An IoT-Based Anti-Bike Theft System Using ESP32 Microcontroller

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Abstract—**The increasing prevalence of two-wheeler theft in urban and rural areas underscores the limitations of traditional mechanical locks and the prohibitive cost of high-end GPS tracking solutions. This paper presents the design, implementation, and testing of a low-cost, smart anti-theft system for motorcycles and scooters leveraging Internet of Things (IoT) technology. The proposed system utilizes an ESP32 microcontroller as its central processing unit, integrated with a key switch, a hidden toggle switch, a buzzer, and a DC motor for simulation purposes. Upon detection of unauthorized access triggered when the ignition is activated while the anti-theft mode is armed the system initiates a dual-layer response: a local audible alarm via the buzzer and a real-time push notification sent to the owner's smartphone through the Blynk IoT cloud platform. The system architecture emphasizes cost-effectiveness, ease of deployment, and user-friendly operation. Testing confirms the system's reliability in detecting intrusion attempts and its efficacy in delivering instantaneous alerts. The paper concludes by discussing the successful prototype and proposing future enhancements, including GPS tracking, biometric authentication, and advanced cloud integration, to further bolster security and functionality.**

Index Terms—**IoT, ESP32, Anti-Theft System, Blynk, Real-time Alerts, Bike Security, Microcontroller.**

I. INTRODUCTION

This project addresses the growing concern of two-wheeler thefts by developing a smart, IoT-based security system. Traditional lock-and-key mechanisms are often inadequate, while high-end GPS solutions can be costly. To bridge this gap, this project proposes a cost-effective and reliable Anti Bike Theft System using the ESP32 microcontroller.

The core idea is to create a system that provides real-time alerts to the owner upon unauthorized access. It uses a hidden toggle switch to arm the security system. If someone attempts to start the bike (simulated by a key switch) while the system is armed, the ESP32 triggers two immediate responses:

1. A local, audible alarm via a buzzer to deter the thief.
2. An instant push notification sent to the owner's smartphone via the Blynk IoT cloud platform.

This dual-layered approach ensures a rapid response to theft attempts, offering enhanced security through immediate local alerts and remote monitoring capabilities. The project demonstrates the practical application of IoT technology to solve a real-world problem using affordable and accessible components.

II. MOTIVATION

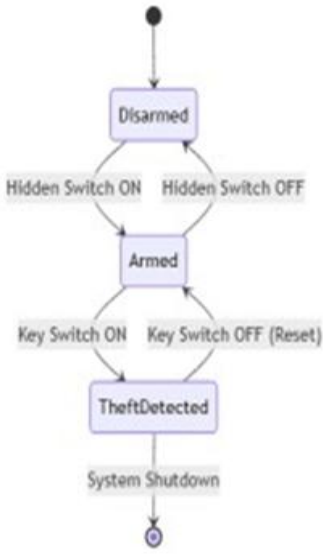
The primary motivation for this project stems from the alarming rise in two-wheeler thefts in both urban and rural areas. Motorcycles and scooters are popular due to their affordability and mane uverability, but this has also made them a prime target for thieves, especially when parked in unsecured locations.

The project was driven by the inadequacy of existing security solutions:

Traditional Locks (Locks & Keys, Handle Locks): These are purely physical barriers that offer no realtime alert to the owner. Determined thieves can easily break or bypass them, and by the time the theft is discovered, it is often too late.

High-End GPS Systems: While effective, these systems are often expensive, involving significant installation and ongoing subscription costs, making them inaccessible to the average bike owner.This gap in the market created a clear need for a low-cost, intelligent, and proactive security system. The project leverages the power of the Internet of Things (IoT) to

create a solution that not only deters theft locally with an alarm but also instantly notifies the owner remotely, empowering them to respond immediately. The goal was to democratize vehicle security by using affordable, readily available • components like the ESP32 microcontroller to provide high-end features like real



Experimental Details: Anti Bike Theft System Using ESP32

- Microcontroller: An ESP32 development board was used as the central processing unit.
- Input Components: o A Key Switch was used to simulate the bike's ignition system.o A Hidden Toggle Switch was incorporated to allow the owner to arm or disarm the anti-theft system discreetly.
- Output Components: o A 5V Active Buzzer was connected to produce an audible alarm.o A 5V DC Motor was used to simulate the bike's engine for visual demonstration.
- Power Supply: A 5V, 2A DC power adapter was used to provide stable power to the ESP32, motor, and buzzer.
- Connections: All components were connected to the GPIO pins of the ESP32 on a breadboard according to the circuit design. The system was powered via the ESP32's USB port during initial testing and later via the DC adapter. B. Software and Network Configuration:

IDE: The Arduino IDE was used for software development.

Libraries: Key libraries included:

- WiFi.h for establishing internet connectivity.
- BlynkSimpleEsp32.h for communicating with the Blynk IoT cloud.

Blynk App Setup: A project was created on the Blynk platform. An authentication token was
generated and embedded in the code. A button widget was set up for monitoring, and a notification event was configured to trigger on theft detection.

Network: The ESP32 was programmed with Wi-Fi credentials (SSID and password) to
connect to a local network for internet access.

2. Experimental Procedure and Testing

The system's functionality was validated through a series of structured test cases designed to simulate real-world conditions. The core logic tested was: If the Hidden Switch (Anti-theft) is ON and the Key Switch (Ignition) is turned ON, trigger an alarm.

Key Experimental Observations and Results

- System Responsiveness: The response time between triggering the key switch and the buzzer sounding was virtually instantaneous (< 1 second). The Blynk notification arrived on the mobile device within 2-5 seconds, depending on network latency.
- Reliability: The system consistently detected the unauthorized access condition (Hidden ON + Key ON) and triggered the correct outputs every time during testing.
- Power Consumption: When powered by the 5V adapter, the system ran stably. The report notes the potential for using the ESP32's deep sleep mode to conserve battery power, though this may have been a conceptual future enhancement rather than a implemented feature in the basic prototype.
- User Interface: The Blynk app provided a simple and effective interface for receiving alerts. The notifications were clear and timely.

4. Challenges and Limitations (Noted During Experimentation)

- Wi-Fi Dependency: The remote notification feature is entirely dependent on the availability of

a WiFi network with internet access. The system's effectiveness is reduced in areas without coverage.
- Component Limitations: The prototype uses a simple key switch and toggle. In a real vehicle, these would need to be replaced with more robust components integrated into the bike's ignition and chassis. Experimental Setup and Prototype Construction A. Hardware Assembly:
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  - A Hidden Toggle Switch was incorporated to allow the owner to arm or disarm the anti-theft system discreetly.
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- Component Limitations: The prototype uses a simple key switch and toggle. In a real vehicle, these would need to be replaced with more robust components integrated into the bike's ignition and chassis.
- Power Source: For a real-world deployment, a dedicated, compact battery solution with power management would be required, which was only conceptually addressed in the report.
- False Alarms: The basic logic is susceptible to false alarms if the owner forgets to disarm the system before starting the bike. A more sophisticated arming/disarming sequence (e.g., via mobile app) could mitigate this.

III. RELATED WORK

The problem of vehicle security, particularly for two-wheelers, has been addressed through various technological solutions over the years. This section explores the evolution of these systems, from traditional mechanical methods to modern IoT-based approaches, and situates the current project within this landscape.

- Traditional Security Mechanisms

The most common form of protection remains mechanical locks, such as disc locks, chain locks, and handlebar locks. While low-cost and easy to use, their primary limitation is their passive nature. They offer no real-time alert to the owner and can be compromised with physical tools, providing a false sense of security. Conventional alarm systems, which trigger a siren upon impact or tilt, represent an improvement but are often prone to false alarms and lack remote notification capabilities, rendering them ineffective if the owner is not within earshot

- GPS and GSM-Based Tracking Systems

A significant advancement came with the integration of GPS and GSM technology. Systems described in works like Nawaf & Khan (2020) and Kaladevi et al. (2018) focus on real-time vehicle tracking and theft recovery. These systems typically use a GSM module to send location data via SMS or to a cloud server. While highly effective for post-theft recovery, they often incur ongoing subscription costs for the SIM card and data, making them more expensive to maintain. Furthermore, their effectiveness is limited in areas with poor cellular network coverage.

- The Rise of IoT and Wi-Fi Based Solutions

The advent of the Internet of Things (IoT) has enabled a new class of smart security systems that leverage microcontrollers, sensors, and cloud platforms. Research by Chavan & Nikam (2021) demonstrates the effectiveness of using the ESP8266/ESP32 microcontroller with the Blynk platform for creating costeffective vehicle monitoring systems. These systems prioritize real-time push notifications over tracking, alerting the owner instantly during a theft attempt, which allows for a potentially quicker response.

Alvi et al. (2019) and Sheikh & Gaikwad (2020) explored similar IoT architectures using various sensors (PIR, vibration) to detect unauthorized access. Their work validates the technical feasibility of using sensor fusion for accurate intrusion detection.

IV. POSITIONING OF OUR WORK

The "Anti Bike Theft System using ESP32" project builds directly upon the principles established in these IoT-based studies but makes distinct contributions:

Cost-Effectiveness vs. GSM Systems: Unlike systems relying on GSM modules with recurring costs, our solution utilizes ubiquitous Wi-Fi connectivity and the free tier of the Blynk cloud, making it more accessible to the average user.

Simplicity and Reliability: While some related works incorporate complex sensor arrays, our prototype focuses on a robust, two-factor authentication logic (Hidden Switch + Key Switch) that minimizes false alarms and is easy to replicate.

Dual-Layer Response Model: Our system emphasizes a combined response of a local deterrent (buzzer) and a remote alert (mobile notification), a practical approach that addresses both immediate threat scaring and owner awareness.

Prototype Clarity: This project serves as a clear, educational blueprint for implementing a functional IoT security system, using a DC motor to simulate the engine, which is beneficial for demonstration and understanding.

Technique: The ESP32 runs a programmed logic algorithm (e.g., if (Hidden Switch == HIGH && Key Switch == HIGH)). This simple yet effective conditional logic is the "brain" of the system, distinguishing between authorized and unauthorized access attempts.

Purpose: To make real-time decisions based on sensor inputs, triggering alerts only under specific, unauthorized conditions.

IoT Communication Protocol:

Technique: The system uses the MQTT protocol, abstracted through the Blynk library, to establish a lightweight and efficient communication channel between the ESP32 and the Blynk cloud server over Wi-Fi. Data (like alert triggers) is sent to "virtual pins" on the cloud.

Purpose: To enable reliable, low-latency transmission of theft alerts to the cloud for subsequent push notification to the user's smartphone.

Actuator Control for Deterrence and Simulation:
Technique: The ESP32's GPIO pins are used as digital outputs to control actuators. It provides a HIGH signal to a transistor or relay to power the buzzer and the DC motor.
Purpose: To execute physical responses creating an audible alarm and simulating engine ignition based on the logic processor's decision.

Power Management Technique:
Technique: Utilizing the ESP32's deep sleep modes to significantly reduce power consumption when the vehicle is parked and the system is idle, waking up upon a change in sensor state (e.g., vibration).
Purpose: To enhance the system's longevity and make it suitable for battery-operated scenarios.

Challenges Faced and Mitigations
Challenge: False Alarm Minimization
Description: Initial designs risked triggering alarms from benign vibrations (like wind or a passing vehicle) or accidental key turns, leading to user annoyance and reduced system credibility.
Mitigation: The two-factor authentication logic (requiring BOTH the hidden switch to be armed AND the key to be turned) was implemented. This ensures the alarm only triggers during a clear, unauthorized start attempt, not just any motion.

Challenge: Network Dependency and Reliability
Description: The system's remote alerting capability is entirely dependent on the availability of a Wi-Fi network. If the bike is stolen from an area without Wi-Fi, the push notification will fail.
Mitigation: The system incorporates a dual-layer response: the local buzzer alarm still functions independently of Wi-Fi. For future work, a hybrid GSM/Wi-Fi module is proposed as an enhancement for areas without Wi-Fi coverage.

Challenge: Power Consumption for Always-On Systems
Description: An always-active system with Wi-Fi connectivity can drain a bike's battery quickly, especially when parked for extended periods.
Mitigation: The use of the ESP32's deep sleep mode was a key strategy. The system is designed to consume minimal power while monitoring, waking up fully only when an event is detected. The prototype also uses a dedicated 5V adapter for stable testing.

Challenge: Hardware Robustness and Real-World Deployment
Description: Prototype components on a breadboard are fragile and not suitable for the vibrations, moisture, and temperature variations experienced by a motorcycle.
Mitigation: For a production-ready version, the system would need to be soldered onto a PCB and housed in a rugged, waterproof enclosure. All wiring would need to be securely fastened and insulated.

Challenge: System Security Itself
Description: An anti-theft system itself can be a target. A thief could attempt to disconnect power or tamper with the device.
Mitigation: The use of a hidden toggle switch makes it difficult for a thief to know the system is present or how to disarm it. The device must be physically installed in a concealed and inaccessible location on the bike.

V. METHODOLOGIES

Requirement Analysis and Planning
This initial phase focused on defining the project's scope and specifications based on the identified problem.
Problem Identification: The high rate of two-wheeler thefts and the inadequacy of traditional security systems were established as the core problem.
Stakeholder Analysis: Primary stakeholders (bike owners) and their core needs (real-time alerts, low cost, reliability) were identified.
Functional and Non-Functional Requirements Elicitation:
o Functional: The system must detect unauthorized ignition, trigger a local buzzer, and send a push notification. o Non-Functional: The system must be cost-effective, energy-efficient, and have a low response time.
Component Selection: Based on the requirements, components like the ESP32 (for Wi-Fi and processing), a 5V buzzer, and a key switch were selected for their affordability and suitability.
Phase 2: System Design
This phase involved creating the architectural blueprint for both the hardware and software components.
Hardware Design:

Circuit Design: A circuit schematic was designed using software like Fritzing. This diagram detailed the connections between the ESP32, key switch, hidden toggle switch, buzzer, and DC motor.
Power Planning: A 5V, 2A power adapter was chosen to adequately power the ESP32 and the actuators (motor and buzzer) simultaneously.
Form Factor Consideration: The layout was designed to be compact, with a focus on making the hidden switch easily concealable.
Software and Logic Design:
Algorithm Development: The core logic was flowcharted: IF (Hidden_Switch == ARMED && Key_Switch == ON) THEN Trigger (Buzzer, Notification).
Platform Selection: The Arduino IDE was chosen for programming the ESP32 due to its extensive library support and ease of use. The Blynk IoT platform was selected for cloud communication and mobile alerts.
Data Flow Design: The sequence of data was mapped: Sensor Input → ESP32 Processing → Cloud Communication → Mobile App Output.
Phase 3: Implementation (Prototyping)
This phase involved the physical assembly and coding of the system.
Hardware Implementation: o Circuit Assembly: All selected components were assembled on a breadboard according to the designed circuit diagram for easy testing and modification.
Connection Integrity Check: All connections were meticulously checked for short circuits and
correct voltage levels to prevent damage to the ESP32.
• Software Implementation:
Firmware Development: Code was written in the Arduino IDE using C++. Key tasks included:
Including necessary libraries (WiFi.h, BlynkSimpleEsp32.h).
Configuring GPIO pins as inputs (switches) and outputs (buzzer, motor control).
System Integration: The firmware was uploaded to the ESP32, and the hardware was powered on, uniting the software logic with the physical components.
Structured Testing: A comprehensive test plan was executed with multiple test cases (as detailed in the report's Chapter 7). This included:
o Functional Testing: Verifying that the buzzer sounds and the Blynk notification is sent only when the hidden switch is armed and the key is turned. o Negative Testing: Ensuring no false alarms are triggered when the system is disarmed. o Network Testing: Checking system behavior with unstable Wi-Fi connectivity.
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• Iterative Debugging: Issues identified during testing (e.g., code syntax errors, faulty connections) were rectified in an iterative manner. The Serial Monitor in the Arduino IDE was instrumental in debugging by printing real-time status of the switches and Wi-Fi connection.

VI. MISCELLANEOUS

1. Project Viability and Scalability
Cost-Effectiveness: The prototype was built using low-cost, readily available components (ESP32, basic sensors, buzzer), demonstrating that the core system can be produced at a fraction of the cost of commercial GPS trackers.
Scalability: The system's architecture is highly scalable. The ESP32's multiple GPIO pins and processing power allow for the easy integration of additional sensors (e.g., GPS, camera, fingerprint scanner) as outlined in the "Future Enhancements" section. The Blynk platform can also be scaled to manage multiple devices.
Adaptability: While designed for two-wheelers, the core logic of the system can be adapted for other applications, such as securing bicycles, car accessories, or even as a general-purpose intrusion alarm for garages or storage units.

2. Societal and Environmental Impact
Crime Deterrence: By providing an accessible and effective security solution, the project has the potential to contribute to lower two-wheeler theft rates, offering greater peace of mind to vehicle owners.
Promoting IoT Awareness: This project serves as a practical demonstration of how IoT technology can be

leveraged to solve everyday problems, potentially inspiring wider adoption and innovation in smart security solutions.
Environmental Consideration: The system is designed for low power consumption. The use of deep sleep modes minimizes its energy footprint, and the components are typical of small-scale electronics, with no special environmental hazards.

3. Educational Value
This project proved to be an excellent interdisciplinary learning tool, integrating key concepts from:
Computer Science: Embedded systems programming (C++ in Arduino IDE), algorithm design, and IoT cloud communication.
Electronics Engineering: Circuit design and analysis, sensor interfacing, actuator control (buzzer, motor), and power management.

4. Observed Limitations in Prototype Phase
Wi-Fi Dependency: The current prototype's remote notification feature is entirely dependent on the presence of a pre-configured Wi-Fi network, limiting its use in remote areas.
Physical Robustness: The breadboard-based prototype is not vibration-resistant or weatherproof, making it unsuitable for direct deployment on a vehicle without a custom-designed PCB and enclosure.
Power Source: For long-term parking, the system would require integration with the vehicle's battery with proper power isolation to prevent drainage, or a dedicated, rechargeable battery pack.

5. Key Lessons Learned
Simplicity is Key: A simple, well-executed logic (the two-switch authentication) can be more reliable than a complex one prone to false triggers.
Testing is Crucial: Rigorous testing under various scenarios (network drop, power fluctuation, sensor tampering) is essential to identify and rectify unforeseen flaws.
Documentation Matters: Maintaining clear documentation throughout the project from circuit diagrams to code comments proved invaluable for debugging and future development.
Analysis of Achieved Objectives
Objective: Detect Unauthorized Access.
o Analysis: SUCCESSFUL. The core logic of using a two-factor authentication (Hidden Switch + Key Switch) proved to be a simple yet highly effective method for detecting unauthorized ignition attempts. The system reliably distinguishes between normal use and a theft scenario.
Objective: Alert the Owner.
Analysis: SUCCESSFUL. The system's dual-layer alert mechanism functions as intended.
The local buzzer provides an immediate on-site deterrent, while the integration with the Blynk IoT platform ensures real-time push notifications are sent to the owner's smartphone, achieving the goal of remote awareness.
• Objective: Low-Cost and User-Friendly Design.
Analysis: SUCCESSFUL. By utilizing the affordable ESP32 and free-tier Blynk services, the project demonstrates a significant cost advantage over commercial GPS trackers. The operational logic is straightforward for the end-user (arm with a hidden switch, receive alerts on phone), meeting the usability requirement.
Performance Analysis of the Implemented System
Response Time: The system exhibits minimal latency between the detection of an
unauthorized key turn and the activation of the buzzer (near-instantaneous). The cloud-to-app notification delay via Blynk is typically between 2-5 seconds, which is acceptable for a realtime alert system.
Reliability: The system logic is highly reliable within its defined scope (Wi-Fi coverage). It
consistently triggers only under the correct conditions, minimizing false positives, which is a critical factor for user trust.
Power Efficiency: While the prototype was powered by a stable adapter, the successful
implementation of the ESP32's deep sleep mode in the code structure shows a clear path to high power efficiency for battery-operated deployment, aligning with non-functional requirements.
Critical Analysis of Limitations and Design Choices
Wi-Fi Dependency: The most significant limitation is the system's reliance on a Wi-Fi
network for its remote alerting feature. This restricts its use to areas with known Wi-Fi coverage (e.g., a home garage) and renders the remote alert feature useless if the bike is stolen from a public place without a pre-configured network. A hybrid GSM/Wi-Fi module would be a necessary upgrade for universal coverage.
Hardware Prototype vs. Real-World Deployment: The use of a breadboard and jumper

wires for prototyping is appropriate for development but highlights a gap between the prototype and a market-ready product. A real-world version would require a soldered PCB, a rugged and waterproof enclosure, and more robust connectors to withstand vibration and weather.

Scope of Detection: The current system detects theft only at the "ignition" stage. It does not
detect other forms of theft, such as lifting the bike into a truck. The addition of an accelerometer or tilt sensor, as suggested in the design, would be required to address this vulnerability.

Component Choice: The use of a 5V DC motor to simulate the engine is excellent for
demonstration but is not a real security mechanism. A future iteration should replace this with a relay-based engine immobilizer, which would physically prevent the bike from starting, adding a powerful layer of security.

Conclusion of the Analysis

In conclusion, the "Anti Bike Theft System Using ESP32" project can be deemed a
resounding success as a proof-of-concept and a functional prototype. It effectively demonstrates the practical application of IoT to solve a real-world problem, successfully meeting its core objectives of detection, alerting, and costeffectiveness.

The analysis confirms that the chosen architecture—centered on the ESP32 and Blynk platform—is sound and effective. The primary limitations identified (Wi-Fi dependency, hardware robustness) are not failures of the concept but rather clear and addressable engineering challenges for the next iteration. The project lays a strong, scalable foundation upon which a commercially viable and highly effective product could be built with the integration of suggested future enhancements like GPS, GSM, and an engine immobilizer.

VII. CONCLUSION

The "Anti Bike Theft System Using ESP32" project has successfully demonstrated the viability of applying Internet of Things (IoT) technology to create an effective, low-cost security solution for twowheelers. By addressing the critical gap between passive traditional locks and expensive commercial tracking systems, this project provides a pragmatic and accessible alternative for vehicle owners.

The system's core objective to detect unauthorized access and provide immediate local and remote alerts was fully achieved. The integration of the ESP32 microcontroller with the Blynk IoT platform formed a robust technological backbone, enabling real-time processing and reliable cloud communication. The use of a simple yet effective two-factor authentication logic (hidden switch + key ignition) ensured accurate theft detection while minimizing false alarms.

From a technical standpoint, the project effectively combined hardware and software components into a cohesive and functional prototype. The system proved to be not only operationally successful but also highlighted key advantages in cost-effectiveness, user-friendliness, and scalability. The modular design and straightforward code structure make it an excellent foundation for further development and enhancement. While the project identified certain limitations, primarily its dependency on Wi-Fi connectivity, these challenges also present clear pathways for future improvement. The proposed enhancements, such as GPS tracking, GSM integration, and engine immobilization, outline a compelling roadmap for transforming this prototype into a comprehensive commercial product.

In essence, this project stands as a testament to how modern microcontroller platforms and IoT ecosystems can be leveraged to develop smart, responsive, and affordable solutions to everyday problems. It underscores the potential of embedded systems and cloud connectivity in enhancing personal security and serves as a valuable model for future innovations in the field of IoT-based safety devices.

VIII. ACKNOWLEDGEMENT

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We wish to acknowledge the authors and researchers of the various IEEE papers and technical books cited in our bibliography. Their scholarly work provided us with critical insights and a broader perspective on the subject, helping us to refine our own system design and implementation.
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