Ultrasonic Lidar-Based 2D Room Mapping

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Abstract—**Environmental mapping is essential for robotics, automation, and spatial awareness, but traditional Lidar systems are costly and complex, requiring specialized hardware and computational power. This paper presents a budget-friendly alternative using ultrasonic sensors, an Arduino microcontroller, and Python-based visualization to create a functional 2D map of a room. The system uses two HC-SR04 ultrasonic sensors mounted on an SG90 servo motor, enabling 360-degree rotational scanning to capture distance data across an environment. As the servo moves, the sensors take readings, transmitting the data via serial communication, where Python processes the inputs, converts them into Cartesian coordinates, and dynamically visualizes them using Matplotlib. While ultrasonic sensors have limitations such as reflections, angular resolution constraints, and noise artifacts, their affordability makes them ideal for foundational research and educational projects. Experimental results confirm significant improvements over traditional fixed-time mapping methods, offering real-time adaptability and optimized environmental representation. Combining affordable hardware with intelligent software processing, this research showcases an accessible alternative for environmental mapping, making advanced spatial awareness techniques available to students, researchers, and hobbyists.**

Index Terms— *Traffic control, Traffic light system, Traffic management, Intelligent transport systems, Smart surveillance, Computer Vision, Machine Learning, Object detection, YOLO.*

I. INTRODUCTION

Mapping indoor and outdoor environments is a cornerstone in the development of intelligent systems across diverse fields such as robotics, industrial automation, surveillance, and spatial awareness technologies. The demand for accurate spatial perception has traditionally been met by Light Detection and Ranging (Lidar) systems, which use laser beams to create high-resolution 2D and 3D representations of an environment. These systems have become the gold standard in areas like autonomous vehicles, factory robotics, and military surveillance due to their precision and reliability. However, commercial-grade Lidar devices are prohibitively expensive, often costing several hundred to several thousand dollars, which significantly limits their accessibility for developers, researchers, and institutions working under financial constraints. Moreover, these systems typically require powerful processors, complex software integration, and specialized frameworks such as ROS (Robot Operating System), making them challenging to adopt for smaller or embedded systems with limited computational resources.

As a result of these limitations, attention has increasingly shifted toward more affordable alternatives that can provide functional mapping capabilities without the overhead costs and complexities of Lidar. Among these alternatives, ultrasonic sensors have garnered interest due to their low cost, simplicity, and adaptability. These sensors operate by emitting ultrasonic waves and measuring the time it takes for the echo to return after bouncing off objects, thus enabling basic distance measurement. When integrated with low-cost microcontrollers such as the Arduino platform, ultrasonic sensors can be used to construct a rudimentary scanning system. Although they do not offer the same level of detail or range as Lidar, their performance is sufficient for numerous basic applications, including educational projects, low-budget research, DIY robotics, and indoor automation systems. Furthermore, when combined with Python—a widely used programming language in data science and engineering—such systems can be enhanced to visualize spatial data dynamically, bringing interactivity and real-time feedback into the process.

In light of this potential, this study explores the development of an ultrasonic sensor-based mapping system that replicates some of the essential functions of Lidar without its cost or complexity. The system design involves using two ultrasonic sensors mounted on a servo motor to perform angular sweeps of the environment, effectively collecting a set of radial distance measurements. These readings are processed and visualized in real-time using a Python script, which generates 2D spatial plots representing the mapped area. By combining affordable hardware with flexible and powerful software tools, this approach seeks to create a practical platform that balances cost, functionality, and ease of use. The broader intent is to demonstrate that with careful system design and integration, it is possible to approximate Lidar-like functionality in a way that is scalable, accessible, and suitable for a wide range of real-world applications where affordability and adaptability are key considerations.

II. LITERATURE REVIEW

Reference [1] describes a low-cost scanning system based on an ultrasonic sensor mounted on a rotating servo, controlled by an Arduino Uno. Data from the sensor is transmitted via serial communication and visualized in real-time using Python and Matplotlib. This approach achieves basic 2D mapping capabilities but suffers from noise and inconsistencies in angular measurements due to servo jitter and environmental reflections.

Reference [2]: An enhanced implementation integrates dual ultrasonic sensors mounted on a servo bracket, enabling simultaneous scanning at multiple angles. This configuration reduces blind spots and improves mapping efficiency. However, the system struggles with detecting soft surfaces that absorb sound waves and can result in incomplete maps in such scenarios. Calibration is necessary to ensure consistent angular displacement for accurate plotting.

Reference [3] proposes a distance-mapping robot using HC-SR04 ultrasonic sensors with an Arduino Mega. The scanning data is processed in a Python environment using the tkinter and matplotlib libraries for GUI-based visualization. This system includes filtering techniques to smooth out inconsistent distance spikes but lacks object classification capabilities and depth perception for multi-layered scenes.

Reference [4]: This project introduces a more advanced technique where multiple ultrasonic sensors are placed in a radial pattern to avoid the need for servo movement. Each sensor covers a specific angle, reducing scanning time significantly. The drawback of this system is the increased cost due to multiple sensors and wiring complexity, which can reduce modularity and portability.

Reference [5]: A hybrid method that combines ultrasonic sensors with infrared (IR) sensors is explored for indoor mapping. IR sensors help improve accuracy at short ranges and on glossy surfaces. An Arduino Uno is used to coordinate sensor data and send processed results to a PC over serial communication. Despite its accuracy boost, the system is prone to errors in mixed lighting environments, and IR sensors show reduced performance under direct sunlight.

Reference [6] explores the use of ultrasonic sensors for Simultaneous Localization and Mapping (SLAM) in constrained environments. The project integrates ROS (Robot Operating System) with Arduino for better control and mapping feedback. Ultrasonic readings are fed into a basic SLAM algorithm implemented in Python. However, the low resolution of distance readings and delay from serial communication limit the system's performance in dynamic environments.

Reference [7]: A project uses ultrasonic sensors mounted on a pan-tilt servo mechanism for wide-angle scanning. The sensors collect range data as the servos sweep across horizontal and vertical axes. A 3D point cloud is generated and visualized using Python's open3d library. While this provides a near-Lidar-like mapping experience, the slow movement of servo motors limits real-time responsiveness and makes the system unsuitable for moving platforms.

Reference [8]: A comparative analysis highlights the performance differences between various low-cost distance sensors (ultrasonic, IR, ToF) in mapping applications. The study concludes that while ultrasonic sensors are affordable and easy to integrate, their

accuracy is lower compared to ToF sensors. Still, due to cost constraints and ease of implementation, ultrasonic-based systems are preferred for introductory robotics and spatial awareness systems.

Reference [9]: A practical application of ultrasonic mapping for obstacle avoidance in autonomous robots is demonstrated using Python and Arduino. The setup uses a rotating ultrasonic sensor to continuously scan the environment and map potential obstacles. The data is processed in real time, and path planning is updated accordingly. This system works well in uncluttered indoor spaces but fails to detect complex objects like mesh, curtains, or angled surfaces.

Reference [10]: A DIY Lidar alternative is created using a single HC-SR04 sensor and a 360-degree servo mount. The system collects data at set angular intervals and plots the results as a polar map using Python's matplotlib. Data noise is mitigated using Kalman filters. While effective in simple indoor layouts, the system requires frequent recalibration, and servo backlash introduces angular deviation in the mapping process.

III. PROPOSED SYSTEM

3.1 Proposed System Overview

The proposed ultrasonic mapping system is designed to offer a low-cost yet functional solution for indoor environment scanning using minimal hardware. The system is centered around the Arduino Uno, a versatile microcontroller that acts as the core control unit responsible for managing sensor operations and servo motor control. Attached to the Arduino are two HC-SR04 ultrasonic distance sensors, which are strategically mounted in opposite directions on a rotating bracket. This configuration ensures wider coverage and reduces blind spots by enabling the system to simultaneously scan both the left and right sides during rotation.

The rotation of the sensors is achieved using a SG90 servo motor, known for its lightweight design and high positional accuracy. The servo executes a sweeping motion from 0° to 180°, and then returns back to 0°, enabling full hemisphere coverage. During this motion, the ultrasonic sensors gather environmental distance data at small angular intervals (typically 1° to 2°), providing a relatively high-resolution scan of the environment.

To process and visualize the captured data, the system uses a Python-based graphical interface running on a host computer. The Arduino transmits distance and angle data over a serial USB connection, which the Python script decodes in real time. Using libraries like pyserial, matplotlib, or pygame, the data is plotted on a 2D map that dynamically updates as scanning continues. This setup effectively replicates basic Lidar functionality at a fraction of the cost, making it accessible for hobbyists, students, and low-budget robotics projects.

3.2 Working Mechanism

The operational mechanism of the ultrasonic mapping system is based on the precise coordination between the angular sweep of the servo motor and the distance measurements captured by the ultrasonic sensors. The core idea is to generate a polar map of the surroundings by collecting distance readings at various angles and converting these readings into two-dimensional coordinates for visualization. This mechanism involves a repetitive cycle of motion, measurement, and data processing, as outlined below:

1. Servo Scanning Motion

At the beginning of the scanning cycle, the SG90 servo motor initiates its sweep across a defined angular range, usually from 0° to 180°. This rotation occurs in small, incremental steps (e.g., 1° or 2°), allowing high angular resolution during the scan. After reaching the maximum angle, the motor reverses its direction and sweeps back from 180° to 0°. This bidirectional motion ensures that environmental data is collected efficiently in both forward and reverse directions. At each angular increment, the Arduino sends a control signal to the servo to adjust its position, and a brief pause is introduced to allow the servo to stabilize before measurement is taken. This scanning motion lays the foundation for mapping the environment with a high degree of spatial consistency.

2. Distance Measurement Using HC-SR04

At every stop in the servo's motion, the HC-SR04 ultrasonic sensor is triggered to emit a short burst of high-frequency sound waves (typically around 40 kHz). These waves travel through the air and reflect off any object in their path. The sensor then detects the returning echo and measures the time elapsed between sending the pulse and receiving the echo. This duration is used to compute the distance to the object using the Time-of-Flight (ToF) formula:

Distance=(Time* 34300)/2

Here, Time is the measured duration in seconds, and 34300 cm/s is the approximate speed of sound in air. The division by 2 accounts for the round-trip travel of the sound wave (outward and returning). The result provides an accurate measurement of the distance from the sensor to the obstacle in a specific direction. The HC-SR04 offers a reasonable range (2 cm to 400 cm) and moderate accuracy, making it well-suited for this real-time mapping application.

Once the distance reading is acquired, it is paired with the corresponding angle at which the measurement was taken. This polar coordinate pair (angle, distance) represents the location of a detected object relative to the sensor's position.

d=(v*t)/2

Where:

d = distance to object (cm)

v = speed of sound (343 m/s ≈ 0.0343 cm/μs)

t = echo return time (μs)

3. Continuous Mapping Cycle

This entire scanning and mapping process occurs continuously as the robot operates, allowing for persistent updates of the surrounding environment. Such a mechanism is particularly useful in applications requiring navigation, obstacle detection, or terrain monitoring. The low-cost hardware and simple data flow make it an ideal solution for academic, research, and prototyping environments where LIDAR alternatives may be too expensive or complex.

Angle-Distance Pair Conversion

Each measurement is stored as a polar coordinate (d,Θ) where Θ is the current angle of the servo and d is the distance reported by the sensor.

Cartesian Coordinate Transformation

To enable 2D plotting, the polar coordinates are converted to Cartesian form using trigonometric functions:

x=d*cos(Θ)

y=d*sin(Θ)

Where Θ is in radians. These (x,y) points are then passed to the Python visualizer to render the map.

Real-Time Visualization

The Python interface plots the (x,y) points onto a 2D canvas. The plot refreshes in real-time, giving users a continuously updating map of nearby walls, furniture, and obstacles. This visualization aids in spatial awareness and can serve as the foundation for autonomous navigation or surveillance applications.

IV. SYSTEM IMLEMENTATION

The hardware configuration of the system comprises a cohesive set of components, designed to enable both ultrasonic environmental mapping and autonomous path-following functionality. At the center of this setup is the Arduino Uno, which acts as the brain of the entire system. It is responsible for handling input signals from various sensors, controlling motor outputs, and coordinating the timing of ultrasonic pulses and scanning rotations. The Arduino Uno reads analog and digital inputs, manages timing operations required for accurate distance measurements, and transmits data to a connected computer via serial communication for further processing and visualization.

For spatial mapping, two HC-SR04 ultrasonic sensors are mounted on a rotating bracket driven by an SG90 servo motor. Each sensor emits ultrasonic pulses and measures the time taken for the echo to return after reflecting off an object. The servo motor sweeps from 0° to 180°, and then reverses back to 0°, enabling bi-directional scanning. Since the sensors face opposite directions, the effective coverage approaches 360°, allowing the robot to perceive its environment in nearly all directions. The captured polar coordinates—comprising angle and distance—are then converted into Cartesian coordinates using the equations $x = d * \cos(\theta)$ and $y = d * \sin(\theta)$ This transformation allows the mapping algorithm, written in Python, to plot environmental features in a two-dimensional plane. As the scanning proceeds, newly calculated points are added in real time to dynamically update the map, providing a visual representation of nearby obstacles and open areas.

In addition to mapping, the robot is equipped with a line-following mechanism for autonomous mobility. Two analog infrared line sensors are connected to the Arduino's analog input pins (A0 and A1) to detect the presence of a black line on a lighter surface. These sensors output digital readings based on the reflected infrared light, allowing the robot to determine its position relative to the path. Based on the sensor

readings, the Arduino adjusts the direction and speed of four DC motors, arranged in a differential drive layout. The motors are controlled using the AFMotor library, which simplifies the interaction between the Arduino and a motor driver shield by providing straightforward commands for setting speed and direction.

To ensure stable performance, the entire system is powered by a shared external power supply. The Arduino can be powered via USB, but this is insufficient for high-current components like the servo and DC motors. Therefore, an additional power source—such as a lithium-ion battery pack or portable USB power bank—is connected to supply adequate current. This prevents voltage drops or system resets during operation, especially when multiple components are active simultaneously.

This integrated hardware design enables the robot to perform both intelligent environmental scanning and autonomous movement, laying a strong foundation for future enhancements such as obstacle avoidance, map-based path planning, or even integration into multi-robot coordination systems.

V. RESULTS AND DISCUSSION

The ultrasonic-based environmental mapping system demonstrates a promising alternative to traditional Lidar systems. While Lidar offers exceptional precision with millimeter-level resolution and high-speed scanning, it is typically associated with a *high cost* and demands substantial computational power to process dense point clouds. These features, although powerful, make Lidar unsuitable for hobbyist applications, academic prototypes, or low-budget deployments. In contrast, the proposed ultrasonic-based solution leverages low-cost hardware components and minimal computational requirements, making it a viable option for basic robotics, automation systems, and educational purposes. Despite its moderate resolution on a centimeter scale, the system effectively captures the layout of an indoor environment, and its real-time data processing is efficiently handled using simple Python scripts.

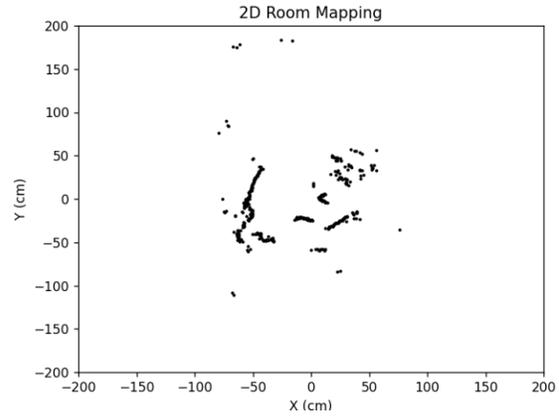| Feature	Traditional Lidar	Ultrasonic-Based System
Cost	High	Low
Resolution	High (mm-scale)	Moderate(cm-scale)
Processing Power	Heavy processing	Lightweight (Python scripts)

Fig 1. Map Generated using sensor data

During testing, several observations were made that highlight both the strengths and limitations of the system. The ultrasonic mapping setup successfully scanned and visualized room environments in real-time, demonstrating stability in data transmission and visualization. However, soft materials such as curtains or cushioned surfaces occasionally resulted in signal absorption, leading to inaccurate or missing data points. Moreover, the system's angular resolution is limited by the servo motor's step granularity—affecting how finely it can detect narrow or closely spaced objects. Despite these constraints, the system is suitable for applications where cost and simplicity are priorities over fine-resolution mapping, such as mobile robotics, educational demos, or early-stage prototyping.

VI. CONCLUSION AND FUTURE WORK

This project demonstrates the effectiveness of a low-cost ultrasonic-based environmental mapping system as a practical alternative to conventional LiDAR setups. By integrating readily available components such as the Arduino Uno, HC-SR04 ultrasonic sensors, and an SG90 servo motor, the system achieves real-time 2D mapping with moderate accuracy at a fraction of the cost of high-end LiDAR solutions. The synchronized scanning mechanism, along with distance-to-coordinate transformation using Python scripts, enables dynamic visualization of surroundings in Cartesian space. Moreover, the additional integration of a line-following mechanism enhances the platform's autonomy, making it suitable for various robotics applications such as path-following, indoor navigation, and obstacle avoidance. Despite

certain limitations in angular resolution and accuracy on soft surfaces, the system showcases the potential of combining basic electronics with intelligent programming for spatial awareness and mapping tasks.

Looking ahead, several enhancements can significantly improve the system's performance and expand its capabilities. One promising direction is the incorporation of multi-sensor fusion, combining ultrasonic sensors with infrared or optical sensors to overcome issues like signal absorption or poor angular resolution. Another valuable improvement would be the integration of machine learning algorithms for obstacle classification and adaptive path planning, enabling the robot to not only map but understand its environment. Additionally, adding wireless communication modules such as Wi-Fi or Bluetooth can facilitate real-time data streaming and remote control, making the system more versatile and scalable. These advancements would move the project from a prototype phase to a more robust, intelligent platform suited for advanced automation, research, and real-world deployments in areas like smart warehouses, indoor robotics, and educational robotics systems.

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