Field Testing and Deployment of Harsh Environment Sensor

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Problem Definition

The health of our infrastructure is an area of growing concern for everyone. As infrastructure ages, it loses its stability and robustness, posing the possibility of sudden and possibly catastrophic faults. Allowing unexpected faults to happen is unacceptable, but constant manual inspections is extremely inefficient and expensive. Additionally, infrastructure such as bridges can often be in locations that are remote and undergo harsh weathering. To prove the viability of an embedded system which constantly monitors structural health, we must develop and deploy such a system which undergoes loads. A parking garage was decided to be the most suitable location for such a deployment.

Motivation

This sensor platform can provide real-time data to monitor the structural health of concrete structures using strain gauges that will measure the load that is being exerted. By leveraging modern microcontroller technologies in combination with traditional analog electronics, we can create a robust system that provides a consistent stream of data. In combination with NuvIoT software, we can deploy a sensor platform that is both very stable as well as modular. NuvIoT also provides a platform that could enable scaling to up any number of devices with different functions and communication protocols.

Proposed Design

Analog Subsystem: The strain gauges are measured with a Wheatstone bridge load cell circuit, which is arranged to amplify changes in a variable resistor. The configuration consisted of two resistors of 100 ohms in positions R1 and R2, a 100-ohm potentiometer and 50-ohm resistor in series (to calibrate the system) in position R3, and the strain gauge of 120-ohm in position Rx. 5V is applied across nodes A & C and the difference in voltage is measured across points B & D. The differential voltage measurement will indirectly measure the resistance of the strain gauge.

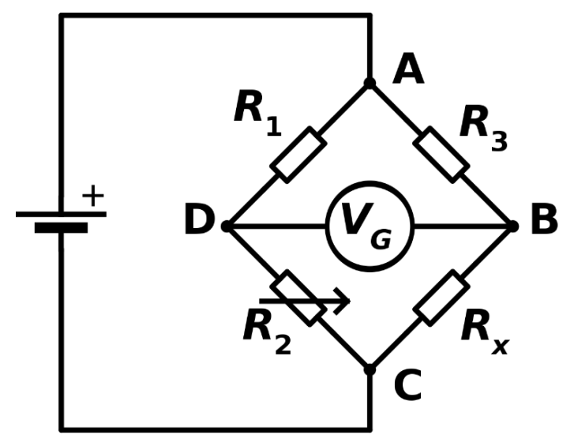

Figure 1. Wheatstone Bridge

Digital Subsystem: The HX711 is a purpose-built 24-bit ADC for reading Wheatstone bridge load cell circuits. Using an ESP32 based microcontroller board we can read and process HX711 data over a serial interface. The ESP32 can then perform any preprocessing needed on the data before sending it to a cloud database via a cellular data module.

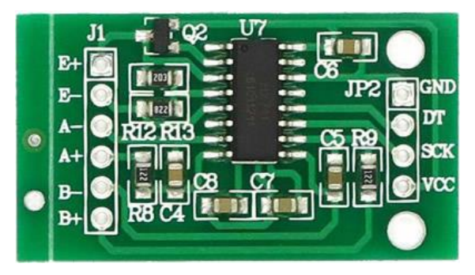

Figure 2. HX711 24-bit ADC

Physical Construction: Electronic componentry is kept inside of a sealed plastic box. Wheatstone componentry and all wire joints are sealed from outdoors with liquid electrical tape.

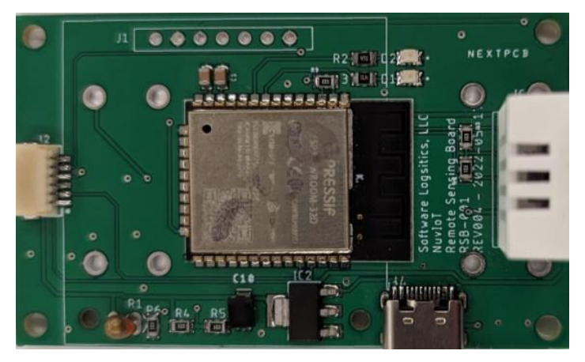

Figure 3. ESP32 Microcontroller

Design Considerations/Methodology

Analog Subsystem: Comparative analysis was performed between two different gauge configurations: Three strain gauges in series compared to a single strain gauge at the same stress point. This determined the practical differences between the configurations.

Digital Subsystem: Derivative of our samples is more relevant to this deployment, and it avoids issues with analog drift. So, we calculate and send the derivative of incoming data using our ESP32 firmware. Integration may be used to regenerate the original data.

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Requirements and Specifications

- Software
  - NuvIoT – Device Management and Configuration Software
  - Device Firmware – Custom Configured for use with NuvIoT
- Communication
  - MQTT – Protocol Used to Transmit Data from IoT Embedded Systems
  - USB UART – Protocol Used to Program and Troubleshoot ESP32 Board
- Hardware
  - BE120-5AA Strain Gauge 5mm – Transducer Used for Strain Measurement
  - HX711 24-bit ADC – Analog to Digital Conversion Subsystem
  - Adjustable AC/DC Power Supply 72W –System Power Supply
  - ESP32 Based Microcontroller Board – Mainboard of Digital System

Simulation Results

After determining that our deployment would be performed at a parking garage, we obtained the dimensions and material specifications of the concrete t-beams of the garage to generate an approximate model of the ramp. Using finite element analysis software, the point of greatest stress/strain were determined.

Using this simulation data, we were able to decide on the optimal positioning for the strain gauges. This ensures that our monitoring platform have the best chance to measure the highest magnitude forces exerted on the structure.

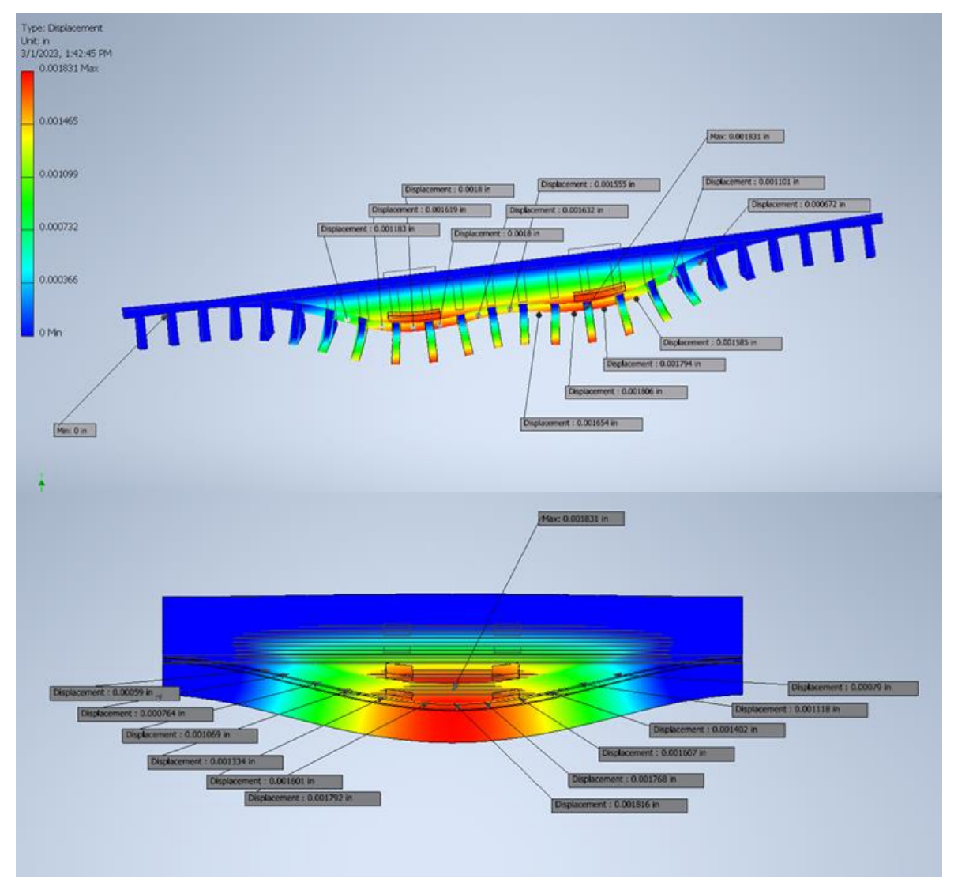


Figure 4. Simulated Stress Analysis

Prototyping

Wheatstone bridge load cell circuit assembled on a breadboard with 5mm strain gauges. The gauge was attached to a cinderblock using concrete-bonding epoxy. A multimeter was attached to the output of the amplified Wheatstone bridge circuit to measure the differential voltage. The circuit reading was then set to read approximately zero using the potentiometer. A vehicle was driven onto the cinderblock, resulting in a positive voltage reading. Consistent readings on the meter confirmed that our circuit produced a signal of acceptable quality and magnitude for our HX711 ADC.

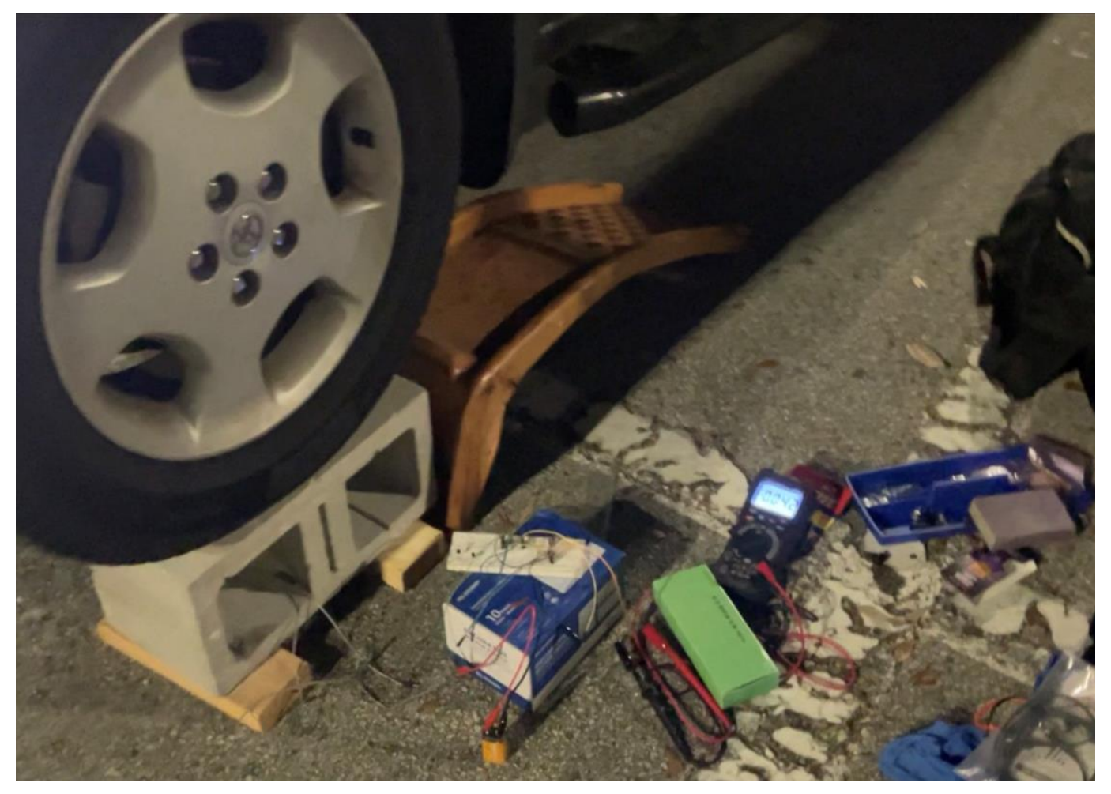


Figure 4. Wheatstone Bridge Validation Test

Testing

The system will monitor the structural health of a parking garage, with permission from Barr & Barr, by observing the deformation in the structure after experiencing the force of a vehicle passing through. To accomplish this, strain gauges are placed on the underside of the first car ramp of the garage to monitor the deformation experienced. The derivative of the sampled data is then calculated and sent to a cloud database where it may be analyzed further to extrapolate patterns and statistical trends.

Analysis of Results

Our data has been processed to determine general functionality of the system. While recording data, the times when there will be the most traffic is assumed to be work hours on weekdays. Comparing this proposition with the actual recorded data we see that our system has the most readings during the expected time, which verifies our system's functionality. The magnitude and frequency of readings may be used to estimate the total stress experienced by a structure over a given period. Further refinement of this system would likely improve the consistency and quality of our data.

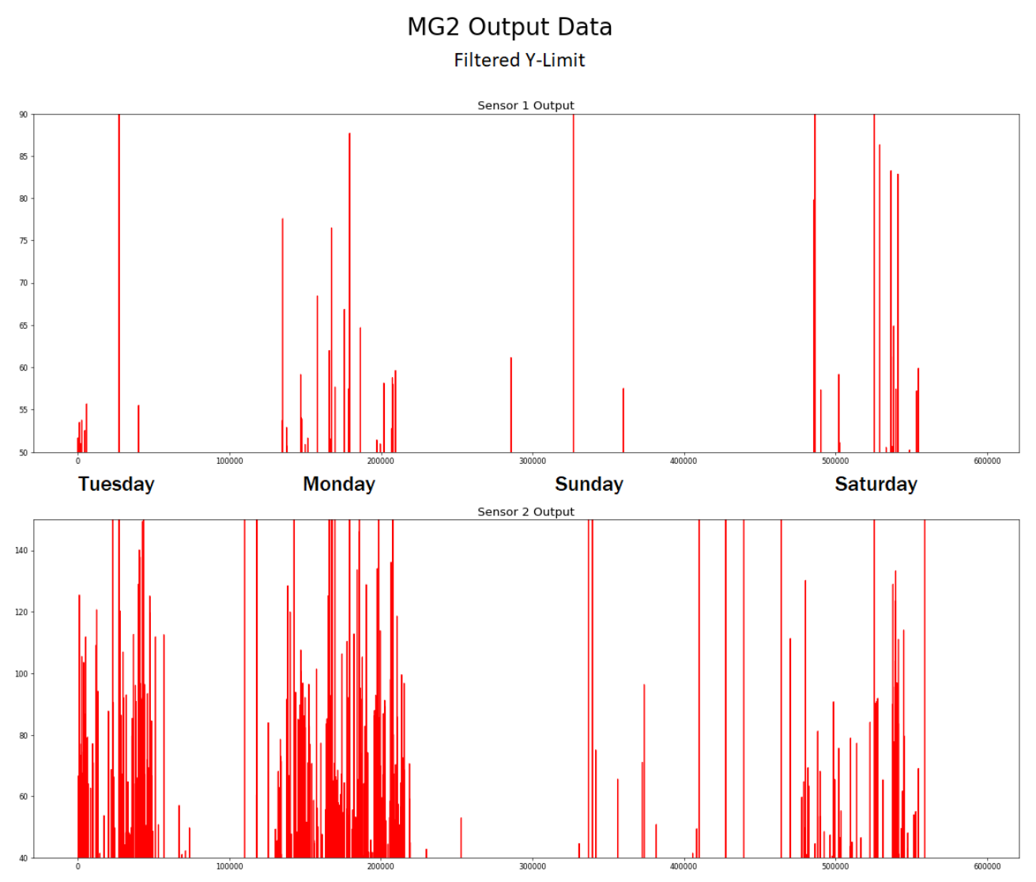
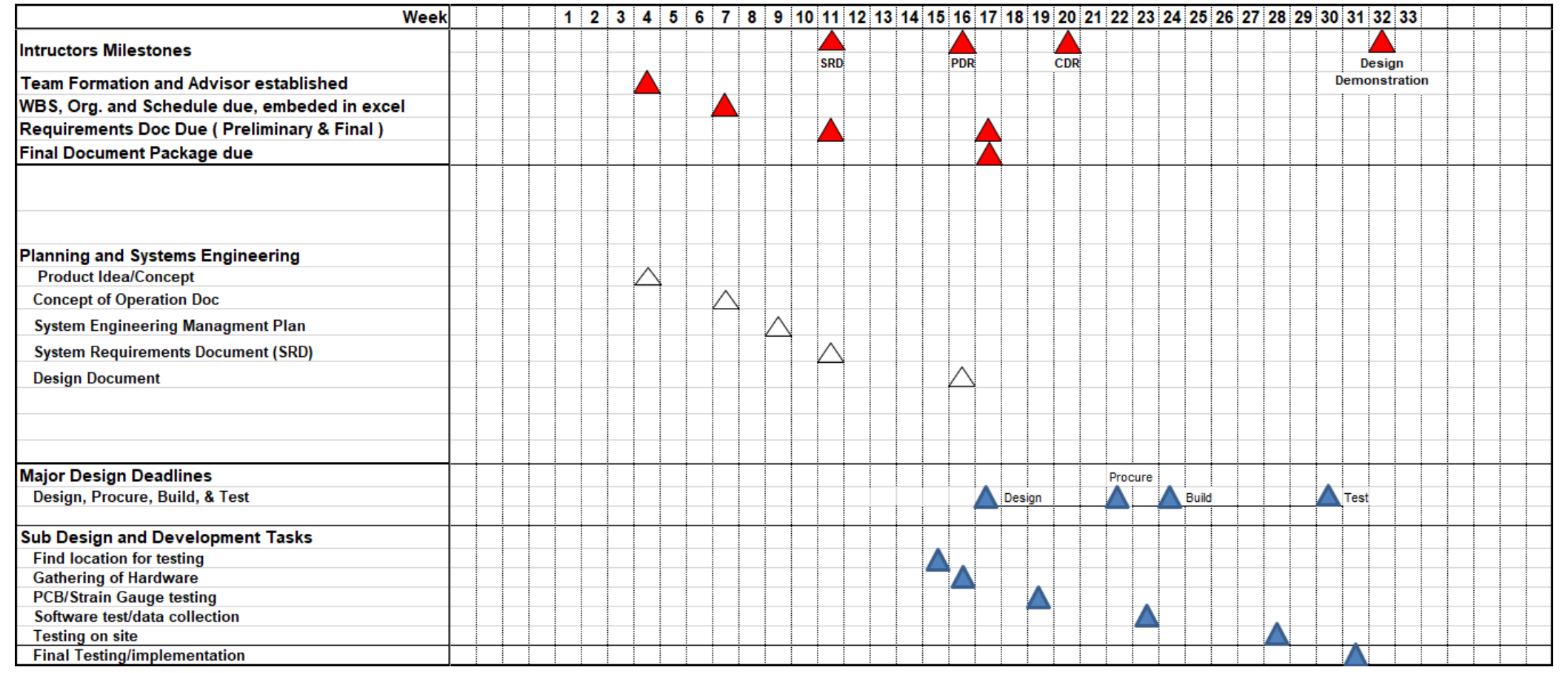


Figure 5. Four Days of Output Data; Weekdays Labeled
Top Graph: 3-gauge; Bottom Graph: 1-gauge

Time-Line



Conclusions

The results demonstrate that the sensor detects vehicles driving across it, as well as the different magnitudes of the cars. After deploying the final iteration of our design, we collected approximately two weeks of valid data. The results also determined that the three-gauge configuration has poorer results than the single gauge, both in terms of noise as well as absolute magnitude of the readings. Further research into the data being collected may be helpful, especially predictive algorithms which may be able to predict faults before they occur.

Work Divisions

Alexander Heisler – Firmware Development, Data Processing, Analog Circuit Design
Karwayne Kelly – Projecting Planning and Management, Correspondence
Greyson Reynolds – Drafting Documents, Recordkeeping, Installation Support
Daniel Garcia – Correspondence, Installation Support, Planning

Acknowledgments

- Kevin Wolf, CEO, Software Logistics
- Paul Scott, Senior Project Manager, Barr & Barr
- Dr. Gray Mullins, Professor, Department of Civil Engineering
- Dr. Arash Takshi, Associate Professor, Department of Electrical Engineering
- Dr. Mia Naeini, Associate Professor, Department of Electrical Engineering
- Shawn Sheng, Student, Department of Electrical Engineering