Departamento de Engenharia Eletrotecnica e de Computadores

Systems Engineering Project Report

# Measuring the Quality of Vehicle Driving Using Arduino and MPU 6050

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# Contents

**Abstract**

”You can’t improve what you cant measure.” Peter Drucker

# 1 Introduction

The quality of vehicle driving is a multifaceted parameter that significantly impacts road safety, vehicle maintenance, and driver behavior analysis. With the advent of intelligent transportation systems, precise measurement and improvement of driving quality have become achievable goals. This project explores the use of an Arduino microcontroller and the MPU 6050 sensor, a MEMS (Micro-Electro-Mechanical System) that combines a 3-axis gyroscope and a 3-axis accelerometer, to create a cost-effective and efficient system for monitoring driving quality.

## 1.1 Background and Motivation

Transportation systems worldwide are experiencing a paradigm shift with the integration of advanced electronics and sensor technologies. Traditional methods of assessing driving quality are often subjective or require expensive equipment and setups. This project is motivated by the need for an accessible, reliable, and objective measurement of driving behavior that can be used for various applications, from personal driving improvement to fleet management and road safety enhancement.

## 1.2 Objectives and Goals

The primary objective of this project is to design and implement a prototype system capable of measuring various aspects of driving quality, such as acceleration, deceleration, turning, and overall stability, using the Arduino and MPU 6050 sensor. The goals include:

- Developing a method for acquiring and processing sensor data to evaluate driving patterns.
- Creating a metric or set of metrics that quantitatively reflect driving quality.
- Ensuring the system is user-friendly and can be easily adapted for different types of vehicles.

## 1.3 Overview

This report outlines the development process of the driving quality measurement system, from conceptualization to prototype implementation. It details the system's design choices, technical specifications, and the rationale behind the selected hardware and software components.

## 1.4 Report Structure

The remainder of this report is organized as follows:

- Section 2 reviews the current state of the art in driving quality measurement and highlights similar systems.
- Section 3 discusses stakeholder expectations and the concept of operation.
- Section 4 presents the technical requirements of the system.
- Section 5 describes the logical decomposition and system architecture.
- Section 6 defines the solution, including hardware and software components.
- Section 7 showcases the results and developments made during the project.
- Section 8 concludes the report and suggests directions for future work.

# 2 State of the Art

Measuring driving quality has become a significant focus in the automotive industry, with various stakeholders interested in accurate and reliable metrics. This chapter presents an overview of the existing technologies and systems developed to assess driving quality. It includes commercial products, academic research initiatives, and proprietary systems used by vehicle manufacturers and transportation agencies.

## 2.1 Existing Technologies in Driving Quality Assessment

Understanding how well someone drives is important for safety and has led to the creation of several tools and apps. Modern cars have built-in systems that help drivers stay safe [Bos], like helping to keep the car in its lane or braking automatically to avoid crashes. These systems use various sensors to control the car and can also track how safely it is being driven.

Apart from cars themselves, many smartphone apps are now available that use the phone's sensors to watch how the driver accelerates, brakes, and turns the car. These apps give feedback to help drivers improve,such as DriveScore [Sco].

Another important tool comes from the insurance industry [Han+14]. Small devices that plug into the car can record how the car is driven. This information can be used to adjust insurance prices based on whether someone drives safely or not. These devices and apps show that there's a lot of interest in finding new ways to measure and improve driving quality.

## 2.2 Comparison with our Project

This project leverages the Arduino platform and MPU 6050 sensor, enhanced by the HC-05 Bluetooth module, to create a user-friendly, do-it-yourself driving quality assessment system. The system's design allows for real-time data transmission to personal devices for analysis, without the need for complex installation. It stands out for its ease of use, affordability, and open-source framework, which contrasts with the high cost and complexity of many high-accuracy commercial systems. Our solution is easily adaptable and encourages community engagement and iterative development.

# 3 Stakeholder Expectations and Concept of Operation

## 3.1 Stakeholder Identification

The stakeholders in this project encompass a diverse group, each with different expectations:

- **Drivers:** Primary users who aim to improve their driving skills for safety and efficiency.
- **Fleet Management Companies:** Interested in monitoring their fleets to reduce fuel and maintenance costs, and enhance the safety of their employees.
- **Vehicle Manufacturers:** Can use this technology to improve existing safety features in vehicles or offer it as an additional service.
- **Insurance Companies:** Looking for reliable data to tailor insurance premiums based on individual driving behaviors.
- **Traffic Safety Authorities:** Could utilize the data to understand driving patterns and implement better road safety measures.
- **Technology Enthusiasts and DIY Community:** Individuals keen on applying Arduino and sensor technology in personal or educational projects.

## 3.2 System Operation

The operation of the system can be outlined in a few key steps:

1. **Installation:** The Arduino and MPU 6050 are installed in the vehicle, with the HC-05 module enabling Bluetooth connectivity.
2. **Data Collection:** While the vehicle is in use, the system continuously collects data on various driving parameters like acceleration, braking, and cornering.
3. **Data Transmission:** The collected data is transmitted wireless to a paired device (smartphone or computer) using the HC-05 Bluetooth module.
4. **Data Analysis and Feedback:** The received data is analyzed, either in real-time or later, to assess driving quality. This analysis can provide immediate feedback to the driver or be used for long-term monitoring and improvement.

## 3.3 Expected Benefits

The anticipated benefits of the system include:

- Enhanced driver awareness and improvement in driving habits.
- Potential reduction in insurance premiums for drivers who demonstrate safe driving behavior.
- Valuable data for vehicle manufacturers to understand real-world usage of their vehicles.
- Insights for traffic safety authorities to identify common driving issues and develop targeted safety campaigns.

# 4 Technical Requirements for Safe Driving Measurement System

## 4.1 Overview

The technical requirements for the driving quality measure device are derived from the needs and expectations of various stakeholders identified in Section 3.1. These requirements will translate stakeholder needs into a defined set of validated "shall" statements to guide the design and development of the device. These will form the basis of the Product Breakdown Structure (PBS) and are critical to ensuring that the final product meets the operational concept as described in Section 3.2.

## 4.2 Constraints, Functional, and Behavioral Expectations

- **Constraints:** Given the diverse stakeholder group, the device must be compact, easy to install, have low power consumption, and be robust enough to operate in the harsh environment of a vehicle. It must also be compatible with a wide range of vehicle models and easy to pair with various devices via Bluetooth.
- **Functional Expectations:** The device shall continuously collect and transmit data on driving parameters such as acceleration, braking, and cornering. Additionally, it shall allow for real-time data analysis and feedback to the driver.
- **Behavioral Expectations:** Based on the system operation described in Section 3.2, the device shall function seamlessly from installation to data transmission, ensuring reliability and accuracy in the data collection process.

## 4.3 Requirements Definition

1. **System Functions:**
    - Data Collection: The system shall collect baseline data on driving parameters such as acceleration, turning (angular velocity), and braking (deceleration) using a calibrated MPU6050 sensor.
    - Calibration: The system shall include a calibration process for the MPU6050 sensor to ensure accurate measurements of driving parameters.
    - Data Analysis: The system shall analyze the collected data to determine driving quality. This analysis shall differentiate between normal and harsh driving behaviors based on predefined thresholds.
2. **System Performance:**
    - Accuracy: The system shall measure acceleration and deceleration with a minimum accuracy of 1g ($9.81\ \mathrm{m/s^2}$) and angular velocity with sufficient sensitivity to detect sharp turns.
    - Operating Conditions: The system shall operate effectively in various environmental conditions, maintaining accuracy and calibration integrity.
    - Data Transmission: The system shall continuously transmit the collected data to the intended device without interruption or loss of data integrity.
3. **Acceptable Requirement Statements:**
    - The system shall accurately collect data on acceleration, angular velocity, and deceleration to establish driving quality metrics.
    - The system shall include a reliable calibration process for the MPU6050 sensor to maintain measurement accuracy.
    - The system shall perform data analysis to identify driving behaviors that exceed established thresholds for acceleration, turning, and braking.

- The system shall ensure the precision of measurements across a range of environmental conditions without recalibration.
- The system shall provide continuous data transmission to the user's device for real-time monitoring and analysis.

## 4.4 Requirements Validation

1. **Experimental Testing**
   - **Straight Path Testing:** Conduct multiple trials of aggressive braking and acceleration on a straight path to obtain consistent sensor data on the y-axis.
   - **Curvature Testing:** Perform tests on a curved road to record high lateral inclinations and aggressive variations in the z-axis, indicative of sharp turns.
2. **Threshold Determination**
   - **Braking and Acceleration Thresholds:** Use the y-axis inclination data to calculate thresholds for dangerous braking or acceleration.
   - **Turning Thresholds:** Establish thresholds for aggressive turning based on lateral inclination and z-axis variations during curved path testing.
3. **Data Collection and Analysis**
   - **Sensor Data Collection:** Collect driving data using the MPU6050 sensor, and transmit it to a computer via the HC-05 Bluetooth module.
   - **Real-Time Analysis:** Utilize the Arduino IDE serial monitor plotter for real-time data visualization and analysis, identifying normal versus hazardous driving patterns.
   - **Transmission Stability:** Ensure the Bluetooth connection remains stable and reliable to maintain data integrity during transmission from the remote-controlled car to the computer.
4. **Environmental and Reliability Testing**
   - **Environmental Adaptability:** Validate the system's operation in temperatures ranging from -10°C to 50°C, in humidity up to 80%, and ensure it can withstand typical driving vibrations and shocks.
   - **Sensor Calibration Adjustments:** Adjust the sensor calibration to account for the specific size and mass of the remote-controlled car to ensure accurate sensor readings that reflect the impact of these factors on driving behavior.
5. **Stakeholder Involvement**
   - **Feedback Incorporation:** Engage stakeholders to review data and provide feedback on system performance, specifically addressing the environmental adaptability and calibration accuracy for the size and mass of the car.
   - **Threshold Refinement:** Refine thresholds and analysis methods based on stakeholder feedback to ensure the system's measurements are accurate and meaningful.

# 5 Logical Decomposition and System Architecture

This section outlines the methodologies used to define the system's structure, including the relationships between its hardware and software components, ensuring that all elements operate cohesively to meet the project's objectives.

## 5.1 Subsystems and Their Functions

The system is conceptualized as an integration of several key subsystems, each with distinct roles:

### 5.1.1 Sensor Subsystem (MPU 6050 Sensor):

This subsystem is the heart of data acquisition, capturing real-time vehicular motion parameters such as acceleration and orientation. Some technical specifications are:

- **Type:** 6-axis MotionTracking device combining a 3-axis gyroscope and a 3-axis accelerometer.
- **Gyroscope Range:** Selectable ranges of $\pm 250$, $\pm 500$, $\pm 1000$, and $\pm 2000$ dps.
- **Accelerometer Range:** Supports ranges of $\pm 2$g, $\pm 4$g, $\pm 8$g, and $\pm 16$g.
- **Digital Motion Processor (DMP):** Capable of processing complex 9-axis MotionFusion algorithms.
- **Interface:** Primarily uses I2C bus for communication.
- Notable for its small size and low power consumption.
- Supports programmable interrupts for functionalities like gesture recognition, orientation detection, etc.
- Includes an on-chip temperature sensor for temperature compensation.

### 5.1.2 Processing Subsystem (Arduino Microcontroller):

It interprets data from the sensor, transforming raw measurements into actionable driving quality metrics. Some important features, and specifications are:

- **Processor:** Based on Atmel microcontrollers (ATmega328 for Arduino Uno, in our case).
- **Memory:** Includes both flash memory (for storing code) and RAM (for runtime data).
- **Input/Output:** Digital and analog I/O pins for connecting various sensors and actuators, in our case, HC05, MPU6050 and others.
- **Power Supply:** Can be powered via USB connection or an external power source.
- **Accessibility, Flexibility, Extensibility:** User-friendly, with a large community and extensive resources for learning and troubleshooting, it supports a variety of shields and add-ons for expanded functionality and is suitable for complex, integrated systems.

### 5.1.3 Communication Subsystem (HC-05 Bluetooth Module):

This unit ensures the seamless transfer of processed data to an external device for further analysis or real-time feedback.

- **Frequency Range:** Operates in the 2.4GHz ISM band.
- **Modulation:** Uses Gaussian Frequency-Shift Keying (GFSK) modulation.
- **Range:** Typically offers a communication range of about 10 meters (33 feet), which is enough for our needs.

- **Power Consumption:** Designed for low power operation, making it suitable for battery-powered applications, which is our case.

Interface and Configuration:

- Uses serial communication (UART interface) for connecting with micro-controllers like Arduino.
- Can be configured as either a master or a slave device for communication.

Integration with our system and considerations of use:

- **Data Transmission:** Responsible for sending collected and processed data from the Arduino to an external device like a smartphone or computer.
- **Real-time Feedback:** Enables real-time transmission of data for immediate feedback or analysis.
- **Range and Interference:** The effective range can be impacted by physical obstructions and interference from other wireless devices.
- **Pairing and Connectivity:** Ensuring reliable pairing and connectivity with external devices is crucial for uninterrupted data transfer.

### 5.1.4 Power Management Subsystem:

Critical for sustaining long- term operation, this subsystem manages power distribution efficiently across the device. In our project, we employed a 5V battery input to power the Arduino Uno, focusing on efficiency and reliability. The following measures were taken:

- **Direct Connection Approach:** We used the USB port of the Arduino Uno for the 5V battery input. This method bypasses the onboard voltage regulator, enhancing the efficiency of power usage.
- **Battery Selection:** For our power source, we chose a 5V battery with a capacity sufficient to meet the operational duration requirements of our system.
- **Stability and Safety Protocols:** We ensured that the power source was stable to avoid erratic system behavior. Additionally, safety measures like current limiting fuses were incorporated to prevent potential overcurrent damage.

### 5.1.5 User Interface Subsystem:

A proposed future development to enable direct interaction with users for data visualization and feedback, but in our aproach we only use LEDs and a Buzzer:

- **Functionality:** Describes the real-time display of analysis results through LEDs and the use of a buzzer for driver alerts.
- **Integration with Arduino:** The interface's integration with the Arduino allows for dynamic feedback based on the analysis of sensor data.

## 5.2 Subsystem Interactions

In the context of system architecture, it is imperative that each subsystem not only functions efficiently on its own but also seamlessly integrates with the other subsystems. The interactions between the subsystems for our Driving Quality Measurement Device are as follows:

- **Sensor to Data Processor:** The MPU6050 sensor subsystem captures motion data and communicates this information to the Arduino-based data processing unit via the I2C interface. This interface is a critical link that allows for the high-speed transmission of sensor data while minimizing the complexity of interconnection.

- **Data Processor to User Interface:** The data processing unit analyzes the sensor data and translates the results into actionable insights. These insights are conveyed to the user through a series of LEDs for visual feedback and a buzzer for auditory alerts. The communication here is managed by the digital and analog I/O pins on the Arduino, which control the LEDs and buzzer directly.
- **Data Processor to Communication Subsystem:** Post-analysis, the processed data is sent from the Arduino to the HC-05 Bluetooth module. This data is packaged into a serial format suitable for Bluetooth transmission, allowing for real-time data relay to an external device, such as a smartphone or computer.
- **Power Management Across Subsystems:** Each subsystem is powered through a centralized power management system that ensures a consistent supply of electricity from the 5V car battery input. This subsystem regulates the distribution of power to the sensor, data processor, user interface, and communication module to maintain optimal performance without energy waste.
- **Environmental Adaptability:** The system is designed to operate within a wide range of environmental conditions, ensuring that each subsystem is not only robust in isolation but also maintains its functionality when interacting with other subsystems. For example, the MPU6050 sensor's temperature compensation feature is crucial for accurate readings, which directly affects the data analysis quality in the processing unit.

This detailed interaction ensures that the system's architecture is not only theoretically sound but also practically viable, with each subsystem contributing to a harmonious and effective whole.

## 5.3 System Diagrams

**Hardware Interconnection Diagram, Fig 1.** Includes a visual representation of the system's hardware interconnections, serving as an illustrative example of the physical layout and relationships between components.

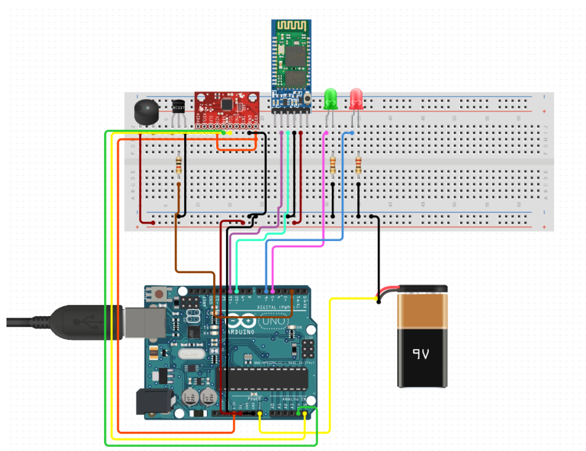


Figure 1: Hardware Interconnection Diagram.

## 5.4 System Integration and Data Flow

Our design philosophy emphasized a continuous flow of data and functionality:

- Continuous data feed from the Sensing Subsystem to the Processing Subsystem.
- Efficient analysis and data relay from the Processing Subsystem to the Communication Subsystem.
- Real-time data transmission to an external device, bridging the gap between data acquisition and user interaction.

## 5.5 Alternative Architectures

Throughout the development, we explored various architectural possibilities:

- **Advanced Microcontrollers:** Initially considered but set aside due to cost considerations.
- **Additional Sensors:** GPS integration was explored for enhanced data accuracy but deferred for future iterations to maintain system simplicity.
- **Alternative Communication Methods:** Wi-Fi and LoRa were potential candidates, but Bluetooth was chosen for its balance of range, power efficiency, and ubiquity.

## 5.6 Conclusion

A systematic functional analysis was conducted, translating high-level requirements into specific functions, and then allocating these to various subsystems. This process involved iterative refinement of the system architecture, ensuring alignment with our core objectives of efficiency, cost-effectiveness, and user accessibility.

The driving quality measure device architecture represents a harmonious blend of functionality and practical design. While keeping future scalability in mind, the current architecture meets our initial objectives, laying a solid foundation for potential enhancements and adaptations in response to evolving user needs and technological advancements.

# 6 Design Solution Definition

## 6.1 Overview

In the pursuit of enhancing road safety through innovative technology, we have embarked on designing a state-of-the-art driving quality measure device. This device will leverage the Arduino UNO platform, MPU-6050 sensor capabilities, and HC-05's wireless communication prowess to provide real-time feedback on driving patterns, aiding drivers in improving their driving habits for a safer journey.

## 6.2 Alternative Design Solutions

In our quest to optimize the driving quality measure device, we explored various alternative design solutions, particularly focusing on sensor configurations, data processing algorithms, and user feedback mechanisms:

### 6.2.1 Sensor Configurations

- **Single Sensor vs. Multi-Sensor Setup:** We evaluated the use of a single MPU-6050 sensor against a multi-sensor arrangement that includes additional accelerometers and gyroscopes for enhanced data accuracy and redundancy.
- **Integrated GPS Module:** An alternative involving the integration of a GPS module was considered to provide location-based data and correlate driving patterns with geographical contexts.
- **Environmental Sensors:** The incorporation of environmental sensors, such as temperature and humidity sensors, to study their impact on driving behavior was also explored.

### 6.2.2 Data Processing Algorithms

- **Basic vs. Advanced Motion Analysis:** We compared simple threshold-based algorithms for motion detection with more sophisticated machine learning models that can learn and adapt to different driving styles.
- **Real-Time vs. Batch Processing:** The trade-off between processing data in real-time for immediate feedback and batch processing for detailed later analysis was assessed.
- **Data Compression Techniques:** For efficient data transmission, especially in areas with limited connectivity, we examined various data compression algorithms.

### 6.2.3 User Feedback Mechanisms

- **Auditory vs. Visual Alerts:** The effectiveness of auditory alerts (like beeps or spoken warnings) was compared with visual cues on the device or a connected smartphone app.
- **Customizable Dashboard:** We considered a design with a customizable dashboard on a app, allowing drivers to personalize the data they see and how it's presented.
- **Haptic Feedback:** The use of haptic feedback, such as vibration alerts, was another avenue we explored, especially useful for situations where auditory or visual cues might be less effective.

Each alternative was evaluated for its feasibility, effectiveness, and alignment with the end-users' needs and the overall project goals. The ultimate choice of design solutions was made to balance innovation, practicality, and user experience.

## 6.3 Create Alternative Design Concepts

Our exploration of alternative design concepts for the driving quality measure device considered various aspects of physical layout, power management, and real-time feedback. Here we detail three distinct concepts:

### 6.3.1 Compact Integrated Design

- **Physical Layout:** This design integrates the MPU6050 sensor, Arduino UNO, and HC-05 Bluetooth module into a single compact unit. It's small enough to be mounted unobtrusively on the vehicle's dashboard.
- **Power Management:** It draws power directly from the vehicle's battery through a regulated power supply, ensuring minimal energy consumption while maintaining constant operation.
- **Real-Time Feedback:** Feedback is provided to the driver through a series of LED indicators embedded in the device, offering immediate visual cues about driving quality.

### 6.3.2 Modular Design with Enhanced Data Processing

- **Physical Layout:** This concept separates the sensor unit from the data processing unit. The sensor module is placed close to the vehicle's center of gravity for accurate data collection, while the processing unit remains accessible to the driver.
- **Power Management:** Both units have independent power controls, allowing for energy-saving modes when the vehicle is idle. The processing unit features a rechargeable battery, supplemented by the vehicle's power.
- **Real-Time Feedback:** A small LCD screen on the processing unit displays detailed analytics, and a mobile app provides comprehensive real-time feedback and historical data analysis.

### 6.3.3 Advanced Design with Cloud Integration

- **Physical Layout:** This design adds cloud connectivity to the device for advanced data processing. The physical unit remains sleek, housing only essential components for data collection and initial processing.
- **Power Management:** Incorporates an advanced power management system that adjusts energy use based on data transmission needs, enhancing battery longevity.
- **Real-Time Feedback:** Real-time feedback is provided through a dedicated smartphone application, offering an interactive interface with personalized driving tips and long-term trend analysis.

Each design concept was evaluated for its feasibility, user experience, and alignment with the project's overall objectives. The final selection balanced the need for accurate and actionable feedback with practical considerations of installation, power management, and user interaction.

## 6.4 Analysis and Selection of Design Solution

### 6.4.1 Analysis of Alternative Design Solutions

In our analysis of the three proposed design solutions, we considered several key factors:

- **Cost Considerations:**
  - The Compact Integrated Design is the most cost-effective, utilizing fewer components and simpler assembly, ideal for this academic project with limited budgets.
  - The Modular Design, while offering enhanced data processing, incurs higher costs due to its additional components and sophisticated power management system.
  - The Advanced Design with Cloud Integration demands ongoing costs for cloud services, making it less viable for a budget-constrained academic environment.
- **Technical Feasibility:**
  - The Compact Integrated Design is technically feasible with readily available components and straightforward integration, aligning well with the academic setting.
  - The Modular Design presents moderate technical challenges, particularly in synchronizing the separate units.
  - The Advanced Design poses significant technical complexities, especially in ensuring reliable cloud connectivity and data processing.
- **Stakeholder Value:**
  - The Compact Design meets the basic stakeholder needs for real-time driving feedback without extraneous features.
  - The Modular Design offers more detailed feedback but may exceed the requirements and expectations of our stakeholders.
  - The Advanced Design, while feature-rich, may not align with the immediate needs and capabilities of the typical users in our academic context.

### 6.4.2 Selection of the Best Design Solution Alternative

After a thorough evaluation, we have chosen the Compact Integrated Design as the ideal solution for our academic project. This design strikes a perfect balance between sophisticated data processing capabilities and a user-centric interface, all within a cost-effective and scalable framework. It meets the essential requirements for real-time driving quality measurement, providing clear feedback to drivers while being feasible and practical within the constraints of our academic resources. The simplicity of this design also facilitates easier understanding and replication, which is crucial in an educational and research setting. By focusing on the core objectives of the project and aligning with the stakeholder's needs and expectations, the Compact Integrated Design ensures that our project remains both impactful and manageable.

## 6.5 Risk Assessment

Our risk assessment identified potential challenges such as sensor accuracy under extreme conditions and reliable data transmission in areas with signal interference. Mitigation strategies include using higher-grade components for better performance and integrating fallback communication protocols.

## 6.6 Enabling Products and Services

For the successful implementation and operation of our driving quality measure device, several enabling products and services are identified. These elements not only support the device's functionality but also enhance its usability, maintenance, and educational value:

- **Data Analytics Platform:**

  - A cloud-based platform is developed for in-depth analysis of driving data. This platform allows for extensive data processing, including pattern recognition and trend analysis.
  - Features an intuitive dashboard for researchers and educators to visualize and interpret driving behavior data.

- **Mobile Application:**
  - A user-friendly mobile application is designed to provide drivers with real-time feedback and insights into their driving patterns.
  - Includes features like historical data review, personalized tips for driving improvement, and configurable alert settings.

- **Maintenance and Support Services:**
  - Scheduled maintenance services and a support hotline are established to assist users with technical issues or queries.
  - Regular firmware updates are provided to enhance device capabilities and address any identified issues.

These enabling products and services are fundamental to the comprehensive operation and maintenance of the driving quality measure device. They ensure that the project remains not only technically robust but also educationally valuable and operationally sustainable.

## 6.7 Outputs

Our outputs include a comprehensive technical package with detailed specifications, interface designs, and compliance documents. The technical package encompasses all aspects of the design, from hardware schematics to software code, ensuring a comprehensive blueprint for product realization.

# 7 Results/Work Developed

## 7.1 Simulations

### 7.1.1 Simulation Setup

We create a simulation of various driving scenarios. These simulations replicated real-world driving conditions to test the device's response under different scenarios, the simulation environment was designed to mirror various driving behaviors.

### 7.1.2 Simulation Results

The results demonstrated the device's capability to accurately detect and analyze driving patterns, such as sharp turns, sudden stops, and varying speeds. The MPU6050 sensor effectively captured motion data, and the Arduino processed this data in real-time. Simulations highlighted the device's robustness in diverse conditions and its effectiveness in identifying driving quality metrics.

### 7.1.3 Insights Gained

The simulations provided vital insights into the device's performance. We identified the need for fine-tuning the sensor's sensitivity to ensure accurate data collection in different driving conditions. These simulations also allowed us to optimize the data processing algorithms for more efficient and accurate analysis.

## 7.2 Software Development

### 7.2.1 Development Process:

The software for our device was developed using C++ in the Arduino IDE. Key features included real-time data processing algorithms, integration with the Bluetooth module for data transmission, and a user-friendly interface for data display. Emphasis was placed on ensuring the software was lightweight and efficient to facilitate quick processing and minimal latency.

### 7.2.2 Challenges and Solutions:

One challenge was ensuring uninterrupted data transmission via Bluetooth, especially in environments with potential signal interference. We addressed this by implementing robust error-handling and data caching mechanisms. Another challenge was optimizing the algorithm for real-time analysis, which was resolved through iterative testing and performance tuning.

### 7.2.3 Software Features:

The final software included features such as live data plotting, driving event detection (like hard braking or rapid acceleration), and a user-friendly dashboard for displaying driving quality metrics. The software's modular design allows for easy updates and integration of additional features in the future.

## 7.3 Experimental Testing

### 7.3.1 Test Setup:

The device was tested on a variety of vehicles under different driving conditions, including city roads and highways. The tests were conducted over several weeks to gather a comprehensive set of data under varied conditions.

### 7.3.2 Data Collection:

Data collected included acceleration, angular velocity, and braking patterns. This data was then wirelessly transmitted to a the laptop. Additional parameters such as time of day, weather conditions, and GPS location can also be recorded to contextualize the driving data, on a future approach.

# 8 Conclusion and Future Work

## 8.1 Conclusion

This project successfully developed a driving quality measure device, demonstrating its capability to accurately analyze driving behaviors. Integrating the Arduino UNO, MPU-6050 sensor, and HC-05 Bluetooth module, the device stands out for its real-time data processing and user-friendly interface. The findings from simulations and experimental tests underscore its potential in enhancing road safety.

## 8.2 Future Work

Future enhancements for the project include:

- Upgrading sensors for improved accuracy.
- Incorporating machine learning for advanced driving pattern analysis.
- Enhancing connectivity with vehicle systems and smart city infrastructure.
- Researching user interaction to further impact road safety positively.
- Exploring commercialization avenues and sustainable production methods.

In summary, the project has laid a foundation for ongoing innovations in automotive safety, providing a significant stepping stone towards safer driving practices.

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