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An edge AI based real-time spatial monitoring system

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Abstract

Sensors 4.0 are indispensable components of Industry 4.0. Ultrasonic sensors play a crucial role for enabling automation in the current era of Industry 4.0. The purpose of this study is to explore the potential of using affordable and accessible technology to tackle contemporary spatial management challenges. The proposed system caters to the growing need for effective personal space management due to increasing population density and offers a practical solution for remote monitoring and supervision of occupancy spaces. An independent proximity sensing system is developed by utilizing an ultrasonic sensor (HcSr04) integrated with the STM32F401RE microprocessor board. The methodology involves employing ultrasonic sensors for precise distance measurement and real-time spatial boundary monitoring. The major findings highlight the system's effectiveness in ensuring accurate and timely detection of obstacles with a classification of 100% precision within the predefined distance ranges. The study indicates that this system can significantly enhance spatial management and opens avenues for further innovations in proximity sensing applications.

Subject Classification: *68T27.*

Keywords: *STM32F401RE microprocessor board, Ultrasonic sensors, Distance monitoring, Obstacle detection, Edge AI.*

1. Introduction

Sensors have been playing a crucial role in both routine and commercial applications in various industries. With the advent of Industry 4.0, whose primary goal is to automate industrial tasks, there was an increase in the production of the manufacturing industries. Different

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types of sensors, their capabilities, the implementation process, and applications of sensors beneficial for Industry 4.0 are discussed in [1]. Conventional manufacturing processes have undergone paradigm shift because of implementation of cutting-edge technologies [2]. The article of [3] provides a bibliometric evaluation of the role of Industry 4.0 sensors in digitization process. Ultrasonic sensors can add value throughout the supply chain and are used in Industry 4.0 to automate and exchange data in manufacturing. Among the applications of these in Industry 4.0 are packaging, robots, membrane fouling, anti-collision detection, crowd detection, contouring or profiling, detection of presence, box sorting, trash collection vehicle control, pallet detection with forklifts and bottle counting. A collision detection and alert mechanism using an ultrasonic sensor interfaced with a microprocessor, as well as an alarm unit is proposed in [4].Further, these sensors enable designing of intelligent systems like an affordable detection (hands-free) and obstacle avoidance system with increased mobility for visually impaired individuals [5,6]. Further, automatic object detection and technology to avoid collision is increasingly popular and essential in unmanned vehicles e.g. in obstacle detection in Self-Controlled Cars [7]. In [8,9], authors proposed object detection and tracking from video with varying illumination. Besides these specified usages, technology holds immense potential across various industries, revolutionizing safety, efficiency, and automation [10-13]. Spatial monitoring, using a more relevant and cheap technology, i.e., using ultrasonic sensors, an application which has not been discussed till date by researchers, is being discussed in this paper. Our research paper aims to provide a basic approach for making such remote monitoring systems which can also serve for detection of objects as well as applications where collision avoidance is required.

The paper has been structured as, section 1 focusses on the introduction followed by the application scenario of the proposed model as discussed in section 2. The Literature Survey is tabulated in section 3. Section 4 explains the proposed methodology. The result of the conducted experiment is covered in section 5 and section 6 discusses the conclusion and future scopes in this area.

2. Application Scenario

The proposed module can be used in several places where proximity and space maintenance are concerned, like in public queue monitoring, parking spaces, in Elderly Care, enhancing patient care and support. The prime application is in Autonomous Vehicles i.e. in self-driving vehicles, where the stopping and starting of the car is defined as a function of a specific distance classified by the speed of the car [14]. Other applications

Table 1

Use cases and approaches for obstacle avoidance

Ref. No.	Technology Used	Evaluation Metric	Data Set	Advantages	Limitations
[5]	Ultrasonic and IMU sensors were used to collect data using Raspberry Pi4B..	Accuracy, Precision, F1-Score Construction time, Model Size	Data was generated using sensors	Effectively detect obstacles in real time and provide warnings. Highly efficient wearable device.	Sensors used are costly and not so precise. Hence overall system's accuracy and reliability was less.
[10]	USS3 ultrasonic sensors, Reference sensors (laser range finder, FOG, total station) measured actual distances, angles, and positions.	Maximum Error and RMS Error. Orientation: -11.23^0 &4.06^0 position 3cm, 0.714cm	Self-generated	Reduced Labor in Greenhouse Operations: internal noise removal.	Results for orientation was not accurate.
[11]	System for detecting obstacles and avoiding collision in unmanned aerial vehicles (UAVs) using ultrasonic sensors	Maximum peak frequency. Cross correlation of raw data and Power Spectrum Density (PSD). PSD, Energy Spectrum Density.	Self-generated	Low Power Consumption:	Only $+/-6^0$ improvement in the field of view.
Proposed Model	STM32F401RE microprocessor-based board and HcSr04VS sensors were used to create a data set which was in turn used to train the model.	Distance in cm	Self-generated.	Our system enables more precise distance monitoring between sensor and obstacles. This enables system to make decision for further movements.	Models are trained on real time data collected using sensors. Hence data set was not large enough. This affected accuracy of the system.

can be enumerated as drone deliveries in various environments, from urban areas to remote locations [15].

3. Literature Review

Various use cases and approaches for obstacle avoidance are enlisted below with their technology used and their advantages being highlighted in Table 1.

Proposed Methodology

The aim of proposed work is to calculate the distance to the obstacle, classify this distance and provide feedback to the user, with use of an ultrasonic sensor and an LCD screen interfaced to the STM32CubeIDE and Nucleo-F401RE board. This provides real-time distance information and thereby providing smart solution for obstacle avoidance. The detailed flowchart is shown in Figure 1. The sensor used is HC-SR04 which determines the distance between the sensor and the object. The HC-SR04 ultrasonic sensor makes use of sonar technology. It offers efficient contactless range detection with reasonable accuracy and consistent readings in an user friendly environment. It detects objects within range from 2cm to 400 cm [12].

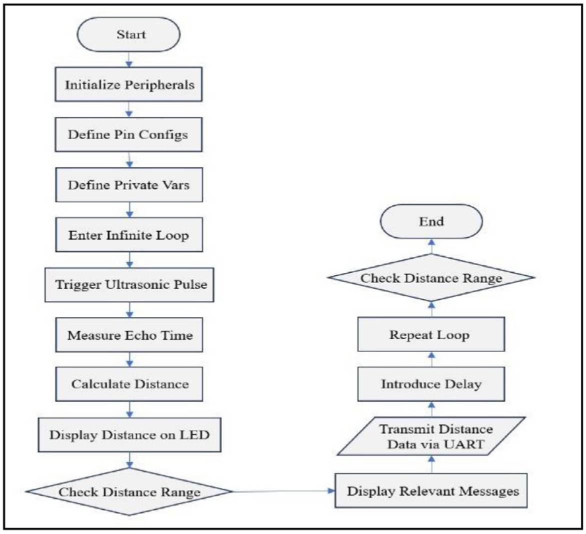

Figure 1

Proposed Methodology

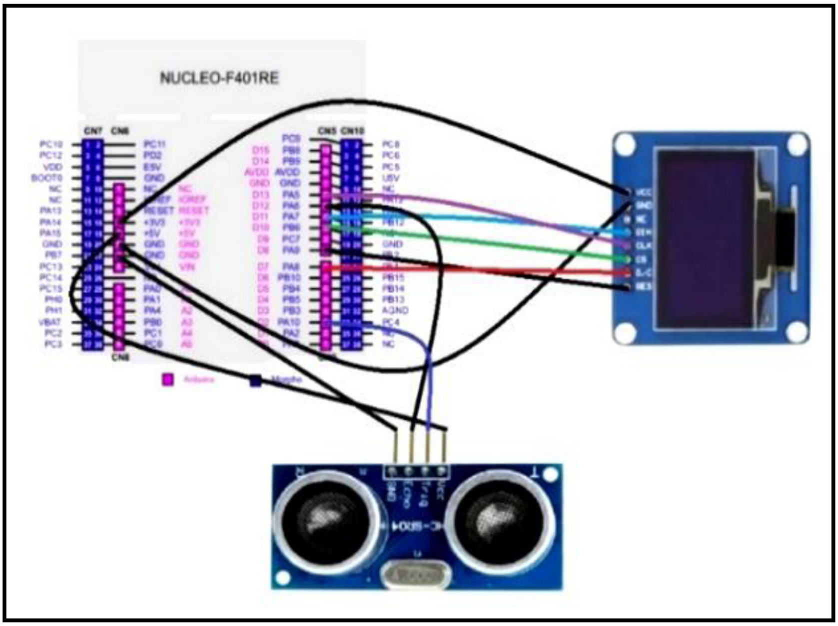

Figure 2

Interfacing Diagram

Sensors operation is unaffected by presence of sunlight or black material like sharp rangefinders. The Interfacing diagram of NUCLEO-F401RE with the ultrasonic sensor and the LCD screen has been shown in Figure 2. When the ultrasonic waves encounter an object, they are reflected back toward the receiver module of the sensor, which in turn detects the reflected waves thereby measuring the time it takes for them to return. The distance between the sensor and the object is determined by the time interval. By knowing the to and for propagation period of the waves between the object and the sensor, the distance can be calculated using the formula: distance = (time * speed of sound) /2.

4. Experimental Results

The real time data set is classified through machine learning models. The project involves real time monitoring data point representing the distance calculated using the relationship of {(time stamp registered on echo pin of ultrasonic sensor) x (speed of sound i.e., 343 m/s at room temperature / 2)} and is discrete. This provides instant classification of

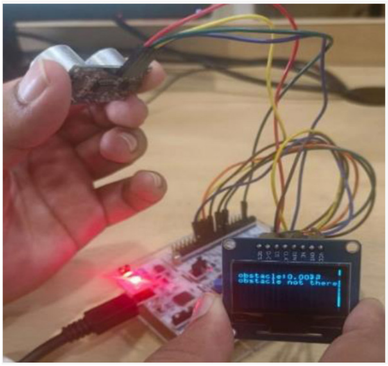

Figure 3

Anomaly (obstacle detection)

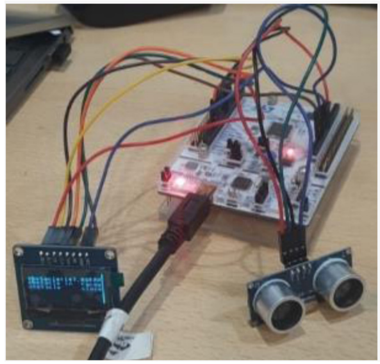

Figure 4

Classification 1 (distance classification)

recorded distance. The LCD display screen displays the distance between the obstacle and the sensor. This is shown in figure 3. The obtained output can be analysed as, Anomaly:- For 2cm to 400 cm: we get the result as "obstacle there" and distance= b/w (20.00 to 4000.00) (in mm). For beyond 400 cm: we get the result as "obstacle not there" and distance=0.00(in mm). Classification1:- For the distance between (50.00 - 1000.00), we get the result as "obstacle close" as shown in figure 4. Classification 2:- For the distance between (20.00 – 50.00), we get the result "obstacle too close" as shown in figure 5.

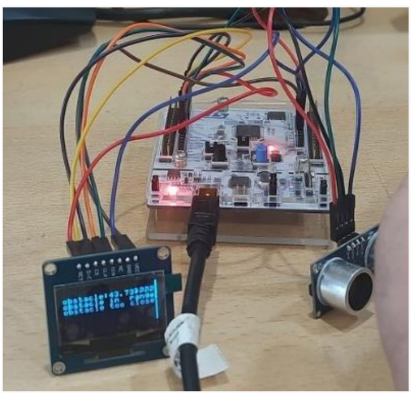

Figure 5

Classification 2 (distance classification)

5. Conclusion

The proposed Ultrasonic Obstacle Avoidance System, powered by an STM32 Nucleo-401RE and ultrasonic sensor, estimates the distance of the obstacle in real time and classifies the range (being too close or not too close) as well as sends text alert to the user about the distance to the obstacle as well as range. To elaborate this, this system classifies measured distances into two classes with “obstacle being within range” and “obstacle not being within range”. According to user input, further, with obstacle “being close” and “very close” when classified into “obstacle within range”, set as the limitation markers to specific distance measured adding specific functionality to it. Thus our project acts as both anomaly (obstacle) detection as well as classification model (for distance classification). Future scope of this work involves the use of a larger dataset for training the model and a more powerful ultrasound sensor for sensing objects at larger distances so that this system can be efficiently used for real-time applications in day - to day life scenarios.

Author’s Contribution :

Individual authors contributed towards, literature survey of existing technologies, the gaps in the existing work, interfacing of various components and generating data sets for training the AI model, testing the hardware in the lab setup, technical content writing, table formation and overall formatting, citing references etc. All the authors declare that they have no conflict of interest.

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