PTSD: Pothole Tracking, Sizing and Detection

By: John Billeci, Travis Grant, Jose Kostyun, Brandon Skervin, Samuel Welch

Motivation

- Potholes create serious safety risks for drivers and pedestrians, leading to accidents, injuries, and costly vehicle damage.

- They place a heavy financial burden on cities and drivers, with repair costs rising the longer potholes go unaddressed.

- Current detection methods are slow and inconsistent, often relying on manual surveys or resident complaints.

- Existing automated solutions require expensive equipment and specialized vehicles, making them accessible only to major cities with large budgets.

- There is a need for a more affordable, reliable, and scalable approach to identifying and tracking potholes in real time.

Goals

- Achieve >95% detection accuracy for potholes larger than 4 inches using the laser line and IR camera.

- Achieve an 8–10-foot detection coverage, allowing the system to scan the majority of a traffic lane in real time.

- Provide reliable measurements of pothole length, width, and depth with low error margins.

- Maintain affordability, keeping the full system cost under $1,200.

- Ensure durability and resilience, with weatherproofing, vibration damping, and protection against real-world conditions.

- Enable timestamped recording of each pothole detection for mapping and later analysis.

- Deliver RGB images alongside measurements, providing visual confirmation of potholes.

- Reduce false positives by integrating AI-based classification and verification.

- Create a modular design that can be adapted for improvements or future upgrades.

- Support universal deployment, with a custom mounting solution compatible with nearly any vehicle.

Objectives

- Use a laser line with IR camera to detect disturbances in the road surface.

- Apply optical filtering techniques to reduce noise and isolate the laser signal.

- Capture RGB images of detected potholes for confirmation and measurement.

- Develop a mobile application for viewing pothole data, images, and timestamps.

- Design universal mounting hardware adjustable for deployment on most vehicles.

- Implement Bluetooth communication to send detections and images to a phone.

- Incorporate AI-based verification to minimize false positives.

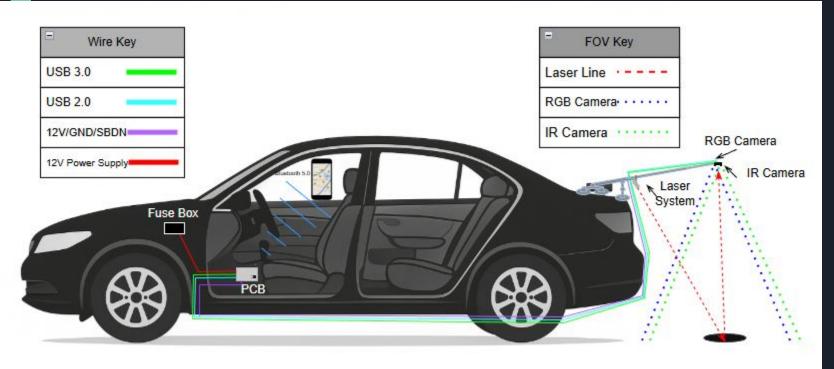- Protect all electronics with weatherproof, vibration-damped housing.

Specifications

Parameters	Specifications	Priority
Operating Temperature	0°C to 48°C	High
Pothole Location Accuracy	Within 20 feet	High
Power Consumption	12 V	High
Cost	< $1,000	Low
Length of Laser Line Coverage	6ft	High
Pothole Size Detection	Recognize potholes at least 4 inches in diameter	High
Laser System Weight	< 5 lbs	Medium

System specifications outlining performance requirements. Highlighted are the specifications that we deemed the most important.
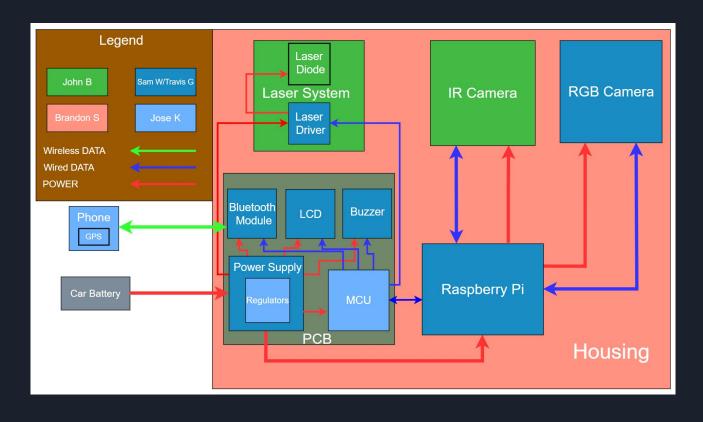
Overall Schematic

Hardware Block Diagram

Electrical Hardware Main Objectives

SBC (single-board computer)

- Process images received from IR laser, IR camera, and RGB camera

Power Source

- Must be able to supply components and peripherals with enough voltage and current

Regulators

- Must step-down voltages in order to supply the correct voltages and currents to components and peripherals

Bluetooth Module

- Allow communication between device and cellular application.

LCD Screen

- Display pothole detection with pothole size.

Buzzer

- Alert user of a pothole being detected.

Electrical Hardware: SBC Selection

Criteria	Raspberry Pi 5	BeagleBone AI-64
Main CPU	Quad-core 64-bit ARM Cortex-A76	Dual Cortex-A72
Frequency	2.4 GHz	2.0 GHz
AI/Vision Accelerators	VideoCore VII GPU at 800 MHz	C71x DSP, C66x DSPs, and MMa up to 8 TOPS
Interfaces	PCIe 2.0 x1, USB 3.0 x2, GbE, microSD	PCIe Gen3 x4, USB 3.0, GbE, dual CAN, PRU ICSS
Memory and Storage	LPDDR4X up to 16 GB	4 GB DDR4 + 16 GB eMMC
Power Consumption	Up to 6-7 W peak	Not Specified
Cost	~$80 (8 GB) - $132 (16 GB)	~$228
Overall	Excellent	Good

- This project requires processing power that our microcontroller can not handle on its own. This is why we chose to use an SBC, or single-board computer.
- Many criteria are met by both boards.
- We chose to use the Raspberry Pi, mainly for cost purposes.

Electrical Hardware: Device Power Source Selection

Criteria	Car Battery	Battery Pack
Runtime	Excellent	Fair
Cost	Excellent	Fair
Size and Weight	Excellent	Poor
Power Quality	Fair	Excellent
Portability	Poor	Good
PCB Design Complexity	Fair	Good
Overall	Good	Fair

Battery Pack

- If portability was an important specification to the design, this would be the clear choice

Car Battery

- Fits best with our design specifications

Electrical Hardware: Regulator Selection

Feature	LMR3360	LM2679
Max Output Current	3A	7A
Input Voltage Range	3.8V – 36V	8V – 40V
Output Voltage Range	Adjustable	Adjustable
Switching Frequency	400 kHz	260 kHz

LMR3360

LM2679

- LM 2679 met all design requirements
- Design Team chose LM2679

Electrical Hardware: Bluetooth Module Selection

Feature	BM71	u-blox NINA-B306-01B
Bluetooth Spec	BLE 5.0	BLE 5.x
Interface to MCU	UART + I2C + SPI	Full SDK Access
GPIO	9 GPIOs	High Number of GPIOs
Ease of Integration	Beginner	Industrial
Price	$7-$10	Higher Cost Tier

Microchip Technology

BM71

u-blox NINA-B306-01B

- BM71 was clear choice for project

Electrical Hardware: Buzzer Selection

Feature	Mallory Sonalert (ASI09N27MFD-03TRQ)	Same Sky (CMT-5023S-SMT-TR)
Rated Voltage	3 V	3 V
Sound Pressure	80 dB	80 dB
Current Draw	30 mA	100 mA
Price	Higher Cost	Lower Cost

- Both very comparable
- Due to current draw limits, the design team chose Mallory Sonalert

Electrical Hardware: GPS Module Selection

Feature	Adafruit Ultimate GPS	u-blox NEO-6M GPS Module
Chipset	MTK3339	u-blox NEO-6M
Fix Updated Rate	1-10 Hz	1-5 Hz
Cold Start Time	34 Seconds	27 Seconds
Position Accuracy	3 meters	2.5 meters
Voltage Input	3.3-5V	3.3-5V
Cost	$29	$15

- Adafruit more expensive but design team chose to go with higher quality module (Adafruit)

Electrical Hardware: Laser Driver Selection

Feature	ATLS500MA104D	ATLS1.5A104D
Max Output Current	500 mA	1.5A
Compliance Voltage	2.5-28 V	2.5-28 V
Control Type	Analog	Analog
Typical Use Case	Low-Power Diodes	High-Power Diodes
Efficiency	>90%	>90%

ATLS500MA104D

ATLS1.5A104D

ATLS500MA104D
S. #: A00108182015
Date: 08/18/2015

ATLS1.5A104D
S. #:A00108182017
Date:08/18/17

- Both drivers very similar
- Laser diode only requires 300 mA
- We chose ATLS500MA104D

Electrical Hardware: MCU Selection

Feature	MSP430FR6989	MSP430FR2355
Core	MSP430 (16-bit)	MSP430 (16-bit)
Clock Speed	16 MHz	24 MHz
FRAM	128 KB FRAM	32 KB FRAM
RAM	2 KB	4 KB
I/O Pins	100 pins	38 pins
Power Consumption	Ultra-Low	Ultra-Low
Best Use Case	Large MCU Applications	Low-Power Embedded Control

MSP430FR6989

MSP430FR2355
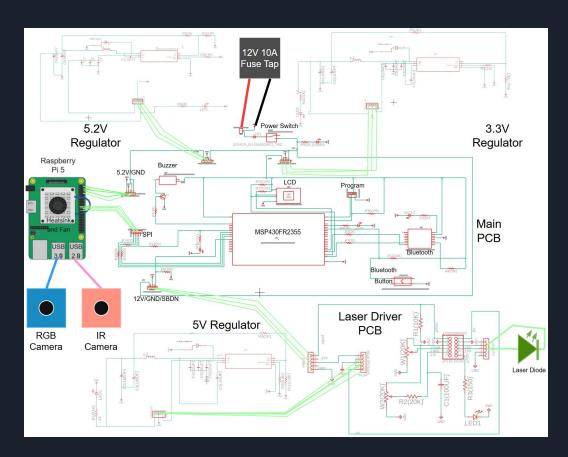
- Project does not require much from MCU
- Design team chose MSP430FR2355

Electrical Hardware: Overall Schematic

PCB Design Objectives

Main PCB

- Houses MCU, bluetooth module, LCD screen, buzzer, and supplies headers for regulators.

5V Regulator Board for Laser Driver

- Regulates voltage for separate laser driver board down to 5V.

3.3V Regulator Board

- Regulates voltages down to 3.3V for MCU, buzzer, Bluetooth module, and LCD screen.

Laser Driver PCB

- Due to the complexity of the laser driver and its components, we felt a separate board was appropriate.

5.2V Regulator Board

- Regulates voltage down to 5.2V for the Raspberry Pi SBC.
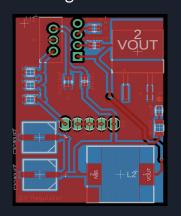
PCB Design Images

3.3V Regulator PCB
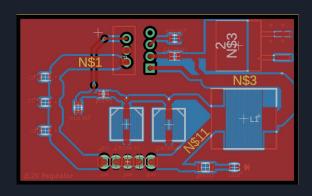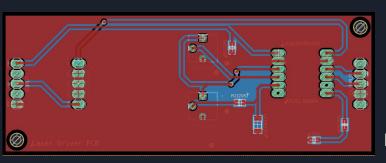
5V Regulator PCB

5.2V Regulator PCB
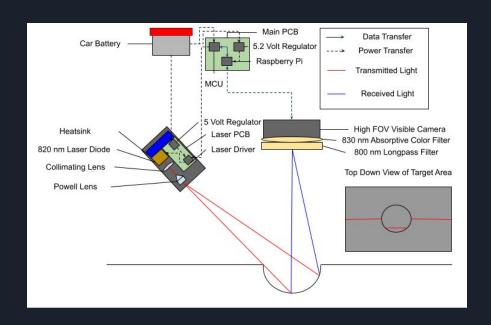
Main PCB

Laser Driver PCB

Optical Schematic

Optical Design
- Project a line of laser light on the road
- Laser is monitored for interruptions
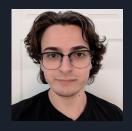- Interruptions are measured to calculate pothole depth and width

Laser Wavelength Selection

Criteria	Visible	Infrared
Safety	Good	Excellent
Cost	Excellent	Good

- Infrared light is invisible to the naked eye
- Drivers are likely to be distracted if they can see the beam
- Infrared light ensures a safer experience for civilians
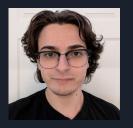
Line Generator Lens Selection

Criteria	Cylindrical	Powell
Beam Distribution	Gaussian	Uniform
Beam Profile	Slightly Elliptical	Near perfect line

- The line generator needs a fan angle of 90°
- A consistent beam is preferred
- The laser line should be as straight as possible

Laser Line Generator Design
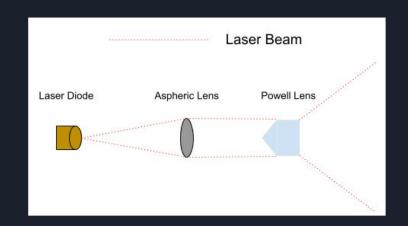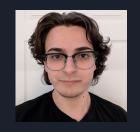
Laser Characteristics

- Input beam is collimated 1mm x 0.5mm
- Output power is 200 mW
- Aspheric lens reflects 5.02% 189.95 mW transmitted

Powell Lens Characteristics

- Powell lens fan angle is 90°
- Farther ends of the line have less intensity

Line Generator Output

- From 4 ft above the ground line is 8 ft across
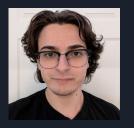- Laser power density: 9.74 W/m^2

Detection System Hardware Selection

Criteria	==Visible Light Camera==	NIR Camera
Cost	==Excellent==	Poor
Complexity	Good	==Excellent==

- Needs to work with near-infrared (NIR) light
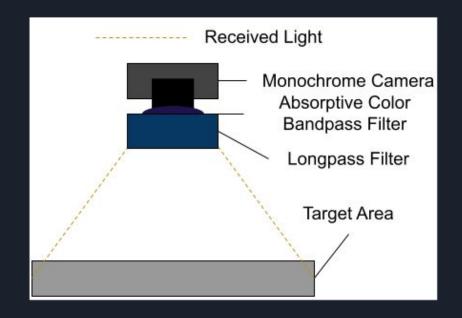- Must be cost effective

Detection System Design

Camera Characteristics
- Captures up to about 1000 nm
- Monochromatic limiting processing power
- 93° Horizontal FOV

Filter Characteristics
- Bandpass filter centered on laser wavelength to lower noise
- Longpass filter cutting out light under 800 nm

System Detection
- Captures about 8 ft from 4 ft above the ground
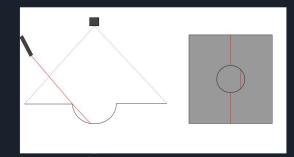- Nearly all sunlight is blocked out
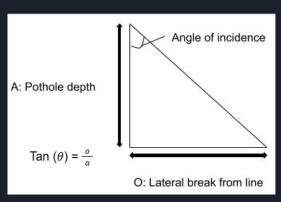
Full Optical System Operation

Hardware Operation
- 9.74 W/m^2 incident on the road
- Diffuse reflection off of asphalt is about 15% resulting in about 1.46 W/m^2 being reflected to the camera
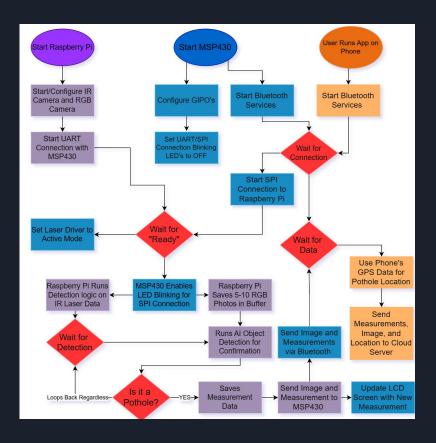
Detection Math
- Beam incident on the pothole travels farther laterally
- Distance between beam in pothole and the rest of the beam can be measured
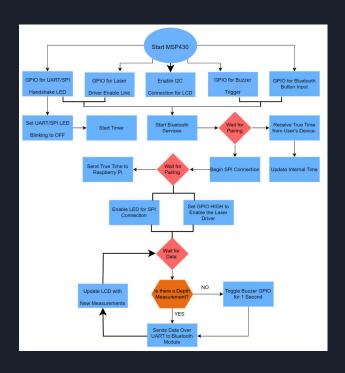- Trigonometry is used to measure the depth of the pothole

Angle of incidence

A: Pothole depth

$$\text{Tan}\ (\theta) = \frac{o}{a}$$

O: Lateral break from line

Software Flowchart
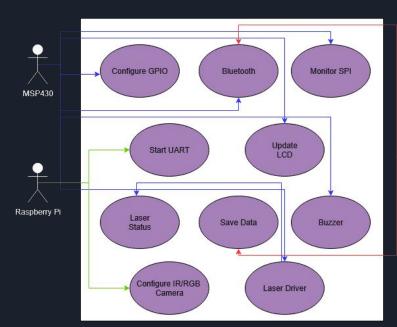
Embedded Software: Flowchart

- Sequential GPIO initialization for all peripheral devices

- Bluetooth pairing and real-time synchronization protocol

- SPI communication interface with Raspberry Pi

- Automated laser driver control and status indication

- Data validation with conditional buzzer alert system

- Continuous monitoring loop for pothole data processing

Embedded Software: Use Case

- Multi-protocol communication: SPI, UART, I2C, and Bluetooth
- MSP430, Raspberry Pi, and mobile device
- Real-time camera processing with YOLOv5 validation
- LCD display updates via I2C for local status monitoring
- GPS integration for precise pothole geolocation

Computer Vision: Objectives

- Detect potholes accurately and reliably

- Prevent duplicate detections

- Use the best frames with potholes fully in view (when possible)

- Measure pothole area and depth

- Differentiate potholes from other road features

- Provide an image of the pothole along with measurements for reporting

- Record each detection with an exact timestamp for GPS backtracking

Computer Vision: Involved Hardware

- Raspberry Pi 5

- Heatsink and Fan

- USB 2.0 IR Global Shutter Camera

- USB 3.0 RGB Global Shutter Camera

- 5.2V / Ground Wires Connected to Pins

- SCLK / MOSI / MISO / CS Wires for SPI Communication

Computer Vision: Object Detection Models

Criteria	YOLOv5	SSD300
Accuracy	Good–Excellent	Fair
Small Object Detection	Good	Poor
Hardware Demand	Fair-Good	Excellent
Speed	Good	Good
Training	Excellent	Poor
Ease of Implementation	Fair	Good
Multi-Scale Detection Support	Excellent	Fair
Community & Documentation	Excellent	Fair
Complexity	Fair	Good
Overall	Good	Fair
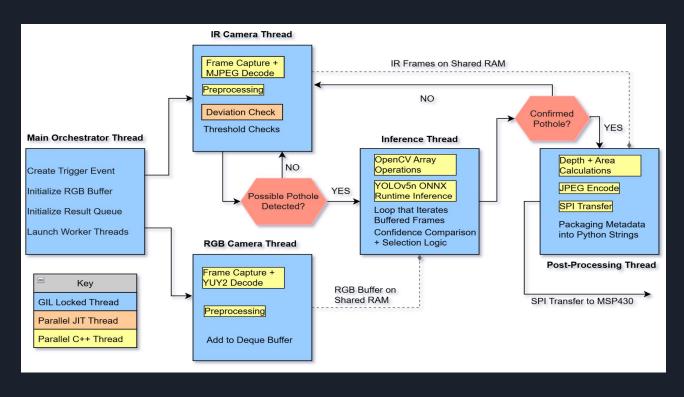
Computer Vision: Optimization Methods

| Criteria	PyTorch	ONNX	NCNN	PyTorch (INT8)	ONNX (INT8)	NCNN (INT8)
FPS	~1.5–2.5	~4-5	~7-10	~3-5	~8-10	~12-15
Accuracy Change	Baseline	Baseline	Baseline	~≤1% drop	~≤1–2% drop	~≤1% drop
Ease of Setup	Excellent	Good	Fair	Good	Fair	Poor
Memory Use	Poor	Fair-Good	Fair	Fair-Good	Excellent	Good - Excellent
Multicore	Poor	Good	Excellent	Fair	Good	Excellent
Overall	Poor-Fair	Good	Good	Fair-Good	Excellent	Excellent
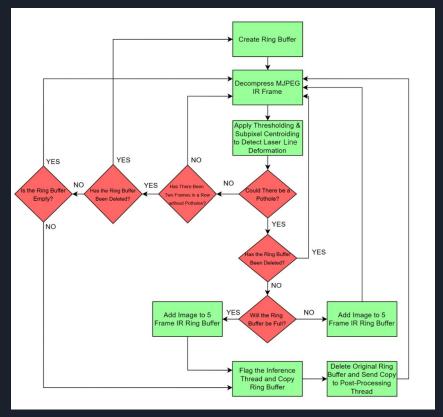
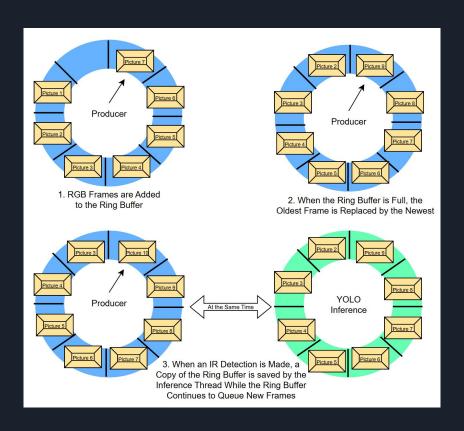# Computer Vision: High-Level Flowchart
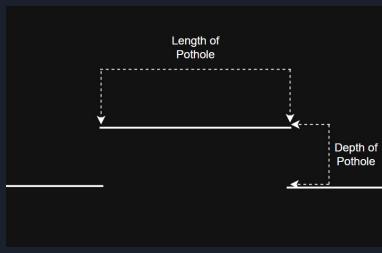
Computer Vision: IR Camera Thread
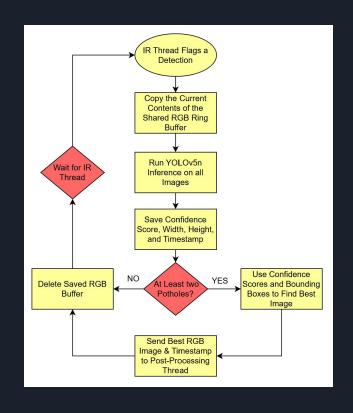
Computer Vision: RGB Camera Ring Buffer

1. RGB Frames are Added to the Ring Buffer

2. When the Ring Buffer is Full, the Oldest Frame is Replaced by the Newest

3. When an IR Detection is Made, a Copy of the Ring Buffer is saved by the Inference Thread While the Ring Buffer Continues to Queue New Frames

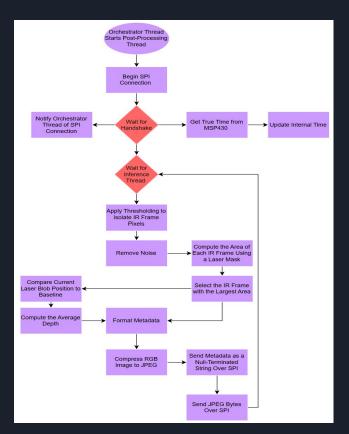# Computer Vision: Inference Thread
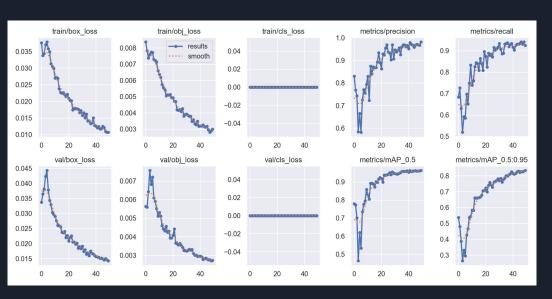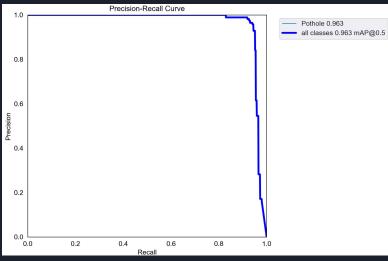
Computer Vision: Post-Processing Thread

- Responsible for SPI connection.

- Selects the IR frame with the largest area.

- Calculates horizontal and depth measurements using the IR laser line.

- Uses the vertical measurement of the RGB frame's bounding box.

- Calculates the approximate area.

- Sends area, depth, timestamp, and RGB image over SPI.

Computer Vision: Object Detection Training

Computer Vision: Object Detection Training

Mobile Application: Objectives

- Seamless Hardware Integration

- Intuitive User Experience

- Precise GPS Integration

- Robust Database Connectivity

- Interactive Map Visualization

Mobile Application: Development IDE

IDE/ Framework	Cross Platform Support	Language Used	Ease of Use	GPS Integration	Database Integration	Performance
Flutter	Yes	Dart	High	Easy via plugins	Easy (Firebase, SQLite, Hive)	High
Android Studio	No (Android only)	Kotlin/Java	Medium	Full native control	Flexible (Room, Firebase)	High
Xcode	No (iOS only)	Swift/Obj-C	Medium	Full native control	Comprehensive (Core Data, Firebase)	High
React Native	Yes	JavaScript	High	Moderate, may need bridging	Good (SQLite, Firebase)	Moderate
.NET MAUI	Yes	C#	Medium	Unified API abstraction	Good (SQLite, Azure, Firebase	Moderate

Mobile Application: Application Architectures

| Application Type	Definition	Common Technologies	Key Use Cases
Native App	Built for a specific OS using platform-native languages (e.g., Swift, Kotlin).	Swift, Kotlin, Objective-C, Java	High-performance apps needing full device access
Cross-Platform App	Single codebase compiled into native binaries for multiple platforms.	Flutter (Dart), React Native (JS), .NET MAUI (C#)	Apps for both iOS and Android with shared business logic
Hybrid App	Web technologies wrapped in a native shell (e.g., using Cordova or Ionic).	HTML, CSS, JavaScript + Cordova/Ionic	Quick deployment apps with moderate device access
Web App	Runs in a browser, not installed, relies on internet and browser capabilities.	HTML, CSS, JavaScript	Public info portals, basic tools, mobile-friendly websites
Progressive Web App (PWA)	Web app enhanced with offline support, push notifications, and installability.	HTML5, JS, Service Workers, Web Manifests	Offline-capable public service tools and interactive sites
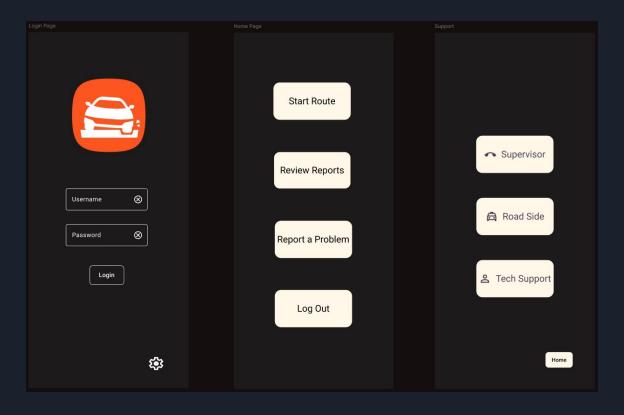
Mobile Application: Database Architecture

| Database	Type	Offline Capability	Geospatial Support	Image/ Binary Support	Scalability	Licensing	Mobile Use
MongoDB	NoSQL	Yes	Yes (2d/2dsphere)	Yes (GridFS)	Horizontal (Sharding)	Free /Paid	Yes
PostgreSQL	Relational (SQL)	Limited	Yes (PostGIS)	Yes (BLOBs/ URI)	Vertical/ Partitioned	Free	Limited
Oracle Database	Relational (SQL)	No	Yes (Spatial & Graph)	Yes (BFILE, SecureFiles)	Horizontal (RAC)	Paid	No
Microsoft SQL Server	Relational (SQL)	No	Yes (SQL Server Spatial)	Yes (BLOB, JSON)	Vertical/ Clustered	Paid	No
SQLite	Embedded Relational (SQL)	Yes (Native)	Limited (via SpatiaLite)	Yes (BLOB)	None (Single File)	Free	Yes
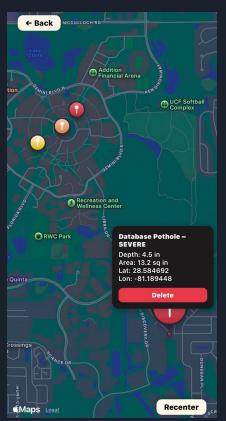
Mobile Application: User Interface
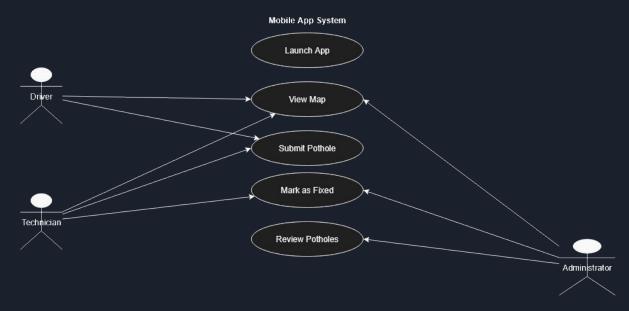
Mobile Application: GPS Integration

- Uses React Native Maps with the Apple Maps provider for smooth, native iOS map rendering.

- Displays live pothole markers on the map based on incoming BLE $PD packets.

- Includes basic de-duplication so duplicate markers aren't added when staying in the same area.

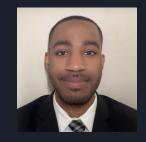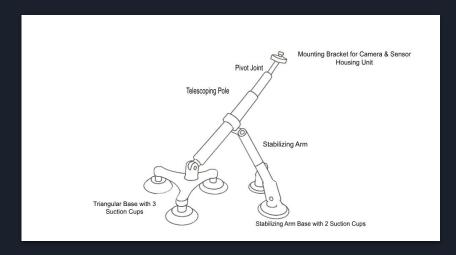- Supports pin details (depth, area, etc.) when a user taps a marker.

Mobile Application: Use Case Diagram

Mobile App System

- Launch App
- View Map
- Submit Pothole
- Mark as Fixed
- Review Potholes
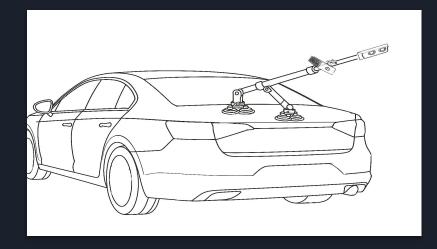
Driver

Technician

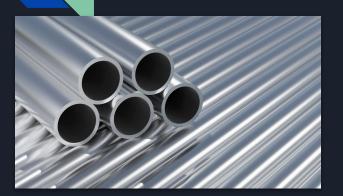Administrator

Mechanical: Mount Design

Schematic of the adjustable mounting system, showing suction base, stabilizing arms, telescoping pole, and camera housing bracket.
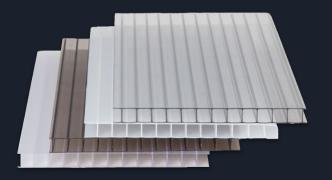

Mounting system installed on the rear of a vehicle, demonstrating suction based attachment and extended positioning for camera and sensor housing.
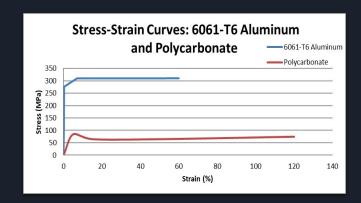
Mechanical: Material Selection

6061-T6 aluminum: lightweight structural material with high strength-to-weight ratio and corrosion resistance

Polycarbonate plastic: impact-resistant, weatherproof material used for protective housings and transparent covers

Stress-Strain Curves: 6061-T6 Aluminum and Polycarbonate

Stress-strain comparison of 6061-T6 aluminum and polycarbonate, demonstrating aluminum's higher strength and stiffness versus polycarbonate's flexibility and toughness.

Mechanical: Weatherproofing & Vibration Dampening

Rubber gasket seals for weatherproofing and preventing dust or moisture entry into housings
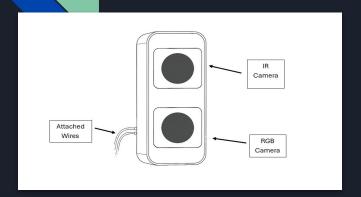

Rubber edge seal for housing enclosures, providing water resistance and protection against debris
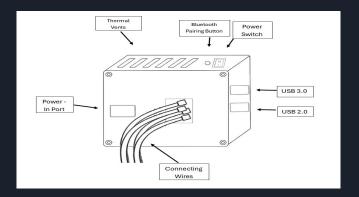
Vibration isolation bushing used to reduce road-induced vibration transmitted to electronics

Mechanical: Housing Unit Designs

Camera housing unit containing RGB and IR cameras with wired connections for image capture and data transfer

PCB housing unit with thermal vents, power and USB ports, and connecting wires for electronics control.

Laser housing unit with adjustable clamp, thermal fins for heat dissipation, and connecting wires for system integration

Administrative Content

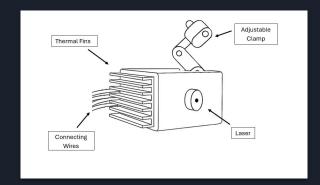| Component	Name	Quantity	Price
IR Sensitive Camera	ASIN:B096ZSSCGH	x1	$49.99
RGB Camera USB 3.0	ASIN:B0DBV8VFJZ	x1	$152.28
Housing Unit Materials	TBD	TBD	~$50.00
12V Car Fuse Taps	Nilight - 50038R	x1	$8.09
PCB	TBD	x1	~$60.00
NIR Laser Diode	Civil Laser 830nm 200mW IR Laser Diode	x1	$74.00
Bandpass Filter	Filter BP Col Hoya RT-830 25.4x2.5mm T	x1	$69.96
Aspherical Collimating Lens	Thorlabs 355230 Molded Aspheric Lens	x1	$68.77
Fast Axis Collimator	Edmund Optics 1.5mm Focal Length Fast Axis Collimator	x1	$209.88
30° Fan Powell Lens	B0C68MK6X7	x1	$37.72
90° Fan Powell Lens	B0C68P8M56	x1	$42.57

Raspberry Pi 5	B0CK2FCG1K	x1	$95.99
16-bit MCU	MSP430FR2355TPTR	x1	$2.69
25 foot USB 2.0 extender and repeater Cable	ASIN: B07P8X2MRX	x1	$18.99
25 foot USB 3.0 extender and repeater Cable	ASIN:B081H4N3KQ	x1	$18.99
Bluetooth v5.0 Transceiver Module 2.402 ~ 2.48GHz	150-RN4871-I/RM140-ND	x1	$9.24
Active Buzzer	CMT-5023S-SMT-TR	x1	$1.72
Thermoelectric/ Peltier Mini Module	00411-9J30-20CN	x1	$35.50
Laser Driver	ATLS1.5A104D	x1	$79.00
TEC Driver	MAX1968EUI+T	x1	$28.56
Total			$1039.33

Bill of Materials for the pothole detection system. The total system cost is approximately $1,039.33 with a project budget of $1200

Table 10.4.1: *Table of Work*

Role	Primary	Secondary	Tertiary
PCB Design	Samuel Welch	Travis Grant	Jose Kostyun
Optics	John Billeci	Travis Grant	Brandon Skervin
Computer Vision	Travis Grant	John Billeci	Jose Kostyun
MCU Programming	Travis Grant	Jose Kostyun	Samuel Welch
Application	Jose Kostyun	Travis Grant	Samuel Welch
Housing Design	Brandon Skervin	Samuel Welch	John Billeci
Mounting Design	Brandon Skervin	Travis Grant	John Billeci

Table of Work for the pothole detection system

Conclusion

- **The Problem** – Potholes create safety hazards, drive up repair expenses, and remain difficult to track with current slow or expensive methods.

- **Our Solution** – A compact, low cost system designed to detect, measure, and log potholes in real time.

- **Key Capabilities** – Combines laser and IR sensing, RGB image validation, AI-based classification, Bluetooth connectivity, and mobile mapping.

- **Built for Real Conditions** – Features a universal mount, protective housings, vibration isolation, and durable materials for consistent performance.

- **The Outcome** – Enhances road safety, lowers maintenance costs, and offers cities a scalable, practical solution for infrastructure management.