Predicting the Distance of Objects in the Blind Zone of an Ultrasonic Array

Yi-Zeng Hsieh[1], *Yong-Yi Fanjiang*[2], *Jan-Pan Hwang*[3*]

[1] *Department of Electrical Engineering, National Taiwan University of Science and Technology, Taiwan*
[2] *Department of Computer Science and Information Engineering, Fu Jen Catholic University, Taiwan*
[3] *Department of Information Management, National Chin-Yi University of Technology, Taiwan*
yzhsieh@mail.ntust.edu.tw, yyfanj@csie.fju.edu.tw, jphwang.academic@gmail.com

Abstract

This study is driven by the primary goal of mitigating ultrasound signal interference within blind spots. The presence of overlapping ultrasound signals and objects often leads to erroneous object detection due to the convergence of reflected waves and accumulated reverberations from obstacles, thus creating a blind zone for ultrasound signals. Consequently, measurements conducted within this region frequently yield inaccuracies in judgment and distance estimation. To address these challenges, this research advocates the implementation of an array wall constructed from multiple ultrasound transducers as a foundational solution. The design of this array wall is intricately crafted based on considerations of diffusion angles and directional coefficients within the sound field. The proposed approach involves the emission and collection of multiple signals for comprehensive analysis, facilitated by a distributed computing architecture for signal processing and visualization. By adopting this innovative methodology, the study aims to achieve effective object identification within the blind zone. Furthermore, the research endeavors to develop a prototype system for object detection within blind spots and path planning. To validate the effectiveness of this solution, the Google Maps API will be utilized, shedding light on the challenges associated with measuring distances using ultrasound signals in blind spots.

Keywords: Blind zone, Ultrasonic array, Optimal path

1 Introduction

Automation has become a prevailing trend in modern industries, gradually shifting towards automated measurement and identification processes. Ultrasonic measurement stands out as a favored choice, thanks to its numerous advantages, including non-destructiveness, non-contact nature, immunity to electromagnetic interference, convenience, and cost-effectiveness. Consequently, it finds extensive applications in distance calculations. Apart from its use in underwater terrain detection, ultrasonic waves play a pivotal role in everyday scenarios like parking sensors and military applications, where ultrasonic radar aids in positioning. However, ultrasonic measurements are susceptible to errors due to specific challenges. For instance, when employing ultrasonic waves for distance measurement, obstacles in the line of sight can obstruct objects located behind them, rendering them undetectable. Furthermore, when multiple ultrasonic waves are used for distance measurement, signal echoes may overlap and cause interference, leading to significant inaccuracies in distance measurements. As a result, the primary objective of this research is to address these challenges associated with ultrasonic distance measurement and enhance the design of ultrasonic measurement techniques, including considerations for diffusion angles.

The motivation of this study is to tackle the critical issue of ultrasound signal interference and blocking in blind spots. Blind spots are areas where ultrasound signals can be compromised due to the overlapping of reflected waves and accumulated reverberation waves from obstacles. This interference often leads to errors in object detection and distance measurement. Our study aims to provide a solution to this problem by proposing an innovative approach.

Since this research mainly focuses on the problems of ultrasonic waves in measurement, the research questions are divided into three parts:

(1) Object detection problem: Methods are for handling the problem of object shielding, which leads to ineffective detection.

(2) Ultrasonic signal problem: overlap Methods are for handling the problem of ultrasonic signal overlap and interference.

(3) Sound field problem: Methods are for adjusting the direction coefficient and diffusion angle of the sound field.

In essence, this study aims to provide a novel solution to improve the accuracy of object detection and distance measurement in areas prone to ultrasound signal interference. It emphasizes the importance of addressing this issue, which has implications for various applications, including autonomous navigation and obstacle avoidance systems.

The study focuses on the following key points:

(1) Ultrasound Signal Blocking Issue: The study highlights the challenge of inaccurate object detection and distance measurement caused by the interference of ultrasound signals in blind spots. This issue stems from the overlap of reflected waves and reverberation waves from obstacles.

*Corresponding Author: Jan-Pan Hwang; E-mail: jphwang.academic@gmail.com
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(2) Proposed Solution: The study proposes the use of an array wall made up of multiple ultrasound transducers as a fundamental solution. This array wall is designed based on diffusion angles and directional coefficients of the sound field. By emitting and collecting multiple signals, the study intends to perform unified analysis.

(3) Distributed Computing Architecture: The paper mentions the utilization of a distributed computing architecture for the analysis and display of the collected signals. This approach is intended to enable the identification of objects within the blind zone more accurately.

(4) Prototype System Development: The study states that a prototype system will be developed to demonstrate the practicality of this solution. The Google Maps API will be used to verify the problem of measuring distances in blind spots using ultrasound signals.

The organization of this paper is as following: Section II describes related works and research survey. Section III proposes method of mitigating ultrasound signal interference within blind spots. Section IV shows performance with our algorithms and analyze the results. Section V is this study conclusion.

2 Related Works

This study primarily utilizes an ultrasonic sensor as its core component, comprising an ultrasonic transmitter, receiver, and control circuit. During measurements, it emits a sequence of high-frequency sound waves and captures the signals reflected back from the nearest object, subsequently converting these signals into distance measurements. Notably, its key advantages encompass non-destructive, non-contact capabilities, and immunity to electromagnetic interference. Its insensitivity to light sources is a particularly significant advantage across diverse applications.

The research as documented in [1-3], has successfully implemented automatic on/off faucets by harnessing ultrasonic sensors in conjunction with fuzzy logic. Leveraging the return characteristics of ultrasonic waves and the principles of fuzzy logic [4], these studies have effectively detected whether the water level surpasses predefined limits, thereby facilitating automated control of bathtub faucets. They underscore the pivotal role of ultrasonic waves in distance sensing, complemented by fuzzy logic.

In [5], a novel near-distance phase difference method is proposed, effectively addressing challenges inherent to reflection-type ultrasonic ranging systems. The authors have devised a system with analogous features to a backup radar module, harnessing this setup to measure the near-distance phase difference method. Their experiments have yielded precise measurements across a wide range of test scenarios, showcasing its robust performance.

Wei-Cyuan Jhang et al. have introduced an innovative method in their publication [6] to enable cost-effective ultrasonic sensors for close-range measurements. This method involves utilizing an analog-to-digital module to sample the received wave signal and subsequently analyzing the acquired analog data to determine the precise time of maximum voltage occurrence. This approach enables accurate distance determination between the ultrasonic sensor and the target object. Experimental results underscore the system's capability to measure distances as small as 6mm with high accuracy.

There are some ultrasonic applications [7-14]. Moving sensor nodes that emit ultrasonic waves induce a Doppler shift in the received signals. In [7], the topic of Doppler compensation is explored for small-scale localization utilizing ultrasonic sensors. In [8], a method is developed to mitigate the adverse effects of obstacles in narrowband, time-division multiple access (TDMA) ultrasonic localization systems. This approach builds upon the robust Bayesian classifier for ultrasonic localization (RoBCUL) algorithm, which employs an iteratively reweighted least-squares (IRLS) scheme. While this algorithm boasts a low computational cost, its performance diminishes in the presence of obstacles. [9] introduces a wind measurement method employing three mutually transmitting ultrasonic sensors. This method utilizes a structure comprising three mutually transmitting ultrasonic sensors combined with a cyclic correlation time delay estimation algorithm for estimating ultrasonic transmission times. Subsequently, wind speed and direction values are derived based on the relationship between ultrasonic transmission time and the wind vector.

Capacitive micromachined ultrasonic transducers (CMUTs) represent the next generation of ultrasound transducers, offering versatility across various applications. CMUTs provide high bandwidth and sensitivity while seamlessly integrating with CMOS processes [10]. In [11], the design and measurement of an ultrasonic wireless sensor network within the on-earth Columbus Module are demonstrated. This module serves as a replica of the original module attached to the International Space Station (ISS) and is typically employed for testing new hardware before deployment to the ISS. The reliability of even the most rugged insertion sensors can be compromised under extreme environmental conditions. [12] addresses this challenge by developing an ultrasonic thermometry system for measuring segmental temperature distributions (MSTD) in solid materials, particularly within the contexts of energy conversion processes. [13] employs a horizontal array of ultrasonic sensors for object recognition. Ultrasonic sensors are favored for their ease in obtaining distances from nearby objects without requiring intensive processing. Recent advancements in ultrasound imaging technology have demonstrated superior classification accuracy compared to surface electromyography for predicting hand motions. However, conventional designs often involve large linear array ultrasonic probes or bulky multichannel ultrasonic transducers. [14] has developed wearable ultrasonic sensors (WUS) using a 110-μm thick flexible piezoelectric polymer film, presenting an ergonomic solution for prosthetic and human-machine interface applications.

The key research problem highlighted in the provided our study is the application and enhancement of ultrasonic sensors for distance measurement in various scenarios. This problem encompasses several aspects:

- Accuracy and Precision: Our study underscores the need for precise and accurate distance measurements, especially in scenarios where traditional methods may fall short. This accuracy is crucial for applications such as automatic faucets and obstacle detection.

- Interference Handling: The study acknowledges the importance of addressing interference factors, such as electromagnetic interference and the influence of light sources, which can disrupt or distort ultrasonic signals. Finding ways to maintain measurement reliability in the presence of these interferences is a significant challenge.
- Automation: The research problem involves automating tasks and processes using ultrasonic sensors, such as the automatic on/off control of faucets. Achieving reliable automation based on ultrasonic measurements, especially in real-world applications, requires careful consideration and solution development.
- Enhancement of Measurement Methods: Researchers are exploring novel methods like the near-distance phase difference method (mentioned in [5]) and innovative techniques (as discussed in [6]) to improve the performance and capabilities of ultrasonic sensors. These methods aim to address inherent challenges in ultrasonic ranging systems.
- Cost-Effective Solutions: Developing cost-effective solutions for close-range measurements is another aspect of the research problem. This includes finding ways to optimize sensor performance without significantly increasing costs, as demonstrated by Wei-Cyuan Jhang et al. in [6].

We compared five factors of measurement functions for ultrasonic wall shown in the following Table 1.

Table 1. Five factors of measurement functions for ultrasonic wall comparison table

Accuracy and precision	[1-4], our proposed method
Interference handling	[7-14], our proposed method
Automation	Our proposed method
Enhancement of measurement methods	[5-6], our proposed method
Cost-effective solutions	[6], our proposed method

Functional Data Analysis (FDA), where each data sample represents a function instead of a vector or a matrix, has garnered significant attention within the statistical community in recent years. In [15], the first fuzzy system approach to FDA is introduced, presenting a functional fuzzy regression model referred to as the Functional Fuzzy System (FFS) and its corresponding data-driven learning method. While the linear regression model boasts simplicity and ease of estimation, the presence of irrelevant features can pose challenges in its task execution. [16] introduces a regression feature selection technique designed for scenarios with unknown noise, named the Mixture of Gaussians LASSO (MoG-LASSO). This method enables simultaneous feature selection and model training. Additionally, the Broad Learning System (BLS), an innovative incremental learning algorithm, has been gaining increasing attention and practical application. In [17], a novel distribution-free variant of BLS for regression analysis is proposed, known as the Broad Minimax Probability Learning System (BMPLS).

Path planning holds a crucial role in autonomous robot systems. In [18], a pioneering learning-based path-planning algorithm is presented, comprising a novel generative model built upon Conditional Generative Adversarial Networks (CGANs) and a modified version of the Rapidly Exploring Random Tree star (RRT*) algorithm, referred to as CGAN-RRT* (combining the principles of Rapidly Exploring Random Trees (RRT) and its improved optimal variant, RRT*). Leveraging map information, our CGAN model efficiently generates a probability distribution of viable paths, which the CGAN-RRT* algorithm employs with a nonuniform sampling strategy to identify an optimal path. The issue of obstacle avoidance, particularly concerning autonomous heavy vehicles characterized by a high center of gravity, substantial carrying capacity, and promising commercial potential, has garnered increasing attention in recent years. To address the nonlinear optimization challenge and derive the optimal control steering angle output, [19] formulates an adaptive weight adjustment strategy and a variable predictive duration approach. Furthermore, [20] investigates time-optimal paths for a car-like mobile robot navigating an obstacle-free planar environment.

In summary, the overarching research problem revolves around the effective application, improvement, and cost-effectiveness of ultrasonic sensors for distance measurements while considering challenges like interference, automation, and precision. Researchers are actively working on innovative solutions to address these issues and expand the utility of ultrasonic sensors across various domains.

3 Method

This study is structured into two main components: hardware and software. The control chip employed is the ARM Cortex-M4, which oversees the rotation and measurement functions of the ultrasonic wall. These functions are managed through a self-designed driving circuit and motor. The resulting measurement data is subsequently transmitted to the software component for analysis and integration. The primary tasks encompass the following: 1. Establishing the ultrasonic array wall, 2. Defining the ultrasonic parameter model, 3. Designing the autonomous car, 4. Setting up coordinate systems and area definitions, and 5. Data visualization and software platform design.

The Establishment of the Ultrasonic Array Wall. Our study is a critical aspect of ultrasonic array wall. The HC-SR04 ultrasonic model is primarily employed for distance measurements between obstacles, objects, and the autonomous vehicle, facilitating the vehicle's smooth navigation to its destination. Operating within a voltage range of 3.3V to 5V, this model emits eight 40KHZ square waves during measurements and calculates distances based on the echo signal's time of arrival. Leveraging this characteristic, the study constructs a 4x4 ultrasonic array wall radar system, effectively mitigating blind spots that can occur with flat radar systems by utilizing height differences as shown in Figure 1.

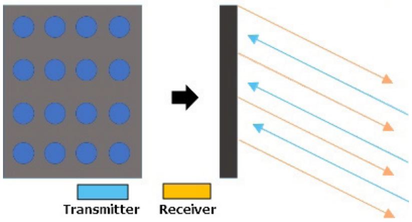

Figure 1. Conceptual diagram of an ultrasonic wall

Establishing the Ultrasonic Parameter Model. Our study involves selecting the appropriate method for ultrasonic ranging, with the two primary methods being the phase shift method and the time-of-flight (TOF) method. In the phase shift method, the distance to be measured is determined by analyzing the phase difference between the transmitted ultrasonic signal and a reference wave reflected from the target object. In contrast, the TOF method, which is the predominant method employed in this study, calculates the distance between the sensor and the target object by measuring the time it takes for the ultrasonic wave to travel through the air.

To compute the time difference (Δt) between transmission and reception in the TOF method, the distance is derived from the length of the reflected echo. Consequently, the time taken for the ultrasonic wave to return is expressed as Δt/2. The distance (d) is then calculated using the speed of light parameter (c), as described by Equation (1).

$$d = c \times \frac{\Delta t}{2}, \quad \textbf{(1)}$$

In the distance calculation system, we can ascertain the energy of the signal emitted by the transmitter by considering the installed impulses and the physical characteristics of the transmitter. If we envision a scenario with a sensor placed in a semi-infinite sound transmission field, comprising a series of points, where each point emits a uniformly frequency-distributed spherical wave outwardly, we can denote "M" as the resultant sound pressure point generated by the superposition of sound pressures at each individual point as shown in Figure 2.

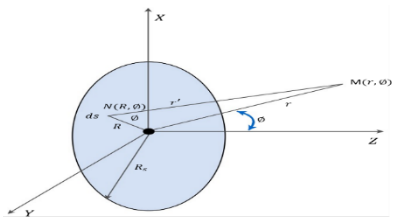

Figure 2. A method for mitigating sound pressure within a magnetic field

In Equation (2), the variables are defined as follows: J1 represents the first-order Bessel function, λ stands for the distance between point M and the sound source, θ represents the angle between the axis originating from point M and the sound source, and K1 is the coefficient that relates to parameters like acoustic impedance, excitation intensity, and the current resonance frequency.

$$P_s(\gamma,\theta) = \frac{K_1 R_S^2}{\lambda_\gamma} \times \frac{2J_1(kR_S sin\theta)}{kR_S sin\theta}, \quad \textbf{(2)}$$

$$D_c = \frac{P_S(\gamma,\theta)}{P_S(\gamma,0)} = \frac{2J_1(kR_S sin\theta)}{kR_S sin\theta}, \quad \textbf{(3)}$$

$$\theta = sin^{-1}\frac{\lambda}{2R_S}, \quad \textbf{(4)}$$

The sound field direction pertains to the beam parameters that channel radiation in a specific direction. The concentration of the beam at point M serves as an indicator of the sound field's intensity. Equation (3) provides the definition of the directional coefficient (DC). When the dimensions of the sensor wafer are predetermined, equation (4) can be utilized to calculate the scattering angle of the sensor. This angle serves as the foundational parameter for the design of the array wall. The analytical data derived from these calculations are subsequently processed by the backend software.

Design of the Autonomous Vehicle. The autonomous vehicle, as conceptualized in this study, incorporates a geared motor (refer to Figure 3) for controlled deceleration. It draws its power from two distinct voltage sources, 5V and 4.7V, derived by dividing the 12V battery. This battery serves as the power source for both the Linkit Smart 7688 and the geared motor. The software determines the required high or low potential, subsequently programming the motor driver based on calculated steps. This adjustment in potential difference governs the vehicle's wheel steering. Commands for forward and backward movements, as well as left and right turns, are executed by configuring the gear's rotation distance. The communication infrastructure is facilitated through the robust computing capabilities of the 7688 and the integrated wireless network module. The communication framework follows a client-server architecture, receiving JSON strings comprising movement instructions sent from the server. Upon parsing these instructions, the vehicle is directed to navigate towards its designated destination.

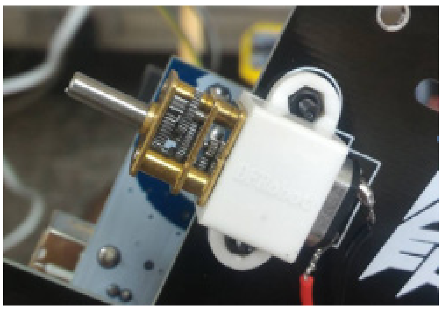

Figure 3. A motor with gear reduction

Setup for Coordinate and Area Conversion: This study necessitates the conversion of a substantial volume of ultrasound data points and their respective spatial coordinates, primarily for visualization on Google Maps. To accomplish this, the data must be transformed from the Matlab format into a structure that can be interpreted by the Map API. Prior to conversion, the data undergoes a classification process based on the scattering angle of the data points, segregating valuable data (within the desired range) from irrelevant noise. The refined data is then transmitted to Matlab for plotting, generating a comprehensive set of points for both radar and path maps.

For converting the distance between the original coordinates at point A and the specified latitude and longitude coordinates at point B, the Haversine formula (as described in equations 5 and 6) is employed. This calculation aids in establishing distance conversions within the user-defined area of interest. The processed data is subsequently integrated with Google Maps to facilitate its presentation and visualization.

$$d = 2R \times \arcsin\left(\sqrt{sin^2\left(\frac{\varnothing 2 - \varnothing 1}{2}\right) + cos\varnothing 1 cos\varnothing 2 sin^2\left(\frac{\lambda 2 - \lambda 1}{2}\right)}\right), \quad (5)$$

In the provided equation, the variable, d, signifies the distance between two points situated on the surface of a sphere, where R corresponds to the radius of the sphere, such as the Earth. The geographical coordinates of these two points are represented as (Ø1, λ1) and (Ø2, λ2), where (Ø1, λ1) denotes the latitude and longitude of the first point, and (Ø2, λ2) denotes the latitude and longitude of the second point.

$$Conversion\ A = \frac{A \times \sqrt{\left(\frac{x_a \times y_a \times 10^{10}}{x_b \times y_b}\right) \times \frac{1}{4}}}{-111.19} + center\ point\ B(x, y), \quad (6)$$

Equation (6) serves the purpose of converting coordinates from the Matlab format (A) to the corresponding geographical location on Google Maps (B) through the application of a scale factor. Within this equation, both latitude and longitude are transformed into kilometers. However, as the base unit of area in A is measured in square centimeters (cm^2), the unit of area in B is adjusted accordingly and scaled up by multiple square kilometers (km^2).

Data Display and Software Platform Design: The analysis and display platform employed in this study encompass a multi-language framework, utilizing a distributed architecture for computation. The data exchange process is structured into four distinct stages.

Firstly, the host computer receives incoming data, conducts data sorting, and executes data grouping and classification tasks using PHP and Visual Studio.

Secondly, the data is transmitted to Matlab for the computation of the optimal path and identification of obstacle points, and subsequently, the data points are stored in the MySQL database.

Thirdly, leveraging the formulas outlined in Equations 5 and 6 to convert the coordinates, the obstacles, and the optimal movement path are visually represented on Google Maps with the assistance of JavaScript (JS).

Lastly, control signals are dispatched to the hardware terminal for command execution.

Design Principle Involving Height Differences. Figure 4 illustrates the experimental setup, where an obstacle is positioned at a distance “x” from the ultrasonic sensor. In this context, we establish the ultrasonic array wall as being situated at the origin, defining the angle between the ultrasonic sensor’s direction and the vertical line as “θ.” The ultrasonic sensor is positioned at a height of “h,” while the separation between the ultrasonic array wall and the obstacle is represented as “d.” We denote the angle between the line connecting the ultrasonic sensor and the obstacle and the vertical line as “φ.” The yellow block delineates the ultrasonic waves’ sensing range.

Figure 4 reveals that the ultrasonic sensors are strategically positioned at varying heights. This design choice enables the ultrasonic waves to effectively detect obstacles located behind other obstacles. Consequently, a four-layer high ultrasonic wall configuration is employed to mitigate monitoring errors stemming from obstruction by obstacles.

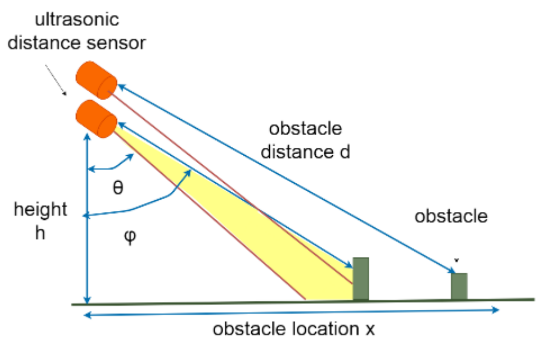

Figure 4. Conceptual diagram illustrating the design for height variation

Design Principle for Angle Differences. Through experimentation, it was determined that the ultrasonic sensor possesses a detection range limited to 70 degrees. To expand the detection capabilities of the ultrasonic array wall to cover a range of 180 degrees, a minimum of three ultrasonic sensors is essential. During observations, it became apparent that arranging the sensors horizontally at a 90-degree angle did not yield significant improvements. Subsequent testing revealed that the optimal configuration, providing maximum coverage while minimizing overlap, occurs when the angle between the sensors is set at 135 degrees. However, since the primary objective of this project centers on detecting nearby objects, adopting a 135-degree design would result in a blind spot that is too substantial for the intended sensing area. Consequently, a compromise was reached, selecting a 165-degree angle, although it doesn’t encompass the full 180-degree range. To achieve extensive detection coverage, the array wall is rotated, with each face covering a 15-degree span, undergoing 12 scans from left to right, as depicted in Figure 5.

4 Experiment Results

To establish fuzzy logic, we use a 12-sensor ultrasonic array wall to reduce radar mapping and noise problems and speed up the system processing time. We use the method of upper and lower threshold values, where data greater than 100 cm or abnormal data is ignored, and the number of sensors processed is reduced to less than 10.

Fuzzy logic is a process of quantifying general cognitive data. First, we must determine which input and output variables to use and decide on the quantity of each linguistic variable term. Then, for each term, we define its membership function. In this project, we use reverse processing to reduce the number of ultra-sonic data received by reducing linguistic terms. We then create a knowledge rule base for fuzzy control by arranging rules based on the desired system response. This knowledge rule base is critical to the correct operation of the system, and we must be clear about the required actions. Once the rule base is established, we use defuzzification to convert the output linguistic variable term into a numerical value.

The physical result of the ultrasonic array wall can be seen in Figure 6. It detects small obstacles behind large obstacles through a four-layer high array wall, which is then transmitted to the software for processing. Figure 7 shows the web page display, where the width of the closer obstacle is narrower while the farther one is wider. This is mainly due to the distortion of the object caused by the rotation of the ultrasonic array wall during scanning, resulting in the opposite situation in the radar map compared to the actual situation.

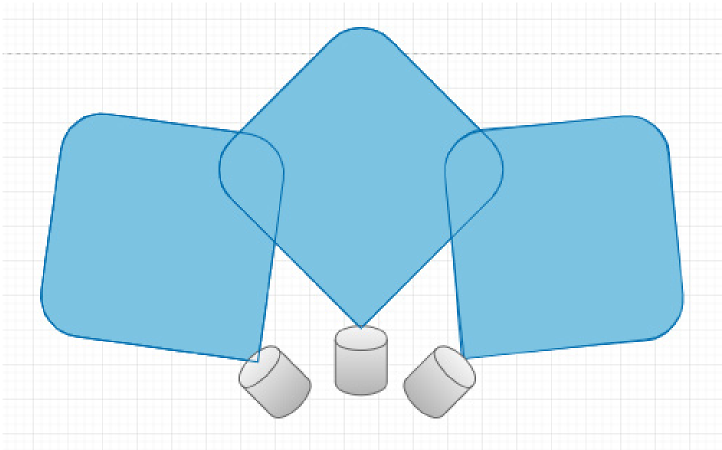

Figure 5. Diagram depicting an ultrasonic sensor array arranged at a 15-degree angle

Figure 6. A photograph of the completed ultrasonic array wall device

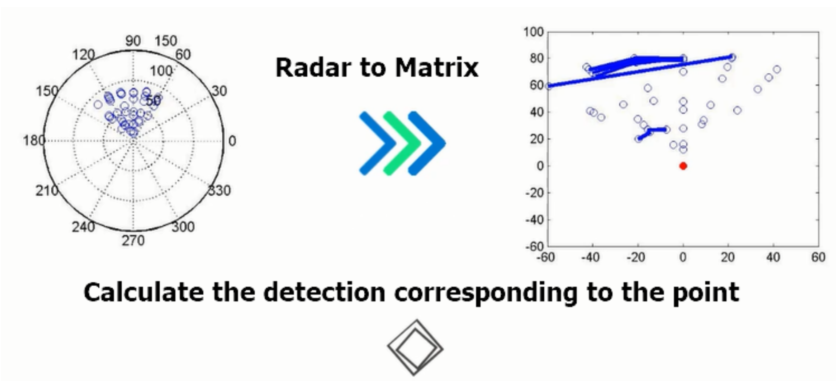

Figure 7. Real-world outcomes from ultrasonic array wall detection

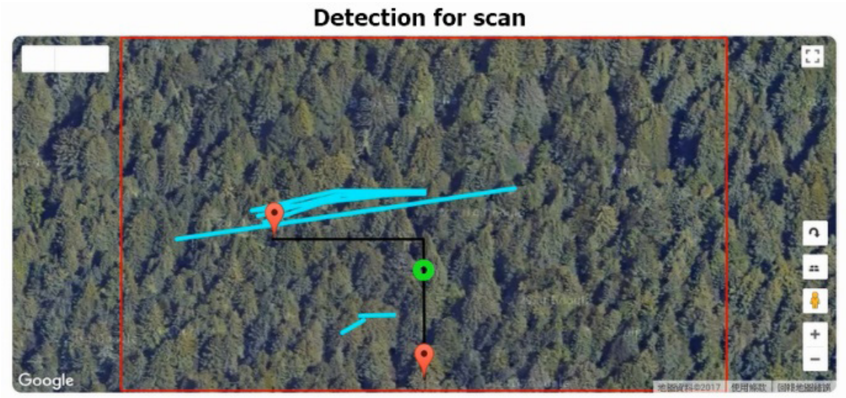

Figure 8. Presentation of the optimal path result (indicated by the dark line) on Google Maps

Table 2. The estimated distance comparison table for 7 zones using different regression models [15-17]

	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G
[15]	20.53 cm	61.8 cm	18.39 cm	32.81 cm	26.97 cm	15.11 cm	19.39 cm
[16]	15.11 cm	40.6 cm	16.22 cm	30.25 cm	25.75 cm	12.85 cm	17.25 cm
[17]	6.03 cm	25.33 cm	15.93 cm	25.78 cm	22.67 cm	7.54 cm	11.74 cm

Table 3. The estimated optimal path comparison table for 7 zones using different path tacking models [18-20] and A* algorithm

	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G
A*	125.38 cm	79.81 cm	37.25 cm	67.31 cm	82.34 cm	26.35 cm	15.68 cm
[18]	112.11 cm	92.33 cm	33.57 cm	65.58 cm	80.11 cm	28.59 cm	17.55 cm
[19]	86.31 cm	106.25 cm	38.45 cm	67.27 cm	85.94 cm	35.73 cm	16.25 cm
[20]	50.77 cm	85.28 cm	33.27 cm	60.91 cm	82.11 cm	20.49 cm	13.81 cm

To obtain the smooth ultrasonic array, the regression method is adopted to estimate the real distance from the target. The three regression methods [15-17] are used to compare the mean square error (MSE) of the real distance for 7 zones as shown in the Table 1. Because our zone is nonlinear distribution, the performance in [17] is better than other nonlinear regression models. According to Table 2, we can find our system can be efficiency to find the blind spot by ultrasonic array.

The result of finding the optimal path for the target object was achieved by using either the A* algorithm or Dynamic Programming (DP) to select the shortest path. Eventually, the A* algorithm was chosen considering the actual coordination of the autonomous car. During movement, it takes several seconds for the car to respond to left and right turns. Although the A* algorithm may not always find the shortest path, it presents the most suitable path for the actual movement of the car.

The A* algorithm is primarily designed to find the path with the lowest cost. It combines the advantages of the Best-First Search and Dijkstra's algorithm, improving the efficiency of the search algorithm while also ensuring the best path at a low cost. If g(n) represents the actual distance from the starting point to any vertex n, and h(n) represents the estimated distance from any vertex n to the target vertex, where the estimated distance changes with the estimation function used, the evaluation equation for the A* algorithm (7) is:

$$f(n) = g(n) + h(n) \tag{7}$$

The primary emphasis of the estimation function shifts to the distance analysis of autonomous cars. It integrates the spatial separation needed for directional changes into the vehicle's overall travel distance, allowing us to ascertain the distance cost related to each grid from the starting point. Additionally, we have conducted a comparative analysis of the A* algorithm with other models [18-20], as depicted in Table 3. Although A* may not excel across all seven zones, its ability to operate efficiently on edge devices without demanding extensive computational resources stands out as a significant advantage. In certain zones, the accuracy of the measured distances might introduce errors, affecting the determination of the most efficient route. Nevertheless, our method proactively addresses this challenge by identifying blind spots and providing a robust solution to the efficient route dilemma.

After inputting the data into the software, the raw data is first redefined in terms of coordinates to be processed in Matlab. Then, the overall coordinates are mirrored to achieve the desired format before being sent to Matlab for computation. To calculate the optimal low-cost path, we mark it along with obstacles on Google Maps. The resulting display is shown in Figure 8.

5 Conclusion

This study employs HC-SR04 ultrasonic arrays at various angles and elevations to emit signals and uniformly stores the returning data in a database. To manage and display this data, Visual Basic calls MATLAB for data retrieval from MySQL, and PHP is used for web presentation. During this process, several challenges were encountered, particularly in determining the most effective algorithm for the shortest path and designing the ultrasonic array wall's angle. While the referenced literature provided optimal angles for broad detection, pinpointing the precise location of the primary target required structural analysis and numerous iterations to achieve the current outcome.

In an era marked by frequent natural disasters, the objective is to harness technology to enhance disaster relief efforts, aiming for speed and efficiency while minimizing human risk. This project's completion is seen as a stepping stone, with hopes for continuous improvement to offer more comprehensive support in the future.

In summary, our primary research revolves around creating an efficient and precise autonomous navigation system utilizing fuzzy logic and an ultrasonic array wall. This entails tackling various challenges related to data processing, control systems, and path planning to enhance the application of autonomous systems in disaster relief and other critical applications.

Acknowledgments

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Biographies

Yi-Zeng Hsieh has received the B.S., M.S., and Ph.D. degrees in computer science and information engineering from National Central University, Taoyuan, Taiwan, in 2004, 2006, and 2012, respectively. He is currently a Professor of Department of Electrical Engineering at National Taiwan University of Science and Technology. His current research interests include neural networks, pattern recognition, image processing, machine learning, and deep learning.

Yong-Yi Fanjiang (Senior Member, IEEE) received a Ph.D. degree in computer science and information engineering from the National Central University, Taoyuan City, Taiwan, in 2004. He is currently a Professor at the Department of Computer Science and Information Engineering and the Director of the Center of Information Technology at Fu Jen Catholic University. His research interests include service-oriented computing, software engineering, and semantic web.

Jan-Pan Hwang received a Ph. D. in Engineering Science from the National Cheng-Kung University, Taiwan. Now, he is an assistant professor of information management at National Chin-Yi University. His research is focused on the emerging application of big data, maker education, IoT-based applications of big data, maker education, IoT-based sensor technology applied in WBL, and educational technology.