Tata Motors

Commercial Vehicle Business Unit Pune

Project Topic: BLE Indoor Positioning System for Assembly Line

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Furthermore, I appreciate the nurturing learning environment provided, which allowed me to engage in significant projects. This internship has profoundly influenced my professional development, and I look forward to applying the knowledge and skills I have acquired in my future pursuits.

ORGANIZATION BACKGROUND

Tata Motors, established in 1945, stands as a testament to innovation and excellence in the global automotive industry. As India's largest automobile manufacturer, it boasts a comprehensive range of commercial and passenger vehicles. Known for pushing the boundaries of engineering and technology, Tata Motors is committed to delivering high-quality vehicles that cater to a global customer base, underpinning its mission with a steadfast focus on sustainability and advanced mobility solutions.

The company's manufacturing prowess is spread across strategic locations in India, including Jamshedpur, Pune, and Lucknow, among others. A landmark partnership with Fiat in 2005 further expanded its production capabilities, particularly at the Ranjangaon plant in Maharashtra, which produces both Tata and Fiat vehicles. This collaboration highlights Tata Motors' innovative edge and its dedication to quality. With an extensive network of over 4,000 touchpoints nationwide, Tata Motors ensures exceptional service and support, reinforcing its position as a leader in India's automotive sector.

INTRODUCTION

Embarking on a journey to redefine efficiency and accuracy in manufacturing, this project introduces a Bluetooth Low Energy (BLE) Indoor Positioning System aimed at revolutionizing assembly line operations. In an era where precision and speed are paramount, the integration of such advanced technology promises to streamline production processes like never before. This initiative seeks to leverage the unique capabilities of BLE technology, ensuring vehicles on the assembly line are tracked with unmatched accuracy, thereby minimizing errors, and enhancing operational efficiency. The essence of this project lies in its ability to blend innovative technology with everyday manufacturing processes, providing real-time monitoring and data analytics to optimize workflow and improve decision-making. Through this innovative approach, the project not only aims to boost productivity but also to set a new standard for smart manufacturing in the industry.

Objectives:

The project sets forth several ambitious objectives designed to transform the assembly line with the integration of BLE technology:

1. Improve Tracking Accuracy: Implement a system that enhances the accuracy of tracking vehicles throughout the assembly process, minimizing errors and streamlining operations.

2. Enable Real-time Monitoring: Develop a solution that allows for the real-time monitoring of vehicles at every stage of assembly, facilitating immediate adjustments and interventions as needed.

3. Increase Operational Efficiency: Utilize the data collected by the BLE Indoor Positioning System to analyse bottlenecks, predict potential delays, and optimize the flow of the assembly line to improve overall operational efficiency.

4. Enhance Data Analytics: Harness the power of BLE technology to gather detailed data on assembly line operations, providing insights that can lead to continuous process improvement and innovation.

5. Promote a Safer Work Environment: By accurately tracking and monitoring assembly line operations, aim to identify and mitigate potential safety risks, promoting a safer workplace for all involved.

PROJECT SCOPE

The scope of this BLE Indoor Positioning System project encompasses the design, development, and deployment of a comprehensive system aimed at enhancing the efficiency and accuracy of vehicle assembly lines. This project is tailored to address the specific needs of a 30-station vehicle assembly line, leveraging advanced BLE technology to provide real-time tracking and monitoring capabilities. The scope includes the following key components:

1. Technology Integration: Integration of BLE technology using ESP32 modules as Bluetooth clients and Raspberry Pi as the central server. This setup will enable precise tracking and communication across the assembly line.

2. Hardware Deployment: Installation of BLE tags at each station of the assembly line and equipping each vehicle with a unique identifier to enable accurate tracking and data collection throughout the manufacturing process.

3. Software Development: Development of custom software solutions on the Raspberry Pi, utilizing Python and job scheduler commands within the Raspbian OS for automatic execution of scripts, ensuring seamless operation and data handling.

4. Data Analytics Implementation: Implementation of a data analytics platform to process and analyse the data collected from the BLE tags for operational insights, bottleneck identification, and efficiency optimization.

5. Operational Optimization: Use of the system's real-time monitoring capabilities to make immediate adjustments on the assembly line, predict potential delays, and optimize workflow for increased operational efficiency.

6. Safety Enhancements: Utilization of the tracking system to enhance workplace safety by identifying potential risks and implementing preventive measures to mitigate them.

SYSTEM SPECIFICATIONS

Hardware Specifications:

1. Bluetooth Clients: ESP32 modules, equipped with BLE capabilities to serve as the tracking devices attached to each vehicle.

2. Server: Raspberry Pi (Model 4 recommended for enhanced performance), acting as the central server to collect, process, and analyse data from the BLE clients.

3. BLE Tags: Small, power efficient BLE tags installed at each of the thirty stations to communicate with the ESP32 modules on the vehicles.

4. Networking Equipment: Wi-Fi router or access points to ensure reliable communication between the ESP32 modules and the Raspberry Pi server.

Software Specifications:

1. Operating System: Raspbian OS, optimized for Raspberry Pi devices, to run the central server software.

2. Programming Languages: Python, for development of the tracking, monitoring, and data analytics software; Bash scripting for job scheduling and automation tasks.

3. Data Analytics Tools: Custom-developed analytics software or use of existing platforms tailored to process and visualize the data collected from the BLE indoor positioning system.

4. Security Measures: Implementation of security protocols for data encryption and secure communication between the ESP32 modules, BLE tags, and Raspberry Pi server to protect sensitive information.

Performance Parameters:

1. Tracking Accuracy: System designed to achieve high tracking accuracy, with minimal error margins, to precisely monitor vehicle progress through the assembly line.

2. Real-Time Data Processing: Capable of processing and analysing data in real-time to provide immediate insights and operational adjustments.

3. Scalability: Designed to easily scale with the addition of more stations or integration of additional technologies for enhanced capabilities.

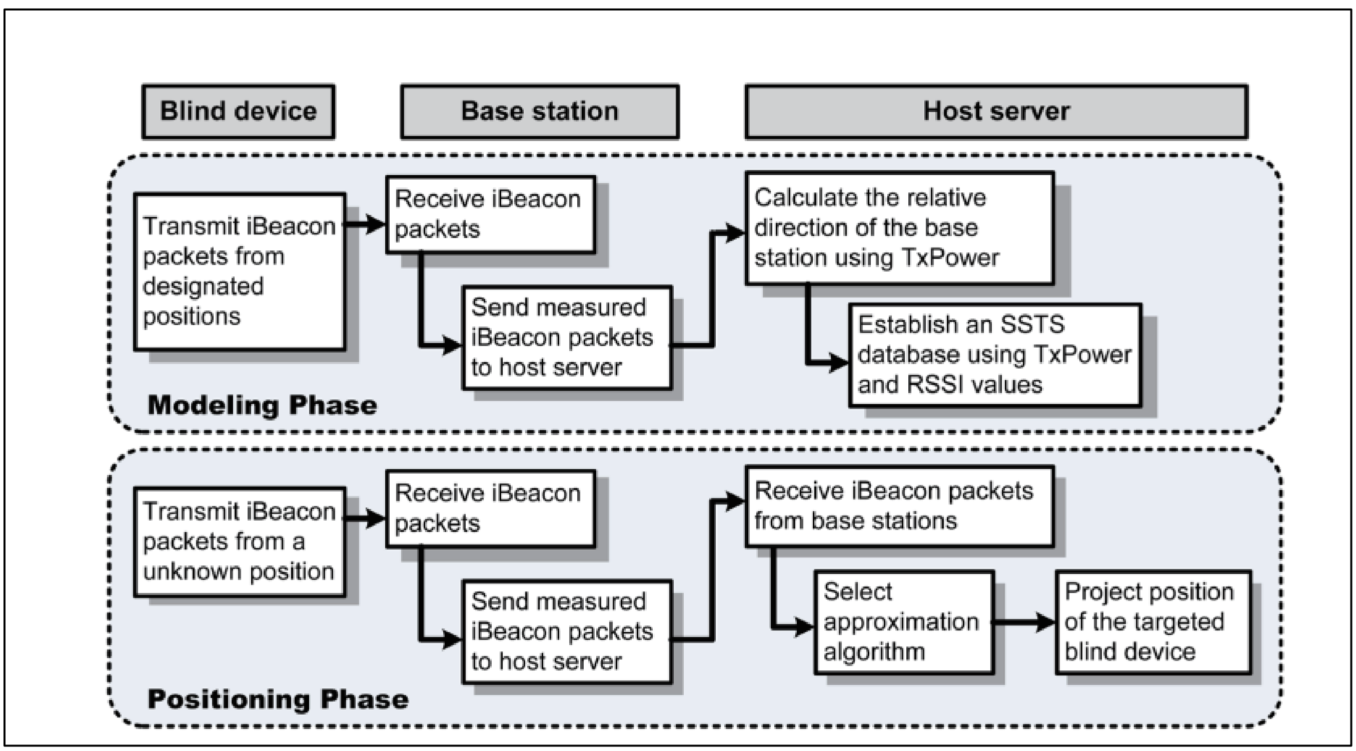
4. Energy Efficiency: Optimized for low power consumption, ensuring that the ESP32 modules and BLE tags can operate efficiently over extended periods.

This BLE Indoor Positioning System project aims to set a benchmark in smart manufacturing, driving significant improvements in efficiency, accuracy, and safety within the vehicle assembly line operations.

DESIGN AND IMPLEMENTATION

System Architecture: The proposed system integrates various devices including blind devices (e.g., vehicles on the assembly line equipped with BLE tags), multiple base stations (Raspberry Pi units), and a host server. These components interact to accurately locate and monitor vehicles within the assembly area.

1. Blind Devices: These are the mobile units or tags attached to the vehicles on the assembly line. They actively send signals to the surrounding base stations. Implemented using BLE technology, they broadcast packet messages at a set frequency, enabling precise location tracking without direct connection to the base stations.
2. Base Station Clients: Positioned strategically around the assembly area, these stations monitor the signals sent by blind devices and relay the information to the host server. They are implemented using Raspberry Pi microcomputers equipped with iBeacon components for signal transmission and reception.
3. Host Server: This central unit processes the data received from all base stations to determine the real-time location of each blind device within the assembly area. It uses the collected RSSI values and a positioning algorithm to project accurate positions.



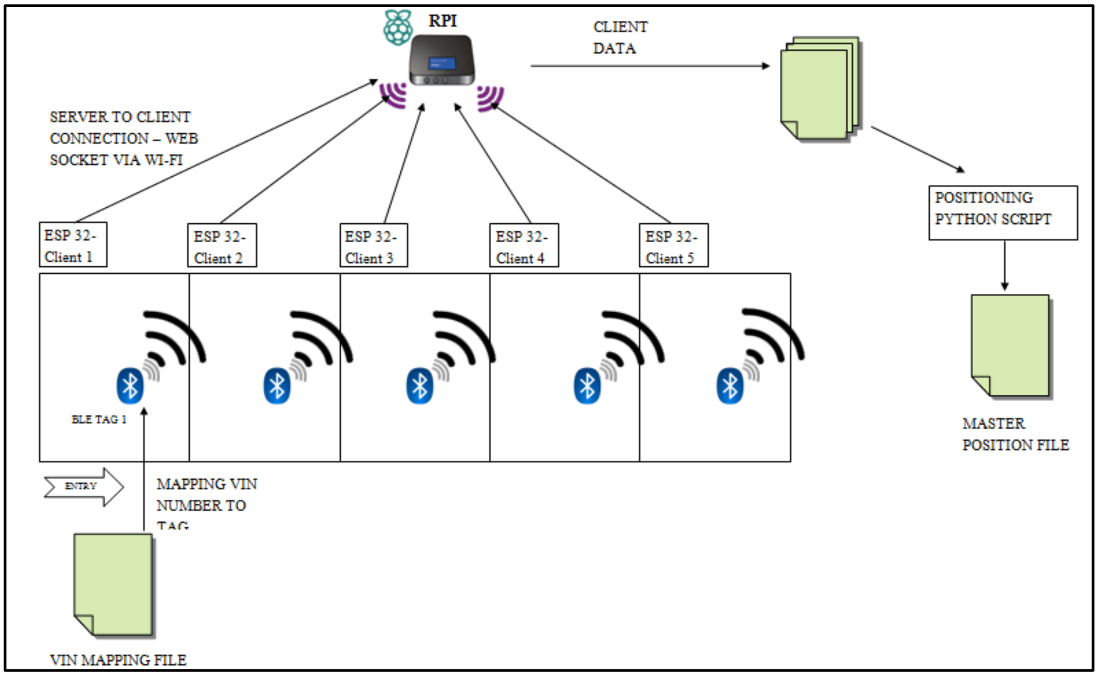


Figure: Hardware Architecture - BLE Indoor Positioning System

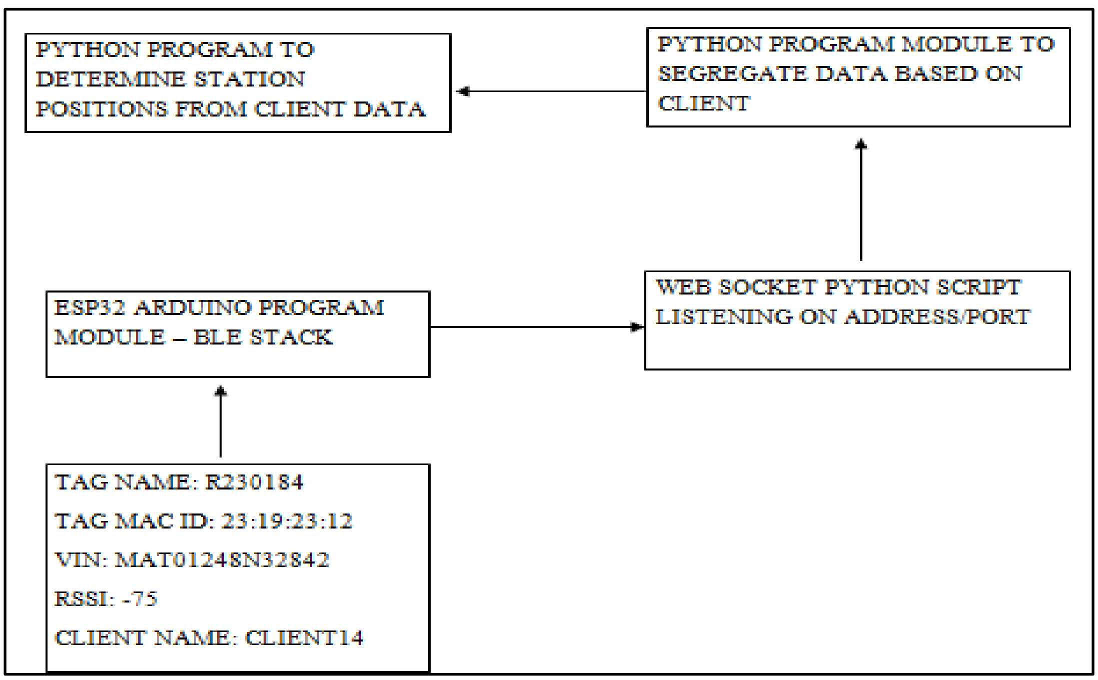


Figure: Software Architecture - BLE Indoor Positioning System

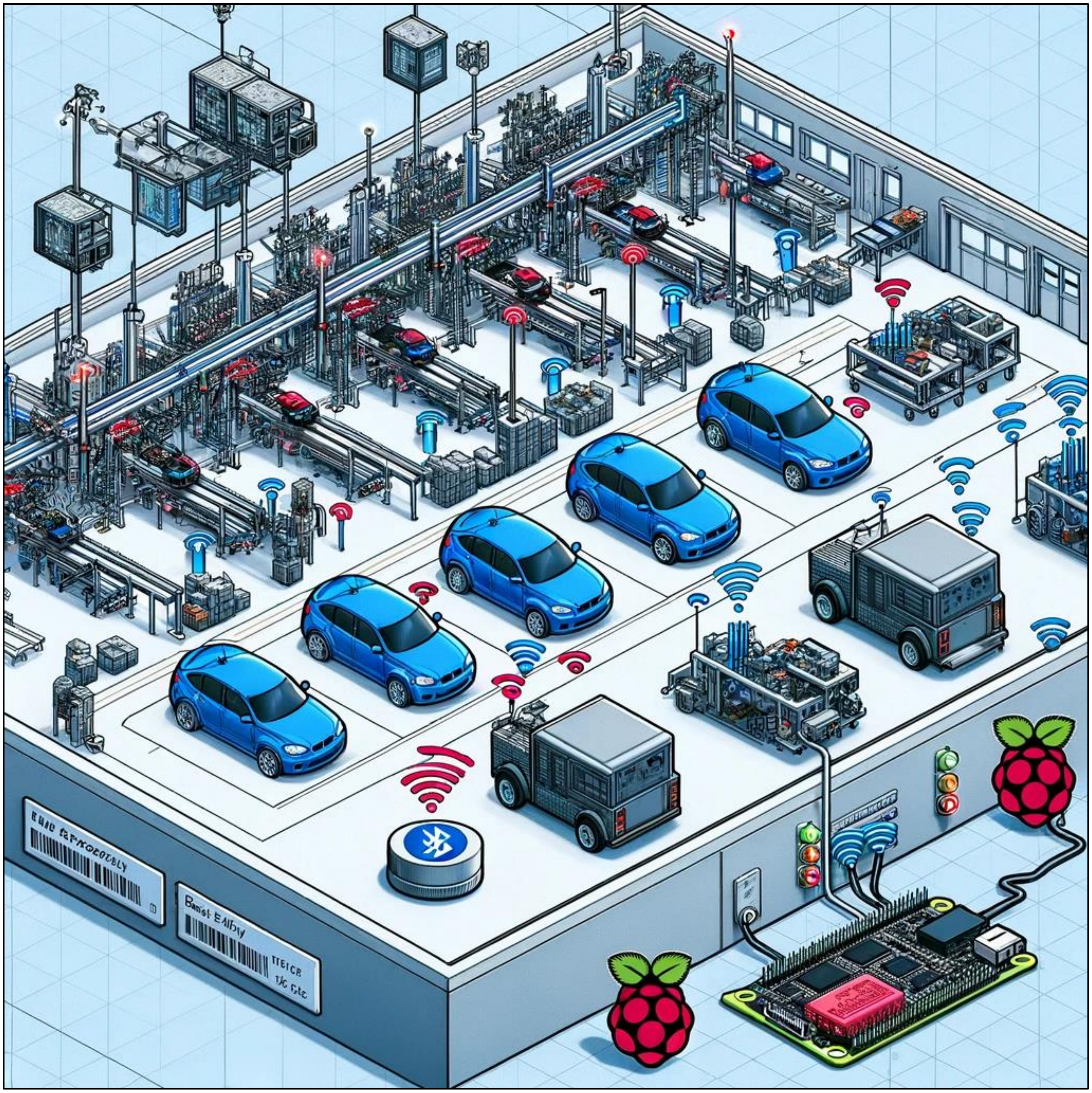


Figure: Pictorial Representation of Assembly Line with BLE Client transmitting data to Server (Raspberry Pi)

IMPLEMENTATION

1. **Tag Initialization on Vehicles:** At the beginning of the assembly line, BLE tags are attached to vehicles. These tags are programmed with unique identifiers (e.g., Vehicle Identification Number, VIN) at Station 1 (S1).
2. **ESP32 BLE Clients Deployment:** ESP32 modules, acting as BLE clients, are deployed strategically along the assembly line. Their role is to scan for BLE tags attached to the vehicles as they pass through different stations.
3. **BLE Tag Broadcasting:** The BLE tags on the vehicles continuously broadcast packet messages, including their unique identifiers and other data, at a set frequency. This allows for their detection by nearby ESP32 modules without the need for a direct connection.
4. **Signal Scanning and RSSI Logging:** As vehicles move along the assembly line, the ESP32 units scan for BLE broadcasts. Upon detecting a signal, they measure the RSSI value, which helps in estimating the proximity of the tag (and therefore, the vehicle) to the ESP32 module.
5. **Data Transmission to the Server:** The ESP32 units are configured to connect to a Wi-Fi network, over which they transmit the collected data (including the unique tag identifier and RSSI values) to the central server system.
6. **Server-Side Processing:** The Raspberry Pi server receives data from all ESP32 modules. It processes this data, utilizing the RSSI values and a positioning algorithm to accurately determine the real-time location of each vehicle within the assembly area.
7. **Timestamp Logging and Tag Memory Management**: Entry timestamps are logged for vehicles as they pass through various stations, based on the data received. At Station 1 (S1), the vehicle's VIN is written into the tag's memory. Upon reaching the final station (S30), the tag's memory is flushed, and a completion flag is set in the database for that vehicle, indicating it has completed the assembly process.

RESULTS

1. **Accurate Tracking Despite Interference:** Successfully tracked vehicles accurately even in the presence of environmental signal interference. Utilized strategic ESP32 placement and signal processing adjustments on Raspberry Pi servers to maintain accuracy.
2. **Identification of Loss Scenarios**: System identified stationary vehicles, indicating production delays or loss scenarios. Analysis of data and timestamps from ESP32 units highlighted inefficiencies at specific assembly stations.

Evaluation:

1. **Adapting to Signal Interference:** Implemented adaptive signal processing to counteract environmental interference, maintaining a low positional error margin. Showed system resilience and capability to uphold tracking accuracy under challenging conditions.
2. **Efficiency Improvements via Loss Time Analysis:** Detailed loss time analysis led to identifying production bottlenecks. Insights gained from the system data prompted workflow adjustments, reducing overall vehicle assembly time.
3. **Operational Impact:** The system's data-driven identification of inefficiencies facilitated targeted improvements, enhancing assembly line productivity. Adjustments made in response to the system's findings led to tangible improvements in assembly line speed and efficiency.
4. BLE indoor monitoring proves to be a cost-effective option compared to RFID implementations, with costs approximately 1/10th of traditional RFID systems.

FUTURE SCOPE

1. Dashboard Integration for Real-Time Monitoring: Develop a comprehensive dashboard that visualizes the real-time locations of vehicles on the assembly line, offering insights into workflow efficiency and identifying bottlenecks. Incorporate analytics features to display historical data trends, loss time analysis, and station-specific performance metrics.
2. Machine Learning (ML) Model Implementation: Utilize ML algorithms to predict potential bottlenecks and inefficiencies in the assembly process based on historical data. Implement anomaly detection models to identify unusual patterns or delays in vehicle movement, facilitating pre-emptive action to mitigate issues.
3. Customizable Alert System: Develop a customizable alert system that notifies managers or operators of critical events, such as unexpected delays or equipment malfunctions, in real-time. Allow for the setting of thresholds for alerts based on specific parameters, such as excessive time spent at a station or rapid movement through a critical checkpoint.

REFERENCES

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