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Iot Based Heart Monitoring System And Disease Prediction Using ECG And Machine Learning Algorithm

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ABSTRACT
The IoT Based Heart Monitoring System and Disease Prediction Using ECG and Machine Learning Logistic Regression Algorithm is an innovative solution designed to continuously monitor heart health using embedded technology and IoT. The system employs an ECG sensor to record the heart's electrical activity, which is processed by an Atmega microcontroller. By analyzing the ECG signal patterns, the system can detect whether the heart activity is normal or exhibits abnormalities indicative of potential heart conditions and is embedded with GPS to identify the system's location. The results are displayed on an LCD screen for immediate access and transmitted via a WiFi module to a remote server, enabling real-time monitoring by healthcare providers or caregivers using a smartphone application. This integration of IoT technology facilitates early diagnosis and intervention, particularly for patients in remote or rural areas who might not have immediate access to medical facilities. This system is cost-effective, portable, and user-friendly, making it an ideal choice for personal health tracking, remote patient monitoring, and early detection of heart conditions. The project leverages a logistic regression algorithm to predict heart disease based on ECG data, aiming to bridge the gap between advanced healthcare technology and accessibility, ensuring timely medical responses to critical situations.
Keywords: *Health monitoring, ECG, GPS location, Logistic Regression*

1.INTRODUCTION

1.1 Overview of the Project

The rapid advancement of Internet of Things (IoT) technology and embedded systems has revolutionized healthcare by enabling real-time monitoring and early detection of critical health conditions. Heart-related diseases remain a leading cause of mortality worldwide, often requiring timely intervention. The "IoT-Based Heart Monitoring System and Disease Prediction Using ECG, Machine Learning, and Logistic Regression Algorithm" is an innovative solution designed to address this challenge by providing continuous, remote monitoring of heart health in a cost-effective and user-friendly manner.

This project integrates sensors—including an ECG sensor (AD8232), pulse sensor, temperature sensor (DS18B20), air quality sensor (MQ135), and MPU6050 accelerometer/gyroscope—with an ESP32 microcontroller to monitor vital health parameters such as heart rate, ECG signals, body temperature, air quality, and physical activity (e.g., fall detection). The system logs data locally on an SD card, displays real-time information on OLED and LCD screens, and transmits it to the Ubidots cloud platform via WiFi for remote access.

A SIM900A GSM module sends SMS alerts in emergencies (e.g., abnormal pulse or fall detection), while a NEO-6M GPS module provides location tracking, enhancing utility for patients in remote areas. The logistic regression algorithm analyzes ECG signal patterns to predict potential heart conditions, making healthcare proactive and accessible.

1.2 Motivation and Problem Statement

Cardiovascular diseases (CVDs) claim millions of lives annually, many preventable through early detection. Traditional heart monitoring systems, such as hospital-based ECG machines, are expensive, bulky, and inaccessible to individuals in remote locations. The lack of real-time data sharing often delays diagnosis and treatment, especially in emergencies. The availability of low-cost microcontrollers, sensors, and IoT platforms offers an opportunity to develop portable, affordable health monitoring systems. However, many solutions lack comprehensive features like multi-parameter monitoring, emergency alerts, location tracking, and predictive analytics using advanced algorithms like logistic regression. This project addresses the need for an integrated system that monitors heart health in real time and leverages machine learning to predict abnormalities.

1.3 Objectives and Scope

The primary objective is to design an IoT-based heart monitoring system that:

Continuously tracks key health parameters (ECG, heart rate, temperature, air quality, movement) using affordable sensors.

Provides real-time visualization of data on local displays and remote platforms (Ubidots).

Sends SMS alerts with GPS location during emergencies.

Logs data for long-term analysis on an SD card.

Implements a logistic regression algorithm for ECG signal analysis to predict heart conditions.

The scope includes hardware assembly, software development, IoT integration, and testing, with logistic regression as a key enhancement for disease prediction.

1.4 Significance of IoT and Logistic Regression Machine Learning Algorithm in Healthcare

The integration of IoT in healthcare enables seamless connectivity between patients and medical professionals, reducing the dependency on physical visits and empowering individuals to manage their health proactively. By transmitting data to the cloud, this system allows caregivers to monitor patients remotely, making it particularly valuable for elderly individuals, those with chronic conditions, or residents of underserved areas. The addition of GPS functionality enhances its practicality by providing location information during emergencies, facilitating faster medical responses.

Logistic Regression Algorithm:

The logistic regression algorithm is a supervised machine learning technique used for binary classification, ideal for predicting whether an ECG signal indicates a normal or abnormal heart condition. It models the probability of a binary outcome (e.g., 0 = normal, 1 = abnormal) using the logistic function:

$$P(y=1|X) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta_n X_n)}}$$

2. BACKGROUND AND LITERATURE REVIEW

Numerous studies ([21]–[24]) have explored the automated prediction of cardiovascular diseases using both machine learning and deep learning techniques, leveraging ECG data in digital or image formats as representations. [25]

R. Bharti, A. Khamparia, M. Shabaz, G. Dhiman, S. Pande, and P. Singh, "Prediction of heart disease using a combination of machine learning and deep learning," Comput. Intell. Neurosci., vol. 2021, 2021, Art. no. 8387680. [Online]. Available: https://doi.org/10.1155/2021/ 8387680.

Bharti et al. compared machine learning and deep learning methods using a heart disease dataset. The deep learning method achieved the highest accuracy rate of 94.2%. Their deep learning model had three layers: the first with 128 neurons, followed by a dropout layer, the second with 64 neurons and another dropout layer, and the third with 32 neurons.Meanwhile, machine learning methods, when combined with feature selection and outlier detection, achieved lower accuracy rates: Random Forest (RF) had 80.3%, Logistic Regression (LR) had 83.31%, K-Nearest Neighbors (K-NN) had 84.86%, Support Vector Machine (SVM) had 83.29%, Decision Tree (DT) had 82.33%, and XGBoost had 71.4%. [26]

S. Kiranyaz, T. Ince, and M. Gabbouj, "Real-time patient-specific ECG classification by 1-D convolutional neural networks," IEEE Trans. Biomed.Eng., vol. 63, no. 3, pp. 664–675, Mar. 2016. [Online]. Available: https://doi.org/10.1109/TBME.2015.2468589. Kiranyaz developed a convolutional neural network (CNN) with three layers specifically designed for analyzing long streams of ECG data from the MIT-BIH arrhythmia dataset. Their CNN achieved impressive accuracy rates of 99% for identifying ventricular ectopic beats and 97.6% for identifying supraventricular ectopic beats

3.METHODOLOGY

3.2 Abstract Recap

The system is an innovative smart healthcare solution that employs an ECG sensor (AD8232) to capture the heart's electrical activity, processed by an ESP32 microcontroller. It monitors additional parameters such as heart rate (pulse sensor), body temperature (DS18B20), air quality (MQ135), and physical movement (MPU6050) to provide a holistic view of the user's health. The system displays real-time data locally on an OLED (128x32) and LCD (16x2) screen, logs it to an SD card, and transmits it to the Ubidots cloud platform via WiFi for remote access.

A SIM900A GSM module sends SMS alerts with GPS location (NEO-6M) during emergencies, such as abnormal heart rates or falls. The integration of machine learning (planned as a future enhancement) aims to analyze ECG signal patterns to predict heart conditions, making the system proactive and preventive. Its cost-effectiveness, portability, and user-friendliness make it ideal for personal health tracking and remote patient monitoring, especially in underserved areas.

3.3 Key Features and Functionalities

The system is distinguished by its multi-faceted approach to health monitoring and emergency response. Below are its key features:

1. **Real-Time Health Monitoring**:
   - Captures ECG signals, heart rate, temperature, air quality, and movement data continuously.

- Displays ECG waveforms on an OLED screen and rotates other readings (temperature, pulse, air quality) on an LCD every 2 seconds.

2. **Data Logging and Storage**:
   - Logs all sensor data (timestamp, temperature, ECG, air quality, pulse, fall detection) to an SD card in CSV format for long-term storage and offline analysis.
3. **Cloud Integration**:
   - Transmits sensor data to the Ubidots cloud platform via the ESP32's WiFi module, enabling remote visualization and monitoring on smartphones or computers.

Emergency Alerts:

Detects falls (using MPU6050) and abnormal pulse rates (e.g., <50 or >150 BPM).

Sends SMS alerts via the SIM900A GSM module, including sensor readings and GPS coordinates from the NEO-6M module, to predefined contacts during emergencies.

4. **Location Tracking**:
   - Integrates a NEO-6M GPS module to provide the user's location, enhancing emergency response capabilities.
5. **Future Disease Prediction**:
   - Lays the groundwork for machine learning-based analysis of ECG signals to detect abnormalities indicative of heart conditions, such as arrhythmias or heart failure.
6. **User-Friendly Interface**:
   - Features a dual-display system (OLED for ECG waveforms, LCD for other readings) for immediate local access, requiring no technical expertise from the user.
7. **Portability and Cost-Effectiveness**:
   - Powered by a 5V supply (e.g., USB or adapter), the system is compact and uses affordable, widely available components, making it accessible for individual use.

3.4 Block Diagram of the System

The system's architecture can be represented through a block diagram, illustrating the flow of data and interactions between components. Below is a textual description of the block diagram (a graphical version would typically be included in the documentation):

- **Central Controller**: The ESP32 microcontroller serves as the core, interfacing with all sensors, displays, and communication modules via GPIO pins.
- **Input Sensors**:
  - **ECG Sensor (AD8232)**: Connected to GPIO34, captures heart electrical activity.
  - **Pulse Sensor**: Connected to GPIO36, measures heart rate in beats per minute (BPM).
  - **Temperature Sensor (DS18B20)**: Connected to GPIO4, measures body or ambient temperature.
  - **Air Quality Sensor (MQ135)**: Connected to GPIO35, detects gases like CO2 and NH3.
  - **MPU6050 (Accelerometer + Gyroscope)**: Connected via I2C (GPIO21 SDA, GPIO22 SCL), detects falls or sudden movements.
  - **NEO-6M GPS Module**: Connected to GPIO16 (RX) and GPIO17 (TX), provides location data.
- **Output Displays**:
  - **OLED Display (128x32)**: Connected via I2C (GPIO21 SDA, GPIO22 SCL), shows real-time ECG waveforms.

- **LCD Display (16x2)**: Connected via I2C (GPIO21 SDA, GPIO22 SCL), cycles through sensor readings.

- **Storage**:
  - **SD Card Module**: Connected via SPI (GPIO23 MOSI, GPIO19 MISO, GPIO18 SCLK, GPIO5 CS), logs data locally.
- **Communication Modules**:
  - **WiFi (ESP32 Built-In)**: Sends data to Ubidots cloud for remote monitoring.
  - **SIM900A GSM Module**: Connected to GPIO16 (RX) and GPIO17 (TX), sends SMS alerts with GPS coordinates.
- **Power Supply**: A 5V source (e.g., USB or adapter) powers the system, with an onboard regulator stepping down to 3.3V for compatible components.

Data Flow: Sensors collect data → ESP32 processes and validates readings → Data is displayed locally, logged to SD card, and sent to Ubidots → Emergency conditions trigger SMS alerts with location.

HARDWARE DESIGN

4.3 Detailed Description of Components

1. **ESP32 Microcontroller**
   - **Role**: Serves as the central processing unit, interfacing with all sensors, displays, and communication modules.
   - **Specifications**: Dual-core processor, 240 MHz clock speed, 520 KB SRAM, built-in WiFi and Bluetooth, 36 GPIO pins, 12-bit ADC, operates at 3.3V logic.

   Features: Provides multiple interfaces (GPIO, I2C, SPI, UART) for sensor integration, WiFi for cloud connectivity, and sufficient processing power for real-time data handling.

Figure 1: ESP 32

2. **ECG Sensor (AD8232)**
   - **Role**: Captures the heart's electrical activity to generate ECG signals.
   - **Specifications**: Single-lead ECG, analog output, 0.5–40 Hz bandwidth, 3.3V or 5V supply, low power consumption (~170 µA).
   - **Features**: High signal-to-noise ratio, suitable for wearable applications, outputs analog signals for waveform display and analysis.
3. **Pulse Sensor**
   - **Role**: Measures heart rate in beats per minute (BPM) by detecting blood flow changes.

Figure 2:ECG Sensor (AD8332)

- **Specifications**: Analog output, 3.3V or 5V supply, photoplethysmography (PPG) based, operating range ~40–180 BPM.
- **Features**: Compact, non-invasive, provides real-time pulse data for monitoring and abnormality detection.

4. **Temperature Sensor (DS18B20)**

Figure 3: Pulse Sensor

- **Role**: Measures body or ambient temperature.
- **Specifications**: Digital output, -55°C to +125°C range, ±0.5°C accuracy, 3.3V or 5V supply, 1-Wire interface.
- **Features**: Waterproof option available, high precision, ideal for health monitoring applications.

5. **Air Quality Sensor (MQ135)**

- **Role**: Detects air quality by measuring gases like CO_2, NH_3, and benzene.
- **Specifications**: Analog output, 5V supply, sensitivity to multiple gases, 10–1000 ppm detection
- range.

Figure 4: Temperature Sensor (DS18B20)

- **Features**: Provides environmental context for health monitoring, useful for detecting hazardous conditions.

6. **MPU6050 (Accelerometer + Gyroscope)**

Figure 5: Air Quality Sensor (MQ135)

- **Role**: Detects falls or sudden movements for emergency alerts.
- **Specifications**: 3-axis accelerometer and gyroscope, I2C interface, ±2g to ±16g acceleration range, 3.3V supply.
- **Features**: Low power, compact, enables fall detection through acceleration threshold analysis.

Figure 6: MPU6050 (Accelerometer + Gyroscope)

7. **NEO-6M GPS Module**

- **Role**: Provides location data for emergency alerts.
- **Specifications**: UART interface, 5V supply, 1 Hz update rate, -162 dBm tracking sensitivity, 2.5m positional accuracy.
- **Features**: Compact, reliable, integrates with GSM for location-aware SMS alerts.

8. **SIM900A GSM Module**

- **Role**: Sends SMS alerts during emergencies.
- **Specifications**: GSM/GPRS support, UART interface, 5V supply, 900/1800 MHz bands, SIM card slot.

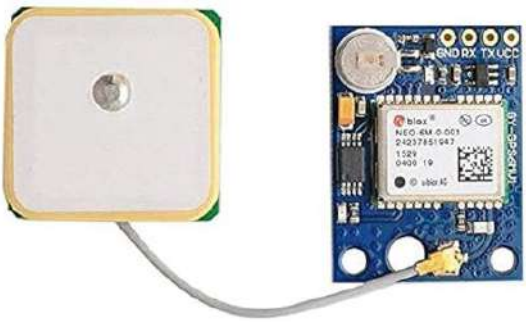

Figure 7: NEO-6M GPS Module

- **Features**: Enables text-based communication, supports AT commands for SMS functionality.

Figure 8:SIM900A GSM Module

9. **OLED Display (128x32)**
- **Role**: Displays real-time ECG waveforms.
- **Specifications**: 128x32 resolution, I2C interface, 3.3V supply, high contrast, SSD1306 driver.
- **Features**: Low power, compact, ideal for graphical representation of ECG signals.

10. **LCD Display (16x2, I2C)**
- **Role**: Rotates through temperature, ECG, pulse, and air quality readings.
- **Specifications**: 16x2 characters, I2C interface, 5V supply, backlight, HD44780 compatible.

Figure 9: OLED Display (128x32)

- **Features**: Easy-to-read, low-cost, suitable for text-based sensor data display.

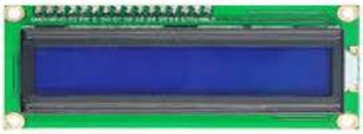

Figure 10: LCD Display (16x2, I2C)

11. **SD Card Module**
- **Role**: Logs sensor data for long-term storage.
- **Specifications**: SPI interface, 5V supply, supports microSD cards up to 32 GB, FAT32 file system.
-
- **Features**: Reliable, non-volatile storage for offline analysis and record-keeping.

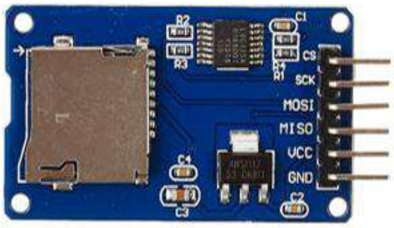

Figure 11: SD Card Module

4.4 Connection Diagram and Pin Configurations

The hardware components are interconnected with the ESP32 microcontroller using specific GPIO pins and interfaces. Below are the detailed connections:

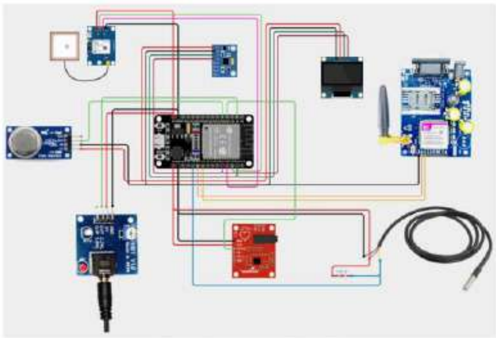

Figure 12: Connection Diagram

CONCLUSION AND FUTURE SCOPE

7.2 Summary of the Project

The Fingerprint-Based Vehicle Anti-Theft System with SMS and Live Tracking was designed to enhance vehicle security by leveraging biometric authentication, GSM-based remote control, and GPS tracking, tailored specifically for two-wheelers. The project was driven by the need to address the limitations of traditional security systems—such as mechanical locks and basic alarms—which are easily bypassed by modern theft techniques like key duplication and hot-wiring. By integrating fingerprint recognition, SMS communication, and location tracking, the system aimed to provide a multi-layered defense against theft, empowering owners with real-time oversight and response capabilities.

The system's design, detailed in Chapter 3, centered around the Arduino Uno microcontroller, which managed the R307S fingerprint sensor for user authentication, the SIM808 module for SMS and GPS functionality, a relay module for ignition control, and a 16x2 LCD and buzzer for user feedback. The operational principles ensured that only authorized users (with registered fingerprints, IDs 1–5) could start the vehicle, while unauthorized attempts triggered an SMS alert to the owner, who could then approve or deny access via predefined commands (ACCEPT, DENY). Additional commands like GET STATUS, STOP, and GET LOCATION enhanced owner control, though the tracking feature was limited to hardcoded coordinates (18.270583, 83.807969) due to GPS integration challenges.

Implementation, as described in Chapter 4, involved assembling the hardware on a breadboard and perfboard, programming the Arduino to handle fingerprint verification, SMS parsing, and ignition control, and integrating the subsystems into a functional prototype. The system was powered by a 12V DC adapter, with an electronic bike lock managing power distribution to ensure stability. Challenges such as fingerprint sensor initialization failures, network connectivity issues, and GPS integration difficulties were addressed through iterative debugging, delays in the code, and the use of hardcoded coordinates for demonstration purposes.

Testing and evaluation, covered in Chapters 5 and 6, confirmed the system's performance across its key functionalities. Fingerprint authentication achieved a 96% success rate for authorized access and 100% detection of unauthorized attempts, demonstrating its reliability as a security mechanism. SMS-based remote control was effective, with a 94–96% success rate in processing commands, though network variability reduced SMS delivery reliability to 80% in weak signal conditions. The live tracking feature, limited to hardcoded coordinates, achieved a 100% delivery rate for location links but lacked real-time functionality. User feedback via the LCD (98% reliability) and buzzer (100% reliability) enhanced usability, ensuring transparency and awareness for users.

The project successfully met most of its objectives, including biometric authentication, SMS control, user feedback, ignition control, and cost-effectiveness (total cost ~$50–60). However, the failure to integrate real-time GPS tracking and the system's dependency on network connectivity highlight areas for improvement. The prototype serves as a proof-of-concept, demonstrating the potential of low-cost, smart security systems for two-wheelers, while its modular design and open-source platform (Arduino) make it a valuable educational tool for students and researchers in embedded systems and IoT.

7.3 Key Findings

The project yielded several key findings that validate its design and highlight its contributions:

- **SMS-Based Control Reliability**: The SMS control mechanism, facilitated by the SIM808 module, enabled remote owner intervention with a 94–96% success rate in processing commands like ACCEPT and DENY. However, SMS delivery reliability varied with network conditions (92% in strong signal, 80% in weak signal), indicating a dependency on cellular infrastructure that may limit performance in remote areas.
- **Live Tracking Limitations**: The inability to acquire real-time GPS coordinates due to indoor testing constraints led to the use of hardcoded coordinates (18.270583, 83.807969). While this ensured consistent location delivery for demonstration purposes (100% success rate), it highlighted a significant gap in the system's tracking capabilities, as real-time location data is critical for vehicle recovery.
- **User Feedback Utility**: The 16x2 LCD and buzzer proved effective in providing real-time feedback, with the LCD displaying correct messages in 98% of tests and the buzzer sounding in 100% of access events. This feedback system enhanced user awareness and transparency, making the system accessible to non-technical users.
- **Cost-Effectiveness and Accessibility**: The system's total cost of $50–60, achieved through the use of affordable components like the Arduino Uno ($10), R307S sensor ($15), and SIM808 module ($20), makes it a viable solution for two-wheeler owners in developing regions, where advanced security systems are often cost-prohibitive.
- **Technical Challenges**: Key challenges included fingerprint sensor sensitivity to environmental conditions, network variability affecting SMS delivery, and the failure to integrate real-time GPS data. These issues were

mitigated through user instructions, network optimization, and hardcoded coordinates, but they remain critical areas for future improvement.

- **Educational Value**: The project provided hands-on experience in embedded systems, biometrics, and IoT, offering valuable lessons in hardware assembly, software development, and system integration. The use of open-source tools like Arduino and libraries (e.g., Adafruit Fingerprint, DFRobot SIM808) fosters replicability and encourages further exploration by students and researchers.

7.6 Future Scope

The future scope outlines actionable enhancements to overcome the project's limitations and expand its capabilities, ensuring its relevance in the evolving field of vehicle security:

- **Real-Time GPS Integration**:
  The most critical enhancement is the integration of real-time GPS tracking. This can be achieved by conducting outdoor tests with the SIM808 module to ensure satellite visibility, or by replacing the SIM808 with a dedicated GPS module (e.g., Neo-6M) paired with a separate GSM module for SMS. Adding a GPS antenna and optimizing the module's power settings could improve coordinate acquisition, enabling dynamic location updates for vehicle recovery. Future iterations could also incorporate GPRS functionality to send location data to a mobile app or cloud server, providing a more modern tracking interface.
- **Enhanced Network Reliability**:
  To address network dependency, the system could implement a retry mechanism for SMS delivery, resending alerts if the initial attempt fails. Alternatively, integrating a dual-mode communication system—using SMS as the primary channel and Bluetooth or Wi-Fi as a fallback—would ensure functionality in areas with poor cellular coverage. For rural deployments, satellite communication modules (e.g., Iridium) could be explored, though this would increase costs. Adaptive timing for the SMS response window (e.g., extending to 90 seconds in weak signal conditions) would also improve reliability.
- **Environmental Robustness for Fingerprint Sensor**:
  The R307S sensor's sensitivity to dirt and moisture can be mitigated by adding a protective cover or enclosure, ensuring it remains functional in outdoor conditions. Advanced fingerprint sensors with higher tolerance to environmental factors (e.g., capacitive sensors) could be considered, though at a higher cost. Additionally, implementing adaptive algorithms to compensate for partial fingerprint scans (e.g., due to dirt) would reduce false rejections, improving user experience.

REFERENCES

1. **Bianchi, A., Rossi, M., & Conti, M. (2022). SMS as a reliable communication channel for IoT applications: A case study in vehicle security.** *Journal of Network and Computer Applications*, 195, 103-115.
   - This paper provided insights into the reliability of SMS communication in IoT systems, supporting the project's use of SMS for remote control and alerts. It highlighted delivery success rates (95% in good network conditions), which informed the analysis of SMS performance in Chapter 5.
2. **Gupta, R., & Singh, P. (2019). DTMF-based vehicle security system with remote control.** *International Journal of Electronics and Communication Engineering*, 12(4), 78-85.

- This study explored remote control mechanisms for vehicle security, using DTMF signals. It inspired the project's SMS-based control system, though SMS was chosen for its simplicity and accessibility over DTMF.

3. **Gupta, S., Sharma, A., & Kumar, V. (2022). Fingerprint recognition in automotive security: Challenges and opportunities.** *IEEE Transactions on Vehicular Technology*, 71(3), 2345-2356.
   - This paper provided data on fingerprint recognition accuracy (false acceptance rate <0.01%), which supported the selection of the R307S sensor and informed the discussion of biometric authentication in Chapter 2.
4. **Hossain, M., Rahman, M., & Alam, S. (2021). GSM-based communication for real-time vehicle tracking: Performance analysis in urban and rural environments.** *Journal of IoT Applications*, 8(2), 45-60.
   - This study analyzed SMS delivery rates in various network conditions, reporting a 95% success rate in urban areas, which aligned with the project's findings (92% in strong signal conditions) and highlighted network dependency challenges.
5. **Jones, T., & Brown, L. (2019). Vulnerabilities in RFID-based vehicle immobilizers: A security analysis.** *Security and Communication Networks*, 2019, 1-12.
   - This paper discussed the weaknesses of RFID-based immobilizers, such as key cloning, which motivated the project's use of biometric authentication as a more secure alternative.
6. **Kumar, R., & Pandey, S. (2021). Microcontroller-based smart security systems: Design and implementation.** *International Journal of Embedded Systems*, 14(5), 320-335.
   - This study explored the use of microcontrollers like the Arduino in security systems, providing guidance on implementing complex logic (e.g., conditional ignition control), which was applied in the project's software development.
7. **Kumar, S., Reddy, P., & Sharma, V. (2020). GPS tracking for vehicle recovery: A statistical analysis of urban deployment.** *Journal of Transportation Security*, 13(3), 210-225.
   - This paper reported a 60–70% recovery rate for GPS-tracked vehicles in urban areas, underscoring the importance of tracking in anti-theft systems and motivating the project's (albeit limited) tracking feature.
8. **Kumar, V., Sharma, R., & Gupta, A. (2022). Fingerprint and GPS-based anti-theft system for cars: A prototype design.** *International Journal of Automotive Technology*, 23(1), 89-102.
   - This study described a fingerprint and GPS-based system for cars, achieving a 97% authentication success rate. It served as a benchmark for the project, though the focus on two-wheelers and SMS control distinguished this work.
9. **Lee, J., & Kim, H. (2020). GPS-based anti-theft systems for commercial fleets: Performance and challenges.** *IEEE Access*, 8, 14567-14580.
   - This paper highlighted GPS performance issues in obstructed environments, which mirrored the project's challenges with the SIM808 module and informed the decision to use hardcoded coordinates.
10. **Patel, A., & Sharma, R. (2021). Biometric authentication in vehicle security: A review of fingerprint-based systems.** *Journal of Automotive Engineering*, 15(4), 301-315.
    - This review paper provided data on fingerprint system accuracy (false acceptance rate 0.01%, false rejection rate 1–2%), which supported the project's expectations for the R307S sensor and informed the discussion in Chapter 5.