Minor Project Synopsis Report

RSSI-Based Gradient Descent Approach for Collaborative Robot Localization and Navigation

Project Category: IoT-Based

Projexa Team Id- 26E1214

Submitted in partial fulfilment of the requirement of the degree of

MASTER OF COMPUTER APPLICATIONS

in

with Specialization AI & ML (Section -A)

to

K.R Mangalam University

by

Ram Kumar Singh (2501940002)
Shubham Goel (2501940014)
Jagdish Nayak (2501940019)
Tushar Singh (2501940055)
Vishakha Gaur (2501940065)

Under the supervision of

Dr. Shweta Agarwal

Department of Computer Science and Engineering

School of Engineering and Technology

K.R Mangalam University, Gurugram- 122001, India

February 2026

INDEX

ABSTRACT

In many real-world environments such as indoor spaces, disaster zones, areh-ouses, and underground locations, autonomous robotic navigation becomes challenging due to the unavailability or unreliability of Global Positioning System (GPS) signals. Conventional localization and navigation techniques largely depend on GPS, pre-installed infrastructure, vision-based systems, or centralized control mechanisms, which often fail to perform effectively in dynamic, unknown, or infrastructure-less environments. Furthermore, traditional rule-based robotic systems exhibit limited adaptability when multiple robots are required to collaborate autonomously.

This project proposes an **RSSI-based collaborative robotic navigation system** that enables multiple robots to autonomously locate and navigate toward each other without relying on GPS or external infrastructure. The system utilizes **Received Signal Strength Indicator (RSSI)** values obtained through wireless communication to estimate relative proximity between robots. A **gradient descent–inspired optimization technique** is employed, where RSSI is treated as an objective function and each robot iteratively adjusts its movement direction to maximize signal strength and achieve convergence.
The proposed system follows a **decentralized architecture**, allowing each robot to independently make navigation decisions based solely on local RSSI measurements. This approach eliminates the need for centralized coordination, thereby enhancing scalability, robustness, and fault tolerance. The system is implemented using **low-cost microcontroller platforms and wireless communication technologies**, making it suitable for Internet of Things (IoT)–based robotic applications.

The proposed solution demonstrates effective collaborative behavior, adaptability to environmental variations, and cost-efficient deployment. It is particularly suitable for applications such as **search and rescue operations, warehouse automation, and intelligent robotic systems operating in GPS-denied environments**.

Keywords: RSSI, Gradient Descent, Collaborative Robots, GPS-Free Navigation, IoT

1. INTRODUCTION

The field of robotics has experienced rapid growth due to advancements in embedded systems, wireless communication, artificial intelligence, and the Internet of Things (IoT). Autonomous robots are increasingly being deployed in various domains such as industrial automation, healthcare, defense, disaster management, and smart infrastructure. These robots are expected to perform tasks with minimal human intervention while adapting to dynamic and uncertain environments.

One of the most critical requirements for autonomous robotic systems is localization and navigation. Localization refers to a robot's ability to determine its position within an environment, while navigation involves planning and executing movement toward a target location. Accurate localization is essential for tasks such as obstacle avoidance, path planning, and multi-robot coordination.

Global Positioning System (GPS) technology is commonly used for outdoor localization. However, GPS suffers from significant limitations in indoor environments, underground locations, dense urban areas, and disaster zones where satellite signals are weak or unavailable. As a result, robots operating in such environments cannot rely on GPS for accurate positioning.

Furthermore, modern applications increasingly require multiple robots to work together collaboratively. Centralized control architectures introduce issues such as communication overhead, single points of failure, and limited scalability. Decentralized and distributed robotic systems offer improved robustness and flexibility but require intelligent coordination mechanisms.

These challenges highlight the need for GPS-free, decentralized, and intelligent localization and navigation approaches that can operate with minimal hardware requirements while enabling collaborative behavior among multiple robots.

2. MOTIVATION

The motivation for this project arises from the growing demand for autonomous robotic systems capable of operating in GPS-denied and infrastructure-less environments. In scenarios such as disaster rescue missions, collapsed buildings, underground tunnels, and warehouses, reliable positioning information is often unavailable, making conventional navigation methods ineffective.

Existing localization techniques frequently rely on expensive sensors such as cameras, LiDAR, or pre-installed beacons, which increase system cost and complexity. For student-level and low-budget applications, these solutions are often impractical. There is a strong need for lightweight and cost-effective approaches that can still provide intelligent navigation capabilities.

Another motivating factor is the importance of collaborative robotics. Multi-robot systems can perform tasks more efficiently than individual robots by sharing information and coordinating movements. However, designing such systems without centralized control remains a challenge.

This project is motivated by the idea that commonly available wireless signals can be exploited for navigation purposes. RSSI values are readily available in wireless communication modules and can be used to estimate relative proximity without additional hardware. By combining RSSI measurements with optimization techniques such as gradient descent, robots can make intelligent movement decisions using simple computations.

The project aims to demonstrate that complex collaborative behavior can emerge from simple algorithms and minimal hardware, aligning with modern engineering principles of efficiency, scalability, and robustness.

3. LITERATURE REVIEW

Several localization and navigation techniques have been proposed in existing research. GPS-based localization is widely used for outdoor navigation due to its high accuracy. However, its performance degrades significantly in indoor and underground environments [1].

Vision-based localization techniques use cameras and image processing algorithms to identify landmarks and estimate position. While effective, these methods require high computational resources and are sensitive to lighting conditions and environmental changes [2].

Rule-based and reactive navigation methods rely on predefined logic and sensor thresholds. These approaches lack adaptability and intelligence, especially in dynamic multi-robot environments [3].

Recent research has explored RSSI-based localization using wireless signals due to its low cost and minimal hardware requirements. Optimization techniques such as gradient descent have been applied in various machine learning and control problems, demonstrating efficient convergence toward optimal solutions [5].

However, limited work has been done on combining RSSI-based navigation with decentralized gradient descent approaches for collaborative multi-robot systems [6].

Table 1:

Key Authors / References	Approach / Technique	Description	Advantages	Limitations
Kaplan & Hegarty, *Understanding GPS*, 2006 [4]	GPS-Based Localization	Uses satellite signals to determine absolute position of robots in outdoor environments.	High accuracy in open outdoor areas; globally available technology.	Ineffective indoors and underground; signal loss in dense urban and disaster environments.
Davison et al., *IEEE Transactions on Pattern Analysis & Machine Intelligence*, 2007 [1]	Vision-Based Localization	Uses cameras and image processing to identify landmarks and estimate robot position.	Rich environmental information; useful for mapping and localization.	High computational cost; sensitive to lighting conditions and occlusion; requires powerful hardware.
Faragher & Harle, *IEEE Communications Surveys*, 2015 [2]	Beacon-Based Systems	Uses pre-installed wireless beacons (e.g., Bluetooth) for localization and navigation.	Reliable and accurate within controlled environments.	Requires infrastructure setup; limited scalability and flexibility.
Brooks, *IEEE Journal of Robotics and Automation*, 1986 [3]	Rule-Based Navigation	Uses predefined rules and thresholds for robot movement decisions.	Simple implementation; low computational overhead.	Lacks adaptability; ineffective in dynamic and multi-robot environments.
Patwari et al., *IEEE Transactions on Signal Processing*, 2003 [5]	RSSI-Based Localization	Uses wireless signal strength to estimate relative distance between nodes.	Low cost; minimal hardware; suitable for indoor environments.	Noisy signal measurements; affected by multipath and environmental interference.
Borenstein & Koren, *IEEE Journal of Robotics and Automation*, 1989 [6]	Ultrasonic & IR-Based Navigation	Uses ultrasonic and infrared sensors for obstacle detection and proximity-based navigation.	Simple and inexpensive; effective for short-range obstacle avoidance.	Limited sensing range; no global localization; unsuitable for goal-oriented navigation alone.

4. GAP ANALYSIS

A detailed analysis of existing robotic localization and navigation approaches reveals several critical limitations that restrict their applicability in real-world environments.

Most traditional robotic systems rely heavily on GPS-based localization techniques. While GPS provides accurate positioning in outdoor environments, its performance degrades significantly in indoor spaces, underground areas, dense urban regions, and disaster zones. This makes GPS-dependent systems unsuitable for many practical applications where reliable positioning information is required.

Vision-based localization and navigation systems use cameras and image processing algorithms to detect landmarks and estimate position. Although these methods offer good accuracy, they demand high computational power, consistent lighting conditions, and complex hardware. Similarly, LiDAR-based systems provide precise mapping and localization but involve expensive sensors and sophisticated processing, increasing overall system cost and design complexity.

Many existing multi-robot systems adopt centralized control architectures, where decision-making is handled by a central unit. Such architectures suffer from scalability issues, high communication overhead, and single points of failure. In dynamic environments, centralized systems struggle to adapt to changes and failures.

Rule-based and reactive navigation methods are simple to implement but lack adaptability and intelligence. These systems cannot effectively handle uncertain environments or coordinate efficiently with multiple robots.

Despite these approaches, there is a lack of lightweight, decentralized, and cost-effective solutions that enable collaborative robotic navigation using minimal sensing and communication. This gap highlights the need for a GPS-free, infrastructure-less, and decentralized robotic system that leverages RSSI measurements and optimization techniques to achieve autonomous and intelligent multi-robot coordination.

5. PROBLEM STATEMENT

Robotic systems operating in indoors, underground, and dynamic environments face significant challenges due to the unavailability of GPS and reliance on costly or complex localization infrastructure. Existing navigation techniques either require expensive sensors, centralized control, or predefined environmental information, limiting their applicability in real-world scenarios.

Furthermore, simple rule-based systems lack the intelligence and adaptability required for collaborative multi-robot operation. There is no efficient mechanism that enables robots to autonomously locate and navigate toward each other using minimal hardware and decentralized decision-making.

Therefore, there is a need to design an intelligent, GPS-free, and decentralized robotic system that allows multiple robots to collaboratively localize and navigate using RSSI measurements and optimization

6. OBJECTIVES

The main objectives of this project are:

1. **To design and implement a GPS-free collaborative robotic system** capable of operating in indoor and infrastructure-less environments where conventional positioning methods are unreliable or unavailable.

2. **To utilize Received Signal Strength Indicator (RSSI) values obtained from wireless communication** between robots to estimate relative proximity and guide navigation decisions without relying on absolute position information.

3. **To apply a gradient descent–inspired optimization technique** that enables each robot to iteratively adjust its movement direction and step size to maximize signal strength and achieve convergence.

4. **To develop a decentralized, low-cost, and scalable solution** that allows multiple robots to autonomously coordinate and navigate using minimal hardware, computation, and communication resources.

5. **To integrate sensor-based obstacle detection and avoidance mechanisms** using ultrasonic, IR, and IMU sensors to ensure safe, stable, and reliable autonomous navigation.

7. TOOLS/PLATFORM USED

Hardware

- ESP32 Microcontroller
- DC Motors
- Motor Driver Module
- Wireless Communication (Wi-Fi / Bluetooth)
- Power Supply Unit
- Robot Chassis

Software

- Embedded C / MicroPython
- Arduino IDE
- Python
- MATLAB (for simulation and analysis)

Technologies

- RSSI-based communication
- Gradient Descent Optimization
- IoT Architecture

8. METHODOLOGY

The proposed system follows a decentralized and iterative methodology consisting of the following steps:

Phase1: System Initialization

Each robot initializes its hardware components and establishes wireless communication with neighboring robots.

Phase 2: RSSI Measurement
Robots continuously measure RSSI values from received wireless signals to estimate relative proximity.

Phase 3: Direction Estimation
Small exploratory movements are performed to observe changes in RSSI values.

Phase 4: Gradient Descent-Based Movement
RSSI is treated as an objective function. Robots move in the direction that increases signal strength, similar to gradient descent optimization.

Phase 5: Adaptive Step Size
Larger movements are taken when RSSI is weak, while smaller steps are used near convergence to improve stability.

Phase 6: Iterative Convergence
The process repeats until robots converge to a common location or target.

Phase 7: Collaborative Coordination
Each robot independently follows the algorithm, resulting in emergent collaborative behavior without centralized control.

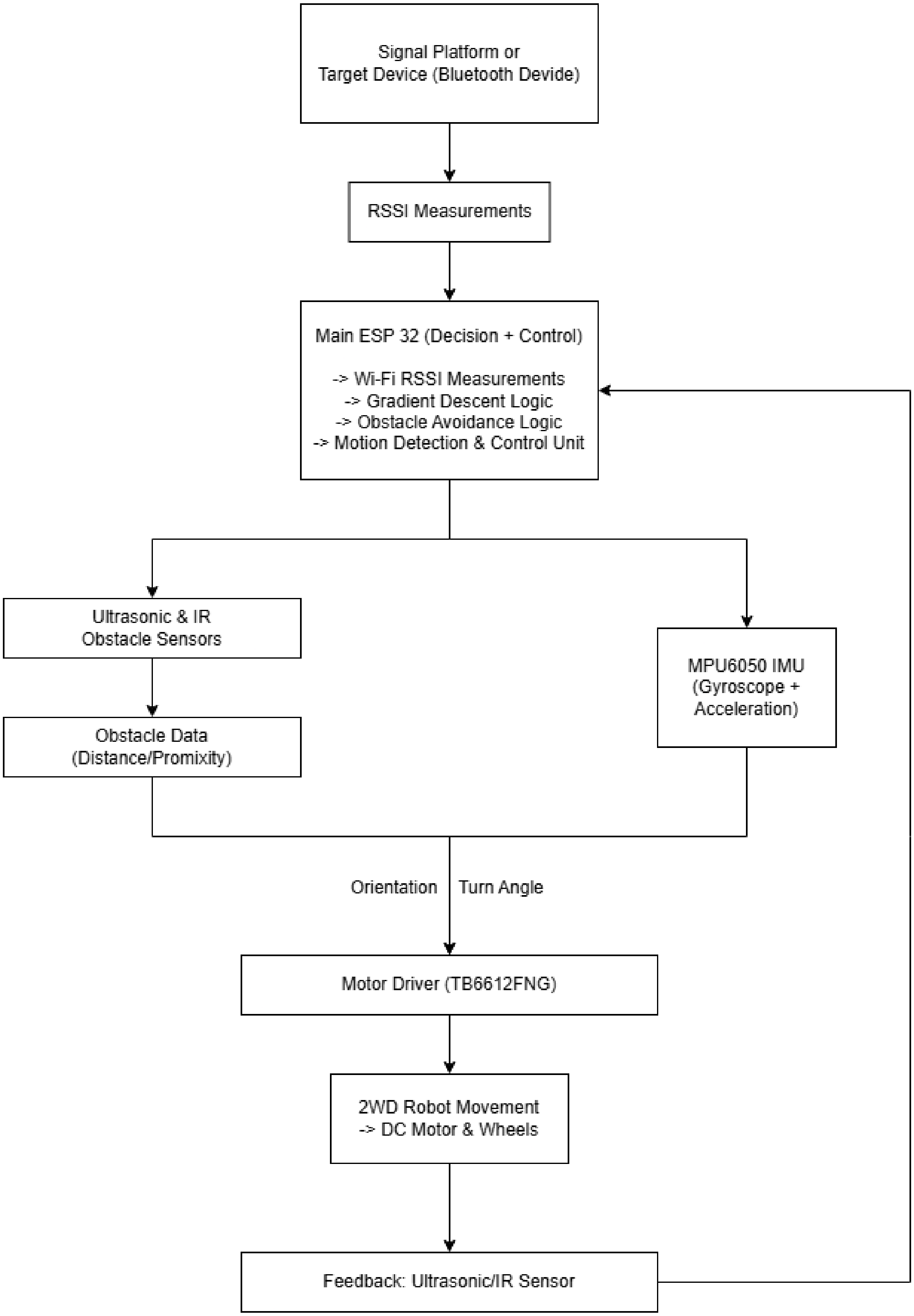

Figure 1: ESP32 based RSSI Robot workflow

9. REFERENCES

[1.] A. J. Davison, I. D. Reid, N. D. Molton, and O. Stasse, "MonoSLAM: Real-Time Single Camera SLAM," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 29, no. 6, pp. 1052–1067, June 2007.

[2.] R. Faragher and R. Harle, "Location Fingerprinting With Bluetooth Low Energy Beacons," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2358–2377, Fourthquarter 2015.

[3.] R. A. Brooks, "A Robust Layered Control System for a Mobile Robot," *IEEE Journal of Robotics and Automation*, vol. 2, no. 1,pp. 14–23, Mar. 1986.

[4.] E. D. Kaplan and C. J. Hegarty, *Understanding GPS: Principles and Applications*, Artech House, 2nd ed., 2006.

[5.] N. Patwari, A. O. Hero III, M. Perkins, N. S. Correal, and R. J. O'Dea, "Relative Location Estimation in Wireless Sensor Networks," *IEEE Transactions on Signal Processing*, vol. 51, no. 8, pp. 2137–2148, Aug. 2003.

[6.] J. Borenstein and Y. Koren, "Real-Time Obstacle Avoidance for Fast Mobile Robots," *IEEE Journal of Robotics and Automation*, vol. 5, no. 1, pp. 90–98, Feb. 1989.