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# 1. Introduction

## 1.1 Problem

Cyclists in high-traffic environments, such as university campuses and urban centers, face a constant risk of collision with distracted or oblivious pedestrians. Currently, bicycle safety is reactive; a cyclist must manually identify a hazard, process the risk, and ring a bell, hoping the pedestrian reacts in time. This creates a high cognitive load for the rider and leaves zero margin for error. There is a critical need for a proactive, automated system that identifies hazards before they enter the cyclist's immediate path, allowing the rider to focus entirely on safe navigation.

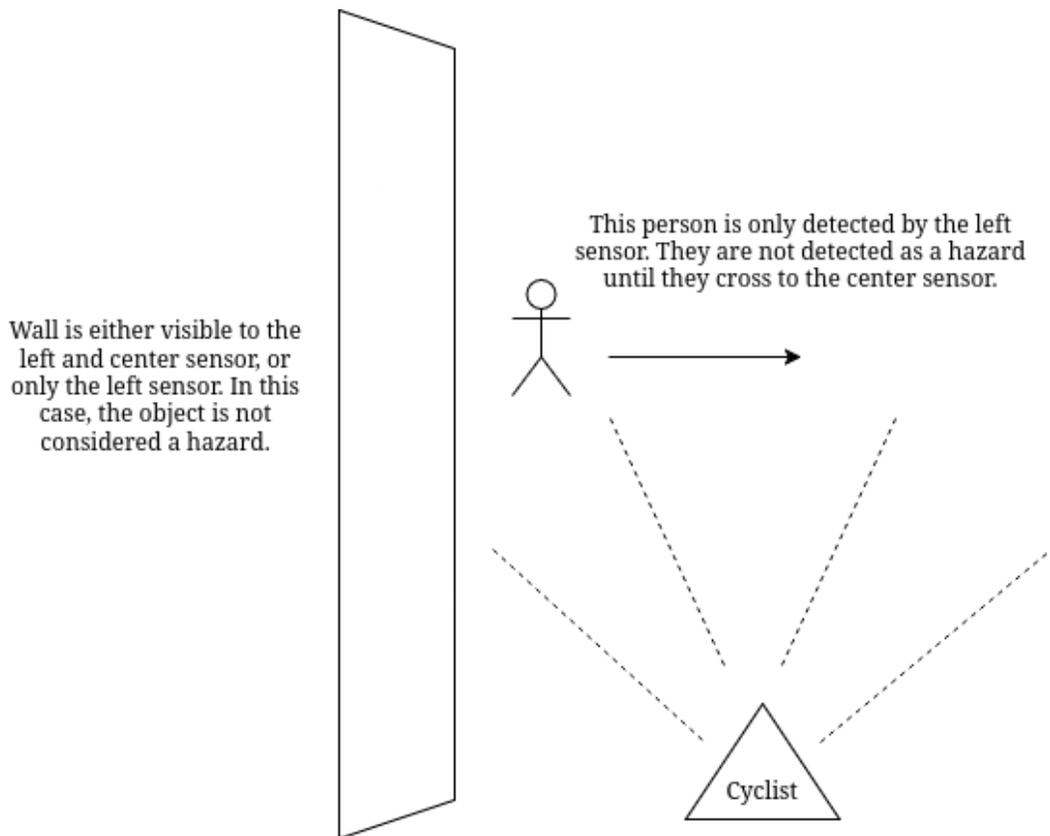
## 1.2 Solution

The Automatic Bike Collision Prevention System is an intelligent, handlebar-mounted safety suite that acts as a digital "peripheral vision" for the rider.

- **Goals:** The system aims to significantly reduce bicycle-pedestrian accidents by providing early-warning alerts, effectively removing human reaction time from the hazard detection phase.
- **Functions:** Using a triple-sensor mmWave radar array, the device continuously scans a 180° field of view. It employs spatial gating logic to track objects moving from the periphery into the forward path and uses a Time-To-Collision (TTC) algorithm to determine the urgency of an approaching hazard.
- **Benefits:**
  - **Reduced Cognitive Load:** The rider no longer needs to constantly scan for hidden side-street hazards.
  - **Increased Safety Margin:** Automated alerts provide the crucial extra half-second needed to brake or swerve.
- **Features:**
  - **Smart Peripheral Sensing:** Three HLK-LD2411S sensors for accurate distance tracking.
  - **Adaptive Alert System:** A three-stage audible alarm that increases in intensity as the collision risk grows.
  - **Customizable Sensitivity:** An on-board potentiometer allows riders to tune the detection threshold for quiet paths versus busy streets.
  - **Full Day Use:** Integrated 18650 power management provides 8+ hours of continuous safety on a single charge.

### 1.3 Visual Aid

Figure 1 Visual Aid



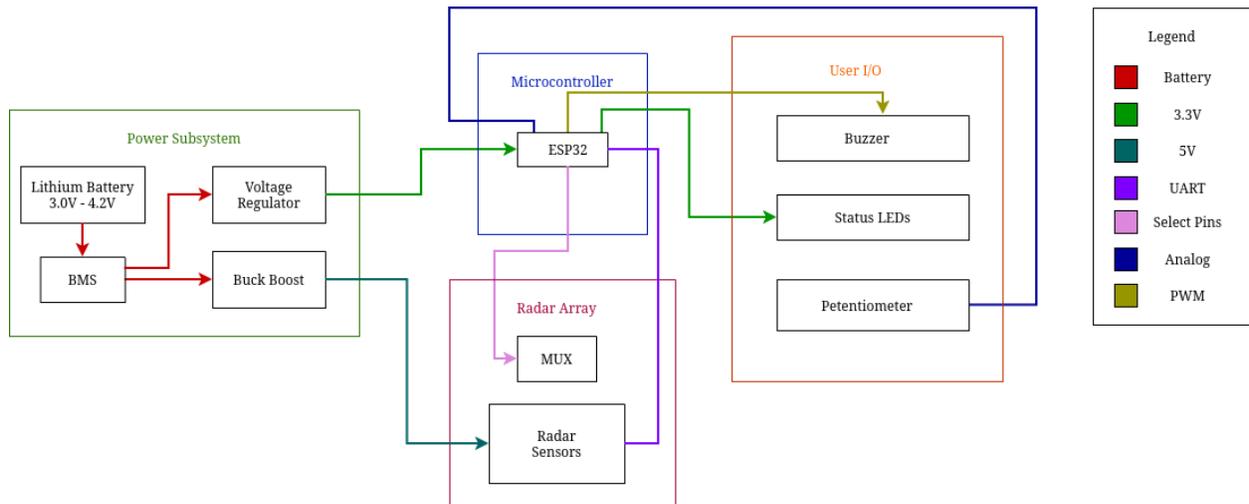
### 1.4 High Level Requirements

- The system must achieve a minimum 95% detection rate for moving hazards within a 5-meter range while maintaining a false-positive rate of less than 5% for static environmental objects like curbs or walls.
- The total elapsed time from the initial sensor detection of an object to the activation of the audible alert must not exceed 150 milliseconds to ensure the cyclist has sufficient time to react.
- The power management subsystem must provide a minimum of 8 hours of continuous operation on a single charge of the 18650 battery, ensuring the device remains active for a standard commuting or delivery shift.

## 2 Design

### 2.1 Block Diagram

Figure 2 Block Diagram



### 2.2 Power

The Power Subsystem provides regulated energy to all active components while ensuring battery safety. It utilizes a Li-ion 18650 Battery as the primary source, managed by a DW01A BMS to prevent overcharge and short-circuit conditions. A TPS63060 Buck-Boost Converter regulates the varying battery voltage to a stable 5V rail for the radar sensors and buzzer, while a dedicated 3.3V AMS1117 LDO provides low-noise power to the ESP32 Microcontroller.

#### 2.2.1 Power Requirements

The system must maintain a stable  $5V \pm 0.2V$  output to the radar sensors, and the BMS must disconnect the battery if current draw exceeds 1.5A.

### 2.3 Radar Array

The Radar Array will serve as the data collection part of the systems, communicating with the microcontroller using UART. To achieve a 120 degree detection radius ahead of the rider, three HLK-LD2411-S 24GHz mmWave Radar Modules system will be utilized. With shielding, each radar will offer a 60 degree detection radius, so a singular forward facing detector along with two more detectors 30 degrees right and left will create a system capable of 120 degrees of detection [1].

#### 2.4.1 Radar Array Requirements

The radar detectors used in the system must achieve a range up to 5 meters, and cover a 60 degree detection angle. Critically the radars must reliably be able to detect humans within the detection zone. The sensors are required to operate on a 5V power supply while maintaining a compact form so as to not

distract the rider. The radars must be able to communicate data using UART to the Microcontroller system [1].

## 2.4 Microcontroller

The ESP32 will be used as the central processing unit of the system, processing data collected from the Radar sensors. The microcontroller will send and receive controlled signals to the different LEDs, sound devices, and potentiometer.

Given the variety of environments this project will encounter, the Microcontroller must be capable of functioning reliably in a wide temperature range. Additionally the system's limited battery power makes the microcontroller power usage another decisive factor due to its low power consumption [2].

### 2.4.1 Microcontroller Requirements

The TTC algorithm must calculate and update the hazard status within 20ms of receiving a UART packet.

## 2.5 User I/O

The User I/O Subsystem translates detections into alerts for the user. It includes a PS1240 Piezo Buzzer for audible warnings and Status LEDs for visual system feedback. This subsystem connects to the Processing Subsystem via output pins and also provides an input for the rider to adjust system sensitivity via the potentiometer.

### 2.5.1 User I/O Requirements

The PS1240 must maintain an output of 75dB at 1 meter to remain audible over ambient traffic noise [3].

## 2.4 Tolerance Analysis

The greatest difficulty lies in the UART synchronization required to multiplex three HLK-LD2411S sensors through a single MUX. Because the ESP32 must switch between sensors at a rate compatible with their 20Hz reporting frequency, even a minor timing jitter can lead to corrupted data packets [1]. Maintaining a total system latency of <150ms is essential to satisfy high-level safety requirements, as any delay beyond this threshold significantly reduces the rider's available braking distance during a high-speed approach. We should aim to have no more than 10% packet loss, as continuously missed packets would require more detection, which would lead to 50+ ms of delay each loss.

## 3. Ethics, Safety, and Societal Impact

The primary contribution is the reduction of physical trauma resulting from bicycle-pedestrian accidents. By providing a proactive alert, the system creates a larger safety margin, potentially reducing the burden on emergency medical services and improving long-term health outcomes for commuters. Collisions carry significant economic weight, including medical expenses, property damage, and potential legal liabilities. This device offers an affordable, low-cost safety upgrade for existing bicycles, making advanced safety technology accessible to students and low-income commuters without requiring the purchase of an expensive e-bike.

This project is designed in strict accordance with IEEE Code of Ethics 1.1, which mandates holding the safety and privacy of the public paramount [4]. A significant ethical consideration for this project is the

potential for automation complacency and risk compensation. There is a risk that cyclists, knowing that they have an automated alarm, may become less vigilant or more likely to engage in distracted riding. To mitigate this, the system is designed as a secondary aid rather than a primary safety measure. The multi-stage alert system is tuned to provide a "safety buffer" that prompts the user to re-engage with their surroundings, ensuring that the technology complements, rather than replaces, rider awareness. Additionally, the use of mmWave radars, as opposed to cameras, ensure that the privacy of the rider and pedestrians is maintained, and all data is processed locally on board in real time, with no capturing of identifiable information, eliminating risks associated with data storage or third-party transmission.

To ensure the physical safety of the end-user, this project adheres to UL 1642 standards regarding the integration of the 18650 Lithium-ion battery. Compliance with this standard ensures that the power source has undergone rigorous testing against thermal runaway and mechanical failure [5], [6].

The development and operation of this system present low inherent risk, provided standard laboratory and electrical safety protocols are maintained. The primary safety concerns are centered on the high energy density of the Lithium-ion battery and the mechanical integrity of the handlebar mount. To mitigate risks of thermal runaway or fire, the power subsystem utilizes the battery management system that monitors the 18650 cell in real-time. It provides hardware-level protection against overcharging, over-discharging, and external short circuits, ensuring the device remains stable during both charging and high-vibration operation.

## References

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