

An Exploration of Sensor-Based Target Localization for Automated Driving

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Abstract. With the continuous advancement of artificial intelligence and measurement technology, autonomous driving technology has emerged as a significant challenge for human research. Autonomous driving, as a crucial aspect facilitating convenience in human life, demands substantial technological advancements. Target localization stands as a pivotal element in the perception layer of autonomous driving technology. This paper provides a detailed overview of fundamental techniques and scenarios associated with target localization in autonomous driving. It covers aspects such as ultrasonic sensors, visual sensors, LIDAR, and comprehensively summarizes research and applications in autonomous driving technology. Specifically, the author emphasizes the application of sensors in reverse radar systems. Furthermore, the author provides a detailed description of the basic operations of a reverse radar through simulation and emulation using Keil and Proteus software. The author conducted extensive data collection and analysis during the simulation experiments, validating that the simulated circuit can achieve the primary functions of a reverse radar. Finally, the author offers an analysis and outlook on future research in the field of autonomous driving.

Keywords: Autonomous Driving, Sensors, Ultrasonic sensor, Reverse Radar.

1. Introduction

Autonomous driving systems integrate components such as artificial intelligence, computer vision, radar, and positioning systems, forming a complex intelligent software system [1]. The entire technological framework of autonomous driving can be divided into three main layers: perception, decision-making, and execution. Environmental perception represents a crucial element of autonomous driving, as the information received from the perception module influences core driving decisions [2]. Within perception technologies, the primary sensing technologies currently include visual, LIDAR, and microwave sensing [3]. Target localization stands as a critical aspect of autonomous driving perception. It involves precisely locating the vehicle in three-dimensional space, identifying surrounding objects, and planning driving paths. By utilizing sensors like cameras, radar, and ultrasonic sensors for real-time data collection and processing, the autonomous driving system constructs accurate models of the surrounding environment, achieving high-precision target identification, tracking, and localization. This level of accuracy in positioning is crucial for ensuring safe vehicle navigation, avoiding obstacles, complying with traffic rules, and achieving preset objectives. Hence, in autonomous driving technology, target localization is not only the foundation for realizing autonomous driving but also the cornerstone for ensuring system reliability and safety.

Autonomous driving technology is currently receiving significant attention, with autonomous driving sensors being pivotal components supporting this technology [4]. Sensors are devices capable of perceiving specific conditions in the environment or objects. They transmit data by converting this information into electrical or digital signals, enabling us to understand real-time changes in the surrounding world. The process of sensor measurement involves gathering data and converting it into signals usable for analysis or control. The value of sensors lies in providing precise real-time data, aiding in monitoring environmental changes, enhancing productivity, improving safety, and fostering automation and intelligence in fields such as healthcare, industry, and transportation. Accurate measurement data empowers various industries to make data-driven decisions, enhancing efficiency, reducing costs, and driving innovation.

This article comprises six chapters. Figure 1 illustrates the logical flow of the article. The first chapter serves as an introduction, outlining the content of the entire article. The second chapter delves into the current research status of sensor-based autonomous driving target localization. In the subsequent third chapter, the author explores various sensors that could be utilized in the field of autonomous driving, including infrared sensors and radar, among others. The following fourth chapter discusses practical applications of autonomous driving in real-world scenarios. The fifth chapter intricately describes experiments conducted in sensor-based target localization within autonomous driving technology. Finally, the sixth chapter summarizes the entirety of the article's content.

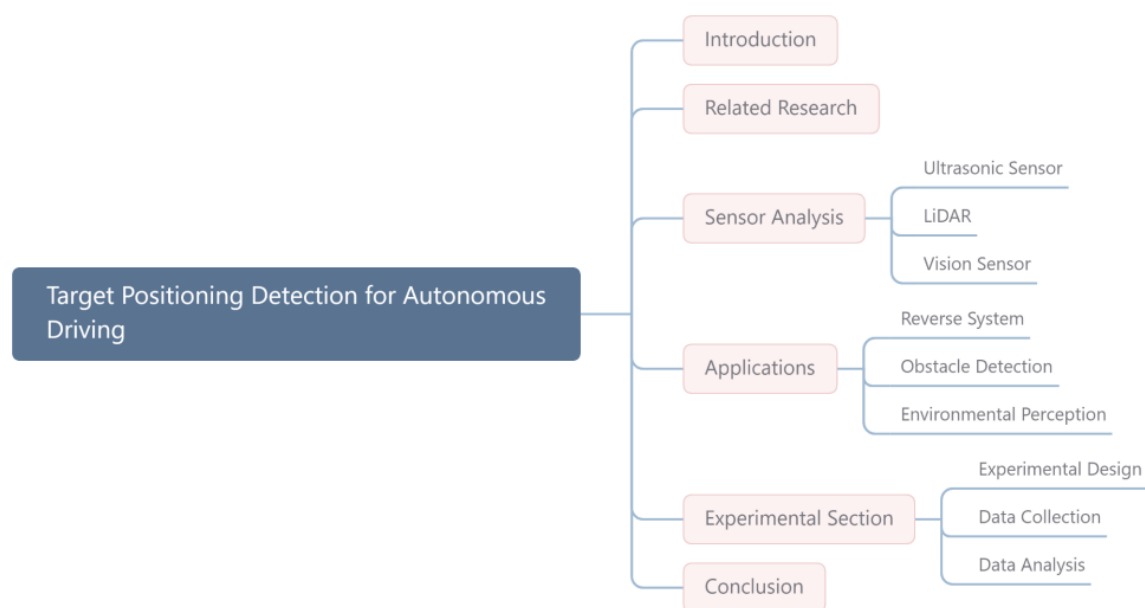


Figure 1: Flowchart of the Writing Process.

2. Relevant Research

Automatic driving is currently a hot field both domestically and internationally[5]. Previous research has provided crucial technological foundations for autonomous driving systems, enhancing vehicles' perceptual abilities towards their surroundings and making significant advancements in target recognition and path planning. For instance, studies conducted by Xiao Nan, Wang Lin, and others focused on the intelligent positioning pattern of unmanned vehicles based on multiple visual sensors [6]. They established a two-dimensional data model based on centroid coordinates of fused images by improving algorithms, achieving precise positioning of intelligent vehicles. Meanwhile, Wang Yan-ling, Zhang Miaosen, and colleagues researched a mobile target positioning system based on LIDAR technology [7], utilizing the Extended Kalman Filtering algorithm for accurate mobile target positioning.

However, there are still challenges that need to be overcome at present. Specifically, achieving accurate target positioning based on sensors in complex environments, varying weather conditions, or different lighting remains a significant challenge. Additionally, ensuring the robustness of autonomous driving systems in diverse environmental settings and achieving cost-effectiveness for large-scale deployment are ongoing challenges. The fusion of sensor data and information processing is also a critical area that needs further optimization to ensure system stability and reliability.

Despite significant progress in autonomous driving technology, continuous investment in more research and development is still required. This is necessary to address the current technical challenges and continuously enhance the performance and safety of systems, thereby achieving wider applications of autonomous driving technology in daily life and industrial settings.

3. Sensors

3.1. Ultrasonic Sensor

Ultrasonic sensors operate based on the principle of Time-of-Flight (TOF). Traditional ultrasonic sensors first emit a sound wave signal, which is then reflected off an object and received by the sensor. Subsequently, the distance of the object is calculated based on the time the sound wave takes to travel back to the sensor, considering the speed of sound in air [8]. Assuming the measured target is parallel to the emitter, the speed of sound is represented as v , and the time taken is Δt , then the distance L between the sensor and the measured target can be expressed as:

$$L = \frac{1}{2} v \times \Delta t \quad (1)$$

However, the ultrasound sensor cannot directly convert sound waves into a time signal; it requires conversion. Taking the HC-SR04 ultra-sonic sensor as an example, as shown in Figure 2, the HC-SR04 triggers ranging through the IO port TRIG pin by providing a high-level signal. Subsequently, the module automatically sends 8 pulses of 40 kHz square waves to detect if a signal returns. If a signal returns, the ultrasonic sensor outputs a high-level signal through the IO port ECHO pin, and the duration of the high level is the time taken for the ultrasonic wave to travel from emission to return. If these pulses are not reflected back, the echo signal will time out and return to a low level after 38 milliseconds (38 ms), indicating no obstruction within the detection range.

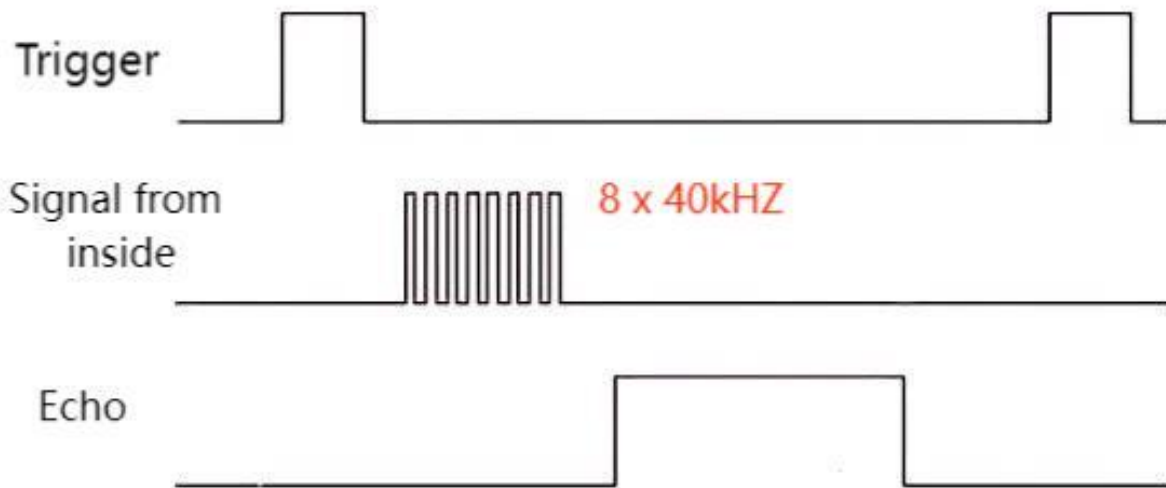


Figure 2: Ultrasonic ranging module HC-SR04 pin timing diagram.

Regarding velocity measurement, the propagation speed of ultrasonic waves is affected by the density of air. The higher the density of air, the faster the propagation speed of ultrasonic waves. Air density is closely related to temperature. According to the temperature compensation principle, after derivation, the relationship between the sound velocity c and temperature T can be described as:

$$c = \sqrt{\frac{\gamma RT}{M}} = c_0 \sqrt{1 + \frac{T}{273K}} \quad (2)$$

The ratio of specific heats, also known as the ratio of heat capacities at constant pressure to constant volume, for air is 1.40. Here, R represents the universal gas constant with a value of $8.314 \text{ kg} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$, while M stands for the molecular weight of the gas, which for air is $28.8 \times 10^{-3} \text{ kg} \cdot \text{mol}^{-1}$. At zero degrees Celsius, the speed of sound in air is 332 m/s. Temperature (T) is measured in Kelvin.

Figure 3 depicts the measurement process of an ultrasonic sensor. Following adjustments for transition time and sound velocity, the ultrasonic sensor accurately measures short distances and finds extensive application in scenarios like backup radars.

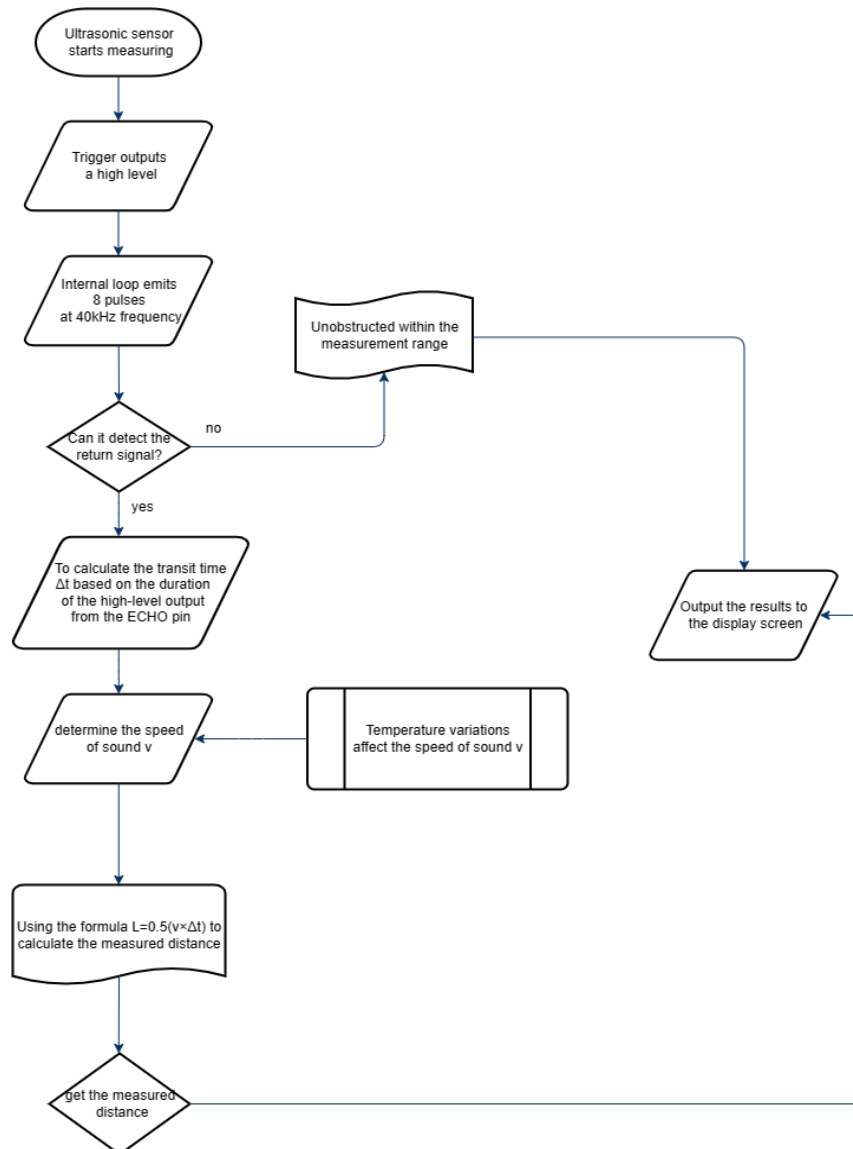


Figure 3: HC-SR04 distance measurement flowchart

3.2. LIDAR

Lidar, short for Light Detection and Ranging, primarily comprises components such as transmitters, receivers, information processing systems, and tracking mechanisms [9]. Its operation relies on the transmission and reception of laser pulses. By emitting high-frequency laser pulses and measuring the time taken for the pulse to return, it determines the distance and position of target objects. The emission and reception of laser beams are extremely rapid, enabling the detection of multiple points in a very short period, thereby constructing precise three-dimensional environmental models. The system achieves the collection, measurement, and transmission of Lidar signals through a Lidar module [7]. Its advantages include high precision, long-range detection capabilities, and rapid data acquisition speed, making it invaluable in applications such as autonomous driving, map creation, and environmental monitoring.

In the context of autonomous driving, Lidar often plays a dominant role in target localization under non-GPS signals. In map creation, as depicted in Figure 4, Lidar observes the surrounding environment and creates maps based on SLAM platforms. However, Lidar also has limitations. While Lidar point clouds contain abundant three-dimensional spatial information, they lack color information and exhibit sparsity [10]. Other drawbacks include high costs, sensitivity to adverse weather conditions (such as rain or snow), and high reflectivity requirements for surface materials. These factors limit its applicability in certain specific scenarios.

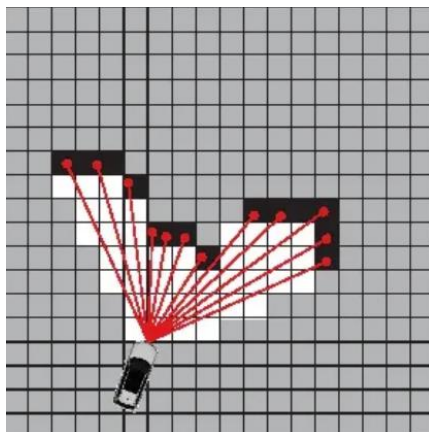


Figure 4: Laser SLAM Schematic Diagram

3.3. Vision Sensor

The working principle of visual sensors relies on optical technology, capturing optical images of the surrounding environment to achieve target localization and identification. Similar to the human visual system, it utilizes cameras or optical sensors to record and convert the light information of objects into electrical signals or digital images. These image data undergo processing and analysis, enabling the system to recognize objects, measure distances and dimensions, and infer the position and orientation of objects. The advantages of visual sensors include high resolution and rich information content, enabling real-time capture of environmental details and providing precise spatial information. They enhance the recognition capability of autonomous driving sensor systems and have a wide range of applications in autonomous driving systems, as depicted in Figure 5 illustrating the layout of visual sensors on Tesla's Model 3 vehicle. However, they are limited by factors such as lighting conditions and weather, which can significantly affect performance in low light or adverse weather conditions, as shown in Figure 6 depicting interference experienced by visual sensors in extreme situations. Additionally, in complex scenes or situations lacking specific textures, their ability to identify objects may be limited, and there may be issues with visual blind spots or obstruction.

Cameras on Tesla Model 3

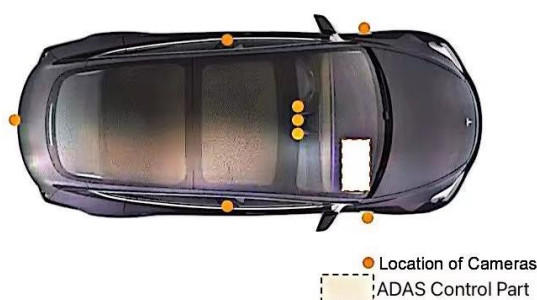


Figure 5: Diagram of Tesla's Autonomous Driving Car Sensor Application.



(a)Obstruction of light causes blurriness.



(b)Extreme weather conditions cause blurriness.

Figure 6: Blurred vision in visual sensors under interference conditions.

4. Application

4.1. Environmental Perception

The reverse radar system, also known as the parking assist system, operates during the process of backing up a vehicle. If there are obstacles in the vehicle's path, the parking distance control system will alert the driver. As shown in Figure 7, the reverse radar system consists of the Reverse Radar ECU, reverse radar buzzer, and several reverse radar sensors installed on the rear bumper. The sensors installed on the bumper include the left, left-center, right-center, and right sensors, embedded from the outside in, as depicted in Figure 8. Each sensor has specified installation positions that must be adhered to; otherwise, it might lead to false alarms. If a rear camera is installed with the reverse radar system, it will display images of the vehicle's rear area on the navigation screen.

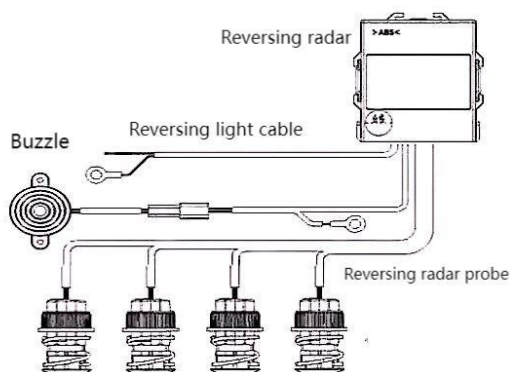


Figure 7: The components of a backup radar system.

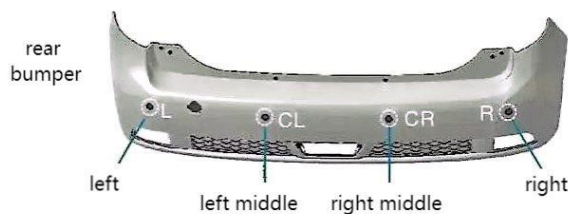


Figure 8: Sensor installation location.

In autonomous driving systems, the reverse radar is typically a part of the vehicle's positioning and perception system, aiding the vehicle in positioning its surroundings and avoiding collisions while reversing. The reverse radar system utilizes ultrasonic signals, controlled by a microcomputer within the reverse radar main unit, to calculate obstacle distances by comparing signal return times during the emission and reception process of the probes. This information is then relayed through different alarm tones by the alarm to alert the driver about the proximity of the vehicle to obstacles.

Reverse radar significantly contributes to the environmental perception and positioning of autonomous vehicles. It effectively harnesses the strong penetration capability, wide emission range, and immunity to light interference of ultrasonic sensors while circumventing their limitations in long-distance measurements. This technology substantially enhances driving safety, reduces accidental collisions, and offers drivers more guidance and convenience when reversing.

4.2. Obstacle Detection

The autonomous driving system is capable of real-time scanning and monitoring of the surroundings of the vehicle. These sensors can identify and accurately locate obstacles on the road, including other vehicles, pedestrians, animals, road signs, and barriers. Through advanced computer vision and deep learning algorithms, the autonomous driving system can analyze and classify detected obstacles in real-time, enabling rapid and precise decision-making to ensure vehicle safety and optimize driving routes. The advancements in autonomous driving sensor positioning

technology enable vehicles to intelligently navigate around ob-stacles, thereby enhancing driving safety and reliability, providing ro-bust support for the development of future transportation systems.

4.3. Vehicle Position

The autonomous driving system collects real-time environmental da-ta through devices such as LiDAR, cameras, radar, and ultrasonic sen-sors. Utilizing deep learning and machine learning techniques, it effi-ciently processes and analyzes this data.

The data gathered by these sensors is used to generate precise envi-ronmental maps encompassing elements like roads, vehicles, pedestri-ans, traffic signals, and obstacles. By merging these maps with real-time sensor data, the autonomous driving system achieves accurate lo-calization and path planning, ensuring safe navigation in complex urban environments or unpredictable road conditions.

Furthermore, autonomous driving technology can continually learn and optimize to adapt to various driving scenarios and road conditions. By accumulating and analyzing data, the system enhances its predictive capabilities for different traffic situations, thereby improving driving safety, efficiency, and comfort. The application of autonomous driving in environmental perception extends beyond the vehicle's own percep-tion abilities, involving connectivity with urban infrastructure and traf-fic management systems, offering broader possibilities for future intel-ligent transportation and city planning.

5. Experiment

Through the above introduction, we have gained an understanding of the sensors and their applications in autonomous driving localization. In this section, the author has designed an experiment to demonstrate the practical application of ultrasonic sensors in a backup radar, illustrating the connection between autonomous driving sensors and the application of autonomous driving localization.

5.1. Experimental Setup

I based on keil software programming and Proteus simulation plat-form to build a reversing radar sensing circuit,, I designed the reversing radar sensing circuit control core for the microcontroller AT89S52, reversing radar system, the physics of the principle of ultrasonic rang-ing is realized by the ultrasonic sensors, so we also want to add the ul-trasonic module [11], ultrasonic transmitter module using the HC-SR04. Because the propagation of the speed of sound is related to the current air temperature, so I additionally added a temperature meas-urement circuit to measure the air temperature at that time, so that the measurement accuracy can meet the requirements. The overall structure includes ultrasonic transmission and reception circuit, microcontroller circuit, keyboard input circuit, power supply circuit, clock circuit, reset circuit, display circuit, temperature measurement circuit and tempera-ture compensation circuit and other parts of the module. Ultrasonic ranging system structure and specific circuit connection diagrams are shown in Figures 9 and 10:

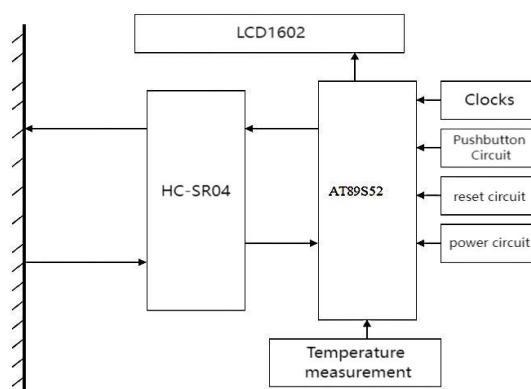


Figure 9: Experimental Circuit Description

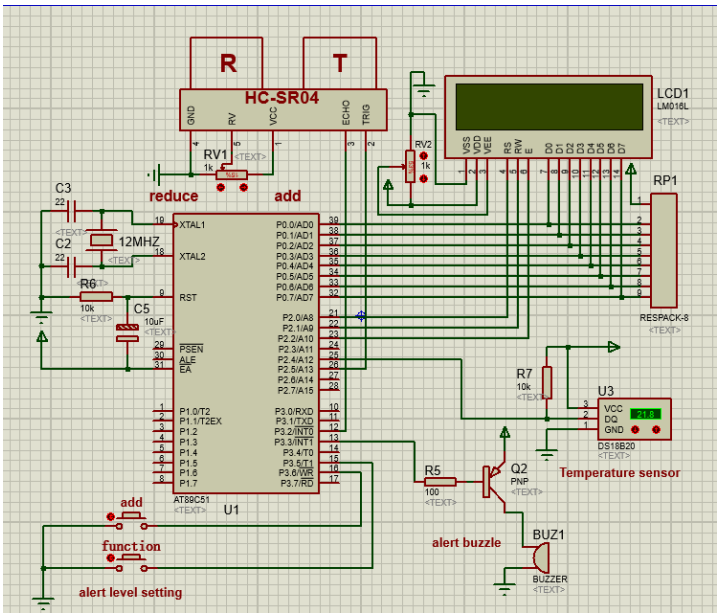


Figure 10: experimental circuit.

Figure 11 shows the working principle of the circuit. Microcontrol-ler to the HC-SR04 Trig pin sends a high level of more than 10us, HC-SR04 will launch 8 cycles of 40kHz ultrasonic waves, when the ultra-sonic waves encountered high-density media reflection bounce back, HC-SR04 automatically calculate the ultrasonic transmission time t , the Echo pin is set to a high level of $t1$ seconds after the pull-down, where $t1 = t$. Temperature measurement circuit to measure the temperature of the air at that time, wait until the data is pulled down, where $t1 = t$. The temperature measurement circuit to measure the temperature of the air at that time, until the data are used to measure the air temperature, and the temperature compensation circuit. The air temperature at that time, wait until the data is sent to the microcontroller after using the software to adjust the ultrasonic propagation speed, so that the measurement ac-curacy can meet the requirements. Then the software to discriminate, calculate, the number of distance and send LED display. Reset the sys-tem with a reset circuit can be carried out after the next test.

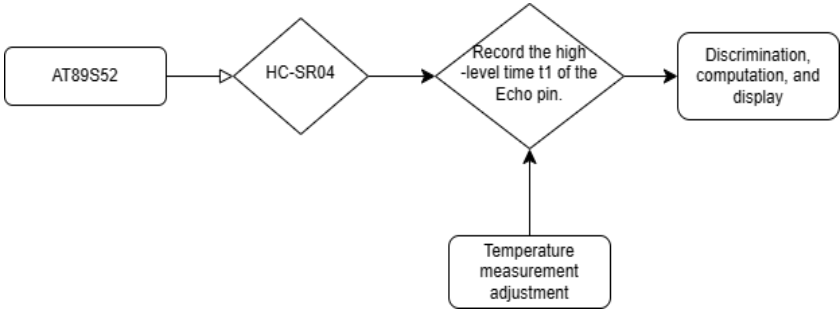


Figure 11: Flowchart of the working principle of the experimental circuit.

The analog circuit can realize a variety of functions, when the meas-urement distance is less than the set distance, the buzzer in the alarm module will beep alarm, and the frequency of beeping increases with the decrease of distance. The circuit also references temperature meas-urements to correct for the speed of sound.

5.2. Data Collection

Through the understanding of the experimental principle, we col-lected a total of two sets of data, respectively, the measurement distance (m) - alarm state data and the measurement distance (m) - buzzer beep-ing frequency (Hz) data, which were used to test the circuit's alarm module and further test the frequency of the beeping with the decrease of the distance of the function. The specific measurement data in the following table1 and table2:

Table 1. Measuring distance - alarm status.

set	real	flag	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35
	1.10		1	1	0	0	0	0	0	0
	1.20		1	1	1	1	0	0	0	0
	1.30		1	1	1	1	1	1	0	0

Table 2. Measuring distance - alarm frequency.

set	real	flag	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15
	1.10		5	4.5	4	3.5	3	2.5	0	0
	1.20		6	5.5	5	4.5	4	3.5	3	2.5
	1.30		7	6.5	6	5.5	5	4.5	4	3.5

5.3. Data Analysis

The author visualizes the above two sets of data separately by Excel drawing, as shown in Figure 12, we can find that the buzzer of the alarm system will work immediately when the measured value is less than the set value. Figure 13 indicates that within the range of the alarm system working, the measured distance is linearly related to the buzzer beeping frequency.

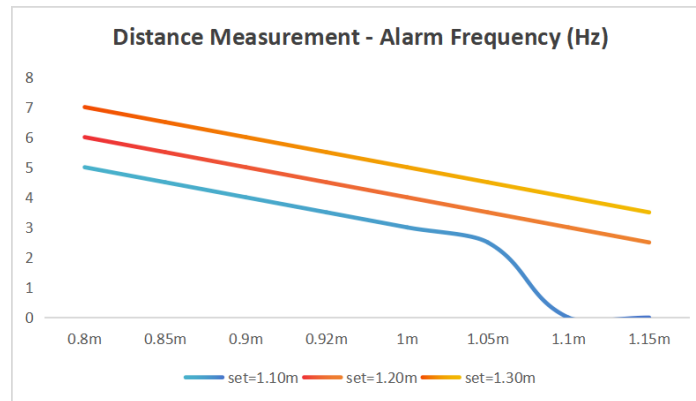


Figure 12: Measuring distance - alarm status.

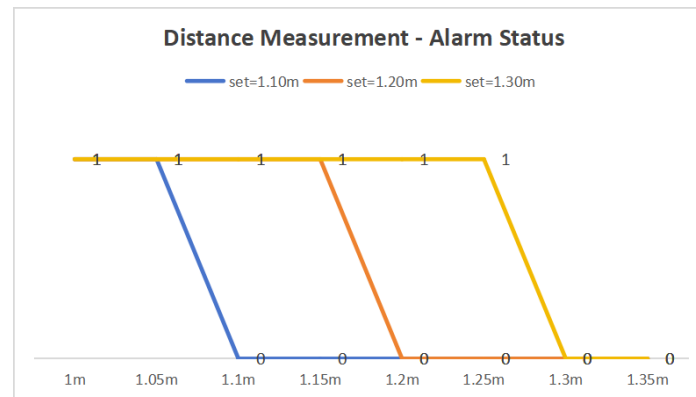


Figure 13: Measuring distance - alarm frequency.

Through the experimental results, we can learn that the simulation experimental circuit designed by the author can realize the main functions of the reversing radar.

6. Conclusion

In this paper, the author provides an overview of targeting techniques for autonomous driving sensors and successfully simulates a reversing radar device, emphasizing the indispensable role of sensors in autonomous driving targeting. These sensor systems provide vehicles with the necessary sensing capabilities for accurate targeting and navigation by collecting, analyzing, and interpreting

data from the surrounding environment in real time. Whether it's LIDAR, cameras, ultra-sonic sensors, or radar, they all work together to form a comprehensive sensing system that helps the vehicle accurately recognize vehicles, pedestrians, road signs, and obstacles on the road.

Future research directions and challenges in the field of autonomous driving lie in the continuous enhancement of sensor technology to achieve higher accuracy and faster target localization and environment sensing. Improving sensor resolution, reducing noise interference, and increasing adaptability to complex roads and adverse weather conditions are among the key challenges. In addition, advances in data fusion and sensor fusion algorithms are essential to integrate information from different sensors and improve system robustness and reliability.

As technology continues to advance, we can foresee that the field of autonomous driving will usher in more advanced and reliable sensor technologies, which will drive the application of self-driving cars in various complex road scenarios. However, to overcome the many challenges, interdisciplinary cooperation and innovation are needed to continuously optimize the sensor system so that it can cope with diverse road situations and ensure the safety and reliability of autonomous driving technology.

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