**Abstract: Today's technology makes it relatively simple to find an efficient solution for a person's detection and recognition in an unstable setting. In an existing system, pedestrian detection happens by means of a sophisticated analysis of ultrasonic signals. Nevertheless, many algorithms fall short of the requirement for greater accuracy. Owing to the intricacy and difficulty of these assessments, our focus is on the development of a robust echo detection reliability test and improvement of sensor system combined with machine learning approaches.**

Reliability test and improvement of a sensor system for object detection

Course Information Technology

Modules Autonomous Intelligent Systems and Machine Learning

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# INTRODUCTION

Our study focuses on forecasting and testing the dependability of a sensor system for distinguishing between an object and a human, In specifically, the objective is to enable driver assistance systems in vehicles to recognize whether an obstacle in front is a pedestrian or a car. The sensor evaluates ultrasonic signals backscattered from the obstacle by task specific signal analysis methods. It consists of an ultrasonic transducer, an embedded system for transducer control and signal acquisition as well as a computer for signal analysis and feature extraction. To record our data, we utilize a sensor and the notion of Fourier transforms.

Once we have modified the output readings during the project and obtained the required sets of values and observations. We use these measurement datasets to build many confusion matrices for our research with the help of supervised machine learning and we use the results of these matrices to further train an Machine Learning model in order to improve the accuracy and dependability of the sensor's output.

# METHODOLOGY

The theoretical background of the experiment is mentioned in the above section which consists of the description of the Ultrasonic Red Pitaya sensor, FFT data analysis, Machine Learning algorithm background and Confusion matrix.

## Ultrasonic sensor and Red Pitaya Measurement Board:

A test and measurement board called Red Pitaya STEM Lab [1] is based on a system-on-a-chip (SoC) [2] from the former company Xilinx. It may be configured to function as an oscilloscope, spectrum analyser, LCR meter, or network analyser and can be remotely controlled. The Ultrasonic Sensor SRF02 [3], a single transducer ultrasonic rangefinder in a tiny footprint PCB, was utilized in this configuration. The minimum range of the SRF02 is greater than that of other dual transducer rangers since it only employs one transducer for transmission and receiving. The smallest measuring range is approximately 15 cm (6 inches). With a 5V grounded power supply, it can operate. The Red Pitaya device makes it possible to wirelessly transfer data to a laptop for additional processing.



Fig.1. Ultrasonic sensor and red pitaya device

The sensor is operated under the GNU/Linux operating system. On a computer or mobile device, they can be used to manage and record measurements. In addition to 16 standard input and output ports, the main Red Pitaya unit incorporates two analog RF inputs and outputs. A micro-SD card slot, an RJ45 socket for Ethernet, a USB port, and a micro-USB connector for the console are also included on the board. transmitted by the Red Pitaya which operates in the frequency range of 50MHz.

1. *Measuring Methods using FIUS sensor experimental setup in Robolab:*

In the Machine Learning laboratory, the FIUS sensor is positioned at the top on an elongated black metal stand. The object under consideration is situated directly beneath the FIUS sensor on a short white stand.

• Detection of Hard-Object:

To accomplish this, a rigid box was positioned beneath the sensor at a distance of 1 meter and 15 cm, using a measuring scale for precision. Discrepancies in distances were manually measured and compared with the readings displayed on the UDP\_client application. A total of 1000 ADC data points were collected across five iterations, utilizing the Ultrasonic Sensor SRF02 with a mean frequency of 40 kHz and a power output of 150 mW (as per the manufacturer's specifications) for sensing.

• Detection of Soft-Object/Pedestrian:

In this scenario, an individual stood beneath the sensor at a distance of 1 meter and 15 cm, guided by a measuring scale for accuracy. Distances were manually recorded and compared with the readings on the UDP\_client application. Like the hard-object detection, 1000 ADC data points were collected over five iterations using the Ultrasonic Sensor SRF02.

This experimental setup aims to evaluate the FIUS sensor's performance in detecting both hard objects and soft objects (pedestrians), involving meticulous measurements and data collection for further analysis.

## A person standing in a room Description automatically generated

Fig.2a. Detection of hard-object Fig.2b Detection of soft-object

*C. Short Literature overview on ultrasonic distance measurement*

Ultrasonic sensors find extensive applications in distance measurement owing to their dependability, precision, and adaptability. These sensors employ ultrasonic waves, characterized by frequencies beyond the upper threshold of human hearing, usually exceeding 20 kHz, to ascertain the distance between the sensor and an object. An overview of distance measurement methods using ultrasonic sensors:

1. *Time-of-Flight (ToF) Principle:*

Basic Concept: Ultrasonic sensors emit a burst of ultrasonic waves, and the time it takes for the waves to travel to the target object and back is measured. The Time-of-Flight (ToF) principle is a method commonly used in various applications, particularly in the field of distance measurement and imaging. This principle relies on measuring the time it takes for a signal or wave to travel from a source to a target and back again.

In the context of distance measurement, such as with ToF sensors or LiDAR (Light Detection and Ranging) systems, the ToF principle involves sending a signal, often a light pulse or an ultrasonic wave, toward a target. The sensor then measures the time it takes for the signal to travel to the target and be reflected to the sensor. [4]

Distance Calculation: The distance (D) is calculated using the formula: D = (Speed of Sound × Time) / 2.

Accuracy: ToF-based ultrasonic sensors can provide high accuracy in distance measurements.

1. *Pulse-Echo Method:*

Working Principle: Ultrasonic sensors generate short ultrasonic pulses and measure the time it takes for the pulse to travel to the object and return as an echo.

In ultrasonic testing, such as in medical imaging or non-destructive testing of materials, the Pulse-Echo method involves the following steps:

1. Pulse Transmission: A short burst of ultrasonic waves is generated and directed towards the object or material being examined.
2. Reflection: When these waves encounter a boundary or interface within the material (due to a change in acoustic impedance), a portion of the waves reflects back towards the source.
3. Echo Reception: A sensor or receiver detects the reflected waves, known as echoes, and measures the time it takes for them to return.
4. Distance Calculation: The distance to the reflecting surface can be determined by multiplying the time of flight by the speed of sound in the material and dividing by two, as the signal travels to the object and back. [5]

Transducer: The sensor typically consists of a transducer that functions as both a transmitter and a receiver.

Application: Commonly used in industrial automation, robotics, and obstacle detection systems.

1. *Phase Shift Measurement:*

Basic Concept: The distance is measured by the phase shift between the transmitted and received ultrasonic waves. [6]

Advantages: This method can provide high resolution and is less affected by environmental conditions.

1. *Multi-Echo Detection:*

Working Principle: Utilizes multiple echoes from different surfaces to improve accuracy and reliability. [6]

The process of multi-echo detection typically includes the following steps:

1. Pulse Transmission: A burst of ultrasonic waves is transmitted towards the target or object whose distance is to be measured.
2. Echo Reception: The ultrasonic waves encounter surfaces or boundaries within the environment, leading to multiple echoes being reflected back toward the sensor.
3. Time-of-Flight Measurement: The time it takes for each echo to return to the sensor is measured. Using the time-of-flight principle, distances to the various reflecting surfaces can be calculated.
4. Echo Analysis: Multiple echoes may be received due to reflections from different surfaces or objects. The sensor distinguishes between these echoes based on their respective time delays or time-of-flight measurements.
5. Distance Calculation: The distances to each reflecting surface are calculated individually using the time-of-flight measurements. This information provides a comprehensive understanding of the spatial configuration of the environment.

Applications: Particularly useful in environments with multiple reflective surfaces or in applications where accurate measurements are critical.

1. *Dual-Transducer Systems:*

Setup: Involves separate transducers for transmitting and receiving ultrasonic waves. [5]

Benefits: Reduces the impact of signal crossover and enhances performance in challenging conditions.

1. *Temperature Compensation:*

Challenge: Ultrasonic wave speed is affected by temperature variations. [4]

Solution: Sensors may incorporate temperature sensors to compensate for temperature-induced changes in the speed of sound.

*D. ML method used for finding first reflection*

Implementing a machine learning method for identifying the first reflection in an audio or acoustic environment involves several key steps. Below is a generalized approach that you can follow:

1. *Define the Problem*:

Clearly define the problem and the objectives of identifying the first reflection.

Understand the characteristics of first reflections in the context of your application. [7] [8]

2. *Data Collection*:

Gather a dataset that includes audio recordings with labeled information about the presence and characteristics of first reflections.

Ensure diversity in the dataset to capture various acoustic conditions. [7] [8]

3. *Data Preprocessing*:

Audio Segmentation: Divide audio recordings into segments relevant to the analysis.

Feature Extraction: Extract relevant features from the audio segments (e.g., spectral features, time-domain features, MFCCs).

Labeling: Ensure accurate labeling of the dataset, marking segments with and without first reflections. [7] [8]

4. *Data Splitting*:

Split the dataset into training, validation, and test sets to evaluate the model's performance. [7] [8]

5. *Model Selection*:

Choose an appropriate machine learning model based on the nature of the problem.

Experiment with different algorithms such as SVM, decision trees, CNNs, or hybrid models depending on your dataset and problem requirements.

6. *Model Architecture*:

Design the architecture of the chosen model, considering input features, hidden layers, and output layer.

For deep learning models, experiment with architectures like CNNs or hybrid CNN-LSTM models. [8]

7. *Feature Scaling and Normalization*:

Standardize or normalize the input features to ensure that the model trains effectively and converges faster.

8. *Model Training*:

Train the model using the training dataset.

Fine-tune hyperparameters through iterative training and validation. [7]

9. *Model Evaluation*:

Evaluate the model's performance on the validation set to avoid overfitting.

Adjust the model architecture or hyperparameters as needed. [8]

10. *Testing*:

Assess the final model on the test set to gauge its generalization performance.

11. *Post-Processing (if needed):*

Implement any post-processing steps, such as filtering or thresholding, to refine the model's output.

12. *Interpretability and Visualization:*

Analyze and visualize the model's predictions to gain insights into its decision-making process. [8]

Understand which features are most informative for detecting first reflections.

13. *Deployment*:

If the model meets the desired performance, deploy it in the target environment. [7]

Consider real-time or batch processing depending on the application requirements.

14. *Continuous Monitoring and Improvement*:

Implement a monitoring system to track the model's performance over time.

Consider retraining the model periodically with new data to adapt to changing conditions. [7]

15. *Documentation*:

Document the entire pipeline, including data preprocessing steps, model architecture, hyperparameters, and any insights gained during the development process.

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