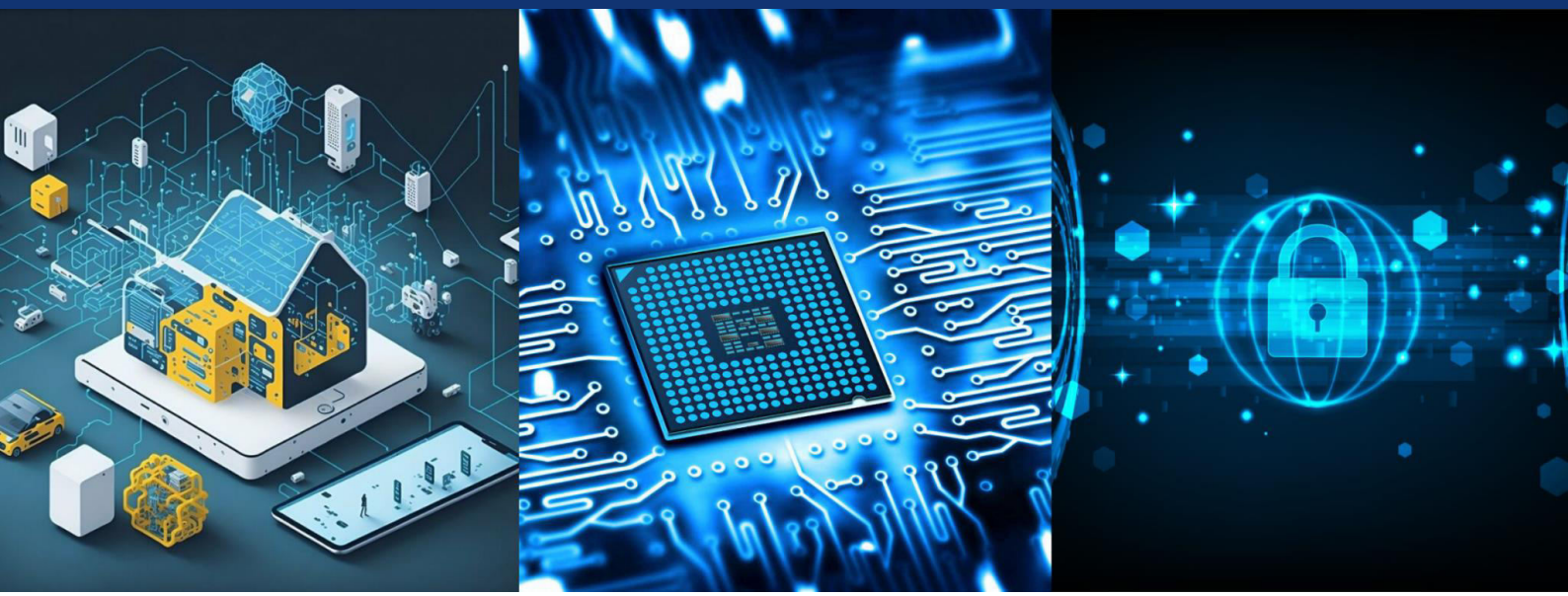
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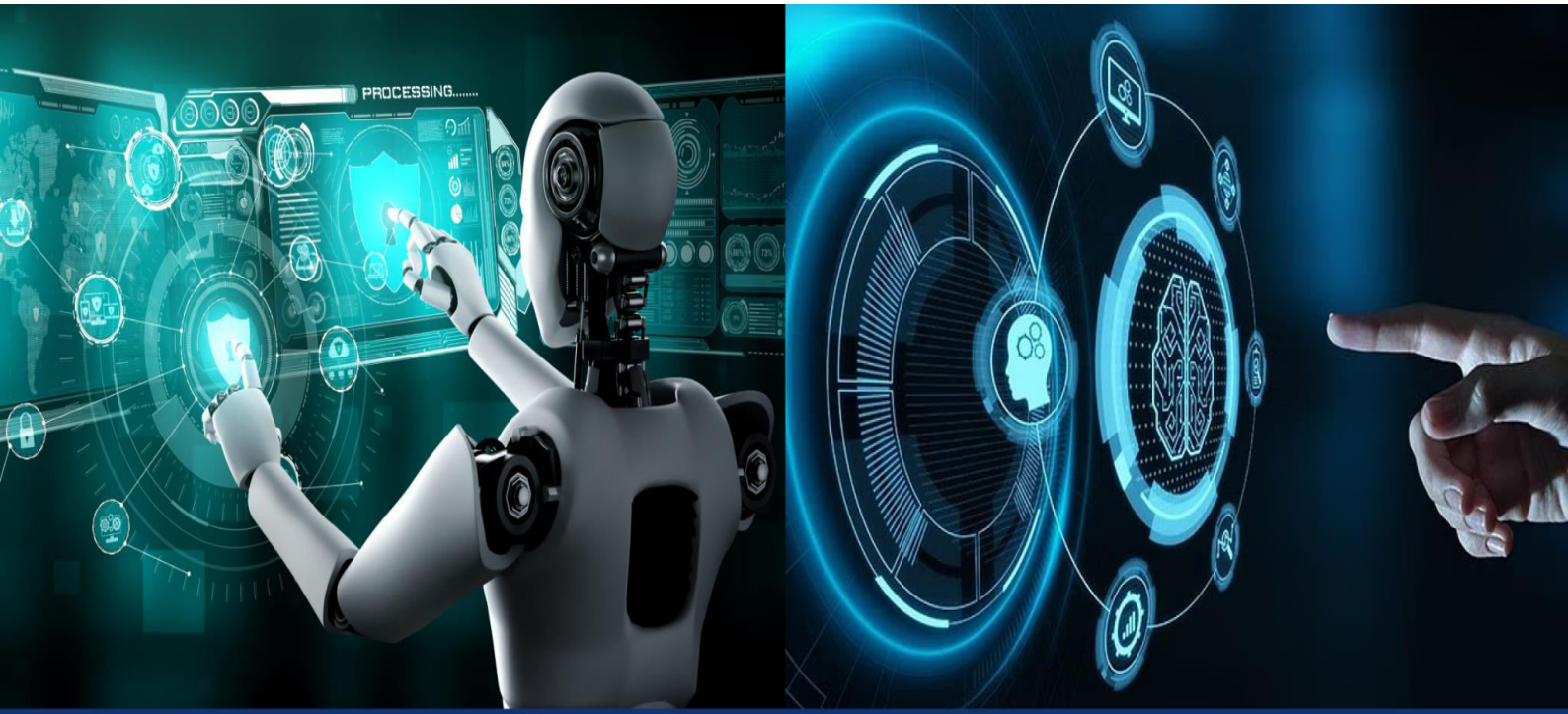
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IoT-Enabled Real-Time Public Transport Monitoring with Predictive Passenger Smart Notification System

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ABSTRACT: Public transportation systems require reliable, accessible information to reduce passenger waiting uncertainty, manage overcrowding, and improve travel safety. Conventional schedule-based services and GPS-only tracking applications provide limited visibility into vehicle occupancy and offer insufficient support for destination-specific passenger alerts. This paper presents an Internet of Things (IoT)-enabled public transport monitoring system that combines vehicle location tracking, passenger occupancy estimation, cloud-based data processing, and predictive notification functionality. The proposed architecture uses an ESP32 microcontroller to acquire geographical coordinates from a GPS module and passenger boarding and alighting events through infrared (IR) sensors, with pressure sensors providing additional occupancy information. The collected data are structured into JSON payloads and transmitted through wireless connectivity to a cloud platform for storage and processing. A web-based interface integrates live map visualization, route information, occupancy status, alert management, and passenger prediction features. The notification mechanism is designed to inform passengers approximately three to four stops before their selected destination. The implemented interface modules demonstrate the intended monitoring workflow and user interaction. The system provides a modular foundation for more informed, safer, and efficient public transportation management.

KEYWORDS: Internet of Things (IoT), Public Transport Monitoring, GPS Tracking, Passenger Occupancy Estimation, Predictive Notifications, Cloud Computing.

I. INTRODUCTION

Public transportation systems face challenges such as uncertain bus arrival times, passenger overcrowding, and limited access to real-time travel information. Conventional schedules and GPS-based tracking provide limited insight into vehicle occupancy and offer insufficient support for destination-specific passenger notifications. These limitations can affect commuter convenience, travel planning, and passenger safety.

This project presents an Internet of Things (IoT)-enabled public transport monitoring system integrating GPS tracking, passenger occupancy estimation, cloud data processing, and a web-based monitoring interface. An ESP32 microcontroller collects location information from a GPS module and passenger boarding and alighting events through infrared (IR) sensors, with pressure sensors providing supplementary occupancy information. The collected data are transmitted to a cloud platform for processing and display

.

The system provides live bus locations, route information, occupancy indicators, and destination-aware notifications designed to alert passengers approximately three to four stops before their destination.

The main contributions of this work are:

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- Real-time bus location monitoring using GPS.
- Passenger occupancy estimation using sensor data.
- Destination-based passenger notification.
- Integrated web interface for routes, live maps, and alerts.
- A modular architecture supporting future transport analytics and performance evaluation.

II. RELATED WORKS

Existing public transport monitoring approaches employ GPS tracking, Internet of Things (IoT) sensors, cloud computing, and passenger-counting techniques to improve transit visibility and operational management. However, differences in sensing methods, computational requirements, and prediction capabilities leave opportunities for integrated passenger information systems.

Dhope et al. [1] combined GPS tracking, camera-based passenger estimation, and Firebase cloud storage to support bus monitoring. Saravanakumar et al. [2] integrated GPS and infrared sensors for passenger counting, together with driver-safety monitoring. In contrast, Kamble [3] employed RFID-based tracking and ThingSpeak, although tracking accuracy depends on the placement and availability of RFID readers.

Other studies explored real-time monitoring and passenger prediction. Sharma [4] and Verma [5] investigated IoT-based monitoring and passenger counting, while Reddy [6] examined data-driven passenger-demand prediction. Salih and Younis [7] developed a smartphone-oriented monitoring approach using map-based vehicle tracking. Although these methods improve access to transport information, occupancy awareness and predictive passenger notifications are not consistently integrated.

Advanced approaches have also investigated intelligent demand management and automated passenger counting. Nayak and Chaubey [8] combined deep learning with fuzzy logic to support demand-based rerouting. Radovan et al. [9] reviewed passenger-counting methods, while Labit-Bonis et al. [10] explored camera-based deep tracking. These methods offer opportunities for detailed analysis but may introduce computational, privacy, or data requirements. Sutar et al. [11] demonstrated a smartphone-based IoT tracking alternative, reducing the need for dedicated tracking hardware but introducing device-dependency concerns.

A. Comparative Analysis of Existing Approaches

Study	Approach	Identified limitation
Dhope et al. [1]	GPS, camera-based counting, Firebase	Camera maintenance and processing requirements
Saravanakumar et al. [2]	GPS, IR sensors, driver-safety monitoring	Integrated destination-specific notification is not established in the report
Kamble [3]	RFID and ThingSpeak	Tracking depends on RFID reader locations
Sharma [4] and Verma [5]	IoT monitoring and passenger counting	Limited predictive capabilities
Reddy [6]	Data-driven passenger prediction	Requires substantial historical data and computational resources
Salih and Younis [7]	Mobile application and map-based tracking	Occupancy monitoring is not incorporated
Nayak and Chaubey [8]	Deep learning and fuzzy-logic rerouting	Higher computational complexity

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Study	Approach	Identified limitation
Radovan et al. [9] and Labit-Bonis et al. [10]	Image processing and deep passenger tracking	Privacy, occlusion, and processing considerations
Sutar et al. [11]	Smartphone GPS and mobile-network communication	Device reliability and battery constraints

B. Research Gap and Motivation

The reviewed approaches demonstrate individual capabilities in vehicle tracking, passenger counting, cloud connectivity, and demand analysis. However, the project report identifies a need to combine these capabilities within a unified passenger-facing system. The proposed framework addresses this integration requirement through GPS-based location visualization, sensor-assisted occupancy estimation, cloud-based data handling, and destination-aware alerts designed for delivery approximately three to four stops before arrival. Its distinguishing contribution is the integration of these functions into a common monitoring interface rather than the introduction of a new sensing or prediction algorithm

III. PROBLEM DEFINITION AND CONTRIBUTIONS

A. Problem Definition

Public transportation passengers often lack timely information about bus locations, vehicle occupancy, and destination arrival alerts. Fixed schedules and location-only tracking systems cannot adequately communicate current passenger density or provide integrated, destination-specific notifications. These limitations increase uncertainty during travel and make it difficult for commuters to plan their journeys efficiently.

B. Contributions

The principal contributions of the proposed system are:

Real-Time Bus Tracking: Integrates GPS-based location information with map visualization to help passengers monitor bus movements.

Passenger Occupancy Estimation: Uses infrared sensors to detect boarding and alighting events, with pressure sensors providing supplementary occupancy information.

Cloud-Based Data Management: Organizes vehicle telemetry for transmission, storage, processing, and retrieval through a cloud-connected architecture.

Destination-Aware Notifications: Defines a stop-based alert mechanism intended to notify passengers before their selected destination.

Unified Monitoring Interface: Combines live maps, route information, occupancy indicators, alerts, and passenger estimation features in a web-based application.

Modular System Design: Separates sensing, communication, data processing, and presentation into functional components that can be independently tested and extended.

The contribution of this project lies primarily in the integration of these monitoring and notification functions. Quantitative improvements in tracking accuracy, passenger-counting performance, and notification reliability require experimental validation before they can be claimed

IV. RESEARCH METHODOLOGY

The proposed system follows a modular methodology integrating IoT-based sensing, GPS tracking, cloud-based data management, and passenger-facing web services.

A. Data Acquisition

An ESP32 microcontroller collects geographical coordinates from a GPS module. Infrared (IR) sensors detect passenger boarding and alighting events, while pressure sensors provide supplementary occupancy information.

B. Passenger Occupancy Estimation

Passenger occupancy is estimated by updating the previous passenger count using entry and exit events:

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$$O_t = O_{\{t-1\}} + P_{\{in\}} - P_{\{out\}}$$

where O_t represents the current occupancy, $O_{\{t-1\}}$ is the previous occupancy, and $P_{\{in\}}$ and $P_{\{out\}}$ denote passenger entries and exits, respectively.

C. Data Transmission and Processing

The collected location and occupancy information is organized into structured JSON data and transmitted through Wi-Fi or GSM connectivity. The proposed cloud layer stores and processes the incoming information for retrieval by the monitoring interface.

D. Route Monitoring and Notification

The system combines bus-location information with route and stop-sequence data to display bus positions, route paths, and estimated arrival times. A destination-aware notification mechanism is designed to alert passengers approximately three to four stops before their selected destination.

E. Web-Based Visualization

The web interface integrates live maps, route information, occupancy indicators, alerts, and passenger prediction features. These modules provide a unified view of the information required for journey planning.

F. Evaluation Methodology

The system should be evaluated through controlled tests of GPS update reliability, passenger-counting error, route consistency, notification timing, and data-transmission latency. Since the project report does not provide verified quantitative measurements, these evaluations remain necessary to establish real-world performance.

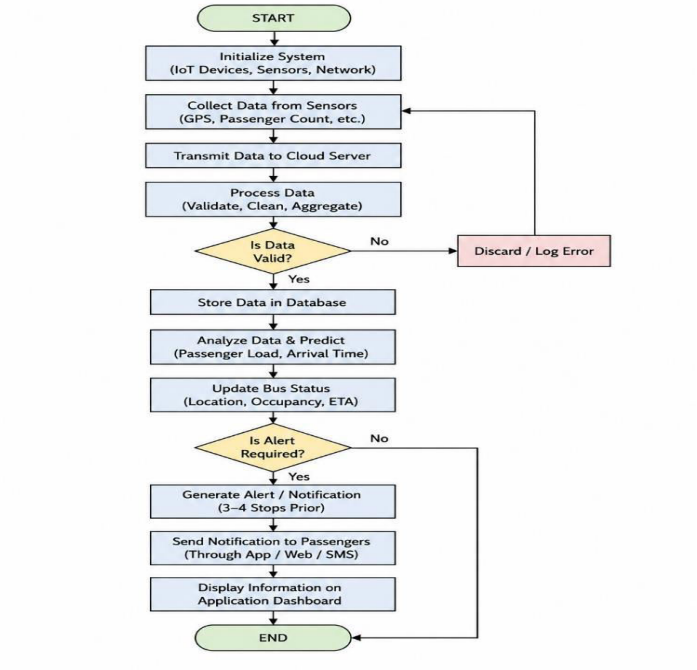


Fig. 1. Flowchart

V. PLATFORM OVERVIEW

The proposed system consists of three main layers: hardware sensing, communication and cloud data management, and a web-based user interface.

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A. Hardware Layer

An ESP32 microcontroller collects location information from a GPS module and passenger boarding and alighting events using infrared (IR) sensors. Pressure sensors provide supplementary information for estimating passenger occupancy.

B. Communication and Cloud Layer

The collected sensor data are organized into structured JSON payloads and transmitted through Wi-Fi or GSM connectivity. A cloud platform supports data storage, processing, and retrieval. The project report identifies Firebase, Blynk as possible platform options; the specific deployment should be confirmed before final submission.

C. Web Application Layer

The user interface is developed using HTML, CSS, and JavaScript. It includes modules for the home page, live bus map, route information, alerts, passenger prediction, and voice assistance. The interface is designed to display bus locations and occupancy indicators while supporting destination-aware notifications approximately three to four stops before the passenger's selected destination.

The modular platform integrates sensor data collection, cloud communication, and passenger-facing information into a unified monitoring framework. Its practical performance depends on the reliability of sensor readings, network connectivity, location updates, and notification delivery as shown in Fig. 2. Also, the system architecture as shown in Fig. 3.



Fig. 2. Landing page of the BMTC Monitor platform

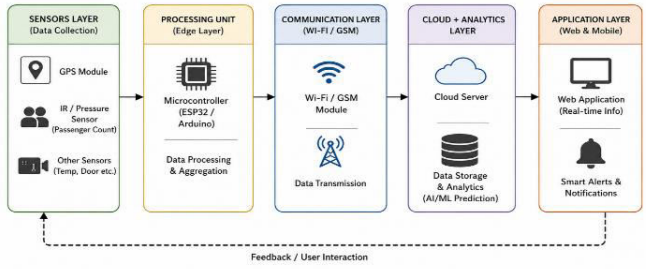


Fig. 3. System Architecture

VI. BMTC TRACKING ROUTES MODULE

The proposed system supports BMTC bus tracking and route discovery across Bengaluru. The Live Map module is designed to display bus locations, route paths, sequenced bus stops, occupancy indicators, and estimated arrival times using an interactive map interface.

The Routes module allows passengers to search for BMTC routes, review stop sequences, and view available timetable information. For example, a route between Majestic and Silk Board can be represented as an ordered sequence of stops to support journey planning and destination-based alerts.

The system design identifies Leaflet.js and OpenStreetMap for map visualization, with Firebase Realtime Database described for location updates. The route-search module separately documents an Express.js API and MongoDB Atlas for route and stops data. These components should be verified against the final deployed implementation.

Route accuracy and reliable arrival estimates depend on valid bus-location updates, correct stop ordering, and current schedule data. The report describes the intended functionality but does not establish verified live tracking accuracy for BMTC services

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VII. PREDICTOR ANALYSIS

The Predictor Dashboard is designed to analyze passenger density patterns and potential transit delays using historical route data, bus location updates, traffic conditions, and time-based information. It presents crowd-density indicators and delay-risk levels to help passengers make informed travel decisions.

The proposed analytics module processes route telemetry to identify changes in bus movement and estimate possible congestion or overcrowding. These outputs are intended to support passenger planning and improve awareness of expected travel conditions.

The project report describes a JavaScript-based analytics engine supported by backend APIs for prediction and data processing. However, the prediction model's accuracy and reliability have not been quantitatively established in the available report. Validation requires historical and observed passenger data, comparison against actual outcomes, and suitable evaluation metrics such as Mean Absolute Error (MAE) or Root Mean Squared Error (RMSE).

Thus, the Predictor Dashboard provides a foundation for data-driven public transport monitoring, while its practical effectiveness depends on data quality, validation, and reliable integration with tracking system, as shown in Fig. 4.

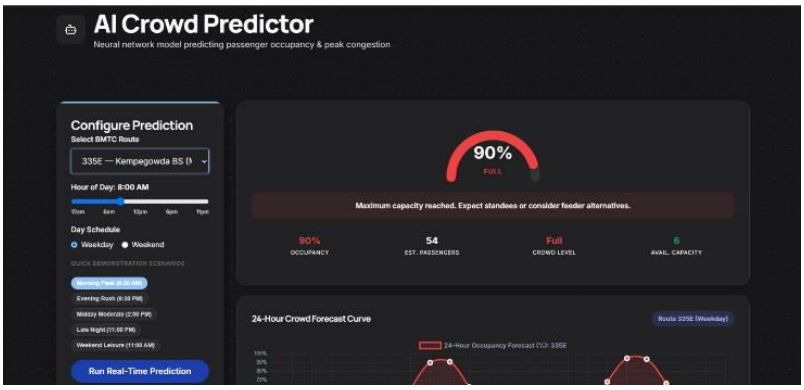


Fig. 4. Interview session with real-time question and response capture

VIII. RESULTS

A. Results

The developed platform presents an integrated interface for public transport monitoring through the following modules:

1. Home Page: Provides an overview of the monitoring platform, including fleet information, active vehicle indicators, navigation options, and system alerts.
2. Live Map: Displays bus locations on an interactive map, with route paths, bus-stop markers, occupancy indicators, and estimated arrival information.
3. BMTC Routes: Provides route search functionality, stop sequences, and timetable information to support passenger journey planning.
4. Alert Management: Provides an interface for managing destination-based and other passenger notifications. The proposed notification mechanism is designed to alert passengers approximately three to four stops before their destination.
5. Predictor Dashboard: Presents passenger-density and transit-delay indicators to support travel decisions.
6. Voice Assistance: Provides an additional interface for voice-based interaction and accessibility.

These modules demonstrate the intended workflow of the proposed public transport monitoring platform, combining route discovery, bus tracking, occupancy awareness, and passenger notification features

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IX. CONCLUSION AND FUTURE DIRECTIONS

A. Conclusion

This paper presents an IoT-enabled public transport monitoring system designed to improve passenger information and journey planning for BMTC services. The proposed framework integrates GPS-based bus tracking, sensor-assisted passenger occupancy estimation, route information, cloud-based data management, and destination-aware notifications.

The web-based platform combines live map visualization, BMTC route discovery, occupancy indicators, predictive analysis, and voice assistance within a unified interface. The passenger occupancy calculation and stop-based notification mechanism provide a foundation for delivering more useful travel information to commuters.

The project demonstrates the design and integration of these functional modules. However, real-world reliability and performance require further validation through hardware testing, live bus trials, and quantitative evaluation.

B. Future Directions

The following improvements are proposed to enhance the system:

1. Hardware Integration: Deploy and calibrate ESP32, GPS, IR, and pressure sensors on actual buses to improve data reliability.
2. Improved ETA Prediction: Incorporate real-time traffic conditions, historical journey data, and route information for more reliable arrival-time estimation.
3. Advanced Passenger Prediction: Use machine learning techniques and historical passenger data to improve crowd-density forecasting.
4. Reliable Notifications: Improve destination and overcrowding alerts through notification retries, duplicate-alert prevention, and delivery-status monitoring.
5. Mobile Application Development: Extend the existing web-based platform into a dedicated mobile application for improved accessibility.
6. Security and Privacy: Strengthen data protection, API security, and passenger privacy during information collection and transmission.
7. Field Testing and Evaluation: Conduct trials on selected BMTC routes to measure GPS accuracy, passenger-counting error, notification timing, and network latency.

These enhancements can help evolve the proposed framework into a more reliable and scalable public transport monitoring solution.

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