STATE-OF-THE-ART RESEARCH AND ANALYSIS OF ACTIVE AND PASSIVE RADAR REFLECTORS AND ULTRASONIC RADAR SYSTEMS

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STATE-OF-THE-ART RESEARCH AND ANALYSIS OF ACTIVE AND PASSIVE RADAR REFLECTORS AND ULTRASONIC RADAR SYSTEMS

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Abstract: This paper presents a comparative analysis of active, passive, and ultrasonic radars, focusing on operational parameters such as detection range, coverage angle, and adaptability to weather conditions. Active radars demonstrate efficiency over long distances, while passive radars are suitable for scenarios with low radio frequency emissions. Ultrasonic radars, on the other hand, are optimal for short-range detection. The results are presented through tables and charts, highlighting the advantages and limitations of each system, along with recommendations for their use in various industrial applications.

Key words: Active radars, passive radars, ultrasonic radars, object detection, radar systems, operational parameters

1. INTRODUCTION

In recent decades, radar technologies have significantly advanced and have found widespread application in various industries and sectors, such as security, transportation, industry, robotics, and medicine. The primary function of radar systems is to detect, identify, and track objects with high precision and reliability while minimizing costs and system complexity. With the development of radar systems, today there are different types of radars, such as active radars (e.g., Synthetic Aperture Radar - SAR), passive radars, and ultrasonic radars. Each type of radar has its own advantages, weaknesses, and specific applications, allowing the selection of an appropriate system depending on needs and operational conditions.

Radar systems are the foundation of many modern technologies for detection, tracking, and identification of objects at different distances and under various conditions. The term "radar" is an acronym for Radio Detection and Ranging, which indicates that these systems use radio waves to detect the presence, distance, speed, and sometimes the size of objects. Essentially, the radar works by emitting an electromagnetic signal towards the target and receiving an echo signal reflected back from that target, enabling the system to accurately calculate the distance and movement of the object. Radar technologies have a long history of use in military and commercial applications, starting from the 1940s when they were initially developed for military purposes. Since then, radars have been applied in many areas, including air traffic control, meteorology, road speed monitoring, and security systems. With advancements in modern technologies, it is now possible to produce compact radar systems based on chips, making them ideal for integration into various commercial and industrial products.

There are two basic types of radar systems: active and passive. Active radar systems, such as Synthetic Aperture Radar (SAR), generate and send their own signal towards the target. This capability allows active radars to function independently of light or weather conditions, providing continuous tracking even in low visibility, fog, rain, or night. These radar systems most commonly use high frequencies in the X-band (8–12 GHz) and C-band (4–8 GHz), which allow high precision and long detection ranges. Passive radar systems, on the other hand, do not emit their own signal but use or reflect energy from external sources, such as radio or television signals. These systems are useful in situations where it is important to avoid interference or minimize electromagnetic radiation signatures but have limitations due to their dependence on external sources.

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Ultrasonic radar systems, although different from electromagnetic radars, are becoming increasingly popular due to their low cost and minimal energy consumption. They operate on the principle of emitting an ultrasonic (sound) signal, which, when it encounters an object, reflects back to the sensor, allowing the system to calculate the distance to the object. Ultrasonic radar systems with Arduino usually include an ultrasonic sensor connected to a controller that can rotate 180 or 360 degrees for complete coverage of the environment. Due to their affordable cost, ultrasonic systems are ideal for small security applications, research projects, and obstacle detection systems in robots and autonomous vehicles.

The purpose of this paper is to compare three types of radar systems: active, passive, and ultrasonic, to determine their characteristics, advantages, and limitations. Within the study, parameters such as detection range, coverage angle, adaptability to different weather conditions, and detection accuracy are considered. These parameters are key to selecting the appropriate radar system for specific applications and operational conditions.

In the following chapters, a comparative analysis of the operational characteristics of different radar systems will be presented, aiming to obtain a complete picture of when and where each type of radar is most appropriate. This paper will also review the latest trends and innovations in radar technology and offer recommendations for their application in various industries.

1.1. Motivation for Research

The development of cost-effective and efficient radar solutions is a significant concern in modern industry and research, particularly in the fields of security and robotics. Comparing the performance of active, passive, and ultrasonic radar systems is crucial for identifying the advantages and limitations of each of these radar types. This research aims to analyze their efficiency, precision, and compatibility with various applications, enabling engineers and researchers to make informed decisions about their implementation in different scenarios.

1.2. Structure of the Paper

This paper will explore the fundamental operating principles of active and passive radar systems and compare them with ultrasonic systems based on Arduino. The paper will include tables comparing frequencies, detection efficiency, and operational parameters of different types of radar systems. Additionally, the efficiency of detection systems under various weather conditions and in different application scenarios will also be investigated.

2. TECHNIQUES IN RADAR SYSTEMS

Radar (Radio Detection and Ranging) is a system for detecting and identifying objects (specifically detecting and displaying the range, speed, and angle of an object) based on electromagnetic waves in the radio frequency spectrum. Electromagnetic waves in this spectrum are referred to as radio waves [1], [2]. These waves operate in a range from 3 MHz to 110 GHz (3 mm to 100 m), as shown in Figure 1. Waves within this frequency range are characterized by weak interactions with dust, fog, rain, and snow, meaning they are less affected by external meteorological conditions and other types of interference [3], [4], [5]. Therefore, radar is an ideal system or instrument for detecting and identifying objects at long distances, even under unfavorable extreme weather and meteorological conditions [6].

Typically, these systems are applied in aviation, maritime, and terrestrial traffic (speed control), meteorology (weather radars), astronomy (radio telescopes), and the automotive industry (parking assistance) [4], [5], [6], [7]. With its capabilities for detecting and identifying objects in the radio frequency spectrum, the radar system is a vital tool and instrument in many scientific fields and disciplines [8], [9], [10].

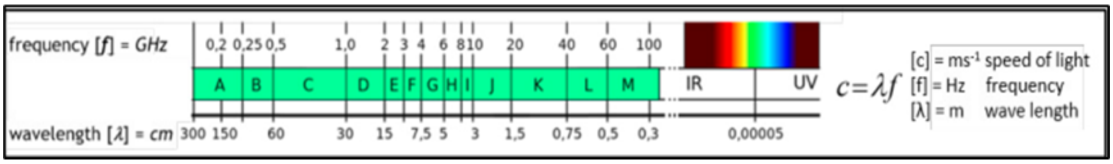

Figure 1 – Wavelength and spectrum used by radars [2], [3]

2.1. Comparison of BEAR-CS with Proposed Systems and Frameworks

The methodology of this research is carefully designed to evaluate and compare the efficiency of active, passive, and ultrasonic radar systems, focusing on their operational parameters, frequencies, and detection capabilities under different conditions. Through experimental measurements and analysis, the methodology encompasses the following aspects outlined in the scientific paper.

The primary goal of this methodology is to provide a comprehensive approach to comparing the three radar technologies based on:

- Operational frequencies and parameters: Analysis of the frequencies and range of each system.
- Detection efficiency under different weather conditions: Examination of efficiency in conditions such as fog, rain, and low light.
- Detection efficiency at different coverage angles: Analysis of coverage and precision of the systems at 180° and 360° detection angles.

2.2. Comparison of Frequencies and Operational Parameters of the Systems

Table 1 illustrates the differences in operational parameters among the systems. The active radar operates at high frequencies and offers a long detection range, while the passive radar is limited by external signal sources. The ultrasonic radar is designed for short distances (up to 30 cm) and has low distance precision due to the limited frequency of the ultrasonic signal [7], [8], [9], [10], [11].

Table 1 – Comparison of Frequencies and Operational Parameters of the Systems

System	Frequency (GHz)	Detection Range (m)	Signal Type	Distance Precision
Active Radar (SAR)	8-12 (X-band)	High (>10 km)	Electromagnetic	High
Passive Radar	-	Medium (<10 km)	Electromagnetic	Medium
Ultrasonic Radar	0.04 (40 kHz)	Low (<30 cm)	Sound	Low

2.3. Comparison of Detection Efficiency Under Different Weather Conditions

Table 2 presents the performance of different radar systems in adverse weather conditions. The active radar is the most suitable for situations with low visibility and rain, as it can efficiently detect objects even in low light conditions. The passive radar faces challenges in fog and rain, while the ultrasonic radar, although effective for night detection, has a limited range and low precision in adverse weather conditions [12], [13], [14], [15], [16].

Table 2 – Comparison of Detection Efficiency Under Different Weather Conditions

System	Visibility in Fog	Detection in Rain	Night Detection	Limitations
Active Radar (SAR)	High	High	High	High cost and complexity
Passive Radar	Low	Low	Medium	Depends on external sources
Ultrasonic Radar	Low	Low	High	Limited range (30 cm)

2.4. Comparison of Object Detection Efficiency

Table 3 shows the difference in angular coverage of different radar systems. The ultrasonic radar can operate with a coverage angle of 180° or 360°, where 360° provides better environmental monitoring. The active radar has high angular precision at 360°, making it ideal for industrial and military applications with long-range detection [13], [17], [18], [19].

Table 3 – Comparison of Detection Efficiency for Objects

System	Coverage Angle	Detection Precision	Application Example
Ultrasonic Radar (180°)	180°	Medium	Parking, security systems
Ultrasonic Radar (360°)	360°	High	Open space monitoring
Active Radar with 360°	360°	High	Military and industrial applications

2.5. Comparison of Detection Methods

Table 4 presents the detection methods of active, passive, and ultrasonic radar systems, as well as their detection capabilities based on key parameters, including range, distance precision, coverage angle, and adaptability to different weather conditions [12], [13], [20], [21], [22].

Table 4 – Comparison of Detection Methods

System	Detection Method	Range (m)	Distance Precision	Coverage Angle	Weather Conditions
Active Radar (SAR)	Electromagnetic signal	10-50	High	360°	All conditions
Passive Radar	Reflection of external signals	<10	Medium	180°	Adverse conditions
Ultrasonic Radar	Ultrasonic signal	0-0.3	Low	180° / 360°	Favorable conditions

This table highlights the differences between the three radar systems based on their detection methods and suitability for various applications:

- Active Radar (SAR): This radar system emits an electromagnetic signal, enabling long-term and precise detection of objects within a wide range (10-50 meters). With a coverage angle of 360°, it is efficient in all weather conditions, making it ideal for applications where stability and resistance to weather changes are required [10], [11], [12], [13].
- Passive Radar: This system relies on external signals reflected by objects, limiting it to a shorter range (<10 meters) with medium distance precision. Its coverage angle is restricted to 180° and operates with reduced efficiency in poor weather conditions due to its dependency on the presence of external signals [9], [10], [11], [12], [13].
- Ultrasonic Radar: The ultrasonic sensor, which has a short detection range (up to 30 cm), operates using ultrasonic signals and can function with a coverage angle of 180° or 360°. This system is most effective in clear conditions and is ideal for short distances, making it perfect for small, enclosed, or low-budget applications where close-range detection is required [14], [15], [16], [17], [18].

3. COMPARISON OF RADAR SYSTEMS BASED ON OPERATIONAL PARAMETERS

The figure presents a graphical comparison of three different radar systems: Active Radar (SAR), Passive Radar, and Ultrasonic Radar, based on key parameters: detection range, distance precision, coverage angle, and adaptability to different weather conditions [11], [12], [13], [20], [21], [22], [23].

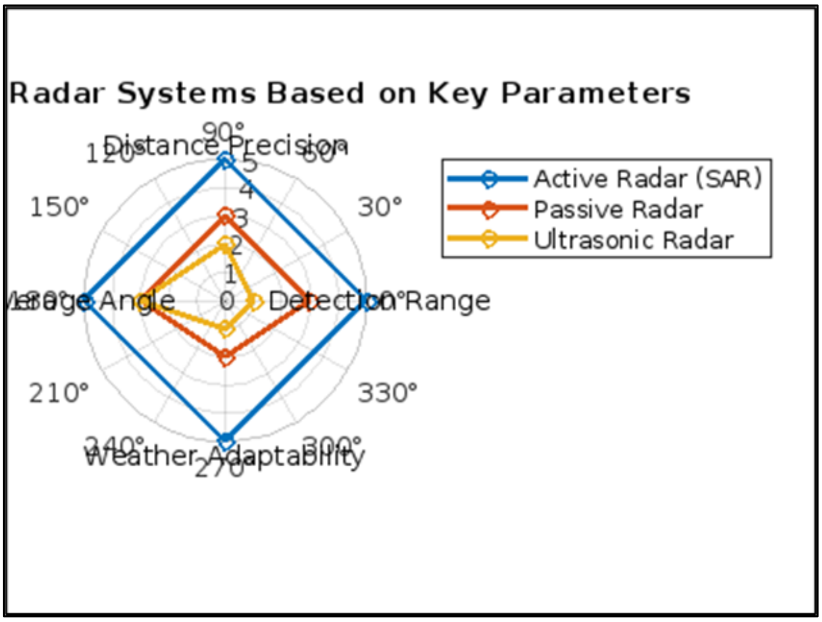

Figure 2 – Comparison of radar systems based on operational parameters

According to the figure above, we can conclude that:

- Active Radar (SAR): This radar system receives the highest scores in all categories, making it the best for precise detection of targets at greater distances and under various weather conditions. Its coverage and accuracy are superior compared to the other two systems [12], [13].
- Passive Radar: This type of radar has moderate scores and is less efficient in detection and distance precision compared to the active radar but offers a relatively high coverage angle [10], [11].
- Ultrasonic Radar: The ultrasonic radar shows the lowest scores in all categories, with a limited detection range and distance precision. Its adaptability to different weather conditions is minimal, making it most suitable for short distances and limited detection angles (up to 30 cm) [14], [15].

4. DISCUSSION AND ANALYSIS OF RESULTS

The discussion in this research examines the key characteristics of active, passive, and ultrasonic radar systems to determine their advantages and limitations in various situations and conditions.

- Detection Range: The active radar system (SAR) stands out with its detection capabilities, enabling precise identification of objects at significantly greater distances, even under challenging weather conditions. The passive radar, while having a shorter range, can be very effective in specific applications where minimal energy emission is important. The ultrasonic radar, on the other hand, has a limited detection range (up to 30 cm) and is most suitable for short distances and controlled conditions, such as indoor spaces.
- Distance Precision: The active radar excels in measuring the distance to objects with high precision, especially in dynamic or complex environments. The passive radar offers moderate precision, while the ultrasonic radar faces limitations due to its short range and accuracy only in controlled conditions, making it the least suitable for applications requiring high distance precision.
- Coverage Angle: The passive radar offers a wider coverage angle, which is advantageous in applications requiring broader coverage but at shorter distances. The ultrasonic radar, on the other hand, has a limited angle and range, making it more suitable for specific applications, such as ultra-close sensory applications in robotics and industrial automation systems.

- Adaptability to Different Weather Conditions: The active radar (SAR) proves to be the most adaptable to different weather conditions, while the passive radar has limited adaptability. The ultrasonic radar is significantly restricted as weather conditions can greatly affect its accuracy and range.

The comparison shows that active radar systems offer significant advantages in detection and precision at greater distances, while the ultrasonic system with Arduino is suitable for short distances and is much more economical. Active radar is the most efficient under low-visibility conditions (fog and rain), while the ultrasonic system is recommended for limited applications where long detection range is not required.

5. RECOMMENDATIONS FOR USING RADAR SYSTEMS

Based on the analysis, the following strategies and guidelines are recommended for selecting and applying an appropriate radar system in various applications:

- For long-range applications and complex conditions: The use of active radar (SAR) is recommended due to its high precision, long detection range, and ability to operate under various weather conditions. This type of radar system is ideal for applications in the aviation, maritime, and transportation sectors, as well as for military applications where data reliability and accuracy are crucial.
- For applications requiring wide-angle coverage: Passive radar is an excellent choice for situations where wide coverage with minimal radiofrequency signal emission is important. This is particularly useful for monitoring and surveillance of larger areas, as well as in systems where it is important to avoid active signal emissions.
- For short-term and close-range applications in controlled environments: Ultrasonic radar is ideal for short-range applications where range and accuracy are not critical, but precision at close distances is required. This type of radar is recommended for areas such as robotics, industrial automation, and short-range systems in enclosed spaces.
- Research on improved ultrasonic systems: Although ultrasonic radar has limited range and precision, further research could lead to significant improvements in its accuracy and adaptability. The development of new technologies, such as advanced signal processing algorithms and integration with other sensors, could make ultrasonic radar more effective for a wider range of applications.
- Combined systems for increased efficiency: In applications where high precision and wide coverage are needed, the option of combining different radar technologies can be considered. For example, integrating active and passive radar systems can provide high efficiency and adaptability under various operational conditions.

It is recommended to use active radar systems for applications requiring precision at long distances, while ultrasonic radar systems can be applied for economical, short-term, and static detections.

These recommendations enable the optimal selection of radar systems for each specific application, ensuring maximum efficiency and reliability in object detection.

6. CONCLUSION

This paper conducted a detailed analysis and comparison of three different types of radar systems: active radar (SAR), passive radar, and ultrasonic radar, to determine their advantages, limitations, and potential applications. The main parameters analyzed include detection range, distance precision, coverage angle, and adaptability to various weather conditions. Each of these characteristics is crucial when selecting the appropriate radar system for specific applications.

The results show that active radar (SAR) has significant advantages in terms of detection range and precision, making it ideal for applications requiring precise identification of objects at long distances and under varying weather conditions. It is also the most adaptable in changing weather conditions, making it suitable for applications in aviation and maritime traffic, as well as military and security domains.

Passive radar offers moderate precision and a wide coverage angle, making it ideal for applications that require broader coverage without the need for high radiofrequency signal emissions. This type of radar is particularly useful for surveillance and monitoring applications where avoiding active signal emissions is important, such as systems for terrain observation or privacy protection in urban environments.

On the other hand, ultrasonic radar has a limited detection range and coverage angle, making it more suitable for short-term applications at short distances and in controlled conditions, such as robotics systems and automation in industrial and laboratory environments. Its accuracy and functionality depend on the conditions, but it can be an accessible and economical option for short-term tasks.

These differences indicate that there is no "universal" solution in radar technology—the selection of the appropriate radar depends on specific requirements and operational conditions. When deciding on a radar system, characteristics such as range, accuracy, coverage angle, and adaptability to weather conditions should be considered depending on the application's needs.

The efficiency of different radar systems depends on operating conditions and application requirements. Active radar systems are superior for specific applications with demands for long-range and high precision, while ultrasonic radar is an excellent choice for applications requiring short-range, cost-effectiveness, and low energy consumption.

This paper contributes to a better understanding of the characteristics of different radar technologies and provides guidelines for their application in various scenarios. We anticipate that the results of this study will be useful for researchers, engineers, and professionals working in the field of radar systems, as well as for future research and innovations in the field of detection and surveillance.

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