MACHINE LEARNING – ML1

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Reliability test and improvement of a sensor system for object detection

1. Introduction

Research and development efforts in contemporary autonomous systems have focused on object-sensing techniques tailored for applications such as autonomous driving, navigation, and security systems. However, as these automated applications become increasingly prevalent, ensuring community safety poses a substantial challenge. Consequently, there is a clear demand for a system capable of detecting objects, and their position using different Machine Learning algorithms to safeguard humans from accidents involving autonomous systems. On the other hand, implementing the embedded system for object sensing in autonomous systems is promising due to its low cost and high level of reliability compared to literature approaches.

This project centers on the exploration and implementation of the ML method to improve an existing embedded sensor system designed for object sensing and distance measurement by detecting the first echo detection of an ultrasonic sensor (US). To measure distance, it is necessary to reliably determine the position of the first echo to calculate the time of flight, and subsequently, compute the distance. The traditional approaches seem to focus on finding the maximum amplitude to discover the first echo position. Despite their efficiency in utilizing minimal computing time, these approaches are error-prone in cases where the later echo exhibits a higher amplitude than the first one. To address this, Machine Learning (ML) models such as NLP or CNN can be trained to reliably detect the position of the first echo, contributing to the precision of distance measurement.

In this project, the primary goal is to evaluate and enhance the reliability of the implemented ML model. For a reliable evaluation, the distance measurement obtained by using the implemented ML method will be assessed through the detection of various objects with different heights and positions.

2. Theoretical Background

This project is to improve an embedded system with an ultrasonic sensor and the embedded system Red Pitaya (RP) for reliable object detection. The system can detect objects and measure the distance by calculating the time of Flight (ToF). The key objective is to detect the position of the first echo and analyze the frequency spectrum of the reflected ultrasound waves from the reflecting surface.

As shown in Fig. 1, the ultrasonic pulse-echo method is used to calculate the distance of the object from the sensor. For that, the time of Flight is measured by the sensor i.e., the time taken by the ultrasonic wave to travel from the sensor to the object and back. The ToF is measured using the time it takes for the ultrasonic signal to be transmitted, reflected off an object, and returned to the sensor. The ToF is then used in the following formula to calculate the distance:

$$\text{Distance (x)} = \frac{\text{ToF (t)} \times \text{Speed of Sound (c)}}{2} + offset$$

where,

- Distance is the distance between the object and the sensor.
- Time of Flight is the time taken for the ultrasonic signal to travel from the sensor to the object and back.
- Speed of Sound is the speed at which sound waves travel in the medium (air, in most cases).

The commonly used speed of sound in air at room temperature is approximately 343.2 meters per second. The division by 2 in the formula is because the ToF represents the total time it takes for the signal to travel to the object and back. To get the one-way distance, we divide by 2.

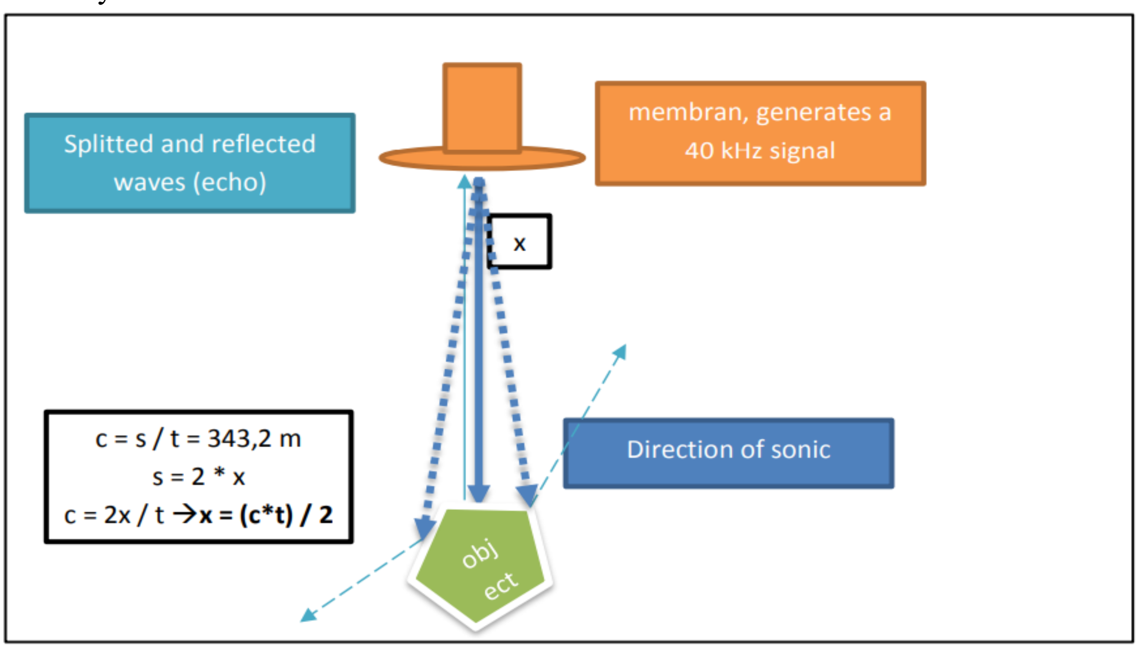

Figure 1: Ultrasonic pulse-echo method

2.1. Hardware and Experimental Setup

This project employs the SRF-02 ultrasonic sensor to determine the position of an object. An analog-digital conversion (ADC) input of the RP is connected to receive the signals from the US sensor in analog form and digitize them. The RP stores and analyzes the data internally. The RP runs a Linux operating system with GCC2 (GNU compiler collection) to compile C code. The RP program is operated in the background and can deliver the data to any PC through UDP. The system utilizes ultrasonic pulsed waves to ascertain the object's position. A graphical user interface (GUI) is employed to both save data in a text file and present visualized results to the user. Figure 2 illustrates the actual hardware of the Red Pitaya (RP) embedded system with ultrasonic sensor. Figure 3 illustrates the simple data flow within the system.

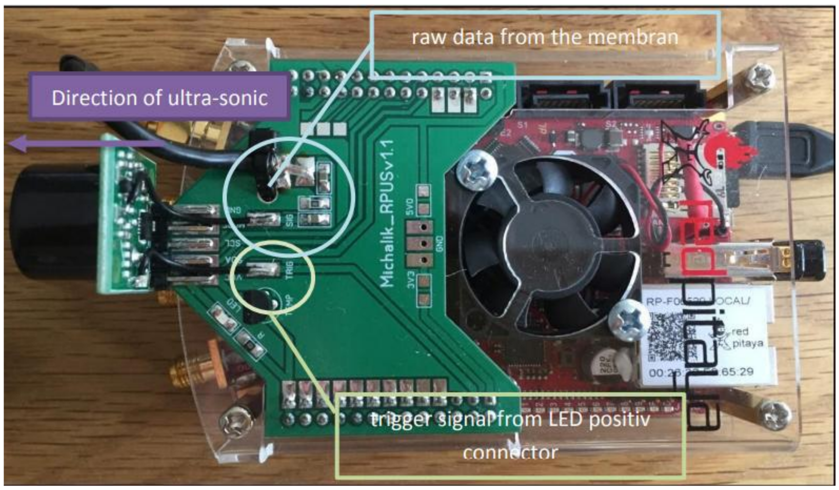

Figure 2: Hardware of Red Pitaya embedded system with ultrasonic sensor

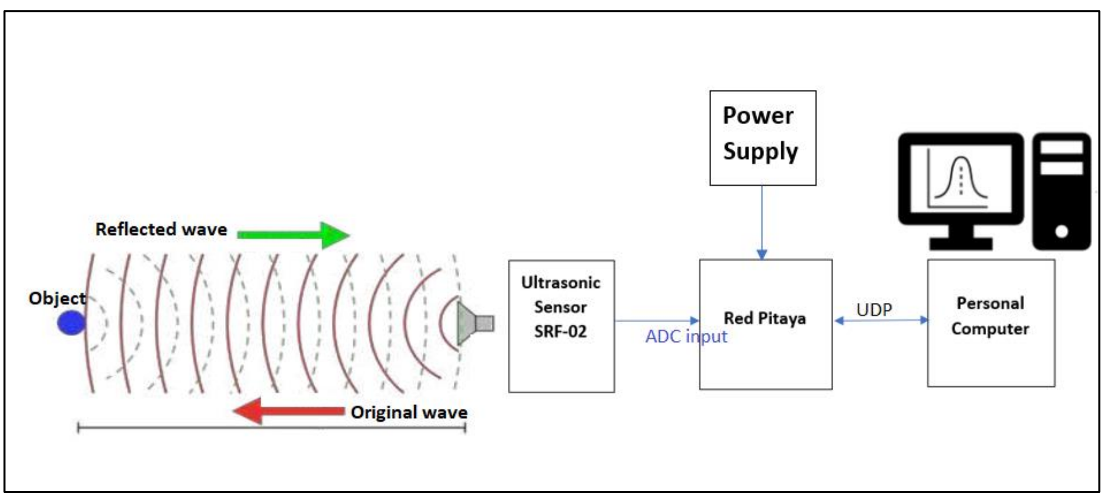

Figure 3: Block diagram of Ultrasonic sensor with Red Pitaya (RP)

The ultrasonic sensor is affixed to a vertical stand in a downward-facing orientation, as depicted in Figure 4. The sensor is positioned at a height of 2 meters and 7 centimeters from the floor. Measurements are conducted using this configuration, focusing on an object, a blue box with a height of 28 centimeters (Figure 5). The analysis involves the examination of ADC measurements to comprehend the functionality of the US wave's ADC feature. Various object positions are explored to observe the alterations in the ADC plots corresponding to reflections.

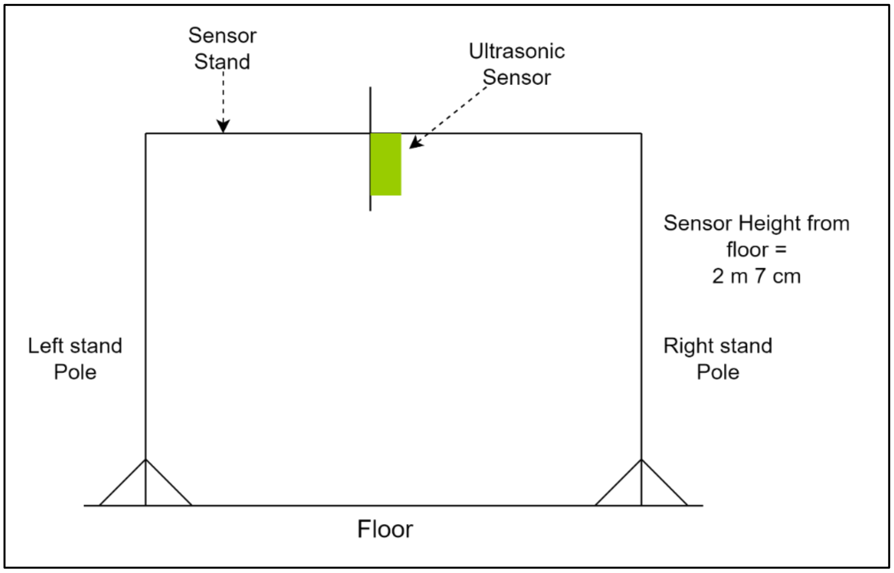

Figure 4: Diagrammatic Representation of Experimental Setup

Figure 5: Blue Box (an object used for measurement)

2.2. Software

All the software for RP is written in C programming language. The software for Microsoft Machine is written in C#. To read, write, modify, compile, and save any kind of software, the following programs are used in this project: VS Code, UDP client, WinSCP, and Putty.

For this project, the experiment aims to determine the distance of the first reflection utilizing the GUI designed for the Red Pitaya (RP) System. This software initiates the ultrasonic sensor "SRF-02" and retrieves the reflected signal captured by the sensor. The obtained data is temporarily stored on the RP System and later analyzed internally. The Red Pitaya software operates as a background daemon, sending data to any PC in the foreground through UDP. The graphical user interface (GUI) of the software can save data in a text file and display real-time data from the RP.

In this context, version GUI SW V0.23 is employed, as illustrated in Figure 6, to comprehend the pattern of object reflection by the ultrasonic sensor. The ADC measurements from the ultrasonic sensor, when plotted, reveal peaks with significantly higher amplitudes, indicating the presence of an object.

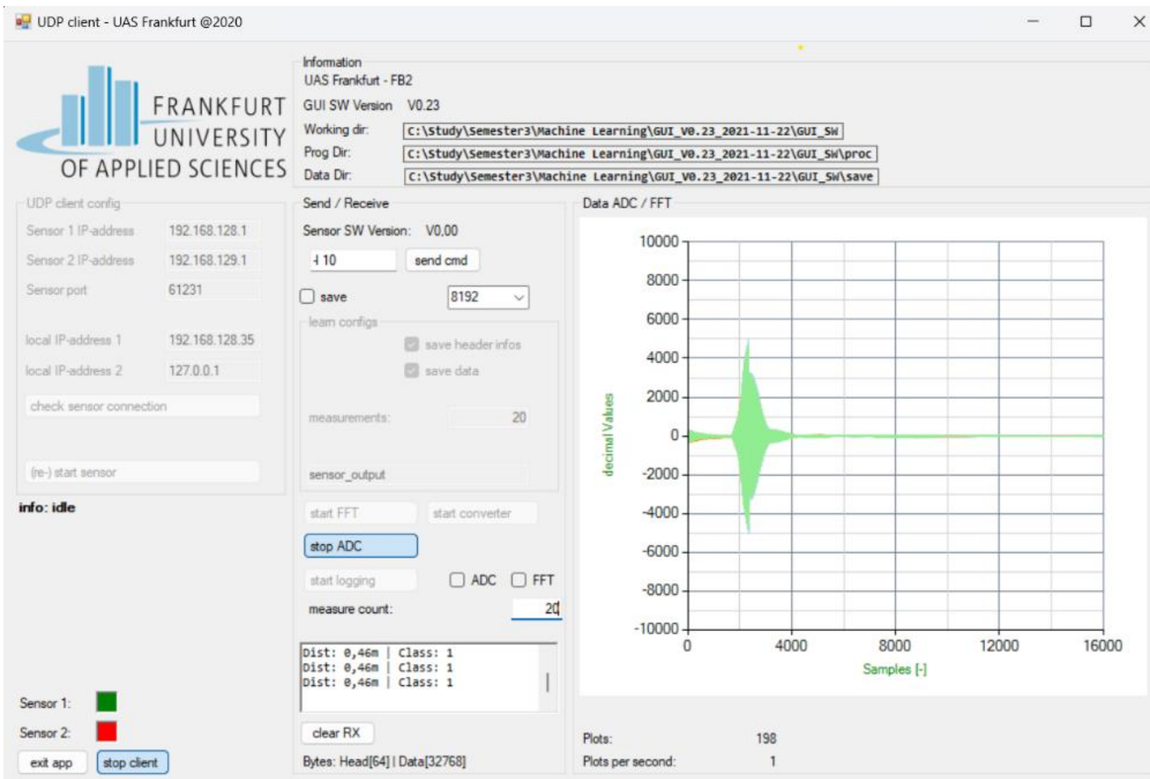

Figure 6: GUI SW V0.23

Implemented Machine Learning method for first echo detection.

Central to this project is the integration of Machine Learning (ML) for the detection of the first echo. The implemented ML method leverages the CNN model to detect the position of the first echo. The idea is to divide the ADC data into small sections. The frequency spectrum of each section is calculated and assessed. A section with a small amplitude will be designated as an empty section with no echo. The spectrogram of the section containing the echo will have a higher amplitude compared to the other sections. The CNN model can be trained with all the spectrograms to differentiate empty sections and an echo. If there are multiple echoes detected, only the first echo is considered.

3. Requirements

The objective of the project is to assess and improve an existing measurement system for detecting the position of the first echo (i.e. first reflection) of a pulsed ultrasonic beam. The measurement data of different objects and persons has to be collected for assessment. The measurement distance has to be automatically calculated by software using the ML first echo detection. To test the precision of the distance calculation, it is compared to the distance that is measured manually, the test results will be used for creating a confusion matrix. On the other hand, further research and implementation on improving system performance (decision speed, measurement accuracy), developing software, and GUI can be done.