ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Bike Alert

Bike Lock with Real-Time Security Monitoring

Team 36

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Introduction

Problem

Bicycle theft is a significant concern in the Champaign-Urbana area, particularly on the University of Illinois campus. Between August 1 and November 13, 2023, 85 bike thefts were reported, up from 69 during the same period in the previous year. Since January 2022, a total of 255 thefts have been reported [1]. Traditional bike locks offer physical security but lack mechanisms to alert owners during theft attempts, leaving bicycles vulnerable to undetected tampering. This gap highlights the need for an enhanced security solution that not only deters theft but also provides real-time notifications to bike owners.

Solution

The Bike Alert system is an advanced security attachment designed to augment standard bike locks with real-time monitoring and alerts. It integrates multiple tamper-detection mechanisms, including Hall-effect sensors to monitor lock engagement and enclosure integrity, and a spring-based adjustable vibration sensor to detect physical tampering. An ESP32 microcontroller processes sensor data and communicates alerts via ESP-NOW and then to a mobile app, providing users with immediate notifications of potential theft attempts. Additionally, the system features an RFID-controlled lock as a secondary locking mechanism, enhancing security even if the primary lock is compromised. The device is battery-powered and rechargeable, ensuring long-lasting and reliable operation. By combining these features, the Bike Alert system offers a comprehensive solution to bicycle theft, addressing both prevention and timely owner awareness.

Visual Aid

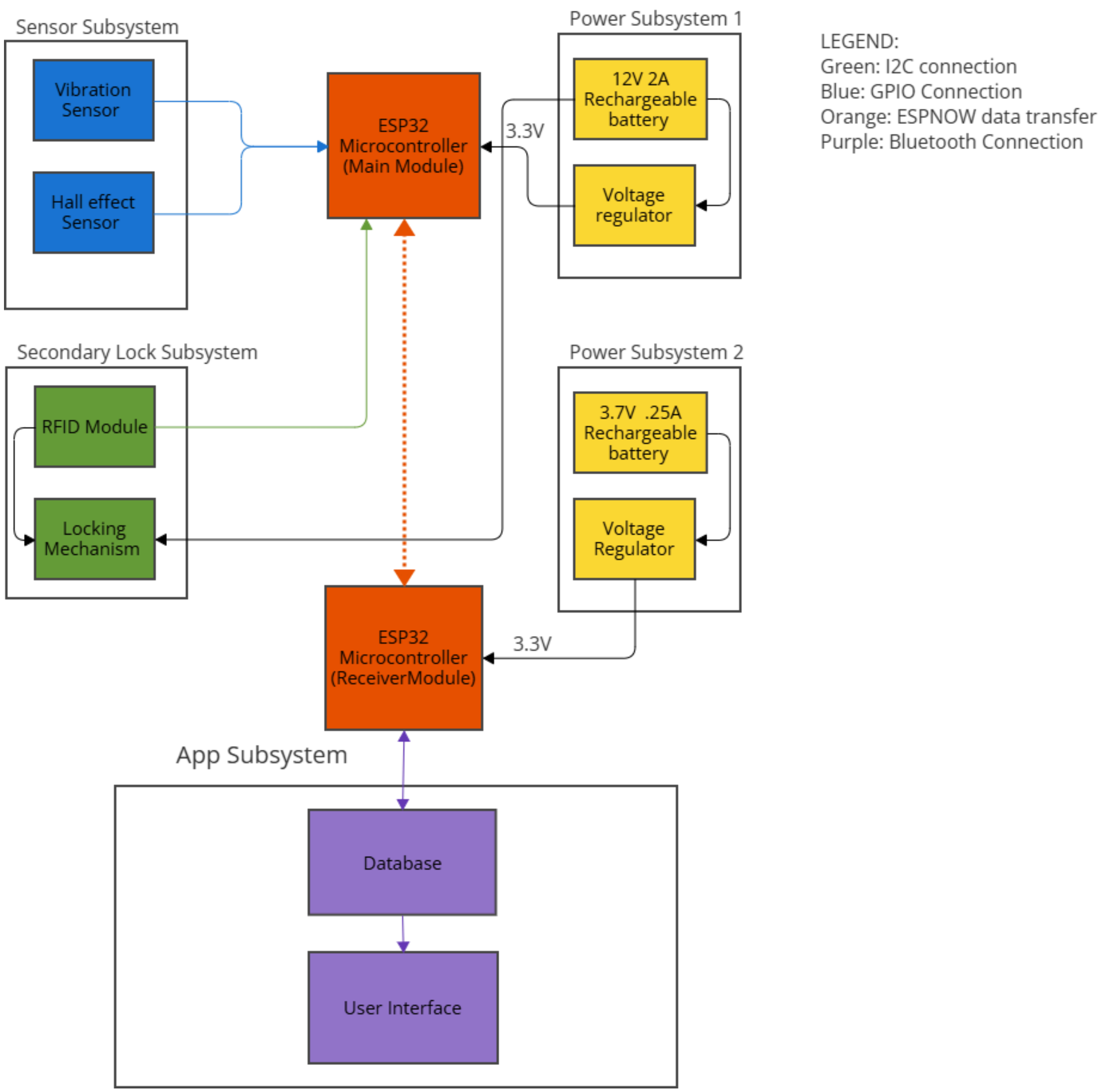
High-Level Requirements List

Our project has the following high-level requirements:

1. The system shall enable real-time communication between the bike lock and the user's mobile device via ESP-NOW, ensuring data transmission within 500 ms over a range of up to 200 meters between two ESP32 modules.
2. The system shall operate for at least 24 hours on a single charge using a rechargeable lithium-ion battery under typical usage conditions.
3. The system shall detect tampering via vibration and Hall-effect sensors, trigger an alert within 1 second, and prevent unauthorized access with an RFID-controlled lock.

Design

Block Diagram



Subsystem Overview

The Tampering & Lock Disengagement Detection Subsystem:

Monitors the lock for unauthorized access and physical tampering. It uses Hall-effect sensors to detect lock disengagement and enclosure breaches, along with a vibration sensor that registers physical disturbances. This subsystem directly communicates with the ESP32 to trigger real-time alerts.

The Power Subsystem

Provides stable voltage levels and ensures efficient energy management. A rechargeable 12V battery powers the motorized locking mechanism, while voltage regulators distribute the required power levels to other components. A secondary 3.7V battery supports the receiver ESP32 for continuous operation.

The Locking Subsystem

Enhances security by integrating an RFID-controlled motorized locking mechanism. The RFID module verifies authorized unlocking, and the ESP32 controls the motor/solenoid to engage or disengage the lock. This subsystem ensures that even if the primary bike lock is compromised, the secondary lock remains secure.

The Application Subsystem

Consists of the receiver ESP32, which processes alerts sent from the main lock ESP32 and relays them to the user. This subsystem ensures that notifications are delivered promptly to keep the owner informed of potential theft attempts.

Subsystem Requirements

Tampering & Lock Disengagement Detection Subsystem

- Function: Detects unauthorized access or tampering attempts using Hall-effect sensors and a vibration sensor. Communicates alerts via ESP32.
- Requirements:
  - Hall-effect sensors must detect changes in the magnetic field with a sensitivity threshold of ±5% [4].
  - The vibration sensor must distinguish between normal environmental vibrations and tampering
  - The ESP32 must process sensor data and transmit an alert via ESP-NOW within seconds of detection.

Power Subsystem

- Function: Supplies stable voltage to all system components and ensures continuous operation.
- Requirements:
  - The primary 12V battery must provide at least 500mA to power the motorized locking mechanism.
  - A 3.3V regulator must supply 500mA ± 0.1V for the ESP32 and sensors.

    - The secondary 3.7V battery must support continuous operation of the receiver ESP32.

Locking Subsystem

- Function: Provides an additional layer of security by integrating an RFID-controlled motorized locking mechanism.
- Requirements:
    - The RFID module must authenticate a valid tag within 500 ms [6].
    - The motorized lock must fully engage/disengage within seconds upon receiving an authenticated signal.
    - The solenoid/motor must operate within a 12V ± 5% range to ensure consistent locking performance [7].

Application Subsystem

- Function: Provide communication from the biking lock itself to a mobile device, allowing real time alerts
- Requirements:
    - One ESP-32 must act as a sender, using ESP-NOW Peers to send data to the receiver
    - Receiver ESP-32 must send data to the mobile application via bluetooth
    - Mobile App must be able to communicate with the ESP-32 and translate real time data into notifications

Tolerance Analysis

An aspect of the design that draws concerns is the ESP-NOW connections between the main ESP-32 connected to our bike lock subsystem, and our receiver ESP-32 that will be uploading the data to our mobile application. The main drawbacks of this have to do with long range connection between the two devices. We can test this by sending out periodic broadcast messages from our sender ESP-32 and checking how many packets are dropped and how many are received by our receiver ESP-32 and how many are uploaded successfully to the cloud. We can use this to calculate a suitable range on the bike lock.

A critical aspect of the Bike Alert design is ensuring that the power subsystem can reliably supply sufficient energy to all components while maintaining efficiency and longevity. The system must support a 12V 0.15A motor, an ESP32 microcontroller, an RFID module, Hall-effect sensors, and a vibration sensor, all running off a 12V lithium battery. The key concern is whether the battery capacity is adequate for daily operation, given typical usage conditions.

Power Consumption Breakdown

1. Motor (12V, 0.15A) [7].

- Operates for a maximum of 3 seconds per use, with an estimated 6 uses per day.
- Energy per use: $12V \times 0.15A \times 3s = 5.4J$
- Total daily energy: $5.4J \times 6 = 32.4J / 3600 = 0.009Wh$

2. ESP32 Microcontroller (3.3V, ~240mA average draw) [8].

- Always active.
- Power consumption: $3.3V \times 0.24A = 0.792W$
- Total daily energy: $0.792W \times 24h = 19.01Wh$

3. RFID Module (3.3V, 26mA) [6].

- Always active.
- Power consumption: 3.3V×0.026A=0.0858W
- Total daily energy: 0.0858W×24h=2.06Wh

4. Vibration Sensor (3.3V, 15mA) [5].

- Always active.
- Power consumption: 3.3V×0.015A=0.0495W
- Total daily energy: 0.0495W×24h=1.19Wh

5. Hall-Effect Sensors, Resistors etc.

- Power draw is negligible. Estimated contribution is minimal (~0.5Wh).

Battery Feasibility Analysis

12V 2.4Ah Battery

- Total capacity: 12V×2.4Ah=28.8Wh
- Total system energy requirement: 19.01Wh+2.06Wh+1.19Wh+0.5Wh+.009Wh=22.78Wh
- The 2.4Ah battery can sustain the system for over 24 hours, making it a good choice

By selecting the appropriate battery the Bike Alert system ensures reliable operation.

Ethics and Safety

The Bike Alert system must adhere to ethical and safety guidelines to ensure responsible development and usage. The project aligns with the IEEE Code of Ethics [2] by promoting user security and preventing theft without infringing on privacy. Ethical considerations include:

- Privacy Protection: The system does not store or transmit personally identifiable information, ensuring compliance with ethical data handling practices.
- Safety in Operation: The lock’s motor/solenoid mechanism must be designed to prevent accidental injury. Electrical components must be insulated to prevent short circuits or fire hazards.
- Regulatory Compliance: The system should comply with FCC regulations for wireless communication and battery safety standards such as UN 38.3 for lithium-ion batteries [3].
- Misuse Prevention: The system must prevent unauthorized access and ensure that only the rightful owner can disable the security features.

By addressing these ethical and safety considerations, the Bike Alert system ensures a secure, responsible, and effective solution to bicycle theft.

Works Cited

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