Development of a Novel Autonomous Column-Climbing Robotic System (AutoBot) for Real-time Detection and Mapping of Surface Cracks on Bridges

Background

Issue Statement

- More than a third of America's bridges, approximately 231,000 [1], are in poor condition. To help assess repair, civil engineers must inspect these bridges.
- However, the sheer number of sites, the high cost of inspection, and the dangerous conditions in such a line of work, presents an urgent need to develop an autonomous system to inspect these sites.

Objective

1. Can climb up a bridge column.
2. Can synchronously and autonomously drive robots using lead and support design.
3. AutoBot can map in real-time by using a combination of methods: YOLO (You Only Look Once) [2], a real-time object detection algorithm, and a 3D mapping technique.

System Design

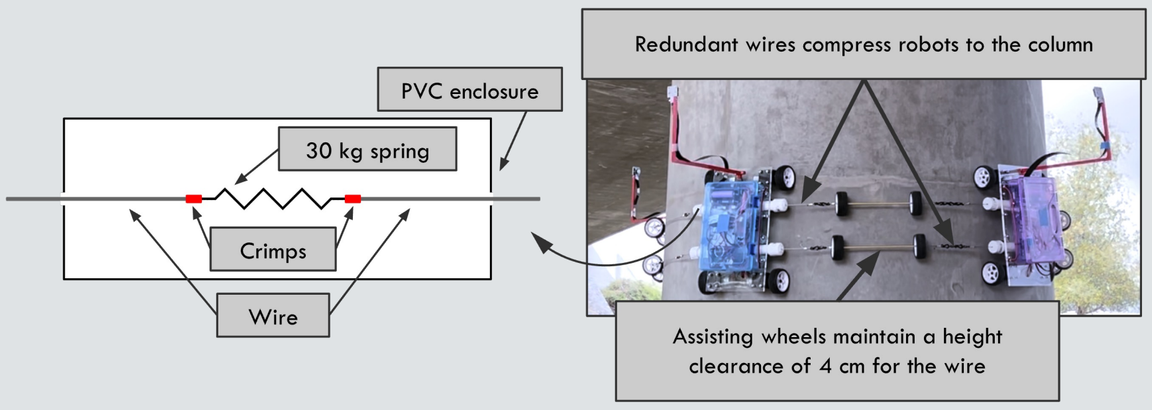

Fig. 1. Diagram of wire retention system and spring module

Hardware Design

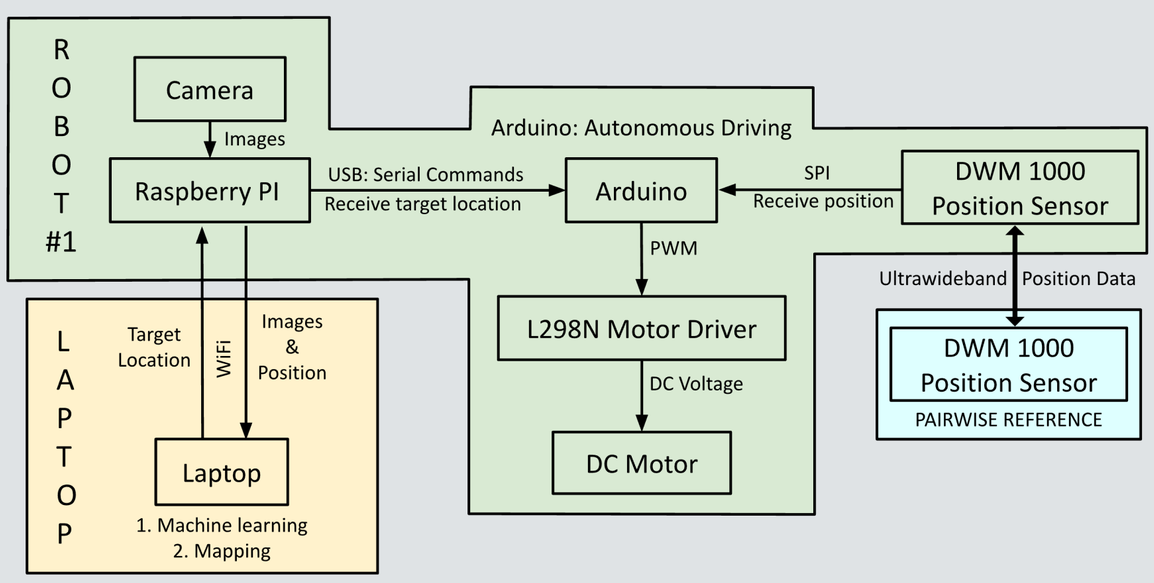

Fig. 2. Diagram of one robot in the AutoBot system; all robots have identical hardware. The system modularizes functionality, with the Arduino, Raspberry PI, and the laptop dividing control.

Driving System Design

- **Lead robot:** PI feedback control with ground reference.
- **Support robots:** uses bang-bang control in reference to leader and minimizes distance from the lead robot

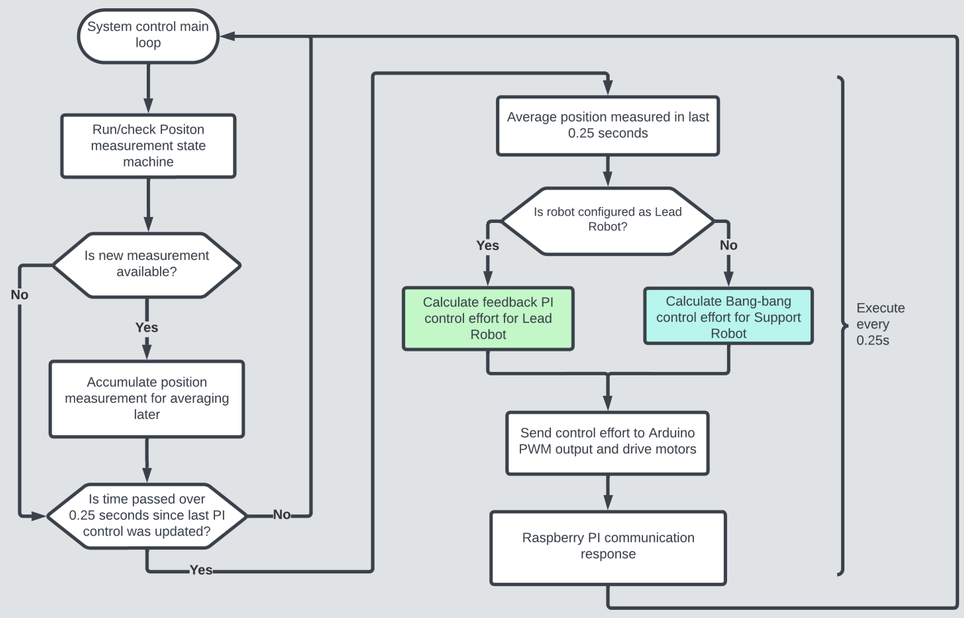

Fig. 3. Robot main driving control loop flowchart dividing PI and bang-bang control effort

Object Detection

- You Only Look Once [2] is the real-time object detection algorithm to locate bounding boxes of cracks in images. It achieved an 82.6% mean average precision.

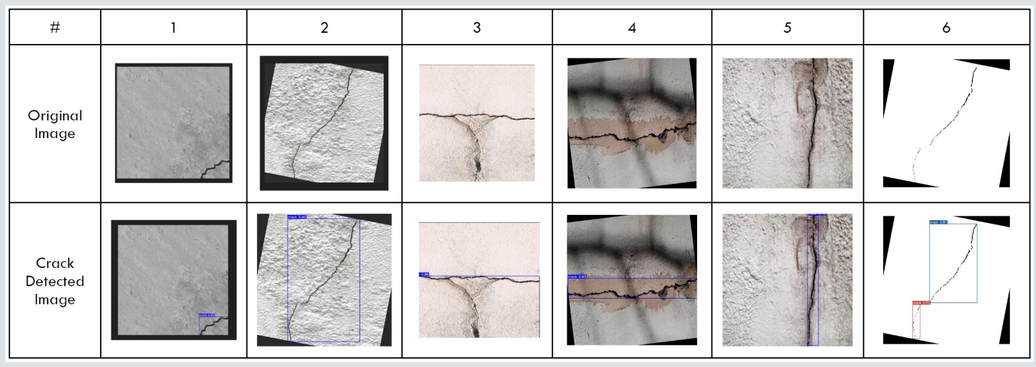

Fig. 4. Example crack detection (images taken from RoboFlow Dataset [3])

- Optimized with ELAN and dimensional anchor boxes.

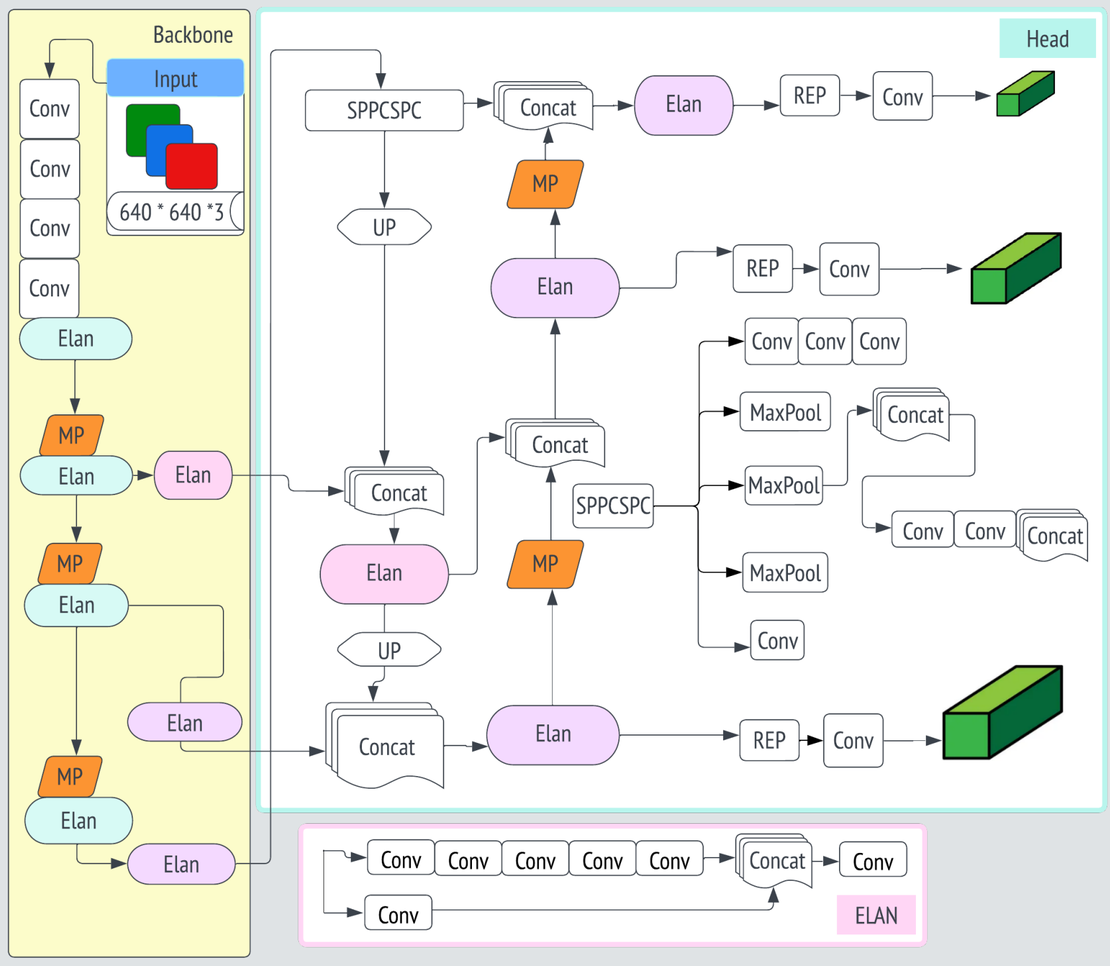

Fig. 5. Diagram of the YOLO architecture created for AutoBot

3D Mapping and Test

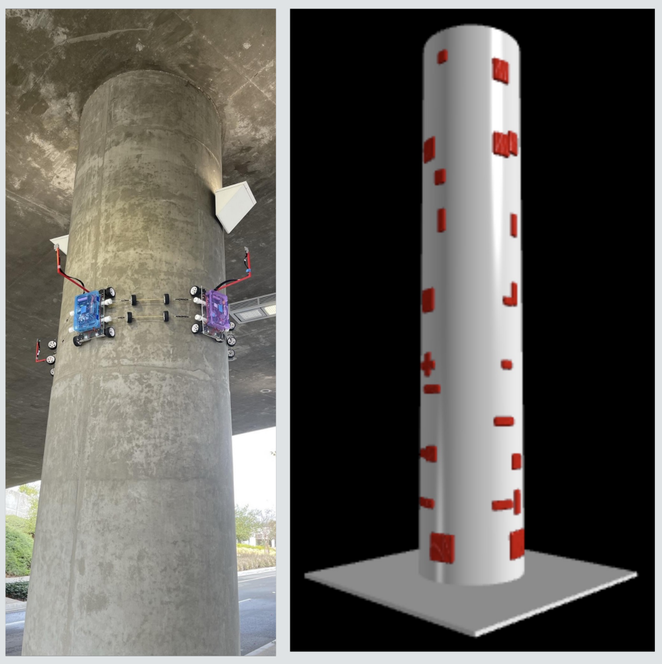

Fig. 6. Real-world tests. Left shows climbing; Right shows mapping

- The mapping algorithm takes 2D bounding boxes and produces a 3D coordinate through overlaying and physical dimension conversion.
- AutoBot was tested on a bridge column 1.33 meters in diameter and 5 meters tall.

Conclusion and Future Application

- AutoBot completed one cycle, defined as the time to climb a meter and map that meter, in 22 seconds. AutoBot climbed at a speed of 4.7 cm/s, and each robot drew a continuous 12 W, making the AutoBot system efficient for long periods of operation.
- The use of robots for bridge inspections can significantly enhance safety. Raw data and analytical results can be stored and reviewed, allowing engineers to track changes. This culminates in comprehensive scientific assessment.

Unless stated, all images are created by me. [1] "230,000 U.S. Bridges Need Repair, New Analysis of Federal Data Finds." ARIBA (American Road & Transportation Builders Association), 12 Apr. 2020. [Online]. Available: http://www.artba.org/2020/04/12/2300000. [2] CY. Wang et al. "YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors". ArXiv, 6 July 2022, 10.48550/arXiv.2207.02696. [3] Dwyer, B., Nelson, J. (2022), Solawetz, J., et. al. Roboflow (Version 1.0) [Software]. Available from https://roboflow.com.