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ML & IoT Based Smart Vehicle Health Monitoring and Predictive Maintenance System

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Abstract: Maintaining modern vehicles in today's fast-paced and technology-driven environment is increasingly complex, especially as vehicle systems grow more sophisticated. Traditional maintenance practices often rely on fixed intervals, which may lead to either premature servicing or delayed interventions, both of which can compromise vehicle performance and safety. This research proposes a ML & IoT Based smart car maintenance framework that leverages Machine Learning (ML) and Internet of Things (IoT) technologies to deliver a predictive and automated solution for vehicle health management. The primary focus is on monitoring and forecasting engine oil degradation, a critical factor in engine longevity and performance. IoT-enabled sensors embedded within the vehicle continuously collect real-time data such as mileage, engine temperature, oil viscosity, and driving patterns. This data is processed by an ML-based predictive model trained to accurately estimate the remaining useful life of the engine oil. Once predefined thresholds are reached, the system autonomously schedules a service appointment through a connected mobile application, ensuring timely and efficient maintenance without user intervention. By enabling condition-based maintenance, the system reduces unnecessary servicing, lowers operational costs, prevents mechanical failures, and enhances the overall driving experience. The proposed solution represents a significant step toward intelligent, connected, and sustainable automotive maintenance systems.
Index Terms: Smart Car Maintenance, Internet of Things (IoT), Machine Learning (ML), Engine Oil Prediction, Predictive Maintenance, Vehicle Health Monitoring, Automotive IoT, Intelligent Transport Systems, Service Automation, Automatic Appointment Booking

I. INTRODUCTION

The automotive industry has undergone a paradigm shift over the past decade, with vehicles evolving into sophisticated systems integrating advanced electronics, telematics, and software-driven functionalities. Despite these advancements, vehicle maintenance practices remain anchored in reactive methodologies, such as scheduled manual inspections or post-failure repairs. These conventional approaches are inherently inefficient, often leading to undiagnosed anomalies, inflated ownership costs, and unplanned operational halts. Industry analyses reveal that nearly 30% of vehicle breakdowns stem from delayed diagnostics, underscoring the urgent need for real-time health monitoring tools capable of empowering users with actionable, data-driven insights [1].

Emerging technologies like the Internet of Things (IoT) and Machine Learning (ML) offer transformative potential to address these inefficiencies. IoT enables seamless data acquisition through embedded sensors, while ML algorithms unlock predictive capabilities by identifying patterns in historical and real-time datasets. However, existing IoT-based solutions often focus on isolated parameters such as engine performance or tire pressure without unifying multi-dimensional data into a cohesive, user-accessible framework [2]. Furthermore, many systems lack scalability, rendering them incompatible with evolving automotive trends like electric vehicles (EVs) or autonomous driving systems due to rigid architectures and dependency on third-party platforms [3].

This research introduces a Machine Learning and IoT Framework for Real-Time Vehicle Health Monitoring and Predictive Maintenance, designed to overcome these limitations through a holistic, modular approach. Unlike prior works, our system integrates multi-sensor data fusion (e.g., engine temperature, battery voltage, oil quality, radiator water levels) with edge computing via microcontrollers (Arduino/Raspberry Pi) to enable low-latency, on-device diagnostics. Processed data is transmitted to a cloud infrastructure (Firebasee) using the API protocol, where ML models trained on supervised and unsupervised learning techniques predict maintenance requirements. Algorithms such as Isolation Forests and Long Short-Term Memory (LSTM) networks are employed for anomaly detection, prioritizing computational efficiency and interpretability over opaque "black-box" methodologies [4].A defining innovation of this work is its modular scalability, which allows seamless integration with future automotive technologies, such as Vehicle-to-Everything (V2X) communication or renewable energy systems. Insights from the cloud are delivered to end-users via a purpose-built Android application developed using Flutter, featuring dynamic health dashboards, predictive alerts, and automated service scheduling, also manual service scheduling. By eliminating reliance on third-party platforms, the system ensures data privacy, reduces latency, and enhances user autonomy.

The implications of this framework extend beyond individual vehicle owners. Fleet operators can leverage its predictive analytics to minimize downtime through fleet-wide trend analysis, while automotive service centers gain access to granular diagnostic data for preemptive repairs. Additionally, optimized maintenance cycles reduce unnecessary part replacements, directly contributing to sustainability goals by curtailing resource waste and lowering emissions linked to manufacturing and logistics [5].

Paper Organization: Section 4 critiques existing IoT-based vehicle monitoring systems and identifies gaps in real-time diagnostics and scalability. Section 5 details the system architecture, emphasizing edge-to-cloud workflows and sensor integration. Section 6 elaborate that the methodology used develop the system. Section 7elaborates the implementation part of the system. Section 8discuses that the how project is completed, and Section 9 concludes with future enhancements.

By harmonizing IoT's real-time data capabilities with ML's predictive precision, this work pioneers a scalable, transparent framework for proactive vehicle maintenance, setting a benchmark for next-generation automotive ecosystems.

II. LITERATURE REVIEW

A. *Summary of Existing Systems or Research Papers*

Several research efforts have focused on enhancing vehicle maintenance using IoT and predictive technologies:

1) Patel and Joshi (2022) proposed a real-time IoT-based vehicle maintenance system using sensors to monitor vital parameters such as oil levels and engine temperature. Their system enables timely alerts and maintenance reminders to reduce unexpected failures [1].
2) Mohammad et al. (2021) introduced a cloud-connected diagnostic model to enable preventive maintenance using real-time vehicle data. The system facilitates early fault detection and improves decision-making in servicing [2].
3) An IoT-Based Predictive Connected Car Maintenance (2021) study presents an architecture that combines predictive analytics and connected IoT devices. It predicts part failure and streamlines scheduling and inventory using AI-enhanced strategies [3].
4) Prajapati et al. (2022) developed an intelligent vehicular maintenance prototype using Raspberry Pi and sensors to monitor battery voltage, engine temperature, and fuel level. Data is sent to the cloud for analysis and alerts, offering a practical implementation for smart maintenance [4].
5) A comprehensive case study in "Predictive Maintenance using IoT" discusses how global enterprises like UPS and FedEx successfully deploy IoT to predict vehicle faults and reduce downtime in large fleets [5].

B. *Technologies Already Used*

Common technologies include:

1) Onboard sensors (temperature, oil quality, vibration)
2) Cloud databases and processing
3) ML-based predictive analytics
4) Wireless protocols (Wi-Fi, GSM)
5) Mobile interfaces for user interaction

C. *Research Gaps Addressed by Our Project*

Our project addresses key limitations identified in existing systems:

1) Most existing models lack engine oil-specific prediction. Our machine learning model focuses on forecasting oil usability based on multiple real-time parameters.
2) Current systems rarely include automatic service scheduling. Our system bridges that gap by autonomously booking service appointments when thresholds are met.
3) Many papers mention alerts but not real-time mobile integration. Our mobile application not only informs users but also allows them to manage bookings and payments seamlessly.
4) No system addresses smart inventory linking with service centers. Our solution lays the foundation for future enhancements such as real-time parts availability tracking.

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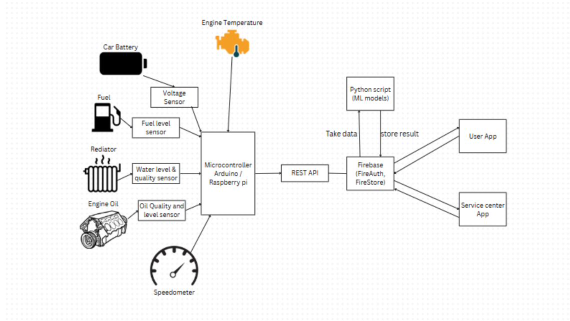
III. SYSTEM ARCHITECTURE/DESIGN

Dig 1:-System Architecture



A. ML & IoT based Smart Car Maintenance System – Architecture Explanation

This system is designed to monitor a vehicle's condition using embedded sensors, process the collected data using machine learning, and provide real-time feedback to users and service centers via mobile applications. The architecture includes several key components working together across hardware, cloud, and software layers.

1) Sensor Layer – Vehicle Data Collection

Various sensors are installed in the car to collect real-time data:

- Voltage Sensor: Measures the battery's health and charge level.
- Fuel Level Sensor: Detects the current amount of fuel in the tank.
- Water Level & Quality Sensor: Monitors radiator coolant level and its quality.
- Oil Quality and Level Sensor: Checks both the quantity and condition of engine oil.
- Engine Temperature Sensor: Detects potential overheating by monitoring engine temperature.
- Speedometer: Tracks vehicle speed and distance traveled, useful for estimating wear and maintenance needs.

All sensors feed their data into a central processing unit.

2) Microcontroller Unit – Data Aggregation

A microcontroller, either an Arduino or Raspberry Pi, acts as the data aggregator. It performs the following functions:

- Collects input from all connected sensors.
- Formats the data into structured messages (e.g., JSON).
- Sends the data to a remote cloud database using a REST API over the internet.

This unit operates at the edge and serves as the bridge between the vehicle's physical environment and the cloud services.

3) REST API – Communication Bridge

The REST API provides a standardized way for the microcontroller to send sensor data to the cloud. This interface ensures compatibility between hardware and cloud services and allows for secure, scalable data transmission.

4) Firebase Backend – Cloud Infrastructure

Firebase is used as the core cloud platform, consisting of:

- Firebase Firestore: A real-time NoSQL cloud database where all incoming sensor data is stored. It also stores the output of the machine learning models and user-related data.
- Firebase Authentication: Provides secure user login and access control for both mobile applications.

Firestore serves as the central hub that stores and synchronizes data across all parts of the system.

5) Machine Learning Script – Predictive Analytics

A Python script runs continuously or at intervals. Its responsibilities include:

- Fetching raw sensor data from Firestore.
- Running pre-trained machine learning models to analyze vehicle health.

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- Predicting issues such as oil degradation, battery failure, or overheating risk.
- Storing the prediction results and maintenance recommendations back into Firestore.

This layer adds intelligence and transforms raw sensor data into actionable insights.

6) Mobile Applications – User and Service Access

Two separate applications consume the processed data:

- *User App:*
  - Displays real-time vehicle health information.
  - Notifies users about potential issues.
  - Allows booking of maintenance services.
  - Book Automatic Appointment
  - Payment
- *Service Center App:*
  - Provides technicians with predictive maintenance alerts.
  - Enables preparation for servicing tasks before the vehicle arrives.
  - Helps in efficiently managing customer requests and vehicle diagnostics.
  - Uploading the progress to the app.
  - Generating the Bill
  - Taking record of the services

7) Data Flow Summary

- Sensors collect real-time vehicle data.
- Microcontroller sends data via REST API to Firebase Firestore.
- Machine learning script processes this data and updates the predictions in Firestore.
- Mobile apps fetch the results and present them to users and service centers.

8) Key Advantages

- Real-time Monitoring: Data is continuously updated for live tracking of vehicle condition.
- Predictive Maintenance: Machine learning models allow the system to predict faults before they occur.
- Cloud Storage & Access: Centralized data accessible to authorized users from anywhere.
- Seamless Communication: REST APIs and Firebase ensure reliable, scalable integration.
- User & Technician Involvement: Both the car owner and service personnel receive timely, relevant updates for decision-making.
- This architecture enables a smart, connected vehicle maintenance ecosystem that enhances safety, reduces unexpected breakdowns, and improves service efficiency.

B. Components Used

1) Sensor Module Details

To ensure accurate vehicle health monitoring and intelligent maintenance prediction, our system uses multiple IoT-based sensors. Each sensor monitors a critical parameter that contributes to overall vehicle performance and maintenance needs.

a) Engine Temperature Sensor

This sensor monitors the engine’s operating temperature in real time. Overheating is a major cause of engine wear and failure. By detecting abnormal temperature patterns, the system can alert users early, enabling preventive maintenance before engine damage occurs.

b) Voltage Sensor

The voltage sensor checks the battery voltage level to assess battery health. It helps identify issues such as undercharging or overcharging. If the voltage falls below a safe threshold, the system notifies the user to inspect or replace the battery, thus avoiding sudden breakdowns.

c) Fuel Level Sensor

The fuel level sensor continuously measures the amount of fuel in the tank. It provides real-time fuel monitoring via the mobile application. This data can also be correlated with mileage and fuel efficiency statistics for advanced diagnostics in future enhancements.

d) Oil Quality and Level Sensor

This is a critical sensor in our system. It measures both the viscosity (quality) and volume (level) of engine oil. Degradation in oil quality is analyzed by the ML model to predict when oil replacement is needed. This prevents engine wear and reduces the frequency of unnecessary oil changes.

e) Speed Sensor

The speed sensor measures the vehicle's current speed and contributes to calculating overall mileage. It also helps detect anomalies in performance and supports the machine learning model in predicting oil degradation based on driving conditions (e.g., frequent high-speed driving).

This sensor network forms the backbone of real-time data acquisition, allowing your system to make intelligent predictions and automate service actions efficiently.

2) Machine Learning Models in Our System

The smart car maintenance system utilizes multiple ML models to intelligently analyze sensor data and predict key outcomes that support vehicle health and user convenience. Below are the four primary ML models integrated into our system:

a) ML Model to Predict Remaining Life of Engine Oil

- Purpose:

To estimate how long the current engine oil will remain usable before it needs replacement.

- Input Features:
  - Engine oil temperature
  - Mileage (distance covered since last oil change)
  - Oil viscosity and quality readings
  - Engine load and speed patterns
  - Time since last service

- Algorithm Used:

Regression algorithms such as Random Forest Regressor or Gradient Boosting Regressor are suitable, as they handle complex, nonlinear relationships between variables.

- Output:

Estimated remaining oil life in kilometers or days.

- Benefits:
  - Avoids premature oil changes
  - Prevents engine damage from degraded oil
  - Optimizes service intervals

b) ML Model to Predict Drivable Kilometers Based on Current Fuel Level

- Purpose:

To estimate how many kilo-meters the vehicle can run with the current fuel level.

- Input Features:
  - Fuel level (in liters or %)
  - Average fuel consumption (km/l)
  - Recent driving patterns (e.g., speed, acceleration)
  - Engine load

- Algorithm Used:

A Linear Regression or Decision Tree Regressor model can predict the remaining range effectively.

- Output:

Predicted range (in kilometers) that can be covered before refueling is needed.

- Benefits:
  - Helps users plan trips and refueling
  - Prevents unexpected vehicle stops due to empty tank
  - Enhances route optimization

c) ML Model to Predict Optimal Time for Booking Service Appointment

- Purpose:

To forecast the ideal time for scheduling vehicle service based on current vehicle health and usage trends.

- Input Features:
  - Mileage since last service
  - Oil life prediction
  - Engine temperature trends
  - Battery voltage trends
  - Tire pressure deviations

- Algorithm Used:

Classification algorithms like Logistic Regression or SVM, or even time-series models (like LSTM), depending on temporal pattern detection.

- Output:

Binary or categorical output (e.g., "Book Now", "Safe for 500 km", etc.)

- Benefits:
  - Automates booking process
  - Reduces last-minute servicing
  - Ensures better vehicle reliability

d) ML Model to Predict When and How Much Fuel to Add

- Purpose:

To suggest the ideal time and quantity of fuel to refill, based on consumption rate and route prediction.

- Input Features:
  - Current fuel level
  - Fuel consumption rate
  - Average trip length and daily usage
  - Past refueling habits
  - Nearby fuel station data (optional)

- Algorithm Used:

Time-series forecasting (like ARIMA or LSTM) or Reinforcement Learning for dynamic refueling strategies.

- Output:

Predicted date/time of next refuel and recommended quantity (in liters).

- Benefits:
  - Helps in planning fuel expenses
  - Avoids overfilling or underutilizing tank capacity
  - Supports budget-conscious or fleet users

3) Mobile Application

The mobile application serves as the user interface and control center for our Smart Car Maintenance System. It bridges the gap between the vehicle's sensor data, the machine learning predictions, and the end user by delivering real-time insights, alerts, and actionable options. The application is designed for Android devices and is built using a user-friendly, intuitive interface to promote ease of use and responsiveness.

a) Key Features

- Real-time Monitoring

The app continuously receives sensor data through cloud integration and displays live information such as:

  - Engine temperature
  - Oil life percentage
  - Battery voltage
  - Fuel level and predicted range

- Intelligent Notifications and Alerts

Based on the ML model outputs, the app provides alerts to the user for:

  - Low oil quality or nearing oil expiry
  - Battery issues
  - Tire pressure drops
  - High engine temperature
  - Fuel refill recommendations

- Predictive Service Booking

The app integrates the ML-based service scheduling feature. It automatically notifies the user when servicing is due and allows one-tap booking at the nearest authorized service center.

- Trip and Usage Statistics

Users can view past trip summaries, fuel usage patterns, maintenance logs, and overall car performance metrics, helping them understand long-term vehicle health trends.

- In-app Service Booking & Payment

The system includes an optional module for booking services and making payments directly through the app, offering a seamless experience from alert to action.

b) Technical Implementation

- Platform: Android (developed in Flutter(Dart) using Android Studio)
- Cloud Backend: Firebase or AWS (for real-time data sync and notifications)
- APIs: Integrated with vehicle IoT device APIs and Firebase Realtime Database
- UI/UX: Designed with clean navigation, responsive layout, and minimal user input requirements

c) Role in the System

The mobile application is an essential component of the system architecture. It acts as:

- A dashboard for data visualization
- An alert engine powered by ML insights
- A maintenance assistant via automated booking
- A feedback loop for collecting user inputs to retrain and improve ML models over time

- Cloud Database System

A robust, scalable, and secure cloud database is essential for managing the vast amount of sensor data, user information, prediction results, and service history in our Smart Car Maintenance System. We utilize either Firebase Realtime Database or Amazon Web Services (AWS) to ensure seamless data storage, access, and synchronization across all system components.

Purpose of the Database:
The cloud database acts as the central data hub, performing the following functions:

- ➢ Storing real-time sensor readings from the vehicle
- ➢ Logging maintenance history and service appointments
- ➢ Storing ML model predictions (e.g., oil life, fuel range)
- ➢ Managing user accounts and vehicle profiles
- ➢ Enabling secure communication between the IoT module, ML engine, and mobile application

4) Firebase Realtime Database (Option 1)

Firebase offers a cloud-hosted NoSQL database that stores data in JSON format and synchronizes it in real time across connected clients.

a) Key Features:

- Real-time updates to the mobile app without polling
- Secure user authentication via Firebase Auth
- Built-in support for Android integration
- Scalability for small to medium-sized IoT applications
- Cloud Functions for backend logic (e.g., triggering alerts)

b) Advantages:

- Easy to implement for mobile-first systems
- Automatically handles data sync and offline caching
- Cost-effective for limited-scale deployments

5) AWS (Amazon Web Services) DynamoDB & S3 (Option 2)

For larger, enterprise-grade systems, AWS provides highly scalable and flexible data storage solutions like DynamoDB (NoSQL) and S3 (object storage).

a) Key Features:

- High throughput and low-latency performance
- Fine-grained access control using AWS IAM
- Integration with AWS Lambda for event-driven processing
- Scalable storage for long-term vehicle logs and analytics

b) Advantages:

- Better suited for handling millions of data points from a fleet of vehicles
- Offers advanced monitoring, analytics, and integration with other AWS services
- Highly reliable and secure infrastructure

IV. METHODOLOGY

The development of our ML & IoT based Smart Car Maintenance System follows a structured and modular methodology that integrates hardware (IoT sensors), software (mobile application), and intelligent analytics (ML models). Each component is carefully designed and synchronized to enable real-time monitoring, predictive maintenance, and user interaction.

A. Data Collection

Real-time vehicle health parameters are collected using a range of IoT sensors installed in the vehicle. The system gathers the following key data:

- Mileage: Collected via odometer or speed sensor to track distance traveled.
- Engine Temperature: Measured using a temperature sensor to detect overheating conditions.
- Oil Viscosity & Quality: Captured using an oil quality sensor to monitor engine oil degradation.
- Battery Voltage: Monitored to assess the battery's charge and health status.

All sensor data is transmitted via Wi-Fi or Bluetooth to a cloud-based database for real-time processing and analysis.

B. Machine Learning Model Development and Training

Multiple ML models are developed and trained to perform predictive analysis on the collected data:

- Oil Life Prediction Model: Estimates the remaining usability of engine oil.
- Fuel Range Estimator: Predicts the distance the vehicle can travel with current fuel levels.
- Service Appointment Predictor: Suggests optimal times for vehicle servicing.
- Fuel Refill Predictor: Forecasts when and how much fuel should be added.

The models are trained using supervised learning algorithms (e.g., Random Forest, Linear Regression), utilizing historical sensor data and service logs. Python-based libraries such as scikit-learn, NumPy, and Pandas are used for model development and training.

C. IoT Sensor Integration

Sensors are connected to a NodeMCU (ESP8266) microcontroller, which acts as the communication bridge between the vehicle and the cloud. The NodeMCU collects sensor data and pushes it to the cloud (Firebase or AWS) using HTTP or MQTT protocols. Key steps include:

- Sensor calibration and wiring
- Microcontroller programming using Arduino IDE
- Real-time data transmission using Wi-Fi

This setup ensures continuous, reliable data flow for monitoring and analytics.

D. Mobile Application and Automation Logic

A user-friendly Android mobile application is developed to display real-time sensor data, ML predictions, and intelligent alerts. Key features include:

- Dashboard with health stats (oil, battery, fuel, tire pressure)
- ML-based notifications for service and refueling

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- One-tap service appointment booking
- Trip logs and maintenance history

The app also receives ML outputs and initiates automated actions like appointment bookings when thresholds are breached.

E. Tools and Technologies Used

Components	Technology
ML Model Development	Python, scikit-learn,jupyter Notebook
IoT & Sensor	Node MCU/ Arduino/ Raspberry, Arduino IDE, C++
Cloud Database	Firebase Real-time DB/ AWS
Mobile App	Android Studio (Flutter ,Dart), Android SDK, Flutter SDK, Firebase SDK
Data Communication	Firebase Cloud Messaging / WiFi (HTTP/MQTT)

This methodology ensures that the system is modular, scalable, and capable of delivering real-time insights and automation, thus achieving the goals of predictive and smart vehicle maintenance.

V. IMPLEMENTATION

The ML & IoT Based Smart Car Maintenance System has been implemented by integrating multiple hardware and software components into a cohesive and intelligent platform. The system leverages real-time vehicle data collection, machine learning-based analytics, and user-friendly mobile application features to provide predictive maintenance solutions.

A. Hardware Setup

The system utilizes a NodeMCU ESP8266 microcontroller as the core unit, interfaced with a range of sensors for comprehensive vehicle monitoring. The hardware configuration includes:

1) Engine Temperature Sensor – Monitors engine heat to prevent overheating.
2) Oil Quality and Level Sensor – Measures the viscosity and quantity of engine oil to assess degradation.
3) Fuel Level Sensor – Detects the amount of fuel present in the tank.
4) Battery Voltage Sensor – Tracks the health and voltage levels of the car battery.
5) Speed/Odometer Sensor – Records mileage and travel data used for maintenance prediction.

These sensors continuously collect data and transmit it wirelessly via Wi-Fi to a centralized cloud platform such as Firebase or AWS.

B. Software Modules

1) Data Analysis and Machine Learning Module

The back-end system, developed using Python, processes real-time sensor data and applies trained machine learning models to generate predictive insights. The models are designed to:

- Predict the remaining life of engine oil
- Estimate how many kilometers the vehicle can travel with the current fuel level
- Forecast the optimal time for service appointments
- Recommend when and how much fuel to refill

2) Mobile Application Interface

The Android-based mobile application serves as the user interface. Key features include:

- Real-time dashboard showing vehicle health status
- Maintenance alerts and notifications
- Machine learning-based predictions
- Service appointment booking system

The app is built using Android Studio and integrated with Firebase for authentication, data storage, and messaging services.

3) Notification and Alert System

A cloud-based alert system using Firebase Cloud Messaging (FCM) sends real-time notifications to users regarding:

- Oil replacement warnings
- Low fuel alerts
- battery issues
- Automatic service bookings

4) Expected Output

The ML & IoT Based Smart Car Maintenance System is designed to generate intelligent, real-time outputs based on data collected from various sensors and analyzed through machine learning models. The expected output will be delivered to the user via a mobile application interface and backend prediction modules. The outputs will take the form of actionable insights, alerts, and system-driven automation. These include:

- Real-time Vehicle Health Monitoring: The system will continuously display updated information such as oil quality, fuel level, engine temperature, and battery status on the user's mobile app. This ensures that users are always informed about the current condition of their vehicle.
- Predictive Maintenance Alerts: Based on the analyzed data, the system will predict the remaining life of engine oil and alert the user when it is nearing degradation. This helps in preventing engine damage and ensures timely servicing.
- Fuel Consumption Estimation: The system will estimate how many kilometers the vehicle can travel with the current fuel level. This assists the user in planning trips and prevents unexpected fuel shortages.
- Automatic Service Scheduling: When a service threshold is reached (e.g., mileage, oil life), the system will automatically book a service appointment and notify the user with the date, time, and service location.
- Intelligent Refueling Suggestions: The ML model will analyze fuel usage patterns and notify the user about the optimal time and quantity to refuel for efficient performance and cost-effectiveness.
- User Notifications: Users will receive timely alerts via push notifications for critical conditions such as low fuel, low oil quality, battery issues. These alerts are designed to be clear, informative, and easy to act upon.
- Mobile App Interaction: The app will allow users to view maintenance history, confirm or modify service bookings, and access visual indicators such as progress bars, warning icons, and color-coded health statuses.

In essence, the expected output of this system is a seamless combination of data-driven insights, proactive alerts, and convenience features that enhance vehicle maintenance, user experience, and overall safety.

VI. DISCUSSION

A. Interpretation of Expected Results

The proposed ML & IoT Based Smart Car Maintenance System aims to revolutionize the way vehicle health is monitored and maintained. Based on the designed architecture and expected functionality, the system is anticipated to provide real-time insights into various vehicle parameters such as oil quality, fuel levels, engine temperature, tire pressure, and battery voltage. Through the integration of machine learning models, the system is expected to accurately predict the remaining life of engine oil, estimate driving range based on fuel availability, and automatically schedule service appointments. These intelligent predictions will help vehicle owners reduce maintenance costs, improve safety, and ensure timely servicing.

The mobile application, designed as the main user interface, is expected to present this data in an intuitive format and send timely alerts and notifications. The use of cloud platforms such as Firebase or AWS will enable reliable data storage, real-time synchronization, and remote access to vehicle health information.

B. Strengths of the Proposed System

Although the system is currently in the design stage, several key strengths have been identified in its planned implementation:

1) Intelligent Predictive Maintenance: Use of ML models to proactively forecast servicing needs, reducing the dependency on fixed intervals.
2) Real-Time Monitoring: IoT sensors will provide continuous, real-time updates on critical vehicle parameters.
3) User Convenience: Automated appointment booking and alerts enhance the user experience and reduce manual effort.
4) Data-Driven Decisions: The system enables more informed maintenance decisions based on real-time data rather than assumptions.
5) Scalability and Cloud Integration: Use of Firebase or AWS allows for scalable, secure, and accessible data management.
6) Enhanced Safety and Efficiency: Early detection of issues like low oil quality or tire pressure can prevent breakdowns and improve driving safety.

C. Challenges faced

During development and real-world deployment, several challenges are expected:

1) Sensor Accuracy and Calibration: Ensuring the sensors provide reliable and accurate readings under varying vehicle and environmental conditions.
2) Machine Learning Model Training: Collecting a diverse and high-quality dataset will be critical to train ML models that can generalize across different vehicles and usage patterns.
3) Hardware Compatibility: Integrating multiple sensors with the NodeMCU and ensuring stable communication may require careful configuration.
4) Mobile App Performance: Ensuring smooth interaction between the app, sensors, and cloud backend while minimizing latency and power consumption.
5) Data Synchronization: Maintaining real-time consistency between the sensor data, cloud database, and user interface.
6) User Privacy and Security: Protecting user data and maintaining secure communication channels will be essential for gaining user trust.

The discussion highlights the technical promise of the ML & IoT Based Smart Car Maintenance System while acknowledging the complexity of bringing the concept to full implementation. Continued development, testing, and refinement will be key to transforming this concept into a reliable and scalable solution.

VII. CONCLUSION

This research presents the conceptual framework and design of a ML & IoT Based Smart Car Maintenance System that integrates Internet of Things (IoT) sensors with Machine Learning (ML) models to provide intelligent, real-time monitoring and predictive maintenance for vehicles. The system is designed to collect and analyze key vehicle parameters such as engine oil quality, fuel level, temperature and battery voltage. These inputs are used to generate meaningful insights, such as predicting the remaining life of engine oil, estimating fuel-based travel range, and automating service appointment bookings.

The final outcome of this project is a smart, interconnected system that empowers vehicle owners with advanced diagnostics, timely alerts, and maintenance automation. By utilizing a user-friendly mobile application and cloud-based services like Firebase or AWS, the system offers a seamless experience for monitoring vehicle health and scheduling services without manual intervention.

This solution significantly benefits users by:

- Reducing the risk of engine damage and breakdowns through timely oil and fuel-related alerts.
- Enhancing convenience with automatic service scheduling.
- Lowering maintenance costs by avoiding unnecessary servicing.
- Promoting vehicle safety and efficiency through real-time health tracking.

Scope for Future Development

While the current system focuses on oil life prediction, fuel management, and automated servicing, there is considerable potential for expanding its functionality. Future enhancements could include:

- Battery Health Monitoring: Predicting battery degradation and replacement cycles.

- Advanced Tire Pressure Monitoring: Detecting pressure imbalances or slow leaks with high precision.
- Brake System Analysis: Monitoring wear patterns and suggesting brake servicing.
- Driving Pattern Analysis: Recommending eco-friendly driving habits based on behavioral data.
- Integration with Vehicle Telematics: Connecting with onboard vehicle systems (OBD-II) for broader diagnostics.

In conclusion, the ML & IoT Based Smart Car Maintenance System lays the foundation for intelligent, data-driven vehicle care. With further development and refinement, this project has the potential to evolve into a comprehensive automotive health platform that enhances safety, reliability, and user experience in the age of connected mobility.

REFERENCES

[1] R. Patel and J. Joshi, "Vehicle Maintenance Using IoT," International Journal of Engineering Research & Technology (IJERT), vol. 11, no. 2, pp. 45–48, Feb. 2022.

[2] A. Mohammad, R. Kumar, and M. F. Ansari, "Cloud-Based Automotive Diagnostic System for Preventive Maintenance Using IoT," International Journal of Scientific Research in Engineering and Management (IJSREM), vol. 5, no. 8, pp. 1–7, Aug. 2021.

[3] S. Joshi and R. Mehta, "An IoT-Based Predictive Connected Car Maintenance," International Journal of Computer Applications Technology and Research (IJCATR), vol. 10, no. 1, pp. 1–5, Jan. 2021.

[4] M. Prajapati and M. Pathan, "Intelligent Vehicular Maintenance System using IoT," International Journal of Computer Applications (IJCA), vol. 175, no. 18, pp. 20–24, Oct. 2020.

[5] K. Singh and P. Kumar, "Predictive Maintenance using IoT: A Case Study on Transportation," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 9, no. 3, pp. 150–154, Jan. 2020.