Pothole Detection, Geospatial Tracking, and Size Measurement

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***Abstract* — This project presents the design and build of a low-cost, real-time pothole detection and GPS tracking system for roadway maintenance. A Raspberry Pi 5 processes data from both infrared and RGB cameras, using a structured-light infrared laser line to detect road surface changes and a lightweight YOLOv5n object detection model to confirm potholes. A custom MSP430-based main PCB manages power regulation, GPS tracking, Bluetooth communication, and laser control. When the laser line is disrupted by a road defect, the Raspberry Pi confirms the pothole and logs its size and location to a mobile app for viewing and maintenance planning.**

***Index Terms* — Bluetooth communication, computer vision, GPS, infrared imaging, machine learning, MSP430 microcontroller, Raspberry Pi 5, YOLOv5.**

I. Introduction

Potholes and road surface deterioration are persistent challenges that compromise driver safety, reduce vehicle lifespan, and place a significant financial burden on local governments. Traditional inspection methods, such as manual surveys, user-reported complaints, and specialized scanning vehicles, are often slow, inconsistent, and expensive to operate. Existing automated solutions typically rely on costly LiDAR or camera systems mounted on dedicated vehicles, making them impractical for small municipalities with limited budgets. However, many government service vehicles already travel these same roads daily for routine operations, providing an unused opportunity for road-condition data collection. By equipping these vehicles with compact and affordable sensing systems, cities can continuously monitor roadway conditions without relying on specialized equipment or costly infrastructure.

This project addresses these limitations through the design of a low-cost, real-time pothole detection system that automates roadway monitoring. The design uses an infrared laser line to project a horizontal beam across the road surface behind a moving vehicle. An infrared (IR) camera continuously monitors the reflected laser line. Any distortion in the beam pattern indicates a surface irregularity such as a pothole or depression. In parallel, an RGB camera captures high-resolution frames in a ring buffer. When a potential defect is detected, the onboard Raspberry Pi 5 retrieves the corresponding RGB frame and analyzes it using a YOLOv5n object detection model trained for pothole identification. The Raspberry Pi records the timestamp of each confirmed detection, which is later used for location tagging.

The system includes a custom MSP430-based main PCB that provides centralized control, power regulation, and communication interfaces. This board integrates both GPS and Bluetooth modules to manage coordinate logging and wireless data transmission. The MSP430 uses timestamps from the Raspberry Pi to associate each detection with its GPS coordinates. The confirmed pothole data is then transmitted via Bluetooth to a mobile application. The app displays detections on a live map, allowing users and city maintenance teams to review locations, verify accuracy, and manage repair updates through a connected cloud database.

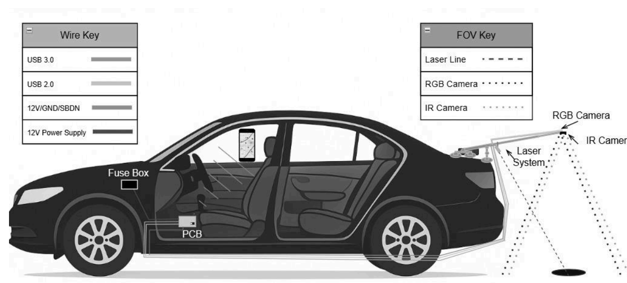

Fig. 1. Overall system design

By combining computer vision, embedded processing, and mobile connectivity, this system achieves a compact, portable, and affordable solution capable of continuous monitoring during normal vehicle operation. The overall goal of this project is to improve road-maintenance efficiency by automating defect detection, enhancing data accuracy, and enabling municipalities to prioritize repairs using reliable, real-time information.

II. System Components

The complete system is composed of several modular hardware subsystems, each serving a specific role in sensing, processing, or communication. This section provides a semi-technical overview of each major physical component and its function within the overall design.

A. Microcontroller

At the core of the embedded subsystem lies the Texas Instruments MSP430FR2355, a 16-bit ultra-low-power microcontroller featuring FRAM (Ferroelectric RAM) memory for fast, non-volatile data storage [1]. Operating at up to 24 MHz, the MSP430 coordinates communication between the system's main hardware modules and manages key control signals [1]. It communicates with the Bluetooth and GPS modules over UART and interfaces with the Raspberry Pi 5 via SPI, acting as the bridge between the embedded control hardware and the image-processing platform. The MSP430 also controls the laser enable line, allowing the structured-light projector to be safely toggled on or off under software supervision.

The MSP430 was selected for its low power consumption, reliable serial communication interfaces, and straightforward integration with peripheral components [1]. It operates at 3.3 V, regulated from the vehicle's 12 V power supply through an onboard voltage regulator. Development and debugging are performed in TI's Code Composer Studio, with firmware written in embedded C and compiled using the MSP430 toolchain. Serving as the system's control unit, the MSP430 synchronizes GPS logging, Bluetooth communication, and laser operation with the Raspberry Pi's image-processing tasks.

B. Single Board Computer

At the core of the high-level perception stack is the Raspberry Pi 5, which executes the image-processing and machine learning pipeline and brokers data exchange with the rest of the system. The Pi 5 integrates a Broadcom BCM2712 SoC (quad-core 64-bit Arm Cortex-A76 at up to 2.4 GHz with a VideoCore VII GPU) and 8 GB LPDDR4X memory, providing sufficient compute headroom for real-time OpenCV filtering, feature extraction, and CNN-based pothole classification [4]. The board runs 64-bit Raspberry Pi OS and leverages the modern libcamera stack and GStreamer for high-throughput image capture and encoding. Inference is executed via ONNX Runtime or TensorFlow-Lite with NEON acceleration.

For I/O, the Pi 5 offers dual USB 3.0 ports and dual USB 2.0 ports for auxiliary peripherals. A 40-pin header exposes SPI, I^2C, PWM, digital I/O lines for embedded interfacing, and UART for low-latency device control. Two 4-lane MIPI-CSI/DSI connectors and a PCIe 2.0x1 FFC provide expansion paths if higher-bandwidth cameras or local SSD logging are required.

Power is supplied via USB-C, with a 5A budget reserved to accommodate peak loads from USB 3.0 devices and bursty inference; a low-profile heatsink and blower fan are specified to maintain sustained clocks under Florida ambient conditions.

C. Bluetooth Module

The BM71 from Microchip is a fully certified Bluetooth 5.0 module that manages wireless communication between the embedded subsystem and the mobile application [2]. Operating in Transparent UART mode at 115200 baud, the BM71 receives ASCII-formatted coordinate data and pothole dimension metadata from the MSP430 and transmits this information to the user's smartphone via Bluetooth Low Energy. The module operates in the 2.402 to 2.480 GHz ISM band with a receive sensitivity of -90 dBm and transmit power of 0 dBm, providing reliable wireless connectivity up to 10 meters with its integrated chip antenna [2]. The module functions as a serial-to-Bluetooth bridge, decoupling the embedded processing hardware from the mobile interface.

The BM71 was selected for its Bluetooth 5.0 certification, extended range, and improved data throughput within the vehicle environment [2]. Operating at 1.9 V to 3.6 V with typical active current consumption below 10 mA and a temperature range of -20°C to +70°C, the module ensures reliable performance across automotive conditions [2]. The Transparent UART mode simplifies firmware development by eliminating complex BLE stack management, enabling structured data transmission with minimal protocol overhead [2]. AES-128 encryption provides data protection during wireless transmission, while the low-latency link enables real-time map updates and immediate driver notification following each detection event [2].

D. GPS Module

The FGPMMOPA6B GPS module from Adafruit, featuring the PA1616S receiver with MTK3329 chipset, provides continuous geolocation data. The PA1616S receiver features 66-channel tracking capability and achieves 3-meter 2D-RMS position accuracy without differential correction [3]. Configured to operate at 4 Hz with a 115200 baud UART interface, the module outputs NMEA 0183 GPRMC sentences containing UTC timestamp, latitude, longitude, speed, and validity status at 0.25-second intervals. The GPS module connects to the MSP430's primary UART channel (UCA0), continuously streaming positional data that the microcontroller stores in a RAM-based circular buffer indexed by timestamp. This circular buffer maintains the ten most recent coordinate samples, providing a 2.5-second sliding window of positional history.

The FGPMMOPA6B was selected for its cost-effectiveness and MTK3329 feature set suited for automotive positioning applications. The module supports update rates up to 10 Hz, with onboard voltage regulation and typical power consumption of 37 mA during active tracking [3]. Its high sensitivity of -165 dBm ensures reliable signal acquisition in urban environments with partial sky visibility [3]. Additional features include DGPS support with WAAS, EGNOS, MSAS, and GAGAN compatibility, along with multi-path detection algorithms that improve position accuracy in challenging signal environments [3]. The update rate and sentence output are configured via MTK Packet Type (PMTK) commands, with an antenna positioned on the vehicle dashboard ensuring reliable satellite acquisition. Cold-start satellite acquisition occurs within 5 to 10 seconds under typical conditions [3].

E. Laser Driver

The ATLS500MA104 from Analog Technologies, Inc. is an ultra-low-noise, high-efficiency constant-current laser driver module designed for driving laser diodes with precision and stability. It delivers up to 500 mA of output current with programmable current limits and supports a compliance voltage up to 4V, allowing direct operation with most low to mid-power laser diodes, including IR and visible-wavelength emitters. The driver operates from a single supply voltage ranging from 4.5V to 16V, making it ideal for compact embedded systems powered by regulated DC rails or portable battery sources.

At the heart of the ATLS500MA104 is a proprietary linear-control architecture that minimizes current noise to below 0.5uA rms over a 10Hz to 10MHz bandwidth which is crucial for applications requiring optical stability such as sensing, metrology, and imaging. The module provides both analog and digital control interfaces: the LIS (Laser Current Setting) pin allows current modulation via an analog voltage, while the SHDNN (shutdown) input permits logic-level on/off control. An internal soft-start circuit ensures smooth current ramp-up at power-on, protecting the laser from transient surges.

The module also integrates current monitoring, over-temperature protection, and laser-diode fault detection. An onboard IOM (Output Current Monitor) pin provides a voltage proportional to the actual laser current (1V per 100mA), which allows closed-loop current verification. With an efficiency exceeding 80% under typical operating conditions, the ATLS500MA104 maintains low thermal dissipation, and its small form factor simplifies PCB integration and thermal management [5].

The combination of low-noise linear regulation, precise current control, and robust protection circuitry are the reasons the design team chose the ATLS500MA104 as the laser driver for the Pothole Detection System.

F. Laser Diode

Providing the light for the active optical system is the Thorlabs L820P200 laser diode, an 820 nm infrared laser diode that produces an average output of 200 mW, ensuring visibility with minimal risk of injury. Producing coherent monochromatic light, the L820P200 is a reliable source of light in a compact 5.6 mm TO-can package. With the output light being infrared, there is little chance of distraction for civilian drivers, increasing safety compared to visible light.

The laser diode is used in tandem with collimating and Powell lenses to generate a line of light across the target surface. These components are aligned in a cage mount, ensuring that everything remains on the same optical axis even in rough conditions. The L820P200 is connected to the laser driver, which ensures the diode receives a consistent flow of power and operates safely. This diode was selected for its affordability, wavelength, power, and consistent output, ensuring a reliable reference for depth detection with increased safety, all at a low cost.

G. RGB Camera

The Arducam 2.3MP AR0234 Color Global Shutter USB 3.0 Camera provides high-quality RGB imaging for visual pothole detection and verification. It uses a global shutter AR0234 CMOS sensor capable of 1080p resolution and up to 80 fps, allowing sharp image capture even when the vehicle is in motion.

The camera connects to the Raspberry Pi 5 through a USB 3.0 interface, enabling fast data transfer and plug-and-play compatibility without requiring extra drivers. Its low-distortion M12 lens offers a 95° field of view, providing excellent road coverage without being so wide that it introduces geometric distortion or reduces image accuracy. This camera was selected for its clarity, high frame rate, and balanced field of view, making it well-suited for continuous road monitoring and real-time object detection in a compact, low-power package.

H. Infrared Camera

The Arducam B0332 camera is a high-quality monochrome camera ideal for affordable near-infrared imaging. The Omnivision OV9281 camera sensor utilizes a global shutter with up to 100 fps and reaches a resolution of up to 1280 x 800, enabling the camera to capture good quality video with little to no blur even at high speeds. The monochromatic data captured by this camera contains less data and is thus easier to process at higher speeds.

This camera is connected to the Raspberry Pi 5 using a USB 2.0 interface. Like the RGB camera, this allows for plug-and-play compatibility but with slower data transfer speeds. Its M12 lens offers a 93° horizontal field of view with no infrared cut filter, allowing the camera to capture near-infrared light over a large area. This camera was chosen for its monochromacy, infrared detection, and high quality at speed, enabling its use for continuous monitoring of infrared light on roadways.

III. System Concept

This system is designed to scan roadways for potholes using two cameras, a computer vision algorithm, and an infrared laser line generator. The first camera captures visible light in color and is paired with a computer vision algorithm, while the second camera is designed to capture infrared light and is used in tandem with the infrared laser line. Upon the detection of a pothole, the geospatial location data is saved and put into a registry of all detected potholes and their locations. The system is aided by a phone application to increase ease of use for the device operator.

A. Computer Vision Concept

The first camera is used to capture the target area with color. With high resolution and fps, this camera operates on a moving vehicle, collecting video of the road. The video data is given to a computer vision algorithm, trained on nearly 2000 images of potholes of all shapes and sizes, that determines if there is a pothole in the image and estimates the width and length of the pothole. When a detection is made, the image can be sent to the operator for additional review.

B. Laser Line Detection Concept

The second camera is used to make detections by monitoring the state of an infrared laser line. By locating and measuring breaks in the line, the detection algorithm can find and estimate changes in depth. Infrared light is used to reduce the chance of distracting drivers on the road and to avoid the increased risk of danger.

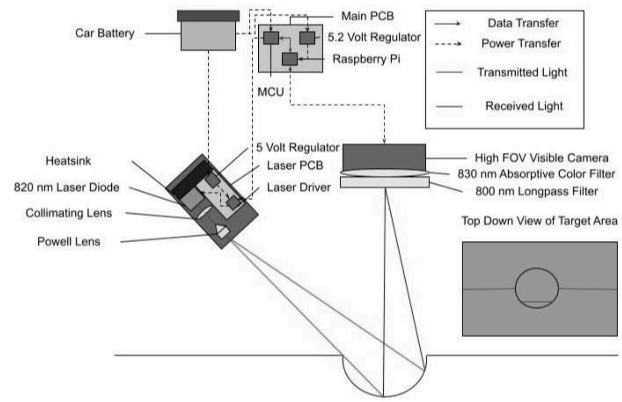

Fig. 2. Overview of the operation of the laser line depth detection system.

The camera used is a visible light camera that has no infrared cutoff filter, allowing it to capture IR light. Using a bandpass filter, the visible light is blocked so that only near-infrared light is captured.

The laser line is generated using three main optical components: an infrared laser diode, a collimating lens, and a Powell lens. Starting with the laser diode as the light source, the system works by collimating the light as it goes into the Powell lens. The Powell lens spreads the light across a large area, enabling the light to be spread out across the road. This system is placed so that the line is incident on the ground at an angle towards the middle of the camera's view

As detections are made, the lateral shift in the laser line is measured and used to estimate depth using Eq. 1 and the known angle of the line generator system

$$tan = \frac{Opposite}{Adjacent} = \frac{O}{A}. \quad (1)$$

C. Mobile Application Concept

The mobile application is designed to provide a simple and effective method of data review for the operators of the system. In the application, the data for detected potholes is displayed in a map view with the option for review in list form. This data is transferred to the operator's phone using a Bluetooth connection between the user's phone and the device. The operator also has the option to connect to a second Bluetooth module in the Raspberry Pi to receive images of detected potholes if further review is desired. After a pothole has been filled, the operator will be able to remove it from the list.

IV. Hardware Detail

A. *Electrical Hardware*

The electrical subsystem of the Pothole Detection System integrates multiple embedded and sensing modules that operate cohesively to acquire, process, and transmit road-surface data. This electrical subsystem begins at the vehicle's battery via fuse-tap, supplying the entire system with the necessary power to operate. The input voltage and current are then branched into three separate voltage regulators.

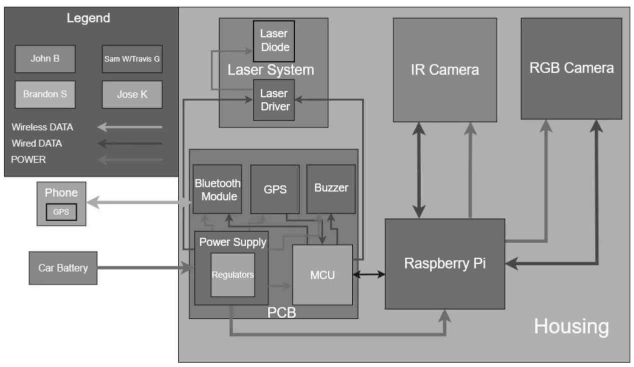

Fig. 3. Hardware block diagram of the Pothole Detection System

The 3.3V voltage regulator of the Pothole Detection System provides a stable, clean 3.3V to the MSP430, buzzer, Bluetooth module, and GPS module. The 5V voltage regulator of the Pothole Detection System provides a stable, clean 5V to the laser driver breakout PCB. The 5V voltage regulator of the Pothole Detection System provides a stable, clean 5.2V to the Raspberry Pi 5 as shown in Figure 3.

Using the LM2576-ADJ buck regulator at the heart of this design, as well as one Schottky diode, one inductor, and multiple resistors and capacitors. With a current rating of 7A, these regulators have more than enough current budget to operate effectively.

The Pothole Detection Systems integrates multiple printed circuit boards. This includes the Main PCB, which hosts the MSP430 microcontroller, buzzer, voltage input, multiple resistors and diodes, as well as multiple pin headers for breakout board attachment.

The laser driver breakout board hosts the ATLS500MA104 laser driver. This was designed as a breakout board in order for the board to be closer to the diode in the rear of the vehicle. This was also designed in this way in case a component failed on the laser driver system, the team would not have to modify the main board.

The Bluetooth module breakout board hosts the BM71 Bluetooth module. This was also designed as a breakout board for flexibility purposes, in case the design team needed to swap the module, further modifications on the main board would not be necessary. This board was also designed this way because it would create space between the main board and the Bluetooth module, giving more room to provide a better signal to the user's phone.

B. *Mechanical Hardware*

The mechanical assembly of the Pothole Detection System provides the structural framework for all optical and electronic components, ensuring protection, alignment, and stability during vehicular operation. The system consists of a dual camera enclosure and an integrated laser housing mounted below, secured to a modular suction cup assembly for rear vehicle installation. Designed for vibration resistance and environmental durability, the housing units were manufactured through additive techniques using ABS plastic. The resulting structure allows accurate sensor alignment, quick installation, and dependable operation across varied road conditions.

The camera enclosure houses both the RGB and infrared cameras within a single sealed unit to preserve alignment between optical centers. Internal mounting posts and recessed windows feature on the housing for the camera lenses. M 2.5 fasteners are used to attach each camera module, ensuring that there is no change in the focal distance. The front plate features clear openings for both lenses, while an internal partition minimizes light interference between the sensors.

The laser housing, mounted directly below the camera enclosure, supports the collimated beam source that is used for depth triangulation. The cylindrical section holds the laser driver, as well as the collimating and Powell lenses at fixed separation, ensuring consistent beam width across varying surface distances. It attaches via a precision alignment bracket that connects to the lower surface of the camera enclosure, preserving the optical axis and minimizing parallax error during detection. It also contains the laser PCB board and heatsink, attached to the bottom of the unit.

The main method of attachment for the entire unit is a rear-mounted suction cup system. The mount consists of multiple suction bases in a triangular configuration that allows the load to be distributed evenly across the contact surface. A central adjustable arm with a ball and socket joint allows adjustment in pitch and yaw to align the cameras and laser parallel to the road surface. The mount provides rigid support while isolating high-frequency vibrations through its contact points.

V. Software Details

The software integrates the Raspberry Pi 5, MSP430FR2355, and a custom mobile application into a unified system. The Raspberry Pi processes infrared and RGB camera data in real time, using a line-distortion algorithm for surface detection and YOLOv5n for pothole confirmation. The MSP430 manages Bluetooth communication, laser control, and GPS timestamp synchronization, while the mobile app displays detections on a live map and stores data in the cloud. Together, these components enable efficient, automated road monitoring.

A. Laser Line Detection

This section covers the laser line detection subsystem, which uses infrared imaging to identify and measure road surface irregularities through structured light. A horizontal infrared laser is projected across the pavement, and the infrared camera captures its reflection as the vehicle moves. The algorithm isolates the laser line by selecting the brightest pixel in each image column, producing a one-dimensional laser profile y(x). A baseline representing the flat road surface is then calculated from stable edge regions. Any portions of the laser line that appear above this baseline indicate downward road deformations such as potholes.

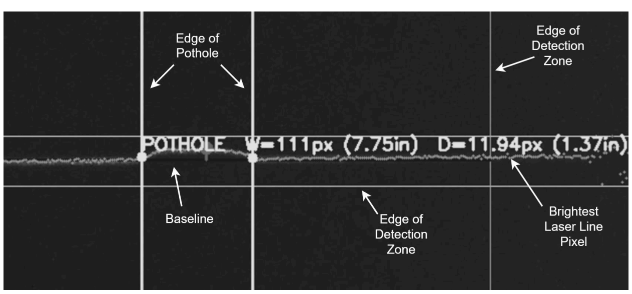

Fig. 4. Visualization of laser line deformation analysis illustrating baseline, detected pothole width, and peak depth.

To quantify these features, the algorithm computes an elevation profile

$$e(x) = y(x) - y_{baseline}, \tag{2}$$

where positive values correspond to potholes. Points below the baseline are ignored since they represent raised surfaces or bumps. The detected regions are analyzed for width (4) and depth (3), which are converted into physical dimensions using the calibrated pixel-per-inch values

$$D_{in} = \frac{e(x_{peak})}{PPI_y} \tag{3}$$

$$W_{in} = \frac{e-s+1}{PPI_x}. \tag{4}$$

Only those exceeding the defined thresholds are classified as potholes, enabling reliable and real-time analysis of the road surface.

B. Visual Pothole Verification Using YOLOv5n

The RGB vision module performs visual confirmation of potholes using a YOLOv5n object detection network trained on labeled images of roadways. The model identifies potholes by drawing bounding boxes around surface defects, as shown in Fig. 5, with the confidence score displayed in the corner.

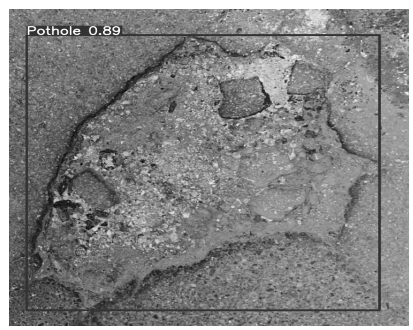

Fig. 5. Example YOLOv5n detection output showing identified pothole with confidence score.

The vertical measurement of each detected pothole is derived from the bounding box's pixel height, which can be correlated to real-world dimensions through camera calibration. Training performance, shown in Fig. 6, demonstrates consistent improvement in both precision and recall, each exceeding 0.9 after 40 epochs, indicating reliable model convergence and strong detection accuracy for real-time operation.

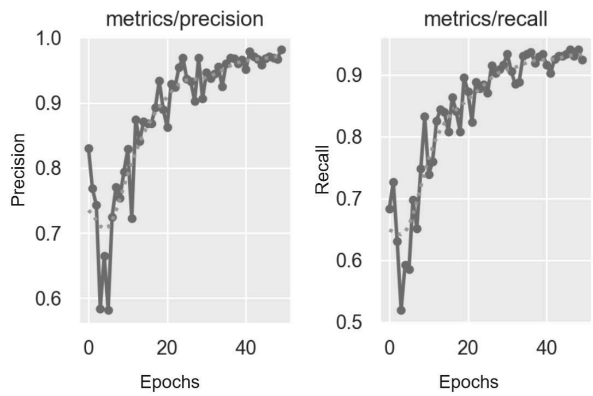

Fig. 6. YOLOv5n training performance showing precision and recall improvement over epochs.

C. MSP430 System Control

The Texas Instruments MSP430FR2355 16-bit microcontroller serves as the central coordinator for the embedded subsystem, managing communication between the GPS module, Bluetooth module, Raspberry Pi 5, and laser projector. Operating at 8 MHz via the FLL-configured DCO, the MSP430 implements dual UART channels for serial peripherals and an SPI slave interface for receiving detection triggers from the Raspberry Pi 5's YOLOv5n vision pipeline. The 4 KB SRAM supports real-time circular buffer management, while 32 KB of FRAM provides non-volatile storage.

The MSP430 operates continuously with the watchdog timer disabled to maintain uninterrupted GPS data acquisition at 4 Hz, providing a rolling 2.5-second historical window for precise timestamp correlation with detection events.

The MSP430FR2355's peripheral functions are mapped to specific GPIO pins via the port selection registers (PxSEL0/PxSEL1). The following pin assignments define the microcontroller's interface connections:

(1) Pins P1.6 and P1.7 are configured for UCA0 UART functionality, connecting to the GPS module's TX and RX lines, respectively.

(2) Pins P4.2 and P4.3 are configured for UCA1 UART functionality, interfacing with the RN4871 Bluetooth module.

(3) Pins P1.0 through P1.3 are configured for UCB0 SPI slave operation, establishing the command interface with the Raspberry Pi 5.

(4) Pin P2.0 is configured as a standard GPIO output for laser enable control.

Both UART channels employ interrupt-driven reception and polled transmission at 115200 baud (8N1). Incoming NMEA sentences trigger the EUSCI_A0 interrupt, accumulating characters in a 100-byte buffer until the newline terminator is detected.

Operating as an SPI slave via the UCB0 module, the MSP430 receives detection triggers and dimensional metadata from the Raspberry Pi 5. When the YOLOv5n network confirms a road anomaly, the Raspberry Pi transmits a data packet containing the detection timestamp and pothole dimensions. The MSP430 extracts the timestamp and searches the GPS circular buffer for the closest temporal match.

A 10-entry circular buffer in SRAM stores GPS coordinates as a FIFO structure with timestamp indexing. Each entry contains latitude, longitude, and UTC timestamp extracted from GPRMC sentences. Operating at 4 Hz, the buffer maintains a 2.5-second window with constant memory utilization of approximately 200 bytes.

Upon receiving a detection trigger via SPI, a linear search identifies the buffer entry matching the detection timestamp. If no exact match exists, the nearest preceding timestamp is selected. This search executes in under 50 microseconds, introducing negligible latency compared to UART and Bluetooth transmission overhead.

The laser system is controlled via a GPIO output driving an external buffer circuit. The output passes through a 33Ω series resistor (R20) to a buffer stage, with a 10kΩ pulldown resistor (R6) ensuring a defined logic-low state. The buffer isolates the MSP430 from the laser driver, enabling software-controlled synchronization between infrared structured light capture and RGB YOLOv5n confirmation.

System initialization configures the FLL to generate 8 MHz SMCLK, initializes both UART channels (transmitting MTK PMTK commands to configure the GPS for 4 Hz GPRMC output), configures the SPI slave interface, and sets the laser GPIO to logic-low. Global interrupts are then enabled, and the microcontroller enters its main processing loop.

D. Mobile Application Interface

The mobile application is developed using React Native, a cross-platform framework enabling deployment to both iOS and Android operating systems from a unified JavaScript and TypeScript codebase. The application receives ASCII-formatted pothole detection data via Bluetooth Low Energy using the react-native-ble-plx library, establishing persistent connections with automatic reconnection to prevent data loss during temporary signal interruptions. Incoming data packets containing GPS coordinates, pothole dimensions, and timestamps are parsed and validated before database insertion. The parsed detection records are uploaded to a MongoDB cloud database, which provides persistent storage, structured query capabilities, and multi-user access to the shared pothole entries. Each database entry contains geospatial coordinates, dimensional measurements, detection timestamp, user identification, and verification status fields, enabling comprehensive tracking and maintenance planning.

The mapping functionality is implemented using React Native Maps, which displays pothole locations as interactive markers on the map view. Map markers are generated in real time as new detections are received, with the application periodically querying the database to synchronize updates across all connected user devices. The map view includes offline caching to ensure continued operation without cellular connectivity. The application architecture supports role-based access, with drivers receiving in-app alerts for detections requiring manual confirmation and maintenance technicians accessing filtered database views for repair prioritization. React Native was selected for its cross-platform compatibility, robust Bluetooth Low Energy support, mature mapping library ecosystem, and reduced development overhead compared to native implementations, enabling efficient prototyping and field deployment across multiple mobile platforms.

VI. Conclusion

The Pothole Detection System successfully integrates mechanical, electrical, and software subsystems into a compact, low-cost, reliable platform for roadway monitoring. The mechanical assembly provides structural stability and environmental protection, maintaining optical alignment between the dual camera module and laser projection system. The embedded control hardware ensures synchronized operation across all sensors, while the computer vision algorithms perform real-time, accurate pothole detection and geospatial tagging.

All combined, these components create a function during vehicle operation. Future improvements include refining vibration isolation, optimizing real-time processing, and expanding data analytics capabilities in a mobile application to further enhance system robustness and scalability for municipal deployment.

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