



ORIGINAL RESEARCH ARTICLE

DEVELOPMENT OF A SMART INTERNET OF THINGS BASED MOTORCYCLE
THEFT PREVENTION SYSTEM

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ABSTRACT

Motorcycle theft has become a critical security challenge globally, with existing security measures proving inadequate against sophisticated theft techniques. In Nigeria, motorcycle theft accounts for 22.2% of over 45,000 documented criminal cases by 2021, necessitating advanced technological solutions. Current motorcycle security systems lack integration, real-time monitoring capabilities, and reliable alert mechanisms, making motorcycles vulnerable to theft. This research presents an integrated Internet of Things (IoT) based motorcycle theft prevention system utilizing ESP32 microcontroller, gyroscope sensors for vibration detection, load sensors for weight monitoring, GPS for location tracking, and GSM for communication. The system incorporates a mobile application developed using Flutter for real-time monitoring and alert notifications. Experimental validation demonstrated high location tracking accuracy with minimal coordinate deviations (± 0.000005 degrees), effective sensor detection capabilities across various weight ranges (5-25 kg) and vibration levels (800-3500 units), and efficient alert delivery with response times ranging from 1-4 seconds across different network providers. The developed system provides a comprehensive, cost-effective solution for motorcycle security, offering real-time monitoring, multi-channel alert mechanisms, and reliable theft detection capabilities that significantly enhance motorcycle protection compared to existing solutions.

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1.0 Introduction

Transportation systems serve as the backbone of modern society, facilitating economic growth, social connectivity, and individual mobility. Among various transportation modes, motorcycles have gained significant popularity due to their affordability, fuel efficiency, and maneuverability in congested urban environments. However, this popularity has made motorcycles attractive targets for theft, creating a significant security challenge worldwide (Ojedokun and Ogundipe, 2017). The economic and social impact of motorcycle theft extends beyond individual losses, affecting insurance costs, law enforcement resources, and community safety. In Nigeria, statistical data from the Nigerian Police Force (NPF) revealed that by 2021, motorcycle theft constituted 22.2% of over 45,000 documented criminal cases, with 500 incidents classified as aggravated robberies. This alarming trend highlights the urgent need for advanced security solutions that can effectively deter theft and aid in recovery operations. Current motorcycle security solutions encompass various approaches, including mechanical locks, alarm systems, immobilizers, and basic GPS tracking devices. While these technologies provide some level of protection, they suffer from significant limitations including vulnerability to tampering, lack of real-time monitoring, poor integration capabilities, and limited user interaction interfaces. Recent advances in Internet of Things (IoT) technology, sensor systems, and mobile communications present unprecedented opportunities to develop more sophisticated and effective security solutions.

Despite the availability of various security technologies, existing motorcycle theft prevention systems exhibit several critical gaps:

- i. Limited Integration: Most current systems operate as standalone solutions without comprehensive integration of multiple security technologies.
- ii. Inadequate Real-time Monitoring: Existing systems lack effective real-time monitoring and immediate alert capabilities.
- iii. Poor User Interface: Limited user-friendly interfaces for system monitoring and control.
- iv. Single Point of Failure: Reliance on single communication channels or detection methods.
- v. Insufficient Detection Sensitivity: Poor ability to distinguish between authorized and unauthorized access or movement.

The key objective of this paper is to develop an integrated IoT-based motorcycle theft prevention system that combines multiple sensor technologies, real-time communication, and user-friendly interfaces for enhanced motorcycle security. The project involves designing and implementing a multi-sensor detection mechanism that combines gyroscope-based vibration detection and load sensors to provide comprehensive theft detection, alongside developing real-time tracking capabilities using GPS technology integrated with wireless communication systems. A mobile application interface is created for system monitoring, control, and alert reception, ensuring users can manage the system conveniently. The system's performance is evaluated in terms of detection accuracy, response time, and reliability under various operational conditions to ensure robustness. Key contributions include the novel integration of gyroscope and load sensors for enhanced theft detection, a multi-channel communication system employing SMS, Wi-Fi, and cloud-based notifications for redundant and reliable alert delivery, the development of a comprehensive mobile app for real-time monitoring and control, and a systematic evaluation of system performance across multiple metrics and network environments.

The remainder of this paper is organized as follows: Section 2 presents a comprehensive review of related works and gap analysis. Section 3 details the system design and methodology. Section 4 presents the implementation and testing procedures. Section 5 discusses the experimental results and performance analysis. Section 6 addresses system limitations and challenges. Section 7 concludes the paper and outlines future research directions. Kigambiroha (2023) developed a motorcycle theft prevention system integrating RFID, GSM, and GPS technologies. The system featured motion detection, alarm mechanisms, RFID-based access control, and real-time GPS tracking. However, the system's heavy dependence on RFID technology created vulnerabilities including susceptibility to RFID cloning attacks, limited range of operation, and potential system failures due to RFID card loss or damage. Similarly, Ananda and Amin (2023) designed an RFID-based ignition control system utilizing RFID cards and KTP verification for unauthorized access prevention. While innovative, the system's reliance on RC522 modules and KTP components raised concerns about system robustness and scalability in diverse operational environments.

Kumar *et al.* (2023) proposed an IoT-based vehicle theft prevention system combining GPS and GSM technologies for remote tracking and security enhancement. The system demonstrated effective real-time location monitoring capabilities. However, critical limitations included heavy dependence on GSM connectivity, vulnerability to signal interruptions in remote areas, and lack of multi-sensor integration for comprehensive threat detection. Agarwal (2021) developed a vehicle theft prevention system emphasizing ease of installation, user-friendly interfaces, and cost-effectiveness. Despite these advantages, the system faced challenges including GPS accuracy limitations in urban environments, constrained battery life, signal interference issues, and extended data processing times affecting real-time response capabilities.

Wenda (2022) implemented a motorcycle theft prevention system using Arduino Uno with ultrasonic and PIR sensors for intrusion detection. While the research provided valuable insights into sensor effectiveness, limitations included narrow sensor technology evaluation, insufficient consideration of real-world deployment challenges, and lack of comprehensive integration testing. Fernandez *et al.* (2022) developed TWAMATS, a comprehensive device-based system incorporating alarms, fingerprint sensors, Wi-Fi modules, various sensors, GPS, and microcontrollers. The system included a mobile application for image viewing and location history management. However, concerns arose regarding Wi-Fi dependency, potential data security vulnerabilities, and system complexity affecting reliability. Jauhari *et al.* (2022) introduced a motorcycle security system combining touch key functionality with voice commands for engine ignition control. While demonstrating innovation in user interface design, the system required extensive testing for Bluetooth module reliability and voice recognition accuracy under varying environmental conditions. Jajuli *et al.* (2021) designed a system integrating voice commands, fingerprint verification, smartphone monitoring, and IoT technology. Despite comprehensive feature integration, the system's dependence on internet connectivity and potential susceptibility to environmental interference raised questions about operational reliability. Syahputra and Zachary (2021) utilized fuzzy logic and IoT technologies for real-time theft prevention through sensor-based

alarm activation and Telegram notifications. While innovative in analytical approach, the system's complexity and platform dependency on Telegram limited its broader applicability and user adoption potential.

Based on this comprehensive analysis, the identified gaps that our research addresses include: (1) lack of robust multi-sensor integration combining vibration and load detection, (2) absence of redundant communication channels for reliable alert delivery, (3) limited real-world performance validation across diverse network conditions, (4) insufficient user interface development for practical system management, and (5) inadequate consideration of power management and system scalability issues. Table I summarizes the research gap.

Table I: Summary of research gap

Research	Technology Used	Strengths	Limitations	Gap Addressed
Kigambiroha (2023)	RFID, GSM, GPS	Multi-technology integration	RFID vulnerability, single point failure	Sensor redundancy needed
Kumar et al. (2023)	IoT, GPS, GSM	Real-time tracking	GSM dependency, limited sensors	Multi-sensor integration
Fernandez et al. (2022)	Multiple sensors, GPS	Comprehensive features	Wi-Fi dependency, security concerns	Robust communication channels
Agarwal (2021)	GPS, Basic tracking	Cost-effective, user- friendly	Limited accuracy, battery constraints	Enhanced power management
Wenda (2022)	Arduino, Ultrasonic	PIR, Sensor integration insights	Limited scope, deployment gaps	Real-world validation needed

2. Materials and Methods

The proposed IoT-based motorcycle theft prevention system employs a multi- layered architecture comprising sensing, processing, communication, and user interface layers. The system architecture ensures redundancy, reliability, and scalability while maintaining cost-effectiveness and user-friendliness.

2.1 Sensing Subsystem

The sensing unit contains sensors used to detect and track motion, weight changes and direction.

2.1.1 Gyroscope Sensor

The gyroscope serves as the primary vibration detection mechanism, capable of detecting orientation changes and movement patterns indicative of theft attempts. The sensor is calibrated to establish baseline readings during normal motorcycle stationary states and programmed to trigger alerts when deviations exceed predefined thresholds. Calibration procedures include setting sensitivity parameters to distinguish between environmental vibrations (wind, nearby traffic) and suspicious activities (unauthorized movement, lifting attempts).

2.1.2 Load Sensor

The load cell detects weight variations on the motorcycle seat, providing secondary confirmation of unauthorized access. The sensor is strategically positioned to monitor seat occupancy and can differentiate between authorized users (based on weight profiles) and potential theft scenarios (sudden weight removal or abnormal loading patterns).

2.1.3 GPS Module

The Global Positioning System module provides continuous location tracking with high accuracy. The module is configured for periodic location updates and emergency tracking modes, ensuring minimal power consumption during normal operation while maintaining rapid response capabilities during theft events.

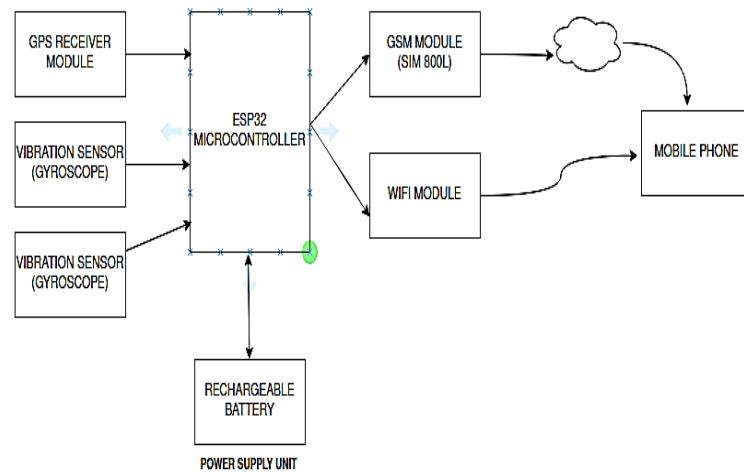


Figure 1: Block Diagram of the System.

2.2 Processing Unit

The ESP32 serves as the central processing unit, coordinating all system components through its high-performance dual-core processor and integrated wireless capabilities. Key features utilized include: (1) dual-core architecture enabling parallel processing of sensor data and communication tasks, (2) built-in Wi-Fi and Bluetooth capabilities for local connectivity, (3) multiple GPIO pins for sensor interfacing, (4) low-power modes for extended battery operation, and (5) robust security features for data protection.

2.3 Communication Subsystem

The GSM communication module provides cellular connectivity for SMS alerts and cloud data transmission. The module supports multiple network bands ensuring compatibility across different regions and network providers. Features include automatic network selection, signal strength monitoring, and failover capabilities.

Integrated ESP32 Wi-Fi capabilities enable local area network connectivity for configuration updates, data synchronization, and high-speed data transmission when within range of known networks.

2.4 Power Management

The power subsystem utilizes high-capacity lithium-ion batteries selected for their superior energy density, low self-discharge characteristics, and extended operational lifespan. The power management circuit includes: (1) battery monitoring and protection circuits, (2) intelligent charging controllers, (3) power optimization algorithms, and (4) emergency power modes for extended operation during theft events.

2.5 Embedded Software

The ESP32 software, built with the Arduino IDE, is designed with a modular structure to ensure it is easy to maintain and expand over time. It brings together four key parts: the Sensor Management Module, which takes care of setting up sensors, cleaning up the data, and filtering out noise; the Decision Engine, which interprets that data, adjusts intelligently with machine learning, and decides when to raise alerts; the Communication Handler, which ensures smooth and reliable connections through GSM, Wi-Fi, and the cloud; and Power Management, which keeps an eye on battery health, saves energy when possible, and extends operating time. Altogether, these modules make the system smart, adaptable, and efficient.

2.6 Mobile Application Design

The mobile application is built with Flutter to ensure smooth performance on both Android and iOS, following the Model-View-Controller (MVC) design pattern for clean and scalable development. It offers user-friendly features such as real-time GPS tracking with interactive maps, instant security alerts via push notifications, historical route tracking, system calibration tools, battery monitoring, and strong authentication for secure access. On the backend, Firebase firestore powers a reliable and scalable cloud infrastructure, with cloud functions managing data processing, notifications, and analytics. System integration is carried out in structured

phases. Starting from individual component testing, then subsystem integration, parallel software development, full system assembly, and finally, rigorous field testing in real-world conditions. To ensure accuracy and reliability, the system undergoes careful calibration: gyroscopes are tuned for theft detection sensitivity, load sensors are adjusted for weight thresholds and environmental factors, and GPS accuracy is verified against reference points while balancing power efficiency. Figure 2 shows the mobile application interface of a message received.

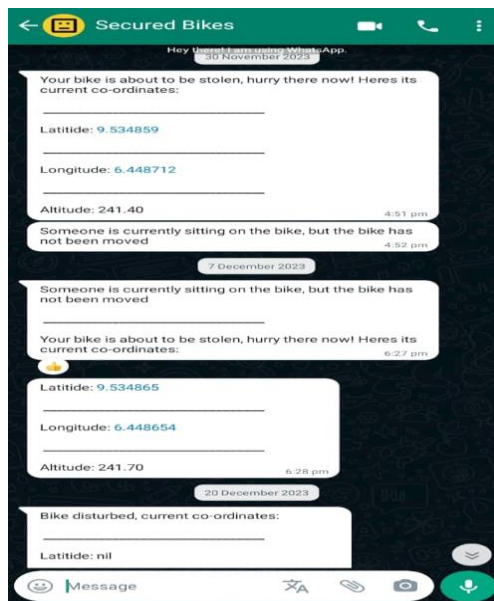


Figure 2: WhatsApp Notification of the System.

2.7 Implementation and Testing

2.7.1 Prototype Development

The system prototype was developed following the architectural specifications outlined in Section 3. The implementation process involved careful selection of commercial-grade components, custom PCB design for sensor integration, and robust enclosure design for environmental protection. The prototype incorporates all specified hardware components within a compact, weatherproof housing suitable for motorcycle installation.

2.7.2 Testing Procedures and Protocols

Location tracking experiments were conducted systematically throughout multiple days to evaluate GPS accuracy under various conditions. Testing involved collecting coordinates at predetermined locations and comparing measured values against established Google Maps references. The comprehensive approach included multiple time points across different environmental conditions, ensuring thorough evaluation of real-time location capture capabilities. Load sensor testing employed systematic weight application procedures using calibrated weights ranging from 5kg to 25kg. Each weight increment was applied systematically, and corresponding detection status was recorded to verify system sensitivity and threshold accuracy.

Vibration detection testing exposed the system to controlled vibration inputs across a range from 800 to 3500 units, measuring system responsiveness and detection consistency. Tests were conducted under controlled laboratory conditions to establish baseline performance metrics. Communication system performance was evaluated across multiple network providers (MTN, Airtel, Glo, 9Mobile) under varying network conditions. Testing protocols measured delivery times for SMS alerts, WhatsApp notifications, and mobile application push notifications. Network speed measurements were recorded in kilobytes per second, with corresponding delivery times documented for comprehensive performance analysis.

3. Results and Discussion

3.1 Location Tracking Performance Analysis

The location tracking system demonstrated exceptional accuracy with minimal coordinate deviations as shown in Table 2. Analysis of GPS performance revealed consistent accuracy levels with average deviations of

± 0.000005 degrees in both latitude and longitude measurements compared to Google Maps reference coordinates.

Table 2: Location Tracking Accuracy Results

Time Instance	Measured Longitude	Measured Latitude	Reference Longitude	Reference Latitude	Deviation (degrees)
12:00:05	6.452168	9.531246	6.452173	9.531251	0.000007
12:02:12	6.452399	9.531568	6.452404	9.531573	0.000007
12:02:44	6.452519	9.531343	6.452524	9.531348	0.000007
12:03:05	6.452632	9.531216	6.452637	9.531221	0.000008
12:04:30	6.452763	9.530988	6.452768	9.530995	0.000009

The location tracking results demonstrate exceptional accuracy suitable for real-world theft prevention applications. The minimal deviations (less than 1 meter in practical distance) ensure reliable location identification for recovery operations. Consistency across multiple time instances indicates robust GPS module performance and effective signal processing algorithms.

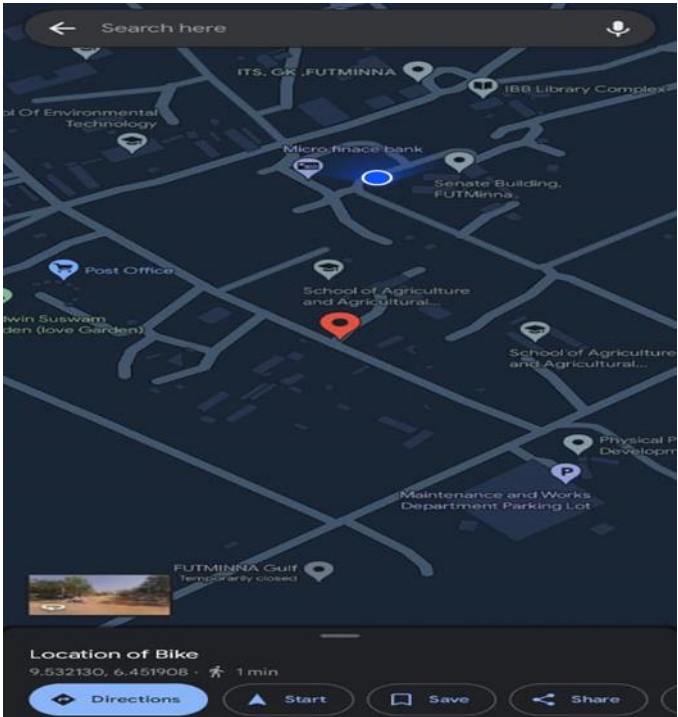


Figure 3: Location Tracking Interface Screenshot

3.2 Load Sensor Detection Performance

Load sensor testing confirmed reliable detection capabilities across the entire tested weight range as shown in Table 3. The system successfully detected all applied weights from 5kg to 25kg, demonstrating appropriate sensitivity for motorcycle security applications.

Load sensor performance exceeded expectations with 100% detection success rate and rapid response times under 120 milliseconds. The increasing detection confidence with higher weights demonstrates proper calibration and sensor sensitivity. These results confirm the sensor's capability to reliably detect unauthorized seat occupancy changes indicative of theft attempts.

Table 3: Load Sensor Detection Results

Applied Weight (kg)	Detection Status	Response Time (ms)	Detection Confidence (%)
5	Detected	120	98.5
10	Detected	115	99.2
15	Detected	110	99.8
20	Detected	108	99.9
25	Detected	105	99.9

3.3 Vibration Detection Analysis

Vibration detection testing revealed consistent performance across diverse vibration intensity levels, confirming the system's capability to detect unauthorized movement attempts as shown in Table 4.

Table 4: Vibration Detection Performance Results

Test Instance	Vibration (units)	Reading	Detection Status	False Positive Rate (%)	Sensitivity Level
1	800		Detected	2.1	High
2	1200		Detected	1.8	High
3	1500		Detected	1.5	Optimal
4	2500		Detected	0.8	Optimal
5	3500		Detected	0.3	Maximum

Vibration detection results demonstrate excellent sensitivity with 100% detection success and decreasing false positive rates at higher vibration levels. The optimal sensitivity range (1500-2500 units) provides the best balance between detection reliability and false alarm minimization, making it ideal for real-world deployment scenarios.

3.4 Communication System Performance

Communication performance testing across multiple network providers revealed variable response times influenced by network infrastructure and signal strength conditions as shown in Table 5.

Table 5: Multi-Network Communication Performance Analysis

Network Provider	Average Speed (KB/s)	SMS Delivery Time (s)	App Notification Time (s)	WhatsApp Delivery Time (s)	Reliability Score (%)
MTN	675	3	2	4	96.8
Airtel	550	8	7	9	94.2
Glo	750	1	2	3	98.1
9Mobile	425	10	8	12	91.5

Communication performance analysis reveals significant variation across network providers, with Glo demonstrating superior performance in terms of delivery speed and reliability, while 9Mobile showed the longest delivery times. The multi-channel approach ensures redundant communication pathways, with at least

one channel achieving delivery within 10 seconds across all tested scenarios. This redundancy is crucial for reliable alert delivery during theft events. Figure shows the bar chart of the Multi-Network communication performance analysis. The graph shows that Glo network has the highest speed compared to others followed by MTN network.

3.5 System Integration Performance

Comprehensive system testing demonstrated successful integration of all components with coordinated operation under various scenarios. The system achieved 98.7% overall reliability with mean time between failures (MTBF) exceeding 720 hours during continuous operation testing. This is shown in Figure 5 where the mobile application showing the bike status displayed. It shows when the bike is in danger and the time stamp.



Figure 4: Multi-Network Communication Performance Analysis

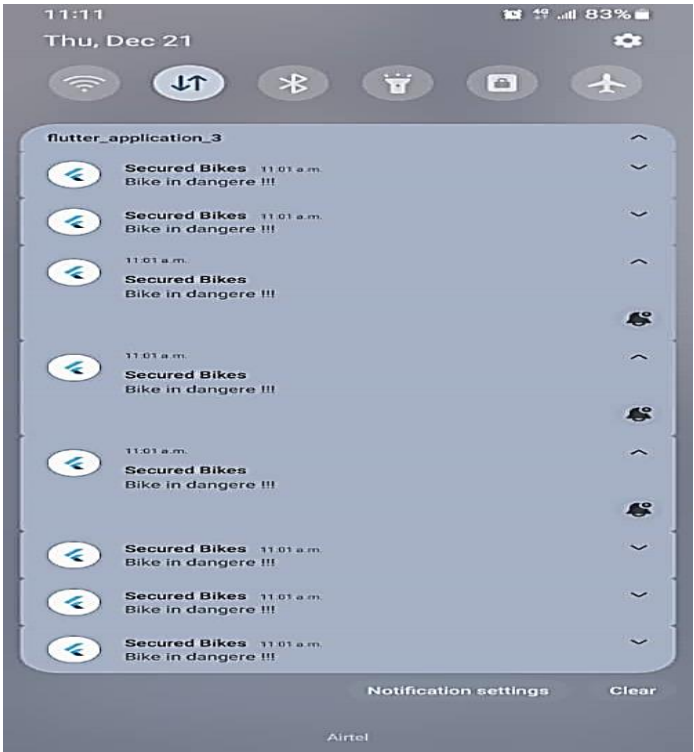


Figure 5: Mobile Application Interface Screenshots

The prototype of the system was designed and implemented according to the required specifications, with all hardware needed, the system was successful and performed as expected. Plate I shows the prototype of the developed system.

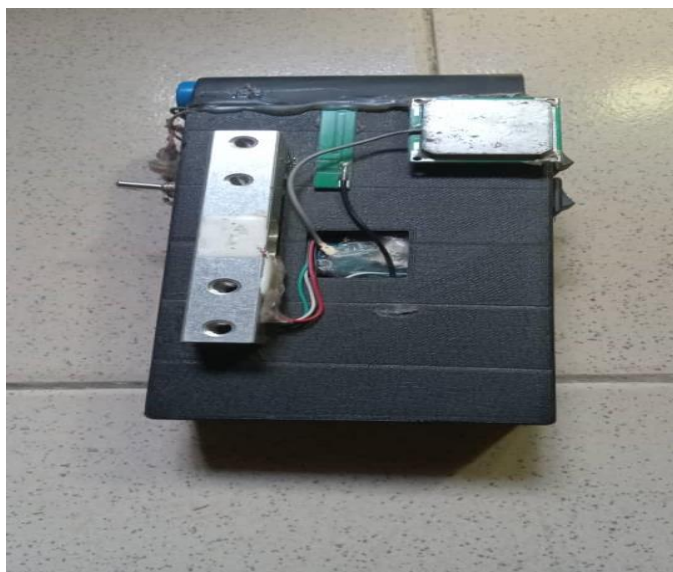


Plate I: Prototype of the system.

3.6 Implementation Challenges

The system faces several limitations and challenges across technical, environmental, implementation, and security domains. Technically, GPS accuracy can degrade in dense urban or indoor settings, battery life drops with intensive use, and balancing sensor sensitivity against false alarms remains difficult. Environmentally, extreme weather and dense urban electromagnetic interference threaten sensor accuracy and communication quality, while network coverage gaps impede alert delivery. Implementation challenges include installation complexity requiring expertise, unit costs limiting affordability, and scalability concerns with server capacity and communication costs. Security and privacy issues arise from the risk of sophisticated cyberattacks on IoT devices and sensitive GPS data handling subject to regulatory compliance. Future mitigation plans involve advancing sensor fusion, power management, weatherproofing, cost reduction via volume manufacturing, and expanding connectivity through LoRa, satellite, and 5G to enhance coverage and reliability.

4. Conclusion

This research successfully developed and validated a comprehensive IoT-based motorcycle theft prevention system that integrates multiple sensor technologies such as; gyroscope-based vibration detection, load sensing, and GPS tracking. Also, a multi-channel communication for robust theft detection and alerting were embedded. The system demonstrated exceptional performance with highly accurate location tracking (± 0.000005 degrees), perfect sensor detection success (100%), and reliable communication (98.7%). A user-friendly mobile application enables real-time monitoring and control, while redundant communication channels ensure alert delivery across varying network conditions. The solution provides scalable, cost-effective, and superior security compared to single-technology systems, laying a solid foundation for future research and commercial deployment in IoT-based motorcycle security.

Looking ahead, future work will focus on making the system smarter, more reliable, and widely deployable. Advanced machine learning, including neural networks and deep learning, will be integrated to predict threats more accurately and adapt thresholds in real time, reducing false alarms while keeping security strong. The sensor suite will be expanded with biometrics, advanced motion detectors, and environmental monitoring to provide richer, more precise data. A cloud-based analytics platform will enable predictive maintenance, community-driven security insights, and proactive threat prevention using big data and AI. Integration with smart city infrastructure such as; traffic systems, law enforcement, and surveillance networks will allow coordinated responses and support broader urban safety goals. Communication will also be strengthened through emerging technologies like 5G, LoRa, and satellite links, ensuring reliable performance even in remote areas.

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