on Arduino.

The detection mechanism of the proposed system is based on an ultrasonic sensor mounted on a servomotor, enabling angular scanning of the environment over a range of 0° to 180° . As the servomotor rotates, the sensor acquires distance measurements at discrete angular positions, allowing the construction of a spatial representation of the surrounding area. These measurements are processed in real time by the Arduino microcontroller to identify the presence of obstacles within a predefined safety threshold. The system outputs are distributed across several interfaces to ensure efficient monitoring. The LCD and OLED modules provide complementary forms of information display, while the LED indicators and buzzer are used for immediate status signaling. The system also includes serial communication with a computer, which enables real-time data exchange with the Processing environment for graphical radar

visualization. The electrical connections and pin assignments used for interfacing all components with the Arduino board are summarized in Table III.1.

Table III.1: Pin configuration and hardware connections of the ultrasonic radar system.

Component	Component Pin	Arduino Pin
Ultrasonic Sensor (HC-SR04)	VCC	+5V
	TRIG	D2
	ECHO	D3
	GND	GND
Servomotor	Signal	D9
	VCC	+5V
	GND	GND
LCD 16×2 (I2C)	SDA	D20
	SCL	D21
	VCC	+5V
	GND	GND
OLED SSD1306 Display	SDA	D20
	SCL	D21
	VCC	+5V
	GND	GND
Buzzer	Positive (+)	D6
	Negative (-)	GND
LED 1 (Green LED)	Anode (+)	D4
	Cathode (-)	GND
LED 2 (Red LED)	Anode (+)	D5
	Cathode (-)	GND

Serial Communication (USB)	TX/RX	USB Port (Virtual COM)
-----------------------------------	-------	------------------------

III.2.2 Program implementation and processing visualization

The system operation is based on a program developed using the Arduino Integrated Development Environment (IDE). After compilation and uploading to the microcontroller, the program controls the overall system functionality, including sensor data acquisition, servo motor operation, and real-time response execution. The following code represents the embedded control algorithm implemented on the Arduino board.

```

#include <Servo.h> // Library to control servo motor
#include <Wire.h> // I2C communication (LCD + OLED)
#include <LiquidCrystal_I2C.h> // I2C LCD library
#include <Adafruit_GFX.h> // Graphics library for OLED
#include <Adafruit_SSD1306.h> // OLED SSD1306 driver

// ----- SERVO -----
Servo servo; // Create servo object

// ----- ULTRASONIC -----
const int trigPin = 2; // Ultrasonic trigger pin
const int echoPin = 3; // Ultrasonic echo pin

// ----- LED + BUZZER -----
const int ledGreen = 4; // Green LED pin (no object)
const int ledRed = 5; // Red LED pin (object detected)
const int buzzer = 6; // Buzzer pin

// ----- LCD -----
LiquidCrystal_I2C lcd(0x27, 16, 2); // LCD I2C address 0x27, size 16x2

// ----- OLED -----
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);

// ----- VARIABLES -----
int angle = 0; // Current servo angle
long distance = 0; // Measured distance in cm
const int DETECT_THRESHOLD = 20; // Detection threshold (20 cm)

```

```
// =====
// FUNCTION: MEASURE DISTANCE
// =====
long getDistance() {

    digitalWrite(trigPin, LOW);          // Ensure clean LOW pulse
    delayMicroseconds(2);

    digitalWrite(trigPin, HIGH);         // Send ultrasonic pulse
    delayMicroseconds(10);
    digitalWrite(trigPin, LOW);

    long duration = pulseIn(echoPin, HIGH, 30000);
    // Measure echo return time (timeout = 30ms)

    if (duration == 0) return 999;       // If no echo, return large value

    return duration * 0.034 / 2;         // Convert time to distance (cm)
}
// =====
// SETUP FUNCTION (RUNS ONCE)
// =====
void setup() {

    Serial.begin(9600);                  // Serial communication (for Processing)

    servo.attach(9);                    // Servo connected to pin 9

    pinMode(trigPin, OUTPUT);            // Ultrasonic trigger pin output
    pinMode(echoPin, INPUT);             // Ultrasonic echo pin input

    pinMode(ledGreen, OUTPUT);           // Green LED output
    pinMode(ledRed, OUTPUT);             // Red LED output
    pinMode(buzzer, OUTPUT);             // Buzzer output

    lcd.init();                          // Initialize LCD
    lcd.backlight();                     // Turn ON LCD backlight

    if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
        while (true);                   // Stop if OLED fails
    }

    display.clearDisplay();              // Clear OLED screen
    display.display();                   // Update OLED
}
```

```

// =====
// MAIN LOOP (REPEATS FOREVER)
// =====
void loop() {

  // ----- LEFT TO RIGHT SCAN -----
  for (angle = 0; angle <= 180; angle += 3) {

    servo.write(angle);          // Move servo to angle
    delay(30);                  // Wait for servo movement

    distance = getDistance();    // Measure distance

    // Send data to Processing (angle,distance.)
    Serial.print(angle);
    Serial.print(",");
    Serial.print(distance);
    Serial.print(".");

    updateSystem(distance);      // Update LCD, LED, buzzer
    drawRadarOLED(angle, distance); // Update OLED radar
  }

  // ----- RIGHT TO LEFT SCAN -----
  for (angle = 180; angle >= 0; angle -= 3) {

    servo.write(angle);          // Move servo
    delay(30);

    distance = getDistance();    // Measure distance

    // Send data to Processing
    Serial.print(angle);
    Serial.print(",");
    Serial.print(distance);
    Serial.print(".");

    updateSystem(distance);      // Update system status
    drawRadarOLED(angle, distance); // Update OLED
  }
}

```

```

// =====
// FUNCTION: LCD + LED + BUZZER CONTROL
// =====
void updateSystem(long d) {

    lcd.clear(); // Clear LCD each update

    // If object is detected within threshold
    if (d < DETECT_THRESHOLD && d > 0) {

        digitalWrite(ledRed, HIGH); // Turn ON red LED
        digitalWrite(ledGreen, LOW); // Turn OFF green LED

        tone(buzzer, 1000); // Activate buzzer at 1kHz

        lcd.setCursor(0, 0);
        lcd.print("Detected Object"); // Display alert

    } else {

        digitalWrite(ledRed, LOW); // Turn OFF red LED
        digitalWrite(ledGreen, HIGH); // Turn ON green LED

        noTone(buzzer); // Stop buzzer

        lcd.setCursor(0, 0);
        lcd.print("No Object"); // Display safe status
    }
}
// =====
// FUNCTION: OLED RADAR DISPLAY
// =====
void drawRadarOLED(int angle, long d) {

    display.clearDisplay(); // Clear OLED screen

    int cx = SCREEN_WIDTH / 2; // Center X
    int cy = SCREEN_HEIGHT - 1; // Bottom center Y

    // Draw radar circles (distance rings)
    for (int r = 15; r <= 60; r += 15) {
        display.drawCircle(cx, cy, r, SSD1306_WHITE);
    }

    // Draw radar angle lines (0° to 180°)
    for (int a = 0; a <= 180; a += 30) {
        float rad = radians(a);
        int x = cx + cos(rad) * 60;
        int y = cy - sin(rad) * 60;
        display.drawLine(cx, cy, x, y, SSD1306_WHITE);
    }
}

```

```

// Draw scanning line (servo position)
float rad = radians(angle);
int x2 = cx + cos(rad) * 60;
int y2 = cy - sin(rad) * 60;

display.drawLine(cx, cy, x2, y2, SSD1306_WHITE);

// Draw detected object point (if within range)
if (d < 60) {
    int tx = cx + cos(rad) * d;
    int ty = cy - sin(rad) * d;
    display.fillCircle(tx, ty, 2, SSD1306_WHITE);
}

// Display text on OLED
display.setTextSize(1);
display.setTextColor(SSD1306_WHITE);
display.setCursor(0, 0);

display.print("A:");
display.print(angle);

display.print("  D:");
display.print(d);
display.print("cm");

display.display(); // Refresh OLED screen
}

```

Once the program is executed, the servomotor initiates a continuous sweeping motion between 0° and 180° , providing full angular coverage of the surrounding area. At each scanning position, the ultrasonic sensor performs real-time distance measurements, enabling the detection of nearby objects within the monitored space.

The acquired data are simultaneously displayed on both the LCD and OLED screens, ensuring continuous local visualization of the measured distance, scanning angle, and system status. In parallel, the system provides immediate feedback through LEDs and a buzzer, which are activated when an object is detected within the predefined threshold distance. Furthermore, the measured distance and angle values are transmitted via serial communication to the Processing environment, where they are processed and visualized in the form of a real-time radar-like graphical interface (see Figure III.3).

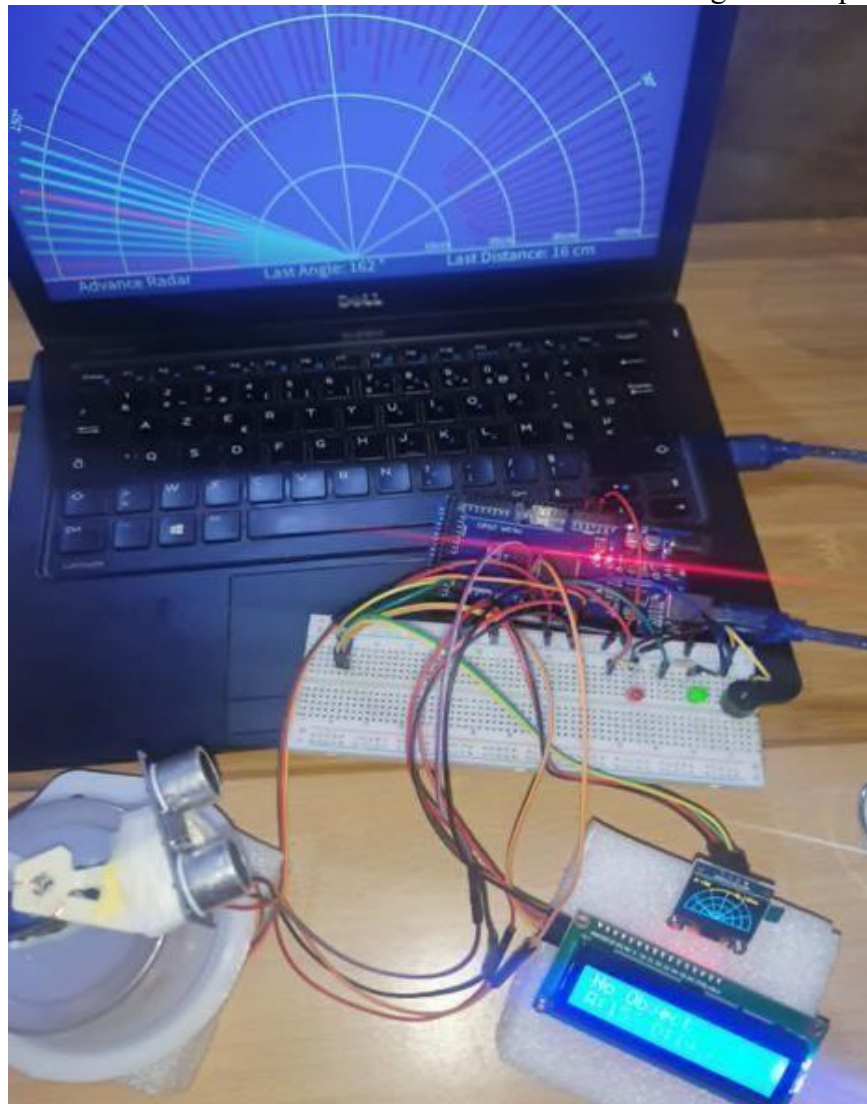


Figure III.3: Implemented ultrasonic radar system integrating program execution, electrical circuit, and Processing visualization interface.

The ultrasonic radar system performs real-time object detection and visualization by transforming spatial information into digital data and displaying it via local interfaces and a radar-like graphical representation. The system operation is structured into the following main stages:

1) Scanning mechanism using the servomotor: The scanning process is achieved using a servomotor connected to digital pin D9 of the Arduino board. The servomotor continuously rotates the ultrasonic sensor from 0° to 180° and then back from 180° to 0°, creating a continuous sweeping motion. This movement allows the system to scan the surrounding environment over a 180-degree field of view. At each angular position, the servomotor briefly stops to allow the ultrasonic sensor to perform a distance measurement before moving to the next position.



Figure III.4: Displayed angular scanning of the ultrasonic sensor.

2) Distance measurement using the ultrasonic sensor: The HC-SR04 ultrasonic sensor is responsible for object detection and distance measurement. It operates using two control pins: the TRIG pin connected to Arduino pin D2 and the ECHO pin connected to Arduino pin D3. The Arduino sends a short trigger pulse through the TRIG pin, causing the sensor to emit an ultrasonic wave. When the emitted wave encounters an obstacle, it is reflected back toward the sensor and received through the ECHO pin. The Arduino measures the return time of the signal and calculates the object distance using the speed of sound. This process provides continuous real-time distance measurements expressed in centimeters.



Figure III.5: Distance measurement using the ultrasonic sensor.

3) Local alert and display system: To improve system interactivity, both visual and acoustic alert mechanisms are integrated into the design. Two LEDs and a buzzer are used to indicate the detection state of the system. The green LED, connected to pin D4, indicates normal operation when no nearby object is detected. The red LED, connected to pin D5, and the buzzer, connected to pin D6, are activated when an object is detected within the predefined threshold distance of 20 cm. In addition, a 16×2 I2C LCD display is used to present real-time information such as the scanning angle, measured distance, and object detection status. An OLED SSD1306 display is also integrated to provide a graphical radar-style representation of the scanning process and detected targets.



Figure III.6: LCD and SSD1306 OLED module displaying real-time information.

4) Serial communication with Processing: The Arduino transmits real-time measurement data to the computer via USB serial communication. The data are structured as paired angle and distance values, enabling the Processing environment to reliably receive, decode, and process the incoming data stream. The Processing application is then executed using the “Run” command, which launches the radar visualization interface. This interface continuously receives the transmitted data from the Arduino and generates a real-time graphical representation of detected objects in a radar format. In case the visualization does not appear or fails to update correctly, the serial communication settings must be verified. Specifically, the COM port defined in the Processing code must match the port assigned to the Arduino board in the Arduino IDE. Correct synchronization between the hardware (Arduino system) and the software (Processing

environment) is essential to ensure stable data transmission and accurate visualization. Once properly configured, the system provides a continuous and reliable realtime radar display of detected objects, as illustrated in Figure III.7.



Figure III.7: COM port communication with Processing interface.

5) Radar visualization in Processing: Within the Processing environment, the received serial data is separated into angle and distance values. These values are transformed from polar coordinates into Cartesian coordinates using trigonometric functions. The Processing application then generates a radar-like graphical interface in which:

- a) The rotating line represents the current scanning direction of the servomotor,
- b) The plotted points represent detected objects,
- c) The position of each point depends on the measured distance and scanning angle.

This graphical interface enables real-time visualization of surrounding objects and enhances the monitoring capability of the system.



Figure III.8: Processing interface for ultrasonic radar visualization.

6) System integration: The overall operation of the ultrasonic radar system is achieved through the synchronized interaction between hardware and software components. The Arduino microcontroller handles sensor control, servo movement, data acquisition, local display management, and alert generation, while the Processing environment manages the graphical radar visualization. Together, these elements form a complete embedded radar detection system capable of real-time environmental scanning, object detection, and visualization.

III.3 Simulation Results

To achieve different detection results, the servomotor scanning angle was continuously varied between 0° and 180° , allowing the ultrasonic sensor to perform directional scanning of the surrounding environment. By collecting distance measurements at multiple angular positions, the system simulates the operation of a radar-based scanning mechanism.

The measured distance is calculated based on the echo time-of-flight of the ultrasonic signal and is directly proportional to the time delay between the transmission and reception of the reflected wave. The system operates within a valid measurement range of 4 cm to 4 m,

corresponding to the physical limitations of the ultrasonic sensor, including its blind zone and maximum detection capability.

The obtained results were exported to a CSV file for further analysis and visualization. The following table, extracted from the file “Table.csv”, presents representative detection results acquired during multiple scanning cycles. The dataset contains valid target reflections as well as occasional noisy measurements, which are subsequently addressed using filtering and signalprocessing techniques.

1) Stable reflection region: A consistent cluster of values between 35 cm and 60 cm is observed. These values are stable across adjacent angles (36° – 60°), indicating the presence of a real reflecting object.

Table III.2: Stable detection zone.

Distance (cm)	Angle ($^{\circ}$)
41	36
39	39
38	42
36	45
37	48
54	51
42	54
43	57
41	60

The results presented in Table III.2 indicate the existence of a stable detection region within the angular interval from 36° to 60° . The measured distances remain relatively consistent, ranging between 36 cm and 54 cm, with only minor fluctuations between consecutive angular positions. Such stability suggests that the ultrasonic sensor is detecting the same physical object during the scanning process.

The gradual variation in distance values can be attributed to several practical factors, including slight changes in the orientation of the reflecting surface, variations in the angle of incidence of the ultrasonic wave, and small measurement uncertainties inherent to the sensor.

Nevertheless, the absence of abrupt distance changes confirms that the detected reflections correspond to a valid and continuous target rather than random noise.

Furthermore, the continuity of detections over multiple adjacent angles demonstrates the effectiveness of the radar scanning mechanism in tracking objects within the monitored area. This behavior validates the proper synchronization between the servomotor rotation and the ultrasonic distance acquisition system. Overall, the obtained results confirm the reliability and stability of the implemented ultrasonic radar system for short-range object detection.

2) Medium-range reflections: Another set of measurements appears between 120 cm and 140 cm, showing a secondary reflection surface or environmental object with stronger distance variability due to angle dependence.

Table III.3: Medium-range variations.

Distance (cm)	Angle (°)
134	120
131	123
137	126
134	129
131	132

The results presented in Table III.3 reveal the presence of a secondary reflection region located at a medium distance from the radar system. The measured distances vary between 131 cm and 137 cm over the angular range from 120° to 132°. Unlike the stable detection zone observed previously, these measurements exhibit slightly greater variability, indicating a stronger dependence on the scanning angle.

This behavior may be explained by the geometric characteristics of the detected object or surrounding environment. Variations in the orientation, surface texture, and reflection angle of the target can influence the propagation and return path of the ultrasonic waves, leading to small fluctuations in the measured distances. In addition, ultrasonic signals tend to become less stable at longer ranges due to signal attenuation and reduced echo intensity.

Despite these variations, the measurements remain within a relatively narrow interval, confirming the existence of a real reflecting surface rather than random sensor noise. The continuity of detections across adjacent angles also demonstrates the capability of the ultrasonic radar system to identify and monitor objects located at medium distances. These results validate

the effectiveness of the implemented scanning mechanism under different spatial detection conditions.

3) Invalid and noisy measurements: Several values fall outside the physical operating constraints of the ultrasonic sensor:

- a) Negative values (-1) correspond to missing echo signals,
- b) Very small values (<4 cm) are caused by the sensor blind zone,
- c) Large isolated spikes (>200 cm) are due to multipath reflections or signal interference,
- d) Very large values 999 cm, representing invalid or error-coded measurements when no reliable echo is detected.

Table III.4: Noise / invalid measurements.

Distance (cm)	Angle (°)
-1	66
6	93
6	105
261	180
314	174
3	39
2	42
999	66

The results presented in Table III.3 contain several abnormal measurements that fall outside the normal operating conditions of the ultrasonic sensor. These values are considered invalid or noisy data and are mainly caused by physical limitations of the sensing system and environmental disturbances during signal propagation.

Negative values, such as -1 cm recorded at 66°, indicate the absence of a valid echo signal. This situation occurs when the ultrasonic wave is not reflected back toward the sensor, either because no object is present within the detectable range or because the reflected signal is too weak to be detected.

Very small measurements below 4 cm, such as 2 cm and 3 cm, correspond to the blind zone of the ultrasonic sensor. In this region, the sensor cannot accurately distinguish between transmitted and reflected ultrasonic pulses due to the very short propagation time.

Large isolated values exceeding 200 cm, including 261 cm and 314 cm, are mainly caused by multipath reflections, environmental interference, or unstable echoes. In such cases, the ultrasonic signal may reflect from multiple surfaces before returning to the sensor, producing incorrect distance estimations.

The extremely large value of 999 cm represents an invalid or overflow measurement generated by the acquisition system when no reliable distance calculation can be obtained. This value is commonly used as an error indicator during data acquisition and processing.

Overall, these abnormal measurements demonstrate the influence of noise, signal attenuation, and sensor limitations on the radar system performance. Consequently, filtering and signal processing techniques are required to remove invalid measurements and improve the accuracy and stability of the obtained detection results.

III.4 Median filter based noise reduction optimization

To improve measurement reliability and reduce the impact of noise, a median filtering technique was considered. This method is particularly effective for ultrasonic radar systems because the acquired data often contains impulsive noise (outliers), such as sudden spikes or invalid echoes. Unlike mean filtering, which is sensitive to extreme values, the median filter preserves edge information while eliminating isolated erroneous measurements.

The median filter operates by replacing each measured value with the median of a sliding window of neighboring samples. Mathematically, for a set of ordered samples within a window:

$$y[n] = \text{median}\{x[n - k], \dots, x[n], \dots, x[n + k]\} \quad (\text{III.1})$$

Each symbol has a specific meaning in digital signal processing:

- $x[n]$: the input signal (raw measured data from the ultrasonic sensor) at sample n .
→ Example: the unfiltered distance value at a given angle.
- $y[n]$: the output signal after filtering (median-filtered distance at sample n).
→ This is the cleaned/processed value used for analysis.
- n : the current sample index (or time step / measurement index in the data sequence).
→ In this case, it can also represent the sequence of angle-based measurements.
- k : the window radius (half window size of the filter). It defines how many neighboring samples are included on each side of the current point.

→ Total window size = $2k+1$

- $x[n-k], \dots, x[n+k]$: the set of samples inside the sliding window centered at n .

→ These are the neighboring distance measurements used to compute the median.

At each point n , the filter takes a small group of nearby measurements, sorts them, and replaces the center value with the median of that group. This removes spikes and keeps the signal stable.

This approach ensures that abrupt deviations such as invalid echoes (e.g., -1 values, blind-zone readings, or multipath-induced spikes) do not significantly affect the final estimated distance. Consequently, the filtered signal provides a more stable and physically consistent representation of the scanned environment.

Therefore, applying median filtering significantly enhances the robustness of the radar system by improving measurement stability, reducing false detections, and increasing the overall reliability of the detected object positions across different scanning angles. The Arduino implementation of the median filter used in this work is provided below.

```
// =====
// MEDIAN FILTER (3 samples)
// Purpose: remove spikes and noise from ultrasonic sensor
// =====
#define FILTER_SIZE 3

long distBuffer[FILTER_SIZE];
int filterIndex = 0;

long medianFilter(long newValue) {

    // store new value in buffer
    distBuffer[filterIndex] = newValue;
    filterIndex = (filterIndex + 1) % FILTER_SIZE;

    // copy buffer for sorting
    long temp[FILTER_SIZE];
    for (int i = 0; i < FILTER_SIZE; i++) {
        temp[i] = distBuffer[i];
    }

    // sort array
    for (int i = 0; i < FILTER_SIZE - 1; i++) {
        for (int j = i + 1; j < FILTER_SIZE; j++) {
            if (temp[i] > temp[j]) {
                long t = temp[i];
                temp[i] = temp[j];
                temp[j] = t;
            }
        }
    }

    // return median value
    return temp[FILTER_SIZE / 2];
}
```

After median filtering, your data can be grouped into three meaningful regions: **1) Stable detection region with reliable filtered targets:** The corresponding filtered stable results are listed in the table below.

Table III.5: Stable detection region after median filtering.

Distance (cm)	Angle (°)
75	33
32	36
32	39
32	42
35	45
33	48

35	51
34	54
34	57
34	60
35	63
35	66
36	69
36	72

The results in this region show a dominant and consistent cluster of distance measurements ranging approximately between 32 cm and 38 cm across the angular interval from 33° to 78° . The minimal variation between adjacent angular positions indicates a high level of measurement stability after applying median filtering. This behavior strongly suggests the presence of a real, stationary physical object located at a relatively short range from the sensor. The consistency of the values confirms that the median filter effectively removed impulsive noise and isolated spikes present in the raw data, allowing the underlying signal structure to emerge clearly. The slight fluctuations observed are attributed to minor angular resolution effects of the servo motor and the finite beam width of the ultrasonic sensor.

- 2) **Medium-range reflection zone with stable secondary echoes:** The corresponding results are listed in this table.

Table III.6: Medium-range reflection region after median filtering.

Distance (cm)	Angle ($^\circ$)
51	102
51	105
52	108
52	111
52	114
52	117
52	120

This region exhibits a stable plateau of distance measurements centered around approximately 52 cm over the angular range from 102° to 120° . The continuity and coherence of the readings indicate that the detected reflections originate from a second distinct surface or object within the environment. Compared to the stable short-range region, this medium-range

cluster shows slightly higher distance values but maintains similar angular consistency, confirming the presence of a continuous reflecting structure rather than random noise. The stability of the plateau suggests a relatively uniform surface, such as a wall or large obstacle, producing consistent echo returns across multiple scanning angles.

3) Residual noisy region with suppressed measurement artifacts: The results are presented in the table below.

Table III.7: Residual noisy and unstable measurements after median filtering.

Distance (cm)	Angle (°)
139	141
14	144
141	147
14	150
141	153
14	156

The final region contains highly irregular and alternating measurements, with abrupt transitions between large and small values (e.g., 139 cm and 14 cm). Such instability indicates that the data in this angular range is dominated by measurement artifacts rather than true environmental reflections. These fluctuations are mainly caused by multipath propagation, weak echo returns at extreme scanning angles, and possible mechanical jitter of the servomotor. In these conditions, the ultrasonic beam is likely partially missing valid reflective surfaces, resulting in inconsistent or corrupted distance estimates. Although median filtering reduces impulsive noise, it cannot fully compensate for severely weak or absent echo signals in these regions.

The comparative analysis demonstrates that raw ultrasonic radar measurements are significantly affected by impulsive noise, multipath reflections, and environmental interference. While basic range constraints eliminate physically invalid values, they do not fully address signal instability. The application of median filtering substantially improves data quality by suppressing outliers and preserving the underlying spatial structure of the environment. As a result, the processed radar output becomes more continuous, stable, and physically interpretable, enabling reliable object detection across different scanning angles.

III.5 Conclusion

This chapter presented the practical implementation of the proposed ultrasonic radar detection system, including both hardware integration and software development. The system

was successfully realized using an Arduino microcontroller as the central processing unit, combined with a servomotor for angular scanning and an ultrasonic sensor for distance measurement. Real-time visualization was achieved through the Processing environment, enabling graphical representation of detected objects and their spatial positions.

In addition, the data acquisition process was enhanced through the application of a median filtering technique to improve measurement reliability. This filtering stage effectively reduced impulsive noise, suppressed invalid echoes, and minimized the impact of environmental disturbances and sensor limitations. As a result, the processed data demonstrated improved stability and consistency, allowing clearer identification of detection regions such as stable targets, secondary reflections, and residual noisy areas.

Overall, the experimental results validate the effectiveness of the proposed system in performing short-range radar-like scanning and object detection. The integration of hardware components, real-time visualization, and signal processing techniques provides a robust and reliable platform for ultrasonic-based environmental monitoring.

General conclusion

General Conclusion

This thesis presented the design, implementation, and evaluation of an ultrasonic radar detection system based on Arduino technology. The work was structured into three main chapters covering theoretical foundations, system components, and practical implementation.

The first chapter introduced the fundamental principles of radar technology, including its historical evolution, operating mechanisms, and key applications. It highlighted how radar systems determine target range, direction, and velocity through the analysis of reflected signals and Doppler effects, forming the theoretical basis for modern sensing technologies.

The second chapter focused on the hardware and software tools used in the development of the system. It presented the role of the Arduino platform as a central processing unit, along with essential components such as the HC-SR04 ultrasonic sensor, servomotor, LCD display, and OLED module. It also introduced the Arduino IDE and Processing environment as key software tools for programming, data acquisition, and real-time visualization, establishing the technological foundation of the project.

The third chapter presented in detail the practical implementation of the proposed ultrasonic radar system, highlighting both hardware integration and software development aspects. The successful combination of the Arduino microcontroller, ultrasonic sensor, and servomotor enabled the realization of a real-time scanning mechanism capable of performing angular object detection across a defined spatial range. This integration allowed the system to simulate radar-like behavior by continuously acquiring distance measurements at different angular positions and transmitting the data for visualization and analysis.

In addition, a median filtering technique was implemented and applied to the raw distance measurements in order to improve the overall quality and reliability of the acquired data. This filtering stage played a crucial role in reducing the impact of impulsive noise, eliminating isolated outliers, and suppressing invalid echo readings caused by sensor limitations and environmental interferences such as multipath reflections and weak signal returns. By replacing each sample with the median value of neighboring measurements, the filtering process significantly improved signal consistency without distorting the actual structure of the detected environment.

The processed results clearly demonstrated a marked improvement in measurement stability and accuracy. The filtered data enabled a more coherent representation of the surrounding environment, allowing distinct detection regions to be identified with greater clarity. These regions included stable targets corresponding to real physical objects, secondary

reflection zones associated with larger environmental surfaces, and residual noisy areas where signal quality was weak or unstable. This classification confirms the effectiveness of the filtering approach in enhancing interpretability of the radar output.

Overall, the experimental results validate the effectiveness of the proposed ultrasonic radar system in achieving reliable short-range object detection and spatial mapping. The synergy between embedded hardware components, real-time visualization using the Processing environment, and signal processing techniques such as median filtering resulted in a robust and efficient low-cost sensing platform. The system not only demonstrates strong performance in experimental conditions but also highlights the practical potential of ultrasonic radar-inspired technologies for applications such as proximity detection, educational demonstrations, and vehicle blind-spot monitoring systems.

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Abstract:

This memory presents the design and implementation of a low-cost ultrasonic radar-inspired system for real-time object detection and visualization. The proposed system is based on an Arduino microcontroller, an HC-SR04 ultrasonic sensor, and a servomotor used for angular scanning. The system acquires distance measurements at different spatial positions to simulate radar-like behavior and provides real-time visualization using the Processing environment. To improve measurement reliability, a median filtering technique is applied to the acquired data to reduce impulsive noise, eliminate outliers, and suppress invalid echoes caused by sensor limitations and environmental disturbances. The filtered results demonstrate improved stability and clearer identification of detection regions, including stable targets, secondary reflections, and residual noise areas. The experimental results confirm the effectiveness of the proposed system in achieving reliable short-range object detection. The integration of embedded hardware, signal processing, and real-time visualization provides a robust and low-cost solution suitable for educational purposes and practical applications such as proximity detection and vehicle blind-spot monitoring systems.

Keywords: Ultrasonic radar, Arduino, HC-SR04 sensor, servomotor, real-time detection, median filtering, signal processing, object detection, embedded systems.

ملخص : تقدم هذه المذكرة تصميم وتنفيذ نظام كشف يشبه الرادار منخفض التكلفة يعتمد على الموجات فوق الصوتية للكشف عن الأجسام وعرضها

في الزمن الحقيقي. يعتمد النظام المقترح على لوحة Arduino ، ومستشعر الموجات فوق الصوتية- SR04 HC ، ومحرك سيرفو يستخدم للمسح الزاوي . يقوم النظام بجمع قياسات المسافة عند زوايا مختلفة لمحاكاة عمل الرادار ، مع عرض النتائج بشكل فوري باستخدام Processing لتحسين موثوقية القياسات ، تم تطبيق تقنية التصفية بالوسيط (Median Filter) على البيانات المجمعة من أجل تقليل الضوضاء النبضية ، وإزالة القيم الشاذة ، والتخلص من الإشارات غير الصالحة الناتجة عن قيود المستشعر والظروف البيئية. أظهرت النتائج بعد التصفية تحسناً واضحاً في الاستقرار ودقة تحديد مناطق الكشف مثل الأهداف الثابتة والانعكاسات الثانوية والمناطق المشوشة. تؤكد النتائج التجريبية فعالية النظام المقترح في تحقيق كشف موثوق للأجسام ضمن المدى القصير. كما أن دمج العتاد المدمج مع تقنيات معالجة الإشارة والعرض في الزمن الحقيقي يوفر منصة منخفضة التكلفة وفعالة مناسبة للتطبيقات التعليمية وتطبيقات عملية مثل كشف النقاط العمياء في المركبات .

الكلمات المفتاحية : رادار بالموجات فوق الصوتية، أردوينو، مستشعر HC-SR04 ، محرك سيرفو، الكشف في الزمن الحقيقي، التصفية بالوسيط، معالجة الإشارة، كشف الأجسام، الأنظمة المدمجة .

Résumé :

Cette mémoire présente la conception et la réalisation d'un système de détection de type radar à faible coût basé sur les ultrasons, destiné à la détection d'objets en temps réel et à leur visualisation. Le système proposé repose sur une carte Arduino, un capteur ultrason HC-SR04 et un servomoteur utilisé pour le balayage angulaire. Le système collecte des mesures de distance à différentes positions angulaires afin de simuler un comportement de type radar, avec une visualisation en temps réel via l'environnement Processing. Afin d'améliorer la fiabilité des mesures, une technique de filtrage médian a été appliquée aux données acquises pour réduire le bruit impulsionnel, éliminer les valeurs aberrantes et supprimer les échos invalides dus aux limitations du capteur et aux perturbations environnementales. Les résultats filtrés montrent une amélioration significative de la stabilité et une meilleure identification des zones de détection. Les résultats expérimentaux confirment l'efficacité du système proposé pour une détection fiable à courte portée. L'intégration du matériel embarqué, du traitement du signal et de la visualisation en temps réel constitue une solution robuste et économique adaptée aux

applications éducatives ainsi qu'aux applications pratiques telles que la détection de proximité et les systèmes de surveillance des angles morts des véhicules.

Mots-clés : Radar ultrasonore, Arduino, capteur HC-SR04, servomoteur, détection en temps réel, filtrage médian, traitement du signal, détection d'objets, systèmes embarqués.