Obstacle Detection Using 24 GHz mmWave Radar Module For Collision Avoidance In Autonomous Vehicle Applications

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in partial fulfillment for the requirements of B.E Degree in Electrical (Telecom) Engineering.

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In the name of ALLAH, the Most benevolent, the Most Courteous

CERTIFICATE OF CORRECTNESS AND APPROVAL

This is to officially state that the thesis work contained in this report

"Obstacle Detection Using 24 GHz mmWave Radar Module For Collision Avoidance In Autonomous Vehicle Applications"

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under my supervision and that in my judgement, it is fully ample, in scope and excellence, for the degree of Bachelor of Electrical (Telecom.) Engineering in Military College of Signals, National University of Sciences and Technology (NUST), Islamabad.

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DECLARATION OF ORIGINALITY

We hereby declare that no portion of work presented in this thesis has been submitted in support of another award or qualification in either this institute or anywhere else.

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All the praises, thanks and acknowledgements are for the creator, Allah Almighty, the most beneficent, the most merciful, who gave us strength and enabled us to complete this task. Countless salutations upon the Holy Prophet (PBUH) and his holy family, source of knowledge for enlightening with the essence of faith in Allah and guiding the mankind to the true path of life. Second, our sincere appreciation goes to our supervisor Dr Zeeshan Zahid, Department of Electrical Engineering, whose guidance, and constructive comments were valuable. His timely and efficient contribution helped us in completing our project. Finally, we are forever indebted to our family members. We cannot forget their kind care and support that is forever responsible for boosting our progress.

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ABSTRACT

The goal of this project is to design and develop an obstacle detection system for collision avoidance in autonomous vehicle applications using a 24 GHz mmWave radar module. The proposed system employs a radar module to detect objects in the vehicle's path and then classifies them based on their distance and relative speed. The system also estimates the position and velocity of detected objects. The effectiveness of the proposed system is demonstrated through simulations and experiments on a test bench. The results show that the proposed system can accurately detect and classify obstacles in real time and issue warnings to the vehicle control system in time, which can be used for collision avoidance. This system provides a robust and reliable solution for obstacle detection in autonomous vehicle applications, especially in adverse weather conditions where other sensor systems may not be effective. The proposed system has the potential to improve the safety and reliability of autonomous vehicles, ultimately leading to safer and more efficient transportation systems.

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Chapter 1: Introduction

Professional skills based on scientific experimental knowledge and science of numbers fashion a new branch of science known as Engineering. This branch of science is extremely important to society and its elements in many ways, especially the developmental research in the engineering domain that is boosting the standard of living for mankind.

Engineering is not only limited to the smaller research areas, but it covers entire industrial setups from visual constructions on some software to on-site practical work. This field of science also defines safety policies and evaluation measures. Engineers, who are practicing engineering principles, use their domain knowledge to invent and develop products that solve problems of society. Either it is an issue of conveyance, medicine, astrology, atmosphere, or entertainment.

Autonomous vehicle development has accelerated significantly in recent years, with the potential to completely change the transportation sector. However, there are still significant safety concerns with autonomous cars, especially with relation to obstacle identification and accident avoidance. The application of millimeter wave radar technology has come to light as a potential remedy to this problem. The utilization of a 24 GHz millimeter wave radar module for obstacle identification and collision avoidance in autonomous vehicle applications is the main topic of this thesis. This study aims to investigate how well this technology works in actual driving situations for recognizing and avoiding obstacles. We hope to further the creation of dependable and safe autonomous vehicles by examining the performance of this radar module.

With the increasing number of autonomous vehicles on the road, it is essential to equip them with reliable and accurate sensors that can detect obstacles and prevent collisions.

1.1 Overview

Today's world is a world of digitalization. The growing tech field and exponential development in the fields of transport, medicine, metropolitan cities have become the most influential developments in the lives of mankind. As the number of autonomous vehicles on the road grows, ensuring their safety and preventing crashes has become a vital concern. This project will conduct a literature assessment on obstacle detection and collision avoidance in vehicles, with a focus on radar-based solutions. The hardware and software components of the 24 GHz millimetre wave radar module will be described, as well as the algorithms utilised for obstacle identification and collision avoidance. To evaluate the module's performance, it will be evaluated in a simulation environment under various circumstances. The results of the studies will be analysed to determine the usefulness of the 24 GHz millimetre wave radar module in autonomous vehicle applications for obstacle identification and collision avoidance.

This project seeks to contribute to the advancement of safer and more reliable autonomous vehicle technology by researching the possibilities of 24 GHz millimetre wave radar technology for obstacle identification and collision avoidance.

1.2 Problem Statement

The expanding number of vehicles on the streets of Pakistan has driven to a noteworthy rise in activity mishaps and fatalities, coming about within the misfortune of numerous lives and causing harm to property.

Following are some highlights.

1. A few of the challenges particular to Pakistan's one-of-a-kind conditions, such as extraordinary climate and destitute street foundation, have been distinguished within the improvement of impediment discovery and collision evasion frameworks.

2. The utilize of radar innovation is generally exceptional in independent vehicles in Pakistan because it is by and large considered to be more costly than other sensors.
3. Extend points to examine adequacy of 24 GHz mmWave radar module for impediment location and collision shirking in Pakistan's particular conditions.

1.3 Proposed Solution

The major goal of our proposed solution is to explore the adequacy of 24 GHz mmWave radar module for deterrent discovery and collision evasion in independent vehicles in Pakistan's interesting activity and natural conditions. The objective is to create a dependable and precise framework for impediment discovery and collision evasion, which can contribute to the decrease of mishaps and fatalities on the streets. The venture will investigate the potential of 24 GHz mmWave radar innovation for impediment location and collision evasion in Pakistan and recognize any challenges particular to the nation that got to be tended to in framework advancement.

1.4 Working Principle

The project mainly works on the principles of emitting and analyzing millimeter wave signals. The radar module emits electromagnetic waves [1] in the millimeter wave frequency range, which are reflected by objects in the vicinity of the vehicle. By analyzing the reflected waves, the radar module can determine the distance and speed of objects in the vehicle's path. The Doppler effect [2] is used by the radar module to calculate the speed of objects in relation to the vehicle.

Depending on the strength of the radiated signal and the sensitivity of the receiver, the radar module can identify objects up to a specified range. The radar module's range can be extended by raising the strength of the transmitted signal or by employing a more sensitive receiver.

1.5 Objectives

1.5.1 General Objectives:

"To build an innovative state of the art software integrated hardware to increase safety by detecting and preventing collisions with impediments in the vehicle's path, to improve the reliability and efficiency of autonomous cars, and to stimulate the development of new technologies in the automotive sector.

1.5.2 Academic Objectives:

- To evaluate the accuracy, range, and resolution of the radar module in detecting obstacles under various environmental conditions and driving scenarios.
- To increase productivity by working in a team.
- To design a project that contributes to the welfare of society.

1.6 Scope

The project's scope is to design, develop, and test a millimeter wave radar module system for obstacle detection and collision avoidance in autonomous cars. The system will be evaluated in various driving conditions and combined with other sensors and control systems in an autonomous vehicle platform to evaluate its accuracy, range, resolution, and reliability. The project will also include the development and optimization of signal processing algorithms to improve object detection and tracking, as well as the evaluation of the impact of the obstacle detection and collision avoidance system on the safety, efficiency, and usability of autonomous cars.

1.7 Deliverables

1.7.1 Hawk eye:

It serves as a hawk eye to build an innovative state of the art software integrated hardware to increase safety by detecting and preventing collisions with impediments in the vehicle's path, to improve the reliability and efficiency of autonomous cars.

1.7.2 Object of Interest:

Main objective is to develop and integrate a reliable and efficient obstacle detection and collision avoidance system into autonomous vehicles, thereby improving their performance and safety. The project's outcome is expected to reduce the number of accidents and fatalities caused by autonomous vehicles and enhance the public's trust in autonomous vehicle technology.

1.7.3 Technological Advancement:

The project involves developing advanced driver assistance systems (ADAS) [3] and collision avoidance technology, promoting technological innovation and advancement in the transportation sector. This will enhance the quality of life and provide new opportunities for people in the field of technology and engineering.

1.8 Relevant Sustainable Development Goals

Following are the related SDGs with our project:

Goal 3 - Good Health and Well-being [4]

Goal 9 - Industry, Innovation, and Infrastructure [5]

Goal 11 - Sustainable Cities and Communities [6]

Goal 17 - Partnerships for the Goals [7]

1.9 Structure of Thesis

Chapter 2 contains the literature review, background, Existing Solution/ drawbacks, and analysis study this thesis is based upon.

Chapter 3 contains uRAD basics design and development of the project.

Chapter 4 contains construction, working and code analysis.

Chapter 5 contains the results and conclusion of the project.

Chapter 6 highlights the future work needed to be done for the commercialization of this project.

Chapter 2: Literature Review

A new product is launched by modifying and enhancing the features of previously launched similar products. Literature review is an important step for development of an idea to a new product. Likewise, for the development of a product, and for its replacement, related to obstacle detection systems, a detailed study regarding all similar projects is compulsory. Our research is divided into the following points.

- Industrial Background
- Existing solutions and their drawbacks

2.1 Industrial background

The automobile industry has been actively investing in the development of autonomous vehicle technologies to improve safety, efficiency, and cost-effectiveness. The detection of obstacles and the avoidance of collisions are key components of autonomous vehicle technology because they assure the safety of passengers and other road users.

In recent years, several companies have been working to create obstacle detection systems based on radar, lidar, or camera sensors. The identification of obstacles with greater precision and resolution is made possible by millimeter wave radar technology, which has emerged as a promising method for autonomous vehicles. In their autonomous vehicles, Tesla, Waymo, and Uber have all incorporated millimeter wave radar technology.

Pakistan is just getting started. The development and deployment of autonomous vehicle technology in Pakistan is relatively new and less advanced than other countries. However, Pakistan's automotive industry has grown steadily in recent years, with several local and international companies operating in the country.

2.2 Existing solutions and their drawbacks

Different solutions are previously provided for the Obstacle detection problem, but every product has some pros and cons. The following are some solutions which are already being prepared and being implemented.

- Camera-based systems
- Lidar-based systems
- Ultrasonic-based systems
- Millimeter wave radar-based systems

2.2.1 Camera-based systems

These systems employ cameras to take pictures of the environment and spot obstacles. However, they are constrained by the need for a clear line of sight of the objects and poor visibility in low light. Additionally, they have trouble detecting things like dark cars that don't reflect enough light.

Cameras take pictures of their surroundings and then use computer vision algorithms to recognize and categorize items. They are reasonably priced and can produce high-resolution images. They can also detect item colours and patterns, which might be useful in recognizing certain sorts of impediments. They are, however, light sensitive and can be influenced by glare, shadows, and reflections. Cameras can also have a restricted range and may be unable to identify small or distant things. Additionally, camera-based obstacle detection systems can be affected by occlusion, which occurs when objects in the field of view are obstructed by other objects.

2.2.2 LiDAR -based systems

LiDAR uses laser beams to detect obstacles and create a 3D map of the environment. However, it can be costly and struggles in bad weather such as rain and fog.

Lasers are used in LiDAR to identify barriers and create 3D maps of the surroundings. The system works by producing a laser beam that reflects off things in its path, and then measuring the time it takes for the reflection to return to estimate the distance to the item. LiDAR has a high level of precision and resolution, making it ideal for identifying minute objects over vast distances. It can also give real-time data for quick decisions. However, LiDAR is costly and susceptible to weather conditions such as fog, rain, and snow. In such conditions, lasers can scatter, resulting in inaccuracies or false readings. Furthermore, LiDAR may be unable to detect certain materials or colours of objects, and it may be interfered with by other LiDAR devices.

2.2.3 Ultrasonic-based systems

These systems use ultrasonic sensors to detect obstacles. However, they have a limited range and can struggle to detect small or low-lying obstacles.

Ultrasonic sensors use high-frequency sound waves to identify obstructions in the vicinity of the vehicle. The technology calculates the time it takes for sound waves to reflect off an item and return to the sensor. Ultrasonic sensors are cheap and simple to install. They can also identify stationary objects and work in low-light circumstances. However, because to their restricted range and precision, they are only ideal for low-speed applications. Furthermore, ultrasonic sensors can be affected by wind, and their performance can degrade over time due to dirt and dust accumulation.

2.2.4 Millimeter wave radar-based systems

Radar uses radio waves to detect obstacles and can work in all weather conditions. However, radar sensors can be expensive and may require complex signal processing algorithms.

Radar systems identify obstructions using radio waves and may work in inclement weather. The system works by sending out radio waves that bounce off things in their path, and then measuring the time it takes for the reflection to return to estimate the distance to the item. Radar can identify a wide range of objects, including automobiles, humans, and animals, and offers precise distance and velocity information. It can also run at fast rates and deliver real-time data for quick decisions. Radar systems, on the other hand, can be expensive and heavy, and they might suffer from interference from other electronic equipment. Furthermore, radar systems have lower resolution than LiDAR and may be unable to detect small objects such as debris or animals.

Chapter 3: uRAD Basics

uRAD [8], is a tiny shield for Arduino that works as a completely functional microwave radar, operating in the free emission 24 GHz ISM frequency band, it has four different operation modes that are ease programmed with Arduino IDE and its distance range is from 0.45 m to 100 m. You will be able to measure distance, velocity, and other magnitudes of your surrounding world with great accuracy.

3.1 Hardware Description

- uRAD is developed by utilizing planar technology on a substrate that offers high performance.
- The topmost layer of the device houses the core, which includes a 24 GHz transceiver along with both the transmitting and receiving antennas. The lower layer of the uRAD device is comprised of power supply and signal processing components, which are under the control of a high-performance microcontroller.
- Four different connectors are placed in both longest sides, which are the interface with Arduino boards.

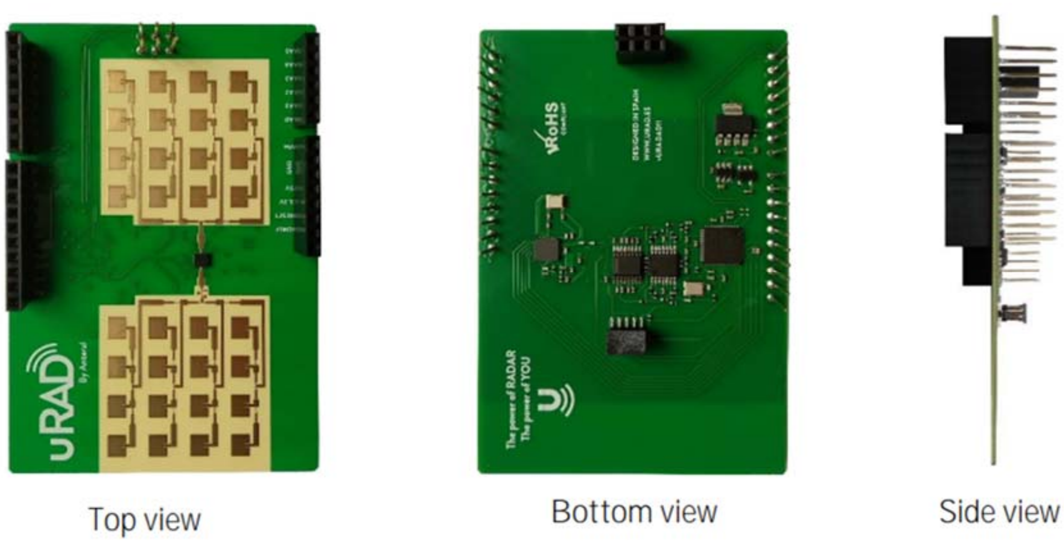

Figure 1 - 24 GHz mm Wave Radar (uRAD)

3.2 Assemble with Arduino

It's easy to assemble uRAD into your compatible Arduino board [9]. Simply insert the male contact pins of uRAD side connectors into the female Arduino connectors. Once assembled, the top layer or antenna side will be visible.

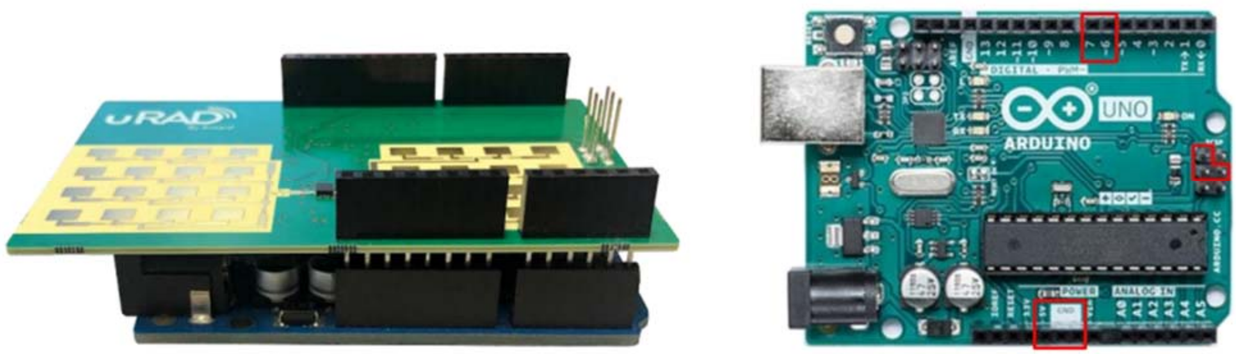

Figure 2 - 24 GHz mm Wave Radar (uRAD) Assemble with Arduino

uRAD is designed to be powered by the 5V power pin on the Arduino board and shares the GND power pins as well. As a result, powering uRAD is as simple as powering up your Arduino board as usual.

Furthermore, uRAD utilizes two digital pins for communication and ON/OFF control in conjunction with Arduino. Additionally, it includes the ICSP connector..

- **Digital pin 6**: The ON/OFF switch of uRAD can be controlled by setting the pin to Logic HIGH/LOW, respectively..
- **Digital pin 7**: This is the Slave Select pin used for SPI communication protocol.
- **ICSP connector**: This connector is used for transmission and reception of data between uRAD and Arduino.

3.3 Configuration Parameters

9x parameters are required for configuring uRAD shield:

- Mode
- f0 (Operation frequency)
- BW (Bandwidth)
- Ns
- Ntar
- Rmax / Vmax
- MTI (Moving Target Indication)
- Mth
- Alpha

3.3.1 Mode

Four distinct operation modes are available for uRAD, and each mode corresponds to a different transmitted waveform: continuous wave (CW), sawtooth, triangular, and dual rate. In CW mode, a single frequency is transmitted, which is commonly used in Doppler radars. On the other hand, frequency modulated continuous wave (FMCW) is used for the remaining modes, wherein a frequency ramp is transmitted. Each mode offers its own set of advantages and disadvantages, and the selection of a specific mode depends on the application requirements. The main characteristics of each mode are summarized in the following table.

Mode	1	2	3	4
Measured parametes	Velocity	Distance	Velocity & Distance	Velocity & Distance
Distance range (m)	“0.45 - 60” m	“0.45 - 100“ m	“0.45 - 100“ m	“0.45 - 75” m
Distance Perfection (m)	-	max. ± “0.04” m or ±0.3%	max. ±”0.04” m or ±0.3%	max. ±”0.04” m or ±0.3%
Velocity - range (m/s)	±(0.7 - 75)	-	±(0.2 - 75)	±(0.2 - 75)
Update - rate max. (samples/ second)	“68”	“45”	“28”	“16”

Table 1- Modes of 24 GHz mm Wave Radar (uRAD)

3.3.2 f0 (Operation frequency)

The parameter being referred to here is the operational frequency during CW mode or the initial frequency of the frequency ramp for the other modes. uRAD is designed to function between the frequencies of 24.005 and 24.245 GHz, allowing for the selection of f0 between 5 to 245 in CW mode or 5 to 195 in the other modes (the minimum frequency sweep allowed for ramp modes being 50 MHz).

3.3.3 BW (Bandwidth)

The bandwidth (BW) is a crucial parameter as it determines the accuracy of the system. Increasing the BW results in improved accuracy. Additionally, choosing a higher BW allows uRAD to better differentiate between targets in close proximity to each other, Range value 50 to (245 - f0).

3.3.4 Ns (Number of samples)

The sampling frequency parameter determines the number of samples taken by uRAD to calculate various parameters such as distance, velocity, and so on, from the reflected wave. In modes 2, 3, and 4, this parameter plays an even more critical role as it determines the duration of the ramps, which in turn determines the update rate of the system..

Ns	Mode 1	Mode 2	Mode3	Mode 4
Range - value	50 - 200	50 - 200	50 - 200	50 - 200
Update-rate [samples/second]	68 - 43	45 - 38	28 - 24	16 - 15

Table 2- Number of samples

Choosing the lowest value for Ns is often preferable to achieve a faster update-rate. Nevertheless, the correlation between the bandwidth (BW) and the number of samples (Ns) also influences the maximum range that uRAD can theoretically detect.

$Distancemax = 75 \times Ns/BW$

3.3.5 Ntar (Number of targets)

The maximum number of targets that can be detected is a configurable parameter, with the limit being set to five targets. If uRAD detects more than 5 objects within its field of view, it provides information on the 5 most significant ones that reflect the highest amount of power.

3.3.6 Rmax / Vmax

Rmax refers to the maximum distance up to which uRAD will search for targets. The parameter Rmax defines the detection range, which is independent of the theoretical maximum distance. This helps establish the length of the zone that needs to be detected. However, the relationship between BW and Ns affects the maximum range that uRAD can theoretically detect. In mode 1, distances cannot be measured, so Rmax refers to Vmax, the maximum velocity range in which the targets will be detected..

3.3.7 MTI (Moving Target Indication)

The MTI (Moving Target Indication) mode can be activated or deactivated using this parameter. To detect only moving targets with respect to uRAD, mode 1 ignores all stationary objects and provides data only on targets in motion. This capability is typically found only in high-performance radars due to the complexity of data processing. Therefore, it is essential to set an appropriate sensitivity for each specific scenario.

When MTI mode is disabled, all targets, regardless of whether they are stationary or in motion, are detected and their information is provided. A value of 0 indicates that MTI mode is turned off.. When the MTI mode is activated, with a value of 1, the information regarding static targets is ignored and omitted.

3.3.8 Mth

This parameter specifies the level of sensitivity of uRAD when it operates as a motion detector. By adjusting the Mth parameter, up to four detection thresholds can be set. These thresholds are determined based on the reflectivity of the target, which is related to its size and distance (larger and closer targets reflect more). When Mth is set to 4, uRAD becomes highly sensitive to any reflectivity. On the other hand, if Mth is set to 1, only targets with very high reflectivity will trigger the alert.

3.3.9 Alpha

In the process of searching for targets, uRAD detects peaks in the spectrum of the received signal using a CA-CFAR algorithm (cell average constant false alarm rate). The algorithm's parameter, alpha, determines its sensitivity in peak detection. The firmware of uRAD considers any peak with an amplitude above alpha to be a detected peak.

Higher values of alpha result in a lower probability of detection, while lower values lead to a higher probability of detection but an increased rate of false alarms. It is important to select the optimal value of alpha for each specific scenario. The selectable range of alpha is between 3 and 25, with a best value that depends on the specific application.

3.4 Why mm wave Radar?

Millimetre-wave (mmWave) radar is used for its ability to provide highly accurate and detailed data on the surrounding environment, much higher resolution, and accuracy than traditional radar systems that operate at lower frequencies.

mmWave radar technology is used in a variety of applications, including automotive radar systems, industrial automation, security and surveillance, and aerospace and defence. One of the main advantages of mmWave radar is its ability to provide highly accurate distance and velocity measurements, even in adverse weather conditions.

In the context of automotive radar systems, mmWave radar can detect and track objects such as pedestrians, other vehicles, and obstacles with a high level of precision. This is particularly important for advanced driver assistance systems (ADAS) and autonomous vehicles, where accurate and reliable data on the surrounding environment is crucial for safe operation.

Overall, the use of mmWave radar offers many benefits in terms of accuracy, reliability, and performance, making it an important technology for a range of applications.

Chapter 4

4.1 Components

The following items are needed for obstacle detection using a 24 GHz mm Wave Radar Module for collision avoidance in autonomous vehicle applications:

4.1.1 24 GHz mmWave Radar Module

This is the system's main component, which transmits and receives electromagnetic waves to detect obstacles [11] in the surrounding environment.

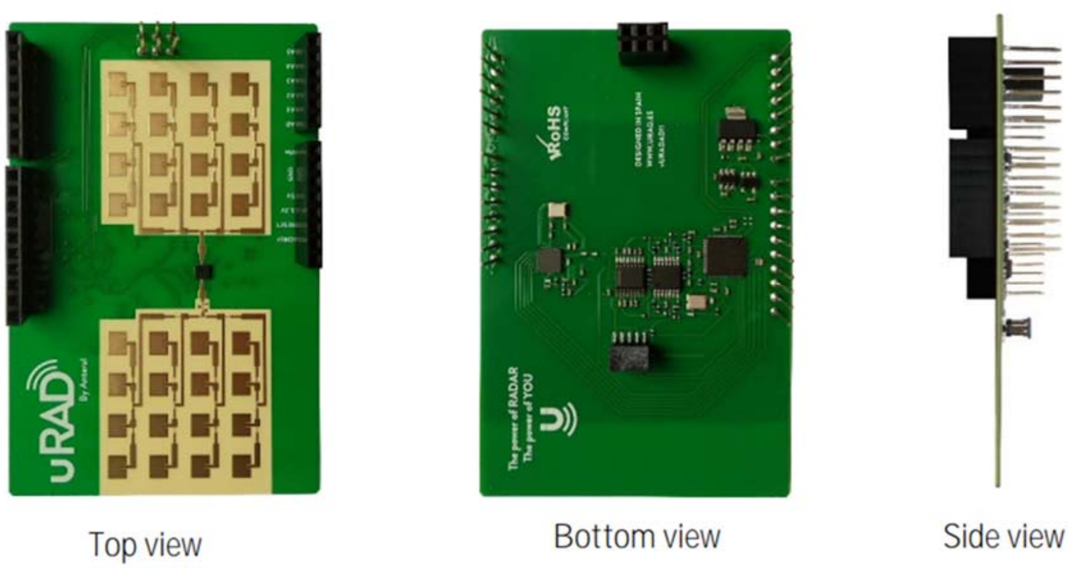

Figure 3 - 24 GHz mm Wave Radar (uRAD)

4.1.2 3.5-inch TFT LCD Shield [10]

A display unit is required to display the detected obstacles and other relevant information to the vehicle driver.

Figure 4- 3.5-inch TFT LCD Shield

4.1.3 Microcontroller

Arduino is a widely used open-source electronics platform that is known for its simple hardware and software. It is made up of a microcontroller board that can be programmed to manage different electronic parts and gadgets.

As a microcontroller that processes the information obtained from the 24 GHz mm Wave Radar Module and regulates the movements of the autonomous vehicle based on the detected obstacles, Arduino plays a crucial role. The C++ programming language and the

Arduino Integrated Development Environment (IDE) can be used to program the Arduino board, making it simple to alter the system's behaviour.

The power supply, display unit, and communication module are just a few of the other parts of the system that the Arduino board can communicate with. It is a popular option for projects and prototyping because it offers a cheap and flexible solution for managing and watching the movements of the autonomous vehicle.

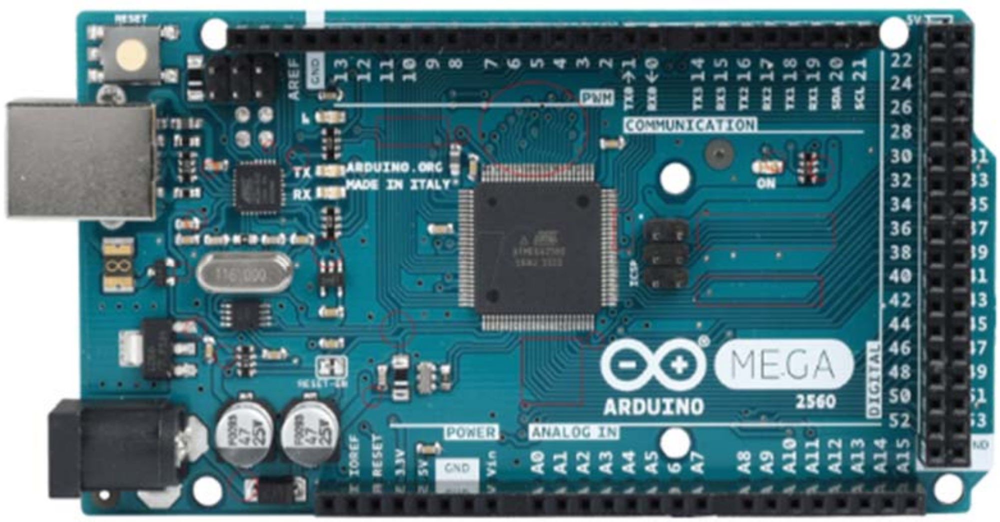

Figure 5 - Arduino Mega 2560

4.1.4 Power Supply

A stable and reliable power supply is required to power the system components.

4.2 Construction

The assembly of various hardware parts and the programming of the software modules are required to build the aforementioned project. The 24 GHz mmWave Radar Module must first be mounted to the vehicle's chassis and connected to the microcontroller board. To achieve a stable and secure connection between the components, this entails soldering the required wires and connectors.

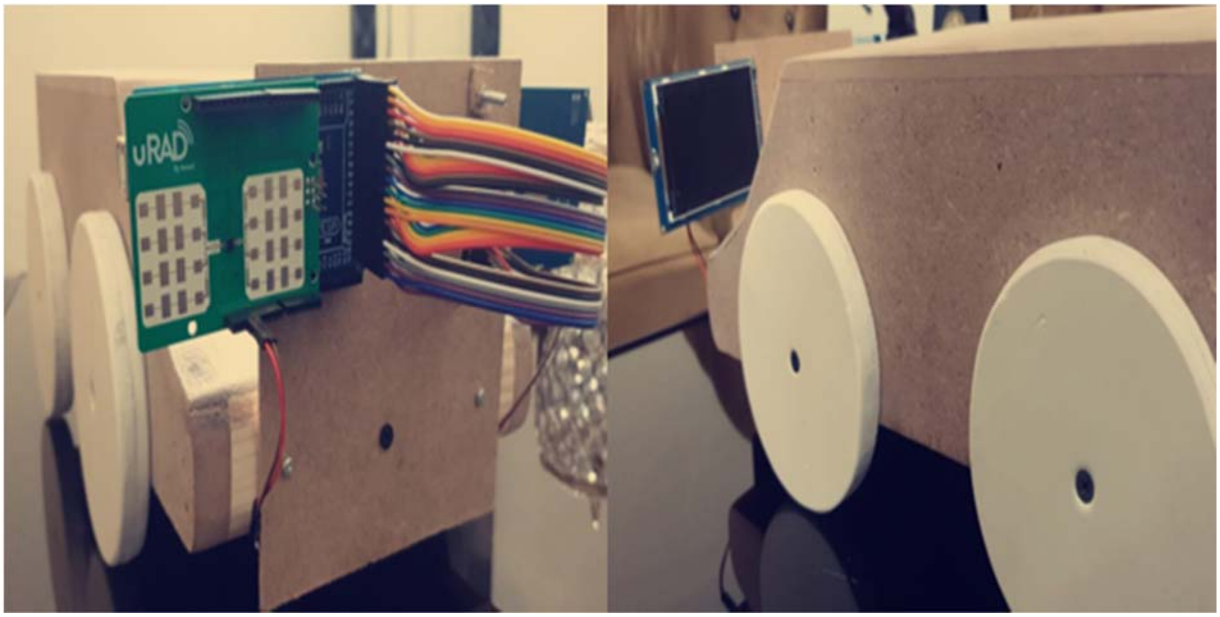

Figure 6- Complete Obstacle Detection Model

The Arduino board must then be set up and programmed, which entails downloading the required software libraries and creating the code to direct the autonomous vehicle's movements in response to obstacles. This involves configuring the signal processing unit, display unit and other parts and making sure they all function together without any problems.

Once the hardware and software components are installed and programmed, the system can be tested and calibrated to ensure that it is working properly [13]. This involves running the system in various environments and conditions to test its accuracy and reliability in detecting and avoiding obstacles [12].

4.3 Working

The system works by emitting electromagnetic waves from the radar module, which then bounce off any objects in the surrounding environment. The radar module then receives these waves and uses signal processing algorithms to analyse the reflected signals and determine the distance and position of any obstacles in the path of the vehicle.

The microcontroller board, such as the Arduino, receives this data from the radar module and processes it to determine the distance and speed of the detected obstacles. The data is then sent to the TFT LCD screen, where it is displayed in real-time as a visual representation of the surrounding environment.

The TFT LCD screen typically uses a graphics library to display the information, with various visual elements such as lines, shapes, and text used to represent the detected obstacles. Overall, the system provides a comprehensive solution for collision avoidance in autonomous vehicle applications, allowing the driver to monitor the surrounding environment in real-time and make informed decisions to navigate complex environments safely and efficiently.

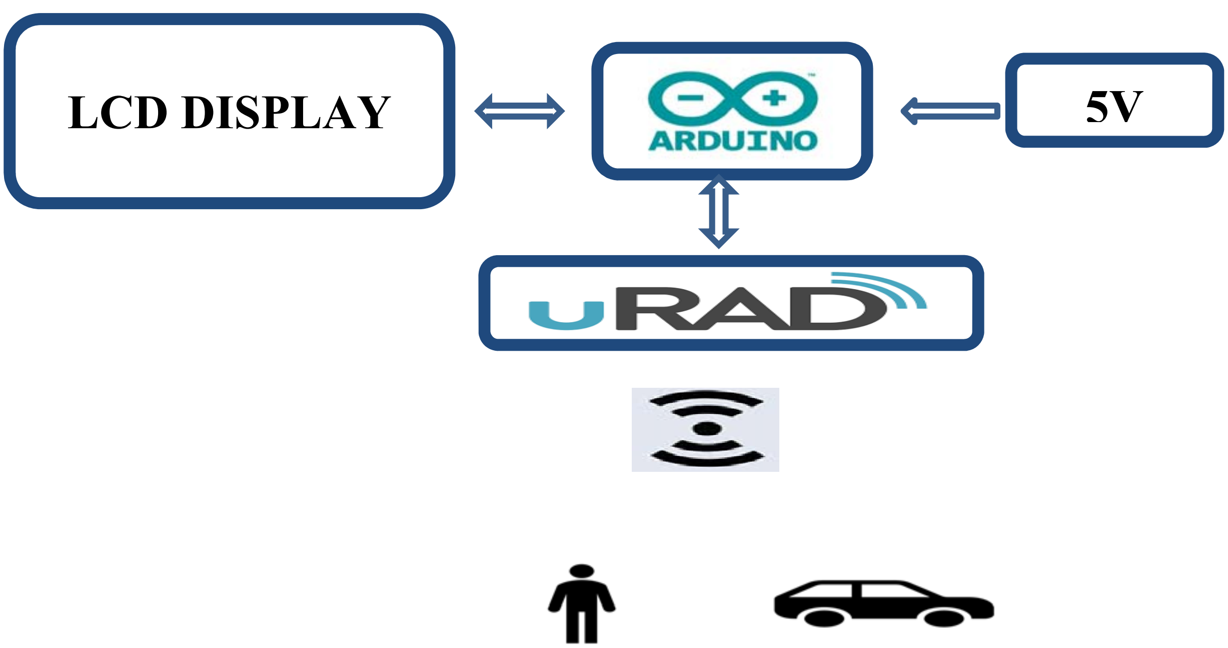

Figure 7- Block Diagram

4.4 Code Analysis and Evaluation

Program uses the uRAD SDK11 library to interface with a uRAD device that performs radar measurements. The program configures the uRAD device and then repeatedly performs radar detections and outputs the results to a serial console and an LCD screen. Here is a high-level overview of the program flow:

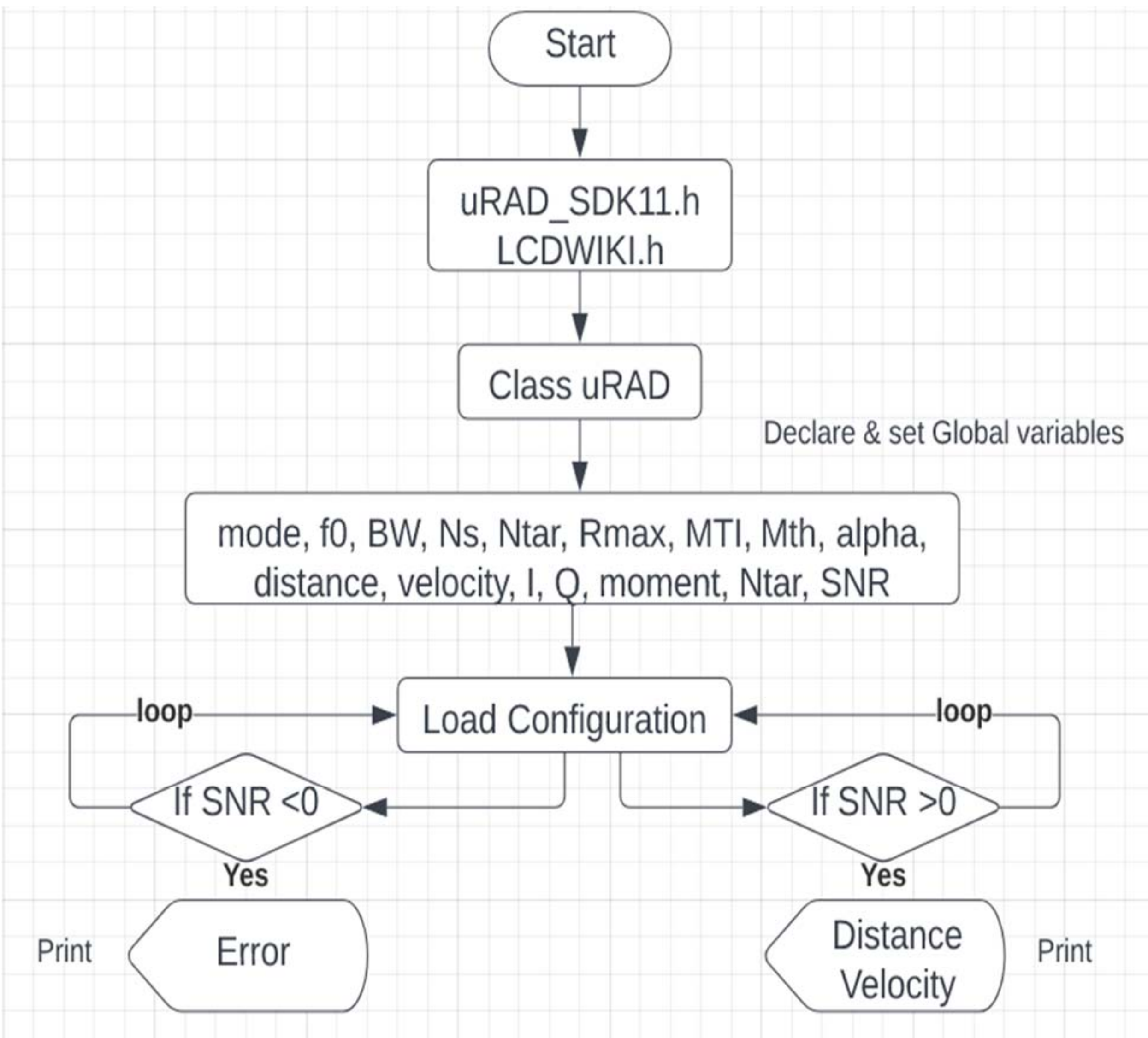

Figure 8- Code Flow Diagram

- First, the required libraries are included: **uRAD_SDK11.h**, **LCDWIKI_GUI.h**, and **LCDWIKI_KBV.h**.
- An instance of the **LCDWIKI_KBV** class is created and initialized to communicate with the specific model of LCD module being used.
- An instance of the **uRAD_SDK11** class is created to communicate with the uRAD device.
- Various input parameters are initialized to configure the uRAD device for radar measurements. These include things like the radar frequency, bandwidth, number of samples, and maximum range.
- In the **setup ()** function, the serial console is initialized and the uRAD device is turned on and configured with the input parameters.
- In the **loop ()** function, the **uRAD.detection()** method is called to perform a radar detection. This method returns information about any targets detected by the radar, including their distance, velocity, and signal-to-noise ratio (SNR).
- If one or more targets are detected and their SNR is greater than zero, the program displays the target's distance and velocity on the LCD screen and outputs this information to the serial console. If no targets are detected or their SNR is too low, an error message is displayed on the LCD screen.

- The program then waits for one second before starting the next detection.

Overall, this program demonstrates how to use the uRAD SDK11 library to interface with a uRAD device and perform radar measurements.

Chapter 5

5.1 Results

The system was designed to provide distance and velocity measurements of obstacles in the environment to enable the vehicle to make informed decisions and avoid collisions. The system was tested using a test setup and various obstacles placed at different distances and angles. The radar module was used to measure the distance and velocity of each obstacle and the results were recorded for analysis.

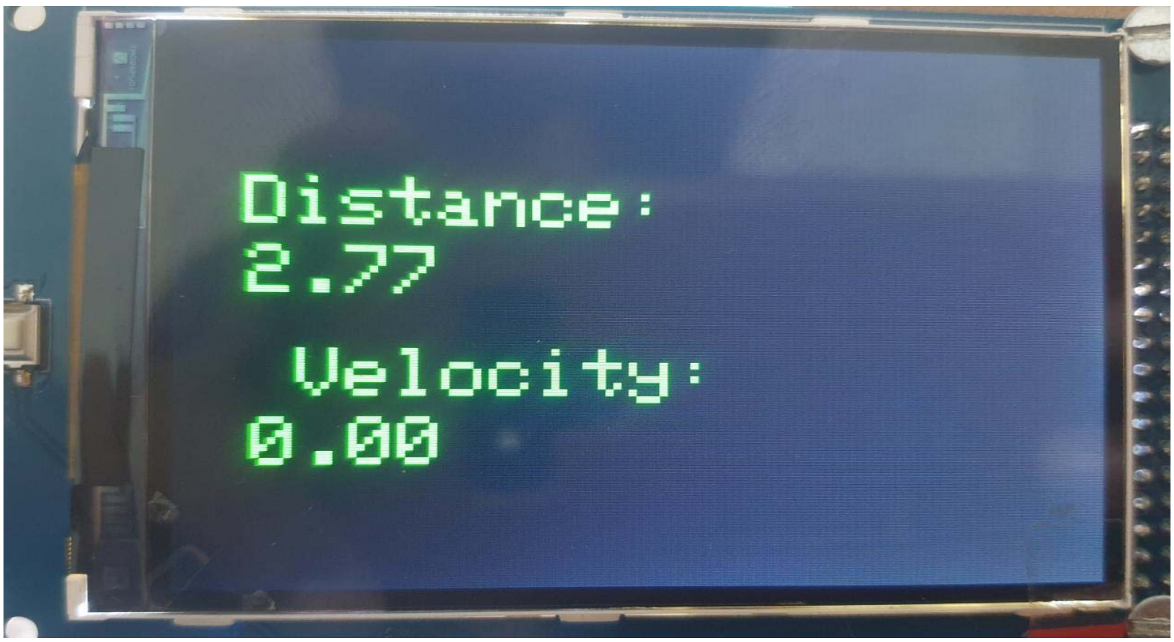

Figure 9- LCD Output

The results showed that the radar module was able to accurately detect the distance and velocity of obstacles in the environment. The system was able to detect obstacles at a distance of up to 100 meters and provided accurate velocity measurements of objects.

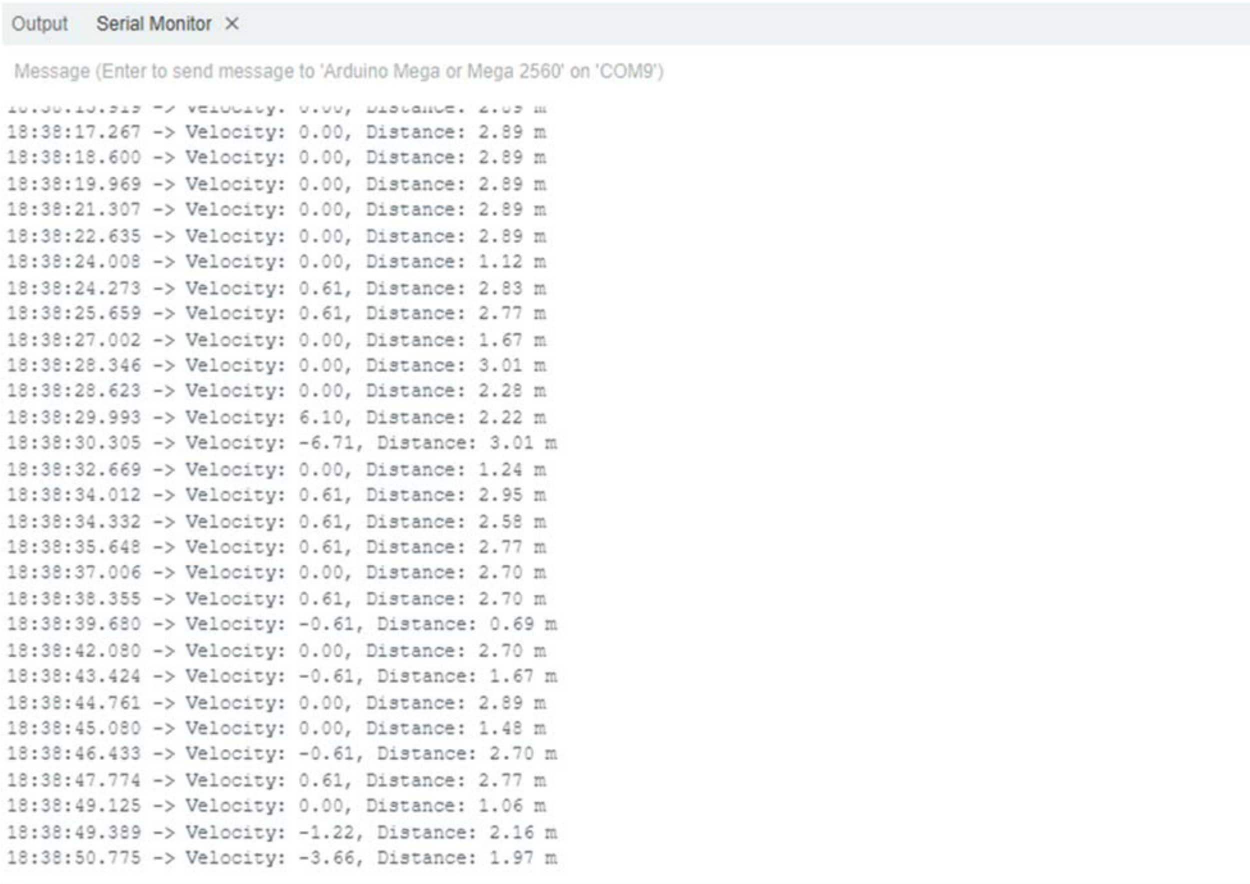

Figure 10-Serial Monitor Display

5.2 Conclusion

In this thesis, we discussed obstacle detection systems for autonomous vehicles using a 24 GHz mmWave radar module. The project has shown that the radar module is a reliable and accurate method for detecting obstacles and can provide critical information for avoiding collisions. One of the main advantages of this project is that the radar module can detect obstacles in all weather conditions, including rain, fog, and snow. This makes it a valuable tool for autonomous vehicles that need to operate in various environments. Additionally, the use of an Arduino microcontroller and a 3.5 TFT LCD display allows for real-time data visualization, which can help drivers make informed decisions and react quickly to potential hazards.

This is relatively inexpensive compared to other obstacle detection systems. The use of off-the-shelf components and open-source software makes it accessible to a wider range of users and allows for easy customization and further development.

By implementing this project, the autonomous vehicles in Pakistan can avoid collisions and accidents, which will ultimately lead to improved road safety. Additionally, this technology can be integrated with the existing transportation system to enhance its efficiency and reliability.

Chapter 6: Future Work

Future milestones that need to be achieved to commercialize this project are the following:

- There are some limitations that need to be addressed in future work, such as the need for further testing in different scenarios and environments, and the incorporation of more advanced algorithms for obstacle classification and identification.
- The system needs to be optimized for performance to ensure accurate and reliable obstacle detection in all weather conditions.
- The cost of the system needs to be reduced to make it affordable for commercialization.

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ABBREVIATIONS

uRAD: Universal radar

TFT: Thin-Film Transistor

ADAS: Advanced Driver Assistance Systems

ISM: Industrial, Scientific and Medical

IDE: Integrated Development Environment

ICSP: In-Circuit Serial Programming

f0: Operation Frequency

BW: Bandwidth

Ns: Number of Sample

Ntar: Number of Target

MTI: Moving Target Indication

CW: Continuous Wave

FMCW: Frequency Modulated Continuous Wave

Lidar: Light Detection and Ranging