E-BIKE THEFT DETECTION SYSTEM

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Abstract

This project addresses the issue of bicycle theft, particularly in urban areas, by developing a Smart Bike Theft Detection System. The system utilizes a low-power microcontroller, motion and vibration sensors, and an electronic alarm to provide real-time monitoring and deterrence for e-bikes using an integrated sensing and alarm platform. Using a Finite State Machine (FSM), the system classifies the activity as idle, suspicious, or a confirmed theft attempt, triggering a loud alarm to deter theft and alert nearby pedestrians. The design incorporates a tamper detection subsystem with an accelerometer, gyroscope, and low-pass filtering to minimize false alarms. The system's performance was tested for detection accuracy, alarm effectiveness, and latency, with a focus on minimizing false positives. The results indicate a high detection accuracy of over 90%, quick alarm activation within 2 seconds, and a reliable alarm response, demonstrating the system's viability for real-world implementation in theft prevention.

Contents

1. Introduction

1.1 Problem

Bicycle theft is a widespread issue in both urban areas and suburban neighborhoods, resulting in significant financial losses for individuals and companies alike. Large, ride-sharing companies, such as Lyft, have frequently reported persistent rattling, shaking, or even brute force attacks on their Divvy bike fleets. While traditional mechanical locks work as a physical barrier to theft, they lack any real-time deterrence necessary to stop a thief once they try to steal a bike. Bikes are also most often stolen late at night when most people are asleep, which makes detection even more difficult.

This loss of a bike results in more than just property loss. From a global and environmental perspective, high theft rates act as a barrier to sustainable green transportation. Economically, the cost of replacing stolen units and repairing damaged docking stations forces companies to divert resources away from service expansion and maintenance, ultimately harming the consumer experience.

The attached article below shows a video in which excessive shaking and attempts to dislodge divvy bikes have been successful. While companies try to improve their mechanical locking systems, theft strategies will always change and improve after new designs are put out. Thieves will look to exploit these systems late at night when there is no public supervision and alarm systems to alert the public.

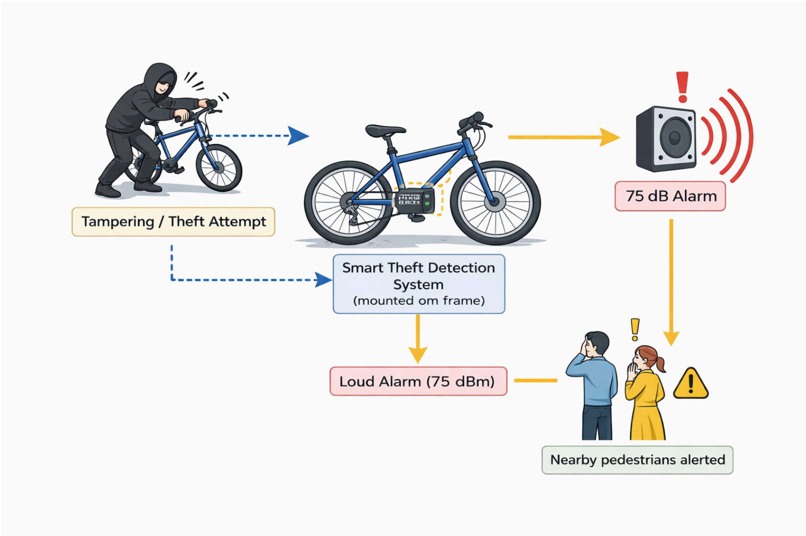
Divvy Responds to Video Showing Bike Methodically Dislodged From Docking Station – NBC Chicago

1.2 Solution

The proposed E-Bike Theft Detection System is an embedded solution designed to provide the real-time deterrence that mechanical locks lack. The system consists of a custom PCB featuring a microcontroller and an IMU to detect vibration, shaking, and rotation of the bike. By placing these sensors directly onto the bike frame, the system can detect the specific physical motion associated with theft.

The implementation relies on a Finite State Machine (FSM) that processes sensor data and categorizes it into three states: Idle, Suspicious, or Alarm. To prevent false positives caused by wind or pedestrians, the system utilizes a Digital Low-Pass Filter (DLPF) and looks at motion over a period of time by using Root Mean Square (RMS) energy calculations. When tampering activity is sustained for more than two seconds, the microcontroller triggers an alarm via a MOSFET driver. This alarm will then produce a 75dB siren to alert anyone that's nearby and deter the thief.

1.3 Visual Aid

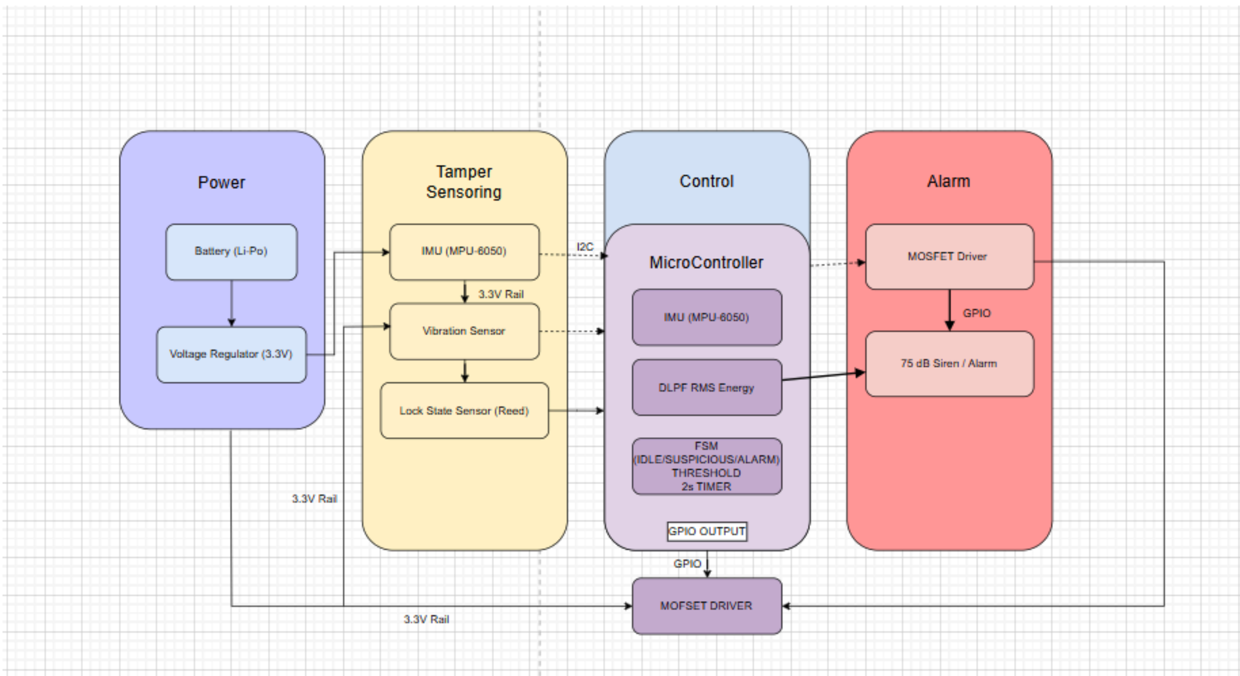


1.4 High Level Requirements

- **Tamper Detection Accuracy:**
  The system must correctly differentiate between normal environmental motion and tampering with at least 90% accuracy over 40 test trials, ensuring that the system reliably detects theft attempts without being triggered by common environmental movements like wind or minor bumps.
- **Detection Latency:**
  The system must transition from the armed state to the alarm state within 2 seconds of detecting sustained tampering activity, ensuring a rapid response to theft attempts.
- **Alarm Effectiveness:**
  When a confirmed theft attempt is detected, the system must trigger an alarm with a sound pressure level of at least 75dB measured at 1 meter from the bike, ensuring that nearby pedestrians are alerted and the thief is deterred.

2 Design

2.1 Block Diagram



2.2 Subsystem Overview and Requirements

2.2.1 Power Subsystem

This subsystem provides stable energy to the electronics. It takes the variable voltage from a Lithium-Polymer battery and regulates it down to a steady 3.3V. It connects to all other subsystems via power rails to ensure the sensors and MCU do not lose power during an alarm event.

Requirement: Must supply 3.3V ± 0.1V at a continuous current of at least 200mA.

2.2.2 Sensing Subsystem

This is the "eyes" of the system. It uses an IMU to monitor 3-axis acceleration and rotation. It is constantly powered and communicates with the Control Subsystem via the I2C protocol, sending raw motion data for analysis.

Requirement: Must support I2C communication and detect acceleration changes as small as 0.1g.

2.2.3 Control Subsystem

This is the "brain" of the device. It ingests data from the IMU, applies a digital low-pass filter to remove noise, and runs a Finite State Machine (FSM). It determines whether the bike is in an Idle, Suspicious, or Alarm state. It connects to the Sensing Subsystem via I2C and the Alarm Subsystem via a digital output pin.

Requirement: Must process the DLPF and FSM loop.

2.2.4 Alarm Subsystem

This is the "voice" of the system. This subsystem converts a low-power signal from the MCU into a high-power physical response. It uses a MOSFET to allow the battery to initiate a high-decibel siren. It is the final output of the design.

Requirement: Must produce a minimum of 75dB sound pressure level at a distance of one meter per siren. Must also be capable of 100% duty cycle (continuous sound) for at least 60 seconds.

2.3 Tolerance Analysis

The most critical risk to this project is the system's ability to distinguish between environmental noise (e.g., wind or a light bump) and theft (e.g., shaking or lifting). If the system is too sensitive, it will initiate false alarms; if it is not sensitive enough, it will fail its core function of theft detection and deterrence.

Signal Processing Methodology

The system utilizes an IMU to monitor 3-axis acceleration. To normalize this motion, the microcontroller first calculates the magnitude of the acceleration vector A_{mag}:

$$A_{mag} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

To prevent false triggers from momentary acceleration spikes, the system evaluates the Root Mean Square (RMS) energy over a short time window rather than triggering on a single data point. A Digital Low-Pass Filter (DLPF) is also applied to block background noise.

Quantitative Verification

The RMS energy E_{RMS} is calculated over a 100ms window (n samples) to isolate dynamic motion from gravity:

$$E_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(A_{mag,i} - 1g\right)^2}$$

Scenario Analysis:

- Environmental Noise Floor: Typical urban vibrations or wind movement produce small A_{mag} deviations (0.1g to 0.2g). In a 100ms window, these yield an E_{RMS} of approximately 0.13g.
- Theft Signature: Brute-force shaking or rattling typically produces sustained oscillations between 0.5g and 1.5g. This results in an E_{RMS} of 0.56g.
- Safety Margin: By setting the Suspicious State threshold at 0.25g, we can effectively filter out any background noise while ensuring that the system still correctly detects theft attempts.

Latency Confirmation

To meet the 2-second latency requirement, the Finite State Machine (FSM) requires sustained E_{RMS} readings above the threshold for a set number of consecutive windows. With a 100ms window, the system can perform 20 full evaluations within the 2-second limit. This would allow for more than enough data to detect a theft attempt.

3. Ethics, Safety, and Societal Impact

3.1 Ethical Considerations

We are committed to the IEEE mandate to "hold paramount the safety, health, and welfare of the public" (Section 1.1). This project directly supports public welfare by protecting personal property and supporting environment-friendly transportation. To avoid breaches related to noise pollution or public nuisance, the system is designed with RMS filtering to ensure the alarm is only triggered during legitimate theft attempts. Furthermore, in accordance with the ACM Code of Ethics, we have prioritized "avoiding harm" (Section 1.2) by ensuring the alarm system does not exceed decibel levels that could cause hearing damage to bystanders.

3.2 Safety and Regulatory Standards

The main safety concerns for this project come from the power subsystem as well as the alarm. We must ensure that the power subsystem sticks to 3.3V to prevent component failure or fire hazards. As such, we will adhere to battery safety standards. On the other hand, the alarm will be capped at around 75dB, which complies with common urban noise ordinances and OSHA standards. This will allow the alarm to be sufficiently loud to function as a deterrent without becoming a public health hazard.

3.3 Societal and Environmental Impact

The societal impact of this project revolves around creating a safer and more secure environment for both individuals and companies. This project aims to reduce bike theft, which would prevent property loss for individual owners. However, this project would also reduce the economic burden of theft on ride-sharing companies such as Lyft and Lime. These companies could then reduce rental fees or expand to increase usage. By reducing bike thefts, the e-bike theft detection system allows individuals to utilize more sustainable transportation systems. This would contribute to a greener environment with less emissions from other means of transportation such as cars and public transportation.

4 References

C. Farr, “Divvy Responds to Video Showing Bike Methodically Dislodged From Docking Station,” *NBC Chicago*, Jul. 24, 2018. https://www.nbcchicago.com/news/local/divvy-bike-theft-video/176532/ (accessed Feb. 13, 2026).

[1]IEEE, “IEEE Code of Ethics | IEEE,” *Ieee.org*, 2020. https://www.ieee.org/about/corporate/governance/p7-8 (accessed Feb. 13, 2026).