# INTRODUCTION

As automotive technology continues to evolve, vehicles are becoming increasingly sophisticated, incorporating complex electronic systems that enhance performance, safety, and user experience. However, this complexity also presents challenges in vehicle maintenance and diagnostics. Traditional diagnostic methods often rely on manual interpretation of error codes and can be time-consuming, leading to increased downtime and costs for vehicle owners and service providers alike.

The On-Board Diagnostics (OBD) system, standardized since the 1980s, has become an essential tool for monitoring vehicle performance and identifying malfunctions. OBD-II, the second generation of this system, provides access to a wealth of data regarding engine performance, emissions control, and other critical functions. Despite the availability of this data, many users lack the tools or knowledge to interpret it effectively. This gap highlights the need for an innovative approach to OBD data visualization that can bridge the gap between complex diagnostics and user comprehension.

In response to these challenges, this study aims to design and develop an OBD Visualization System that simplifies the process of vehicle diagnostics. By integrating advanced data visualization techniques with real-time monitoring capabilities, the proposed system empowers both automotive technicians and everyday vehicle owners to gain deeper insights into their vehicles' health. This introduction outlines the importance of efficient diagnostic systems in modern vehicles and sets the stage for a solution that not only enhances diagnostic accuracy but also improves overall vehicle maintenance practices. Through this work, we seek to contribute to the advancement of automotive diagnostics, ultimately fostering greater reliability and user confidence in automotive technology.

The ECU in vehicle communicate with each other via CAN protocol sharing important information about status of operation and performance of component. These ECU can detect the problems in vehicle systems, the detected problems are logged and alert in shared with other ECU. The problems within vehicle or performance of vehicle can be understood via diagnostic system .

There are primary two types of diagnostic system are available in vehicle.

1. On Board Diagnostic (OBD II)
2. Off Board Diagnostic (UDS)

These project implement some the most important OBD II services for ECU. The project implement request-response mechanism in client-server architecture between ECU and Tester.

# LITERATURE SURVEY

The Design and Development of Automotive Diagnostic Data Visualization System intersects multiple fields, including automotive diagnostics, embedded systems, data communication protocols, and real-time data visualization. This literature survey provides a comprehensive review of existing research and technologies related to these areas to establish a foundation for the project.

### 2.1 Specifications and Analysis of Digitized Diagnostics of Automobiles: A Case Study of on Board Diagnostic OBD II (2020)

This 2020 paper author Medashe Michael Oluwaseyi and Abolarin Matthew Sunday focuses on Specifications and Analysis of Digitized Diagnostics of Automobiles. The OBD over the CAN bus in compliance with the ISO 157652 (ISOTP) transport layer protocol. The research demonstrates the On Board Diagnostic communication stack tailored for automotive diagnostic environments, using CAN for reliable data transport between ECUs and external diagnostic tools.[1]

### 2.2 The Implementation of OBD-II Vehicle Diagnosis System Integrated with Cloud Computation Technology (2018)

This 2018 paper author Pretty C. Joseph and S. Pratap Kumar, focuses on the Design and Development of OBD-II Compliant Driver Information System in a fully integrated automotive electronic system. The research explores the role of OBD II in managing diagnostics, ECU communication, and fault code retrieval.[2]

### 2.3 ISO 15031:2016 Communication between vehicle and external equipment for emissions-related diagnostics

This part of ISO 15031 includes capabilities required to satisfy OBD requirements for multiple regions, model years, engine types, and vehicle types. Those regulations are not yet final for some regions and are expected to change in the future. This part of ISO 15031 makes no attempt to interpret the regulations and does not include applicability of the included diagnostic services and data parameters for various vehicle applications. [3]

### 2.4.ISO-14229: International Standard - Road vehicles - Unified diagnostic services (UDS), 2006.

The ISO 142291:2013 document defines the Unified Diagnostic Services (UDS) protocol, which standardizes communication between vehicle Electronic Control Units (ECUs) and external diagnostic tools. UDS is crucial for performing diagnostics, ECU reprogramming, and fault code management in modern vehicles. This standard defines a comprehensive set of services for vehicle diagnostics, such as Diagnostic Session Control (0x10), ECU Reset (0x11), Read Data by Identifier (0x22), and Clear Diagnostic Information (0x14). UDS operates across various communication channels, including CAN, Ethernet, and FlexRay, enabling diagnostic tools to interact with a wide range of vehicle systems. The document ensures that diagnostic tools and ECUs across different manufacturers can communicate using a unified and standardized approach, promoting interoperability in the automotive industry.[4]

### 2.5 ISO 11898 Controller Area Network (CAN)

The ISO 11898 standard specifies the Controller Area Network (CAN) protocol, which is widely used for communication between ECUs in automotive systems. CAN enables realtime, low latency communication in embedded systems, making it ideal for vehicle applications where reliability and data integrity are critical. The standard defines both the CAN protocol for data link and physical layer specifications. CAN is particularly suited for vehicle diagnostics because it allows multiple ECUs to communicate on the same bus, reducing wiring complexity and ensuring prioritized message handling. The combination of UDS over CAN, known as Diagnostic over CAN (DoCAN), allows diagnostic tools to access ECU data, read diagnostic trouble codes (DTCs), and perform other essential diagnostic functions. [5]

### 2.6 ISO 157652:2016 ISO Transport Protocol (ISOTP)

The ISO 157652 standard, also known as ISO Transport Protocol (ISOTP), provides a communication framework for sending diagnostic messages over the CAN bus. Since CAN frames have a limited data size (typically 8 bytes), larger diagnostic messages such as UDS requests need to be segmented and reassembled. ISOTP ensures the correct transport of UDS messages by defining a method for segmenting large messages, flow control, and message reassembly. This protocol is essential for UDS over CAN, as it enables diagnostic services to send larger payloads efficiently, ensuring communication reliability and data integrity even with the CAN protocol's bandwidth constraints. ISOTP plays a pivotal role in making UDS functional over CAN, as it handles message fragmentation and ensures that services like Request Download (0x34) and Transfer Data (0x36) can be executed seamlessly. [6]

# PROBLEM STATEMENT

In the evolving landscape of automotive technology, vehicles are becoming increasingly sophisticated, equipped with a myriad of electronic systems and sensors designed to monitor and optimize performance. However, with this increased complexity comes the challenge of effectively managing and diagnosing potential issues that arise within these systems. Traditional diagnostic tools, while effective, often lack real-time capabilities and user friendly interfaces, leading to inefficiencies in vehicle maintenance and repair.

The Design and Development of Automotive Diagnostic Data Visualization System seeks to address these challenges by providing a comprehensive and intuitive solution for real-time vehicle diagnostics. The primary problems that this project aims to solve are

### 3.1. Inadequate real-time Diagnostics

Current automotive diagnostic tools often provide data in a raw format that is difficult to interpret quickly and accurately. This lack of real-time visualization can delay the identification of issues, leading to increased vehicle downtime and maintenance costs.

Traditional diagnostic tools may only provide static reports or require manual data interpretation, which can be time consuming and prone to errors.
Solution Develop a system that captures real-time diagnostic data from the vehicle's ECUs and presents it in a clear, visual format. This will enable users to quickly identify and address issues, improving overall diagnostic efficiency.

### 3.2. Lack of UserFriendly Interfaces

Many existing diagnostic tools are designed for professional technicians and may not be user friendly for the average vehicle owner. This lack of accessibility can hinder effective vehicle management and preventive maintenance.

Issue Diagnostic tools with complex interfaces can be challenging for nontechnical users to operate, reducing their effectiveness in everyday vehicle maintenance.
Solution Create a user friendly interface that simplifies the presentation of diagnostic data, making it accessible and understandable for both professional technicians and vehicle owners.

### 3.3. Limited Remote Monitoring Capabilities

The ability to monitor vehicle performance remotely is increasingly important in a connected world. Existing diagnostic tools often lack robust wireless communication features, which limits their utility for remote diagnostics and monitoring.

Without wireless communication capabilities, users are restricted to accessing diagnostic data only when physically present with the vehicle, which can be inconvenient and limit the scope of monitoring.
Solution Implement wireless communication features that allow remote access to diagnostic data via smartphones or web platforms. This will enable users to monitor vehicle health from any location and receive real-time alerts about potential issues.

### 3.4. Inefficient Data Integration and Analysis

Automotive diagnostic data is often fragmented across different systems and formats, making it challenging to integrate and analyze comprehensively. This fragmentation can lead to incomplete diagnostics and missed opportunities for early problem detection.

Issue Fragmented data sources and formats can complicate the process of integrating and analyzing diagnostic information, leading to inefficiencies in identifying and addressing vehicle issues.
Solution Develop a centralized system that integrates data from various sources, processes it efficiently, and provides a holistic view of vehicle performance. This will enhance the accuracy and effectiveness of diagnostics and support preventive maintenance strategies.

### 3.5. Insufficient Support for Multiple Vehicle Models

Diagnostic tools that are not adaptable to different vehicle makes and models can limit their applicability and usefulness. There is a need for systems that can handle a wide range of vehicles and adapt to varying diagnostic protocols.

Limited compatibility with different vehicle models can restrict the tool's usability and effectiveness across diverse automotive environments.
Solution Design the system with flexibility to support multiple vehicle makes and models, and ensure it is adaptable to various diagnostic protocols. This will broaden its applicability and enhance its value for a diverse user base.

# PROPOSED SYSTEM

The Design and Development of Automotive Diagnostic Data Visualization System aims to create a comprehensive solution for real-time vehicle diagnostics through an integrated system comprising hardware, software, and communication technologies. This section outlines the proposed method for achieving the project's objectives, focusing on system design, data acquisition, real-time processing, user interface development, and wireless communication.

## 4.1. OBD 2 Message Structure

In simplified terms, an OBD2 message consists of an identifier and data. Further, the data is split in Mode, PID and data bytes (A, B, C, D) as below.

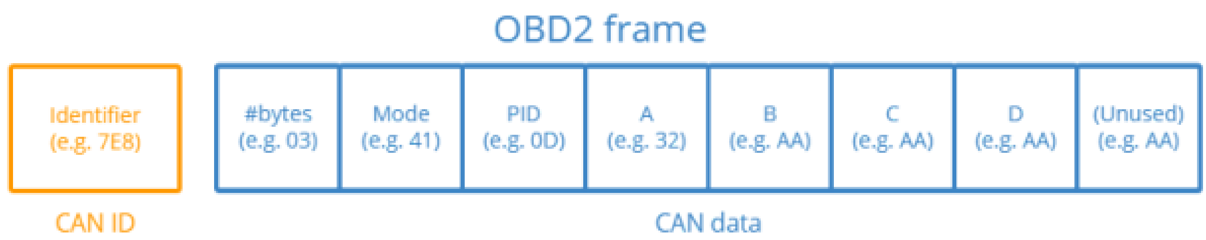


**Fig.1. OBD2 Message Structure**

### *4.1.1 Identifier*

For OBD2 messages, the identifier is standard 11 bit and used to distinguish between "request messages" (ID 7DF) and "response messages" (ID 7E8 to 7EF). Note that 7E8 will typically be where the main engine or ECU responds at.

### *4.1.2 Length*

This simply reflects the length in number of bytes of the remaining data (03 to 06). For the Vehicle Speed example, it is 02 for the request (since only 01 and 0D follow), while for the response it is 03 as both 41, 0D and 32 follow.

### *4.1.3 Mode*

For requests, this will be between 010A. For responses the 0 is replaced by 4 (i.e. 41, 42, … , 4A). There are 10 modes as described in the SAE J1979 OBD2 standard. Mode 1 shows Current Data and is e.g. used for looking at real-time vehicle speed, RPM etc. Other modes are used to e.g. show or clear stored diagnostic trouble codes and show freeze frame data.

### *4.1.4 PID*

For each mode, a list of standard OBD2 PIDs exist e.g. in Mode 01, PID 0D is Vehicle Speed. For the full list, check out our OBD2 PID overview . Each PID has a description and some have a specified min/max and conversion formula. The formula for speed is e.g. simply A, meaning that the A data byte (which is in HEX) is converted to decimal to get the km/h converted value (i.e. 32 becomes 50 km/h above). For e.g. RPM (PID 0C), the formula is (256A + B) / 4.

#### *4.1.5. A, B, C, D*

These are the data bytes in HEX, which need to be converted to decimal form before they are used in the PID formula calculations. Note that the last data byte (after Dh) is not used.

## 4.2. Request vs. Response OBD2 responses

### *4.2.1. Request*

An OBDII request is a message sent by a diagnostic tool or scan tool to the vehicle's ECU to request specific diagnostic information. The request typically consists of several parts

Mode Defines the type of operation or request being made. OBDII defines several modes, each with a specific purpose. For example

- Mode 01 Request Current Data
- Mode 02 Request Freeze Frame Data
- Mode 03 Request Diagnostic Trouble Codes (DTCs)
- Mode 04 Clear Diagnostic Trouble Codes
- Mode 05 Request Oxygen Sensor Monitoring
- Mode 06 Request Test Results for Specific Monitors
- Mode 07 Request Pending DTCs
- Mode 08 Request Control of OnBoard System
- Mode 09 Request Vehicle Information

PID (Parameter ID) Specifies the particular data or diagnostic information requested within the given mode. For example, in Mode 01 (Request Current Data), PIDs represent specific parameters like engine RPM, vehicle speed, coolant temperature, etc.

Data Bytes In some cases, additional data bytes are sent with the request to provide parameters or specific instructions.

Example Request To request the current engine RPM, a diagnostic tool would send a request with Mode 01 and PID 0C (which represents RPM data).

### *4.2.2. Response*

An OBDII response is the message sent by the vehicle's ECU back to the diagnostic tool in reply to a request. The response contains the requested diagnostic data or an indication of the operation's success or failure. The response typically consists of

- Mode Repeats the mode of the request to confirm the type of data being returned.
- PID Identifies the specific parameter or diagnostic information returned.
- Data Bytes Contains the actual diagnostic data requested. The format and content of these bytes depend on the PID and the requested data.
- Status Byte Sometimes included to indicate the status of the request, such as whether it was successful or if there were errors.

Example Response For a request of current engine RPM (Mode 01, PID 0C), the response might include a data byte sequence representing the RPM value. For instance, the response data might be 0C 0A 00 1E, where 0A is a status byte and 001E is the RPM value (in hexadecimal format).

## 4.3. Request and Response Workflow

Diagnostic Tool Initiates Request The diagnostic tool sends a request to the vehicle's ECU. This request specifies the mode and PID for the data or action desired.

### *4.3.1 Vehicle ECU Processes Request*

The ECU receives and processes the request. It retrieves the required data or performs the specified action based on the request.

### *4.3.2 Vehicle ECU Sends Response*

The ECU sends a response back to the diagnostic tool. This response includes the mode, PID, and data requested, or an indication of the operation's outcome.

### *4.3.3. Diagnostic Tool Receives and Interprets Response*

The diagnostic tool receives the response and interprets the data. It displays the information to the user or uses it for further diagnostics.

### *4.3.4 Example Interaction*

#### *4.3.4.1 Request to Read Engine RPM (Mode 01, PID 0C)*

- Request Message 01 0C
- 01 Mode 01 (Request Current Data)
- 0C PID 0C (Engine RPM)
- Possible Response Message

#### *4.3.4.2 Response Message 41 0C 1A F8*

- 41 Mode 01 (Response to the request)
- 0C PID 0C (Engine RPM)
- 1A F8 RPM value in hexadecimal format

1A F8 converts to a decimal RPM value of 7100 (in this case, the actual conversion may vary based on specific PID definitions).

In OBD II systems, the request and response mechanism allows diagnostic tools to query vehicle ECUs for specific information and receive detailed responses. This two way communication is essential for diagnosing vehicle issues, monitoring performance, and ensuring compliance with emission standards. The standardized approach ensures compatibility and consistency across different vehicles and diagnostic tools.

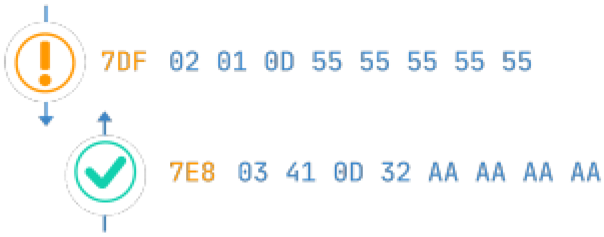


**Fig.2. OBD II Request and Response message structure**

## Block Diagram

The block diagram below illustrates the overall architecture of the proposed method for implementing the complete system over CAN using the STM32 microcontroller.

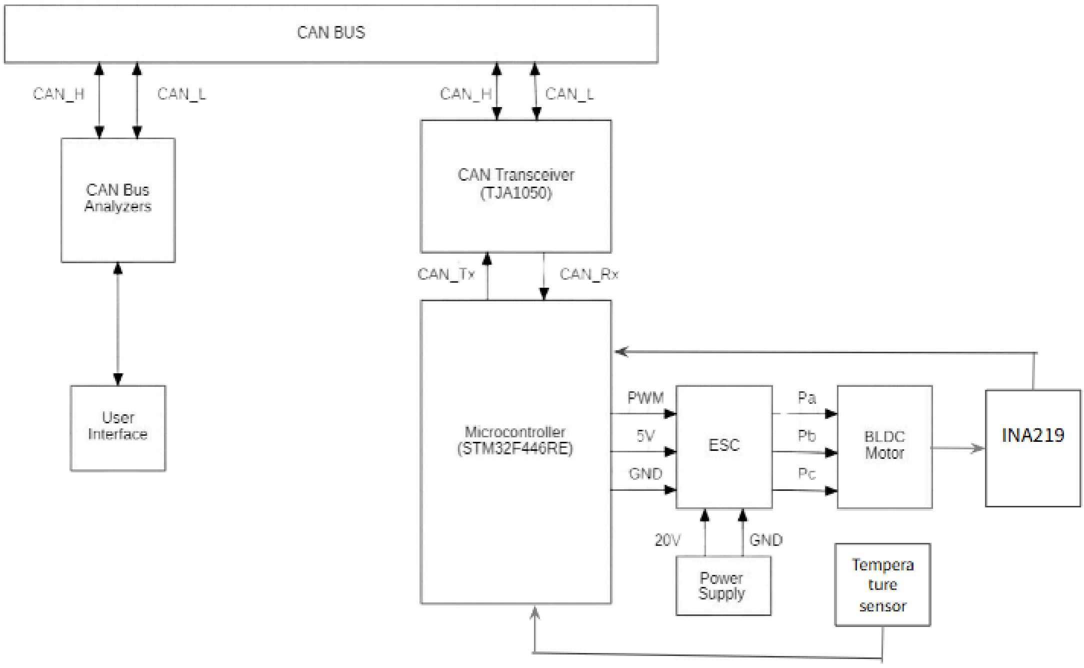


**Fig. 3. Block diagram of OBD protocol implemented system**

### 5.1. Diagnostic Tool (Scan Tool)

The diagnostic tool (or scan tool) is the interface used by technicians or users to communicate with the vehicle's OnBoard Diagnostic (OBD) system. It sends requests to the ECU and receives responses. Request Generator Sends commands to the vehicle's ECU, formatted according to OBD II standards. Data Interpreter Decodes the responses from the ECU to present them in a meaningful way.
Example Requests A scan tool might request current engine RPM, read trouble codes, or clear diagnostic trouble codes.

### 5.2. OnBoard Diagnostic ECU

Function The ECU (Electronic Control Unit) processes the requests sent from the diagnostic tool and returns the appropriate responses. It interfaces with various sensors and actuators to gather and manage vehicle data.
OBDII Interface Connects to the diagnostic tool through a standard OBDII port (usually located under the dashboard). Communication Protocols Supports various communication protocols like ISO 9141, ISO 14230 (KWP2000), and ISO 15765

(CAN). Data Processor Decodes requests, processes data, and formats responses according to OBDII standards.
Example Processing When a request is made to read the engine RPM, the ECU retrieves the RPM data from the engine control module and formats it for response.

### 5.3. Request and Response Flow

The diagnostic tool sends a formatted request to the ECU asking for specific information or to perform an action. This request includes mode and service identifiers, and any necessary parameters. The ECU processes the request, gathers the required data (e.g., engine RPM), and prepares a response. The ECU decodes the request, retrieves the relevant data from its internal systems, and formats it into a standard response format. The ECU sends the response back to the diagnostic tool, which includes the requested data or the result of the performed action.

### 5.4 User Interface (e.g., App/Software)

The user interface is a software application that displays the diagnostic information in a user-friendly format. It can be on a computer, tablet, or smartphone. Data Visualization Platform Presents the data collected from the ECU in graphical formats such as charts, gauges, or tables. It makes the diagnostic data easier to understand and analyze.

# FLOWCHART

## 6.1 Mode 01 Request Current Data

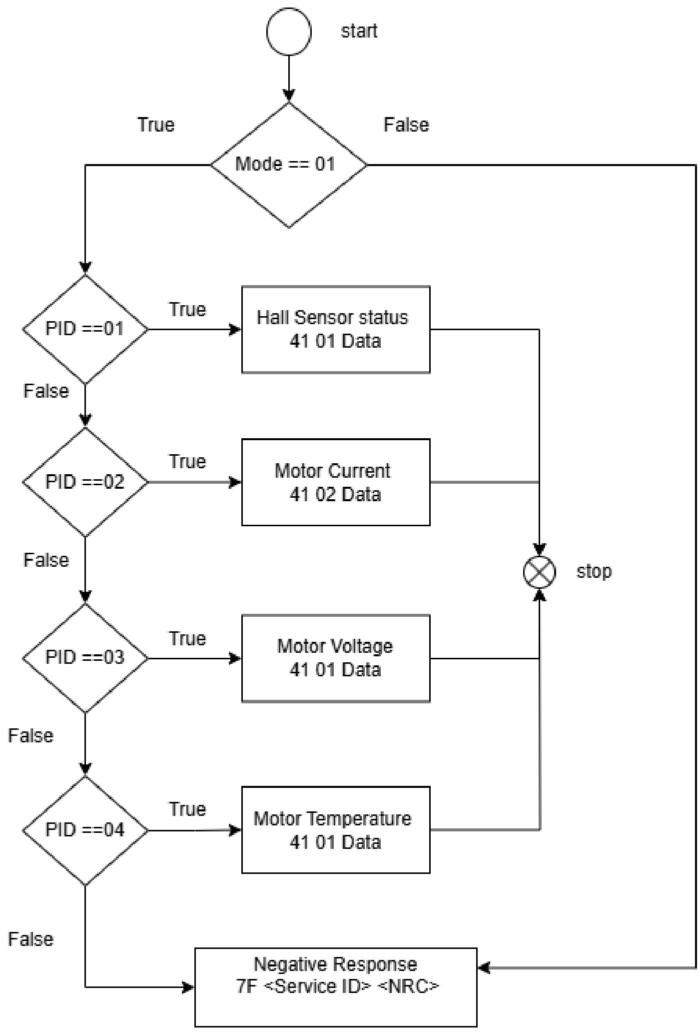


Fig. 4. Mode 01 Request current Data

In OBD Mode 01 (Request Current Data), the flow begins with the scan tool (diagnostic tester) sending a Mode 01 request with a PID (Parameter ID), which specifies the type of real-time data it needs from the vehicle's ECU, such as engine speed, vehicle speed, or coolant temperature. Upon receiving the request, the ECU interprets the PID, retrieves the relevant sensor data, and formats the response message. The ECU then sends this response back to the scan tool, which decodes and displays the requested information for the user. This process enables real-time monitoring of vehicle parameters to assist in diagnostics and performance analysis.

## 6.2 Mode 03 Request Diagnostic Trouble Code

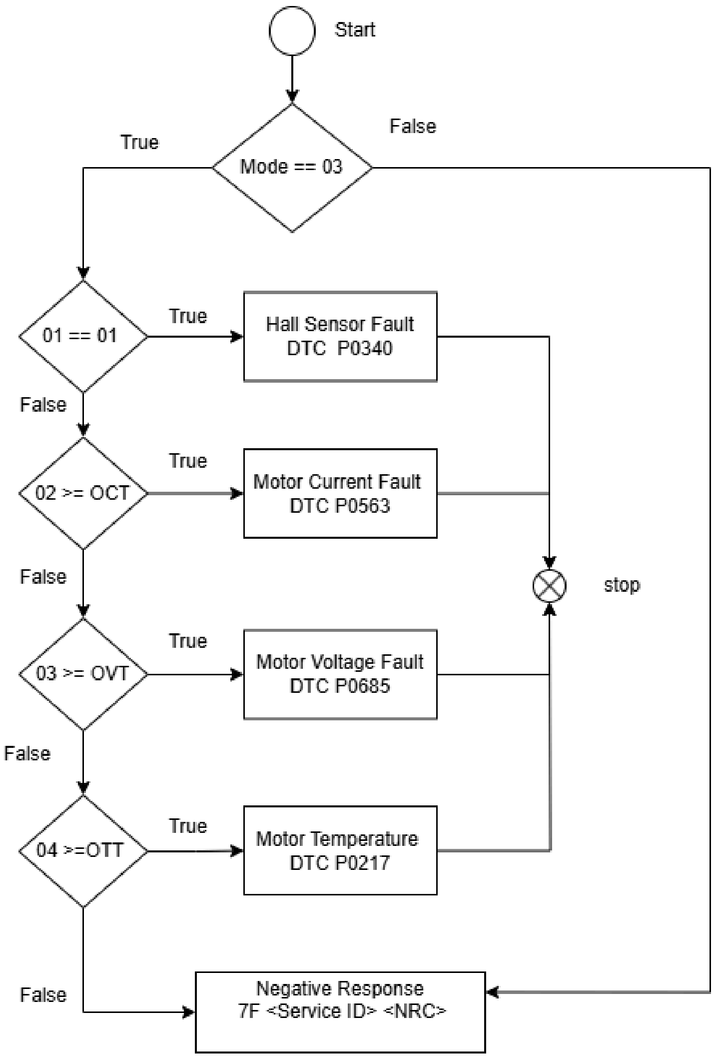


Fig.5. Flowchart for OBD Mode 03 Request DTC

The flow chart for OBD Mode 03 (Request DTCs) involves a sequence where the scan tool sends a request to the vehicle's ECU to retrieve Diagnostic Trouble Codes (DTCs) stored during fault detection. First, the scan tool initiates a request by sending Mode 03 over the OBD interface. The ECU receives this request, checks its internal memory for any stored DTCs, and formats the response accordingly. If DTCs are found, the ECU sends back a list of DTC codes, each identifying a specific fault. If no DTCs are present, the ECU responds with an indication of no faults. Finally, the scan tool displays the retrieved codes, allowing further diagnostics or repairs based on the fault information.

# Application

The Design and Development of Automotive Diagnostic Data Visualization System has broad applications in various domains related to vehicle diagnostics, maintenance, and performance monitoring. This system is designed to enhance the efficiency and effectiveness of automotive diagnostics through real-time data visualization and advanced analysis. Below is a detailed description of the potential applications of this project

## 7.1. Automotive Repair and Maintenance

### *7.1.1 Efficient Diagnostics*

The system provides real-time visibility into vehicle performance metrics and diagnostic trouble codes (DTCs). This allows automotive technicians to quickly identify issues, leading to faster and more accurate repairs. The detailed visualization of data helps in understanding the root causes of problems, reducing diagnostic time and improving repair accuracy.

### *7.1.2. Preventive Maintenance*

By continuously monitoring key parameters and historical data, the system helps in predicting potential issues before they become critical. This enables proactive maintenance, reducing the likelihood of unexpected breakdowns and extending vehicle lifespan.

### *7.1.3. Service Records and History*

The system's ability to store and analyze historical diagnostic data helps in maintaining detailed service records. This information is valuable for tracking vehicle health over time and for making informed maintenance decisions.

## 7.2. Vehicle Performance Optimization

### *7.2.1.Real-time Monitoring*

The dashboard provides real-time data on various performance metrics such as engine RPM, coolant temperature, fuel efficiency, and more. This allows vehicle owners and fleet managers to monitor performance and make adjustments as needed.

### *7.2.2 Performance Analysis*

Historical data analysis helps in assessing vehicle performance trends. This can be used to identify areas for improvement and optimize vehicle settings for better efficiency and performance.

### *7.2.3. Driver Feedback*

The system can provide feedback to drivers regarding their driving habits and vehicle performance. This can help in improving driving behavior, leading to better fuel economy and reduced wear and tear.

## 7. 3. Fleet Management

### *7.3.1 Fleet Monitoring*

For organizations managing multiple vehicles, the system offers a centralized platform for monitoring the health and performance of all vehicles in the fleet. This enables fleet managers to track diagnostics, manage maintenance schedules, and optimize fleet operations.

### *7.3.2 Data Driven Decisions*

Fleet managers can use the data provided by the system to make informed decisions regarding vehicle purchases, maintenance planning, and operational strategies. This helps in reducing costs and improving overall fleet efficiency.

### *7.3.3. Remote Access*

The wireless communication feature allows fleet managers to access diagnostic data remotely. This capability is especially useful for managing fleets operating across different locations or for remote monitoring of vehicles.

## 7.4. Consumer Applications

### *7.4.1. UserFriendly Vehicle Health Monitoring*

Vehicle owners can use the system to monitor their vehicle’s health and performance from their smartphones or computers. The user-friendly interface makes it accessible even to those without technical expertise.

### *7.4.2. Troubleshooting Assistance*

The system helps vehicle owners troubleshoot issues by providing clear and detailed information about diagnostic trouble codes and potential causes. This can assist in understanding the problem before visiting a repair shop.

### *7.4.3. Enhanced Driving Experience*

By providing insights into vehicle performance and efficiency, the system enhances the driving experience. Users can track improvements, manage maintenance more effectively, and ensure their vehicle operates at its best.

## 7.5. Automotive Research and Development

### *7.5.1. Data Collection for R&D*

The system’s ability to collect and analyze diagnostic data makes it a valuable tool for automotive researchers and developers. Data gathered from various vehicles can be used to study performance, reliability, and the impact of different factors on vehicle health.

### *7.5.2.Testing and Validation*

Automotive manufacturers and developers can use the system to test and validate new vehicle technologies and components. The real-time data and historical analysis capabilities provide insights into the performance and reliability of new innovations.

# Expected Results

The Design and Development of Automotive Diagnostic Data Visualization System aims to deliver a robust solution for real-time vehicle diagnostics. The expected results include the development of a web based dashboard and a diagnostic tool that collectively enhance vehicle maintenance and monitoring. Below is a detailed description of the expected results

## 8. 1. PC based Dashboard

The web based dashboard will be a central component of the diagnostic system, providing users with a comprehensive view of vehicle data. The expected features and results for the dashboard are as follows

### 8.1.1. real-time Data Visualization

The dashboard will display real-time data from the vehicle's ECUs, including engine RPM, coolant temperature, fuel level, and other critical parameters. Visualization elements will include gauges, charts, and graphs that update in real-time to reflect the current status of the vehicle.

### 8.1.2. Diagnostic Trouble Codes (DTCs) Display

The dashboard will show a list of active and stored Diagnostic Trouble Codes (DTCs) along with their descriptions. Users will be able to view details of each code, including the associated fault and possible corrective actions.

### 8.1.3. Historical Data Analysis

Users will have access to historical diagnostic data, allowing for trend analysis and performance monitoring over time. Historical data will be presented in graphs and tables, enabling users to track changes and identify patterns.

### 8.1.4. Alerts and Notifications

The dashboard will provide real-time alerts and notifications for critical issues, such as high engine temperature or low oil pressure. Alerts will be customizable based on user defined thresholds and conditions.


Fig.6. Request Response on Graphical View

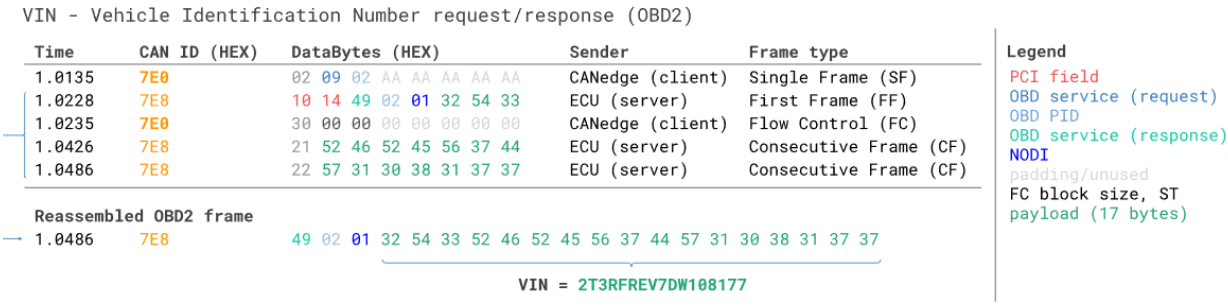


Fig.7. Read Vehicle Identification number

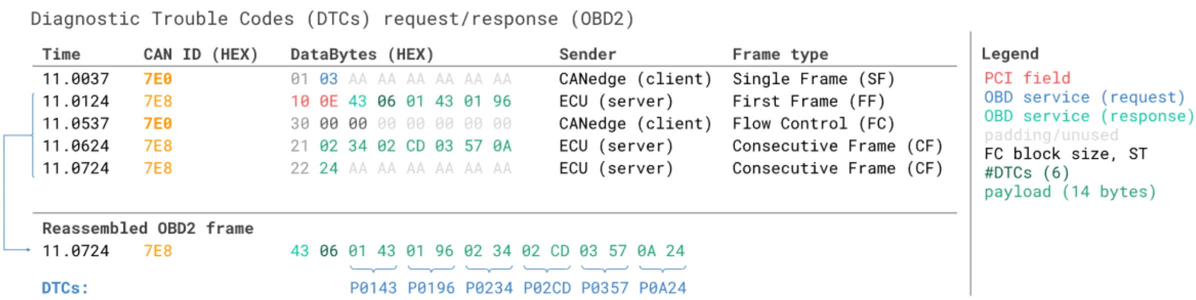


Fig. 8. Read DTC values

## 8. 2. Diagnostic Tool

The diagnostic tool will be a hardware and software solution designed to interface with the vehicle's OBD II system. The expected features and results for the diagnostic tool are as follows

### 8.2.1. OBDII Interface

The tool will connect to the vehicle's OBD II port and support various communication protocols (e.g., ISO 9141, ISO 14230, ISO 15765). It will be capable of retrieving data from different ECUs within the vehicle.

### 8.2.2. Data Acquisition and Processing

The tool will capture real-time data from the vehicle's sensors and ECUs, including engine performance metrics and diagnostic trouble codes. Data will be processed by the tool to decode CAN messages and interpret diagnostic information.

### 8.2.3. Wireless Communication

The tool will include a wireless communication module (e.g., WiFi or Bluetooth) to transmit data to the web based dashboard. It will enable remote data access and monitoring, allowing users to view diagnostic information on their devices.

By delivering these results, the project will provide an effective and user friendly solution for automotive diagnostics, improving maintenance practices and vehicle performance monitoring.

# Conclusion

The Design and Development of an Automotive On-Board Diagnostic (OBD) Protocol System successfully demonstrates the ability to monitor, diagnose, and communicate vehicle faults, enhancing both the efficiency and reliability of automotive diagnostics. This project leveraged the standardized OBD protocol to facilitate real-time fault detection and reporting, allowing for quick identification of issues such as sensor malfunctions and system errors. Through structured implementation, the system achieved effective communication between vehicle ECUs and diagnostic tools, accurately retrieving Diagnostic Trouble Codes (DTCs) and other relevant data. The system's modular and scalable design also supports future expansions for additional diagnostic functions, making it adaptable for evolving automotive technologies. This OBD protocol system stands as a crucial tool for vehicle maintenance, reducing downtime and promoting proactive vehicle care, thereby contributing to improved safety, performance, and environmental compliance in the automotive industry.

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[5] ISO 11898-1:2024 - Road vehicles – Controller area network (CAN) — Part 1: Data link layer and physical coding sublayer.

[6] ISO 15765-2:2016 Road vehicles – Diagnostic communication over Controller Area Network (DoCAN) -- Part 2: Transport protocol and network layer services.