Senior Design Project Final Report for Year 2023

Pothole Detection System

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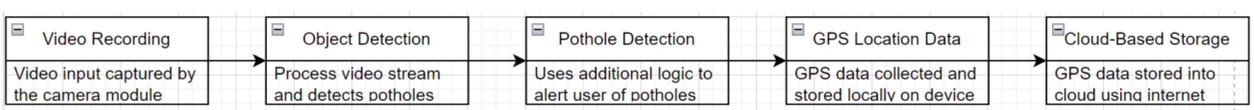
1. Introduction

Potholes are a widespread issue that can cause vehicle damage and pose a significant threat to road safety. To address this problem, our Senior Design Project focuses on the development of a Pothole Detection System to help identify and locate potholes in real-time. This system uses the TensorFlow-lite machine learning repository and OpenCV-Python combined with a Raspberry Pi 3 and Raspberry Pi Camera Module to detect and track potholes, alert drivers to their presence and record the coordinates of the detected pothole into a Thing Speak cloud database.

The average cost of pothole-related repairs is $406, according to a survey conducted by the American Automobile Association [1]. Potholes are a common issue that pose a serious threat to road safety and can cause significant damage to vehicles. The goal of this project is to design and implement a system that can improve road safety and reduce vehicle damage by detecting potholes in real-time. By detecting potholes early, this system can help reduce the risk of accidents and damage to vehicles, as well as reduce the overall cost of city maintenance. In this progress report, we summarize the work completed so far and provide an update on the status of the project.

2. Accomplished Design

System modeling and analysis



The current design only contains the Raspberry Pi Module, the camera module, and the power supply module. As of now, the system captures video using the Raspberry Pi camera module and the video input is analyzed and displays bounding boxes over the specified object containing a label and the confidence rating of the object using TensorFlow-Lite and OpenCV-Python installed on the Raspberry Pi 3 B+. I was unable to record and detect any potholes due to a lack of wireless power, but object detection is currently functional.

Function breakdown and descriptions

Video Recording
The Raspberry Pi Camera module captures a video stream of the road surface ahead of the vehicle. Due to limitations of the Raspberry Pi and camera, video input is recorded on average two frames per second (FPS).

Object Detection
This component processes the video stream and detects objects that are present in the video stream. The system is trained to detect potholes and will produce an output signal when detected.

Pothole Detection Response
This component takes the output of the objection component and uses additional logic to emit an output signal when a pothole is detected. In out case, a piezoelectric buzzer is wired to a Raspberry Pi pin triggered by a pothole detection, alerting the user of a detected pothole.

GPS Data Collection
Once a pothole is detected, the system collects GPS data to determine the location of the pothole using the NEO-6M GPS module and stores it locally on the Raspberry Pi module.

Cloud Server Data Storage
When connected to an internet service, the system sends the GPS location data to a cloud server, where it can be stored and analyzed.

Specification and design constraints

Function Module	Restrictions/Limitations
Camera Module	• Currently for daytime use • Detection range limited to 10 meters
Raspberry Pi 3 Model B+	• Requires a fan for cooling • Requires internet connection to upload GPS data to cloud • Due to limited RAM, video input records on average 2.0 FPS
GPS Module	• Update rate up to 5Hz • Accuracy up to 2.5m circular error probable (CEP)

ThingSpeak Cloud	• N/A
Power Supply	• Battery pack heavy and bulky

Table of specification & design restrictions

Function module	Specification (use bullets)	Why choose this specification?
Camera Module	• **Input Power:** 1.5V to 3.0V DC • **Peak Current:** 300mA • **Sensor:** OV5647 • **Connection:** 15 cm flat ribbon cable to 15-pin MIPI Camera Serial Interface (CSI) connector • **Lens:** Fixed Focus Lens • **Angle of View:** 54° Horizontal x 41° Vertical • **Field of View:** 2.0 x 1.33m @ 2m • **Resolution:** 5 Megapixels, 2592 x 1944 • **Frame Rates:** 30fps@1080P, 60fps@720P, 90fps@480P • **Fixed Focus:** 1m to Infinity • **Dimensions:** 4.7 inches x 0.2 inches x 0.1 inches • **Weight:** 0.32 ounces • **Operating Temperature:** -30 to+70 °C	• Necessary to operate the camera module • Same as previous • Primarily daytime use • Cable necessary for interfacing on the Raspberry Pi 3 Model B+ • Allows for crisper images to capture. • Images need not be large • The potholes need to be detected at a reasonable distance

Raspberry Pi 3 Model B+ Microcontroller	• **Processor:** Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4GHz • **Memory:** 1GB LPDDR2 SDRAM • **Connectivity:** 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless, LAN, Bluetooth 4.2, BLE, Gigabit Ethernet over USB 2.0 (maximum throughput 300Mbps), 4 × USB 2.0 ports • **Access:** Extended 40-pin GPIO header • **Video & Sound:** 1 × full size HDMI, MIPI DSI display port, MIPI CSI camera port, 4 pole stereo output and composite video port • **Multimedia:** H.264, MPEG-4 decode (1080p30); H.264 encode (1080p30); OpenGL ES 1.1, 2.0 graphics • **SD Card Support:** Micro SD format for loading operating system and data storage • **Input Power:** 5V/2.5A DC via micro USB connector, 5V DC via GPIO header, Power over Ethernet (PoE)–	• **Processor:** Necessary for quickly processing signals • **Memory:** Storing the OS • **Connectivity:** Connecting to the internet to send GPS coordinates of detected pothole to cloud • **Access: N/A** • **Video & Sound:** Necessary for interfacing with the Raspberry Pi 3 Model B+ to install the OS and camera module • **Multimedia:** Necessary for interfacing the camera module • **SD Card Support:** The SD card contains the OS for operating the Raspberry Pi • **Input Power:** The Raspberry Pi needs this amount of power to function • **Dimensions:** Small and lightweight for easy transportation • **Weight:** Small and lightweight for easy transportation • **Operating Temperature:** Safe operating temperature to avoid damaging the board and harming users

	enabled (requires separate PoE HAT) • **Dimensions:** 85 x 56 x 17 millimeters • **Weight:** 7.1 ounces • **Operating Temperature:** 0 to +50 °C	
NEO-6M GPS Module	• **Input:** 2.7V to 3.6V DC • **Data Transmission Protocol:** UART, USB, SPI, DDC • **Operating Temperature**: -40°C to 85°C • **Dimensions :** 12.2mm x 16.0mm x 2.4mm • **Weight:** 4.6 ounces	• **Input:** Power needed to operate the GPS module • **Data Transmission Protocol:** Uses UART data transmission to record GPS data. • **Operating Temperature:** Safe operating to avoid damaging the module and harming the user • **Dimensions:** Small and compact to improve portability • **Weigh:** Lightweight to improve portability
Battery Pack	• **Input:** 6-AA Batteries • **Output:** ~9.0V DC (~5.0V DC w/ DC-DC Converter) • **Dimensions:** 3.625 inches x 2.25 inches x 0.625 inches • **Weight:** 0.634 ounces	• **Input:** Requires 6-AA batteries to supply Raspberry Pi • **Output:** Need to know how much the output must be reduced to avoid damaging the board. A DC-DC converter is needed to meet power requirements of the Raspberry Pi • **Dimensions:** Bulky and takes up most space • **Weight:** Lightweight to improve portability
Cloud Service	• **Input:** Coordinates of identified potholes • **Output:** Visual representation of pothole data • **Power Requirements: N/A** • **Data Transmission Protocol:**	

	WebSocket Protocol • **Measurement Range: N/A** • **Constraints:** Data should be transmitted in intervals of 30 seconds to prevent data congestion.	
Entire prototype	• **Input:** User credentials, video camera recording, battery power supply w/switch (Micro-USB) • **Output:** Data uploading to cloud, alarm notification • **Power Requirements:** 5V, 2.5A DC • **Data Transmission Protocol:** WebSocket Protocol, RS232 and TTL UART, 802.11 b/g/n/ac Wireless LAN • **Pothole Detection Range:** Roughly 10 meters • **Weight:** 9.814 ounces • **Constraints:** There should be enough light to detect the pothole and the vehicle should be moving below 45mph for the system to get a good quality video of the road.	• **Input:** The system • **Output:** The system needs to alert drivers of upcoming potholes and their locations • **Power Requirements:** Need to know how much power the system needs to be supplied • **Data Transmission:** To ensure standard data transmission protocols • **Pothole Detection Range:** Early detection of potholes helps warn users with enough time to react • **Weight:** N/A • **Constraints:** The camera needs enough light and speed to detect incoming potholes

Table of employed standards (related to safety, materials, workload, power rate, data transmission, etc.)*:*

Standard	Description	Link or References	Why this standard is employed/necessary?
IEEE Standard for Sensor Performance	This standard ensure that sensor performance data is consistent and accurate, which is important for many applications, including industrial process control, environmental monitoring, and medical diagnostics.	https://standards.ieee.org/ieee/2700/6770/	It helps to ensure that sensors are properly characterized and that their performance is well understood, which can lead to improved system performance and reliability.
Standard for Harmonization of Internet of Things (IoT) Devices and Systems	This standard defines a method for data sharing, interoperability, and security of messages over a network, where sensors, actuators and other devices can interoperate, regardless of underlying communication technology.	https://standards.ieee.org/ieee/1451.99/10355/	The standard defines a communication protocol and data model that allows for the exchange of information between smart transducers in a wireless network, regardless of the manufacturer or communication technology used.
IEEE Draft Standard for Automotive System Image Quality	The standard provides a framework for evaluating various aspects of image quality, including resolution, color accuracy, noise, dynamic range, distortion, and more. It also includes guidelines for selecting appropriate test charts and	https://standards.ieee.org/ieee/2020/6765/	Mainly used in the automotive industry to ensure that their imaging systems meet the necessary performance requirements for safety and reliability.

	equipment, as well as instructions for conducting tests in different lighting conditions.		
CC BY 4.0 License	Anyone is free to share, copy, and redistribute a work in any medium or format, and to adapt, remix, transform, and build upon the work for any purpose, even commercially. However, they must give appropriate credit to the original creator(s) and provide a link to the license.	https://creativecommons.org/licenses/by/4.0/legalcode	This license allows others to share, copy, and redistribute a work in any medium or format, and to adapt, remix, transform, and build upon the work for any purpose, even commercially, as long as they give appropriate credit to the original creator(s). This ensures that the original creator(s) receive proper recognition for their work, while also allowing others to benefit from and build upon it.

Table of employed libraries/datasets/open sources:

Resource name	Resource type & description	Link or References
OpenCV-Python	Software – An open-source computer vision library that incorporates numerous computer vision algorithms for real-time applications. This installation is based in Python.	https://pypi.org/project/opencv-python/
TensorFlow-Lite	Software – Used to deploy machine learning models on devices with limited resources. It allows for the development of machine learning applications that can run directly on the device, without requiring cloud connectivity or a powerful server. TensorFlow Lite enables new use cases in object detection, image classification, speech recognition, and natural	https://www.tensorflow.org/lite/guide

	language processing.	

<u>Table of hardware/budget use and all costs</u>

Part Description	Function	Amount Needed / Unit Price	Subtotal	Purchase Link	Datasheet Link
Raspberry Pi 3 Model B+	Central controller for reading sensor data, alerting the driver and passengers of an upcoming pothole, and uploads the data to a cloud database for future reference and data visualization.	1/$35.00	$35.00	https://www.adafruit.com/product/3775?src=raspberrypi	https://datasheets.raspberrypi.com/rpi3/raspberry-pi-3-b-plus-product-brief.pdf
Arducam 5MP Camera Module OV5647	Camera module for scanning the road and detecting potholes in low-light conditions	1/$9.99	$9.99	https://www.amazon.com/Arducam-Megapixels-Sensor-OV5647-Raspberry/dp/B012V1HEP4?ref_=ast_sto_dp&th=1&psc=1	https://docs.arducam.com/Raspberry-Pi-Camera/Native-camera/source/OV5647DS.pdf
NEO-6M GPS Module	GPS module used to	1/$9.99	$9.99	https://www.amazon.com/Micro	https://pdf1.alldatasheet.com/dat

	record pothole coordinates to the Raspberry Pi locally.			controller-Compatible-Sensitivity-Navigation-Positioning/dp/B07P8YMVNT/ref=asc_df_B07P8YMVNT?tag=bngsmtphsnus-20&linkCode=df0&hvadid=80882941548103&hvnetw=s&hvqmt=e&hvbmt=be&hvdev=c&hvlocint=&hvlocphy=&hvtargid=pla-4584482468252279&psc=1	asheet-pdf/view/1283987/U-BLOX/NEO-6M.html
Jumper Wires (4in and 8in pack)	Connecting the modules to their appropriate pins to perform pothole detection and data uploading.	1/$6.49	$6.49	https://www.amazon.com/dp/B01L5ULRUA?ref_=dp_atch_dss_base_image	N/A
Cylewet 10Pcs 5V Active Buzzer	Buzzer component for alerting the driver of upcoming pothole	1/$6.98	$0.14	https://www.amazon.com/gp/product/B01N7NHSY6/ref=ewc_pr_img_1?smid=A2O4FZ	N/A

				XIRZDLHA&psc=1	
6-AA 9V Battery Pack	Power supply of the system	1/$6.99	$6.99	https://www.amazon.com/Battery-Holder-Enclosure-Connector-Cable/dp/B01N2INSBR/ref=sr_1_8?crid=1LM4N7NY5TJD2&keywords=6+aa+battery+pack+holder&qid=1679283954&sprefix=aa+battery+pack+holder%2Caps%2C203&sr=8-8	N/A
Part Description	**Function**	**Amount Needed / Unit Price**	**Subtotal**	**Purchase Link**	**Datasheet Link**
Total:		$68.60			

3. Evaluation and Demonstration

<u>Demo/Testing of the entire project:</u>

Demo video link:
https://drive.google.com/file/d/1fy0LKNE6UERGIYiNRVxacwQBec6ZZCwT/view?usp=share_link

Description (with screenshots and/or photos if applicable):
This demo showcases the object detection functionality on the Raspberry Pi module. The monitor displays the video input from the camera module, the real-time FPS the camera is recording in, and bounding boxes surrounding the object detected. The objects shown in the

video demo are also given a label based on what the system determines the object is and a confidence level, which is used to quantify the level of certainty in a particular prediction. For example, if the system detects a cat with a confidence level of 90%, then the system is 90% certain the image contains a cat.

4. Encountered Problems

During the development of the Pothole Detection System, we encountered several problems. The original battery pack was too heavy, clunky, and used too many batteries. Additionally, training the dataset took too long on the main PC. We addressed these issues by swapping the battery pack for a Micro-USB cable with a car adapter and using Google Colab to mitigate hardware usage. We also switched to using Tensorflow-Lite, which is easier to use on the Raspberry Pi 3 B+ and reduced software errors encountered during development.

5. Conclusions/Summary

Overall, we have made significant progress on the development of the Pothole Detection System. We plan to continue refining the system and testing it under various conditions to ensure optimal performance. Our current points of interest are implementing pothole detection capabilities, testing the system under various environmental conditions, and implementing the GPS module to record pothole location data locally to the device.

References

[1] "Potholes and Vehicle Damage – AAA Exchange." https://exchange.aaa.com/automotive/automotive-trends/potholes-and-vehicle-damage/ (accessed May 05, 2023).

Appendix

Google Collab YOLOv4-Tiny Notebook:
https://colab.research.google.com/drive/1dg0EZd9bN66MGtEHv1N4QkIAtQrGcStY#scrollTo=u2LAciMh4Cut