Development of a Vision-Based System for Displacement Monitoring

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PEER Lifelines Program, Task Order 4
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Agenda

Background & Previous Work

Proposed Solution

Design and Implementation

Lab and Field Tests

Next Steps / Improvements

Background

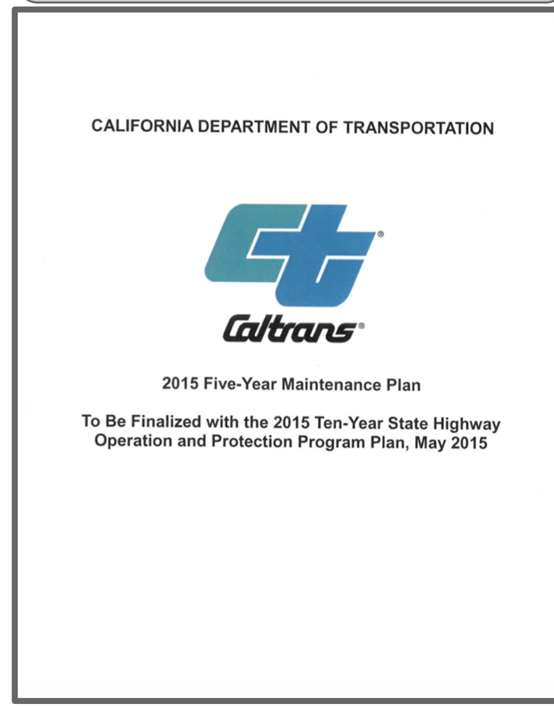
13% of State bridge inventory (1717 bridges) is backlogged

Goal: Reduce backlog to 1090 bridges in 5 years

$450 million over 5 years required

80% increase in bridge maintenance needs since 2005

2015 CalTrans Five-Year Maintenance Plan

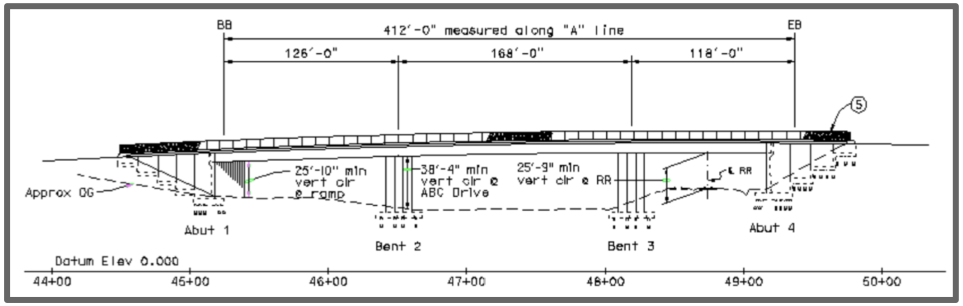

CALIFORNIA DEPARTMENT OF TRANSPORTATION

Caltrans

2015 Five-Year Maintenance Plan

To Be Finalized with the 2015 Ten-Year State Highway Operation and Protection Program Plan, May 2015

Background



Differential settlement (SE): one bent settles and another does not

1 or 2 inches is assumed for foundation design

If geotechnical data indicates SE > 0.5", force effects must be included in superstructure design

CalTrans Bridge Design Practice (2015)

California Amendments to the AASHTO LRFD Bridge Design Specifications (2017 Eighth Edition)

April 2019

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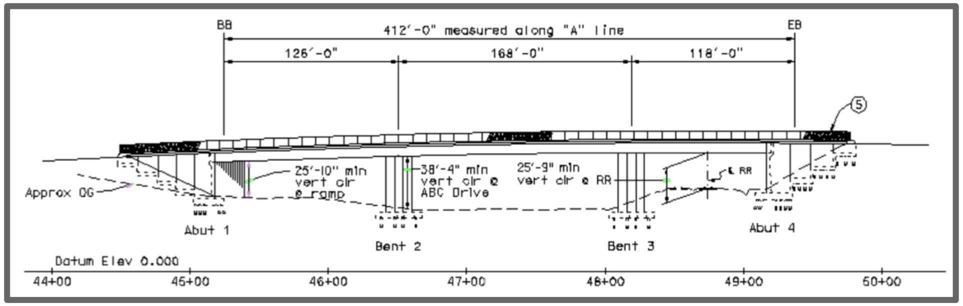
Background



Differential settlement (SE): one bent settles and another does not

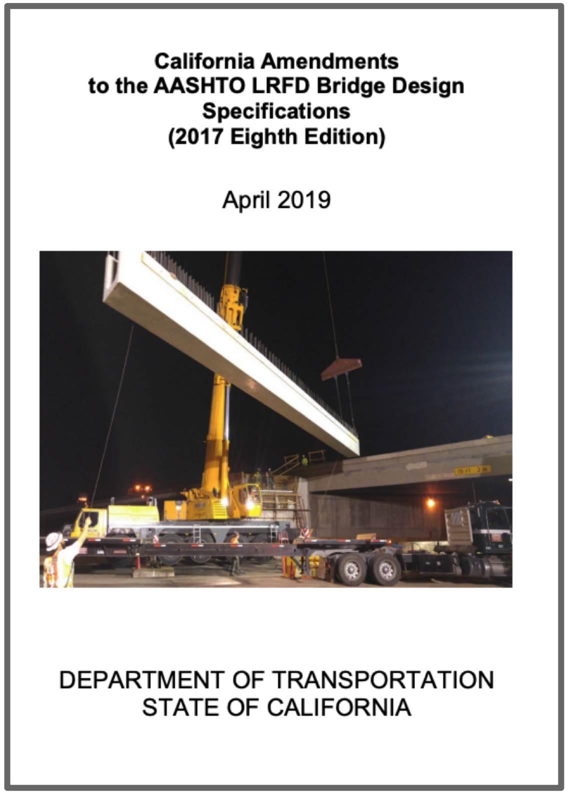
1 or 2 inches is assumed for foundation design

If geotechnical data indicates SE > 0.5”, force effects must be included in superstructure design

If we understand settlement better, we could potentially:

- Reduce design factors
- Accept occasional settlement

CalTrans Bridge Design Practice (2015)



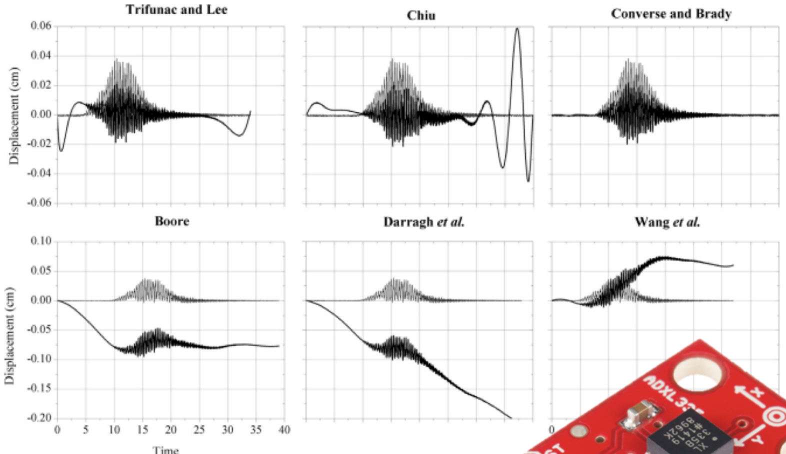
California Amendments to the AASHTO LRFD Bridge Design Specifications (2017 Eighth Edition)

April 2019

DEPARTMENT OF TRANSPORTATION
STATE OF CALIFORNIA

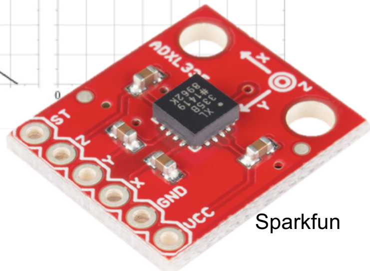
Background

Traditional displacement sensors may not be adequate for long-term monitoring applications

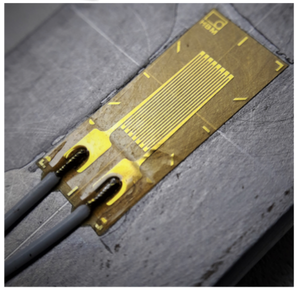


Damaris Arias-Lara, Jaime De-la-Colina (2018)

Accelerometers suffer from integration errors



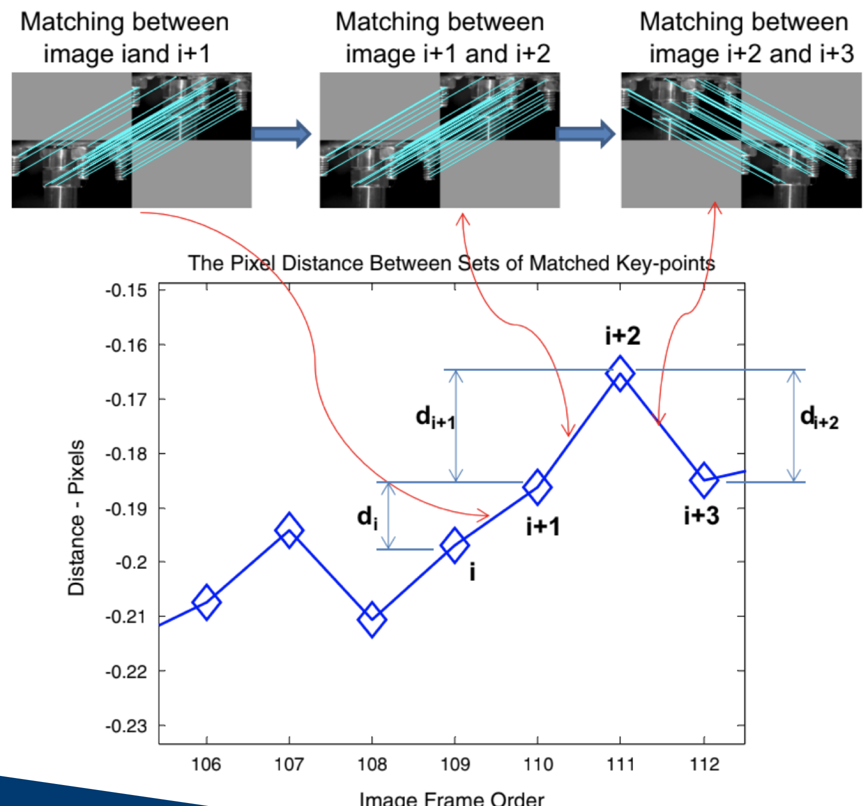
Sparkfun



Contact-type sensors may require in-convenient mountings.

Background

Vision-based systems take a series of photographs, discern the location of a common feature in the series, and track that location through time.



Khuc and Catbas (2017)

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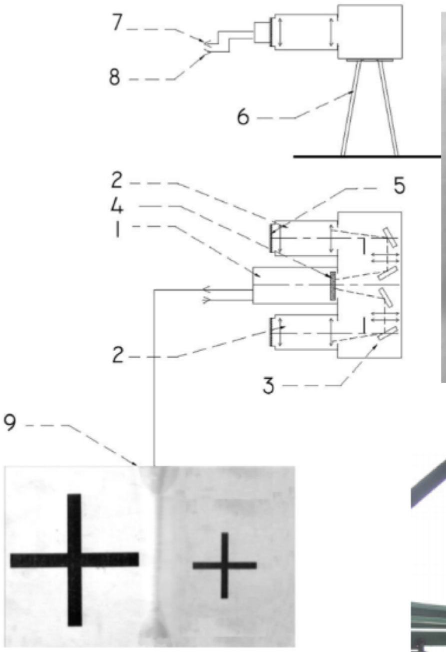
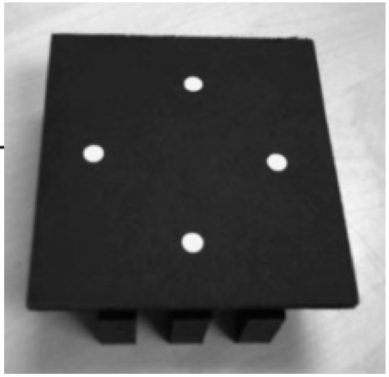
Background

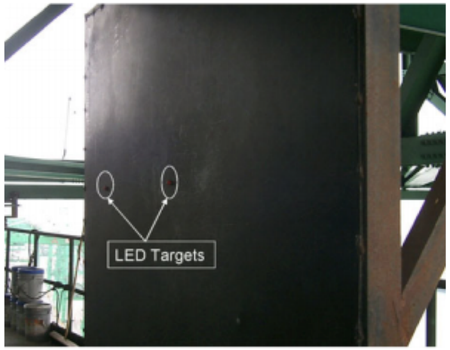
Target-Based Vision Systems



Olaszek (1999)

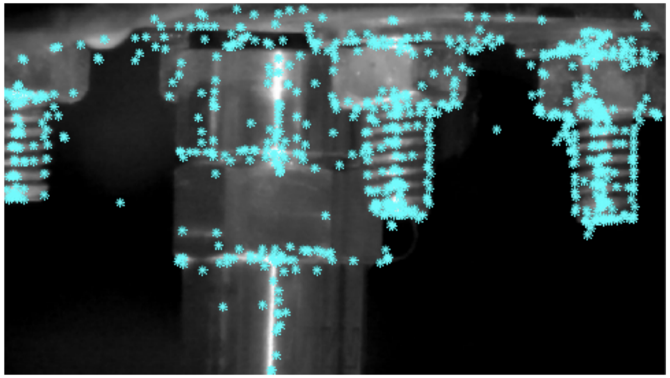


Fukuda (2010)



Wahbeh (2003)

Non-Target Based Vision Systems



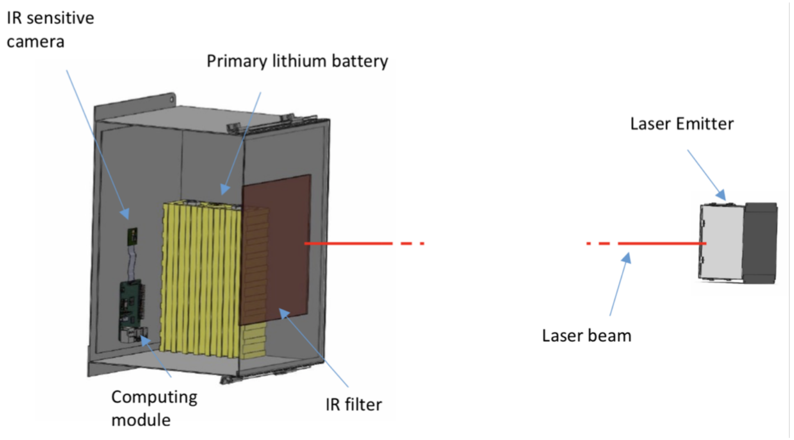
Khuc and Catbas (2017)

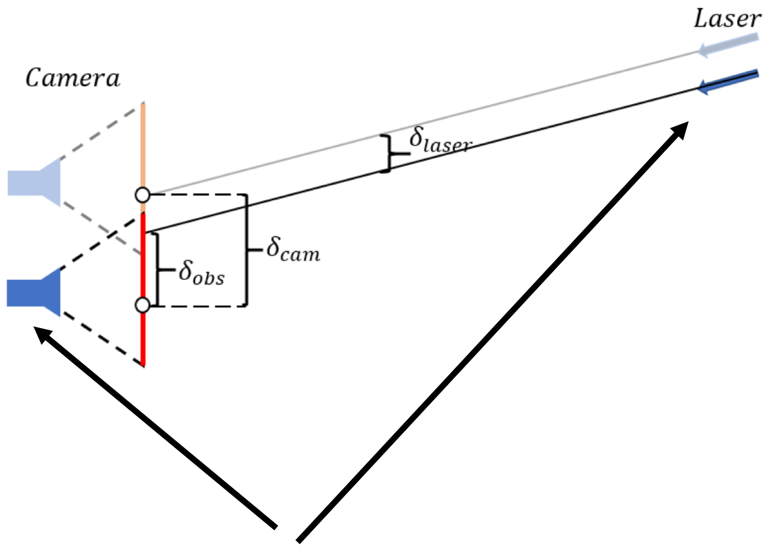
Our Solution

- A camera chamber isolates the camera from the majority of external conditions.
- The camera captures images of the back face of an acrylic screen (filter).
- The laser beam imparts an image on the screen, and the snapshots track its motion through time.

The method perceives settlement only as motion across the acrylic screen.

Has no notion of rotation of either the camera or laser unit, and only tracks relative displacement.





Both the camera and laser unit must be mounted firmly to assume fixed condition

What now?

1. What **product requirements** does the product have to meet?
2. What **"use case"** does the end-user expect from the product?
3. What **hardware** do we use? What sensors, computational units, and communication units?
4. How do these hardware operate? What about **software**?
5. How do we **power** this hardware? What is its power consumption?
6. How do we make it **robust** for field deployment?

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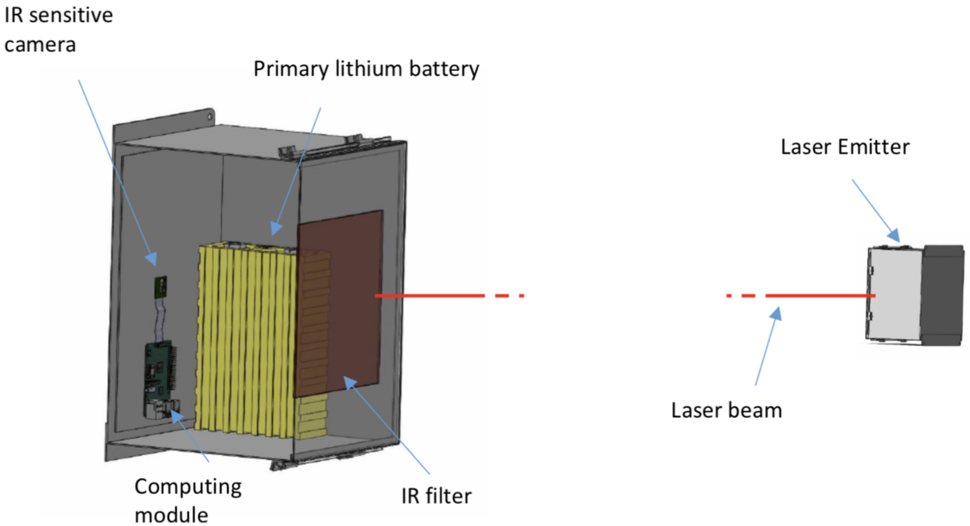
Requirements

Monitor the settlement of foundations of a bridge regularly and report this information wirelessly to decision makers

- Accuracy of 1 mm or better
- Battery life of 1 + years
- Measurement 1/day
- Rugged for field deployment
- Case & ease of installation

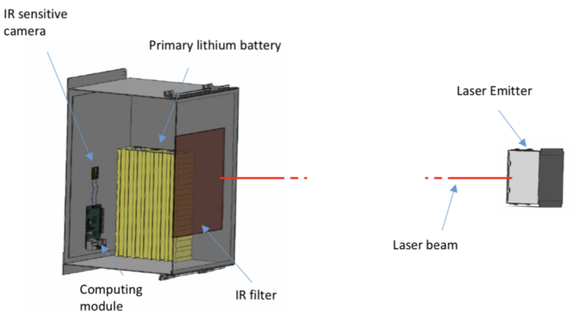


Use Case

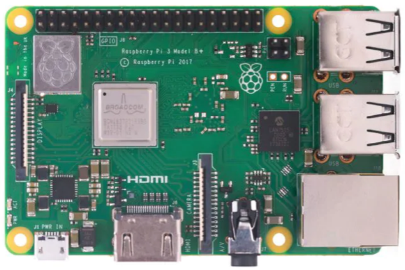
The device will come pre-calibrated, and only require the user to mount onto the structure, align various components, and boot it

1) Upon installation and initial boot up, **begins in idle state**
2) System, comprised of both a laser & camera module, stay in idle until a **measurement request signal** is received
3) Signal is transmitted from the **off-site server**, and triggers the computational units to **commence measurement tasks**
4) After measurement tasks are completed, both modules **return to idle**.

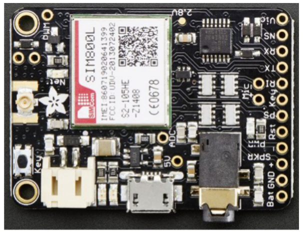
Hardware



Camera Module



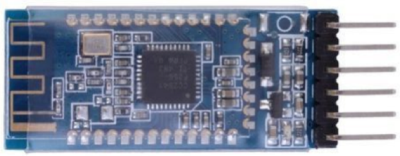
Raspberry Pi 3B+



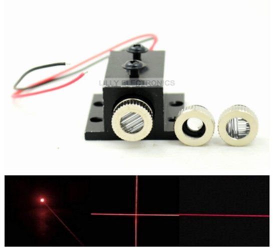
Adafruit FONA GSM Cellular Board

Raspberry Pi Camera v1.3

Laser Module

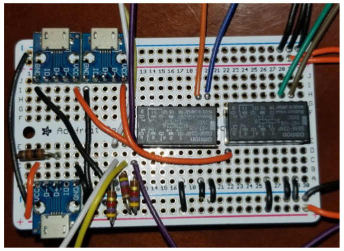


HM-10 Bluetooth Low Energy Transmitter/Receiver

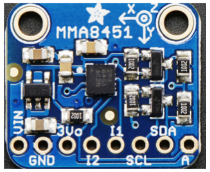


100 mW cross-hair laser

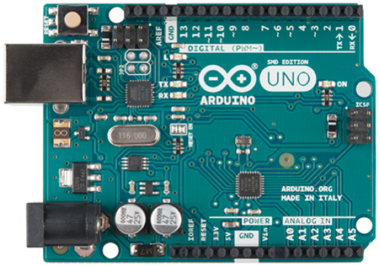
Both Modules



Custom-made relay circuit board



MMA8451 Triple-Axis Digital Accelerometer



Arduino UNO Rev3

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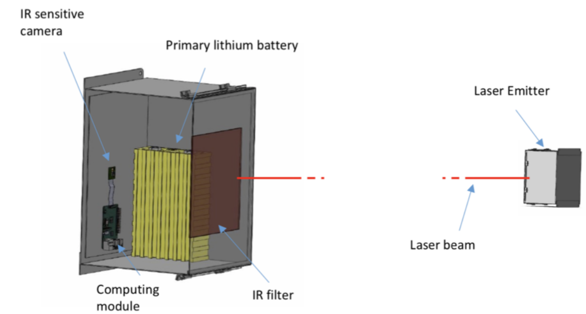
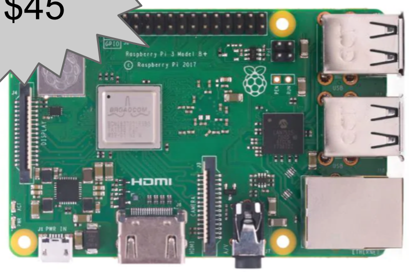
Hardware



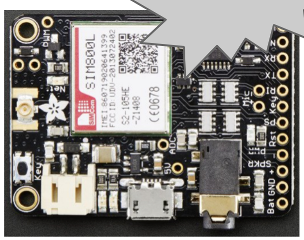
Camera Module

$45



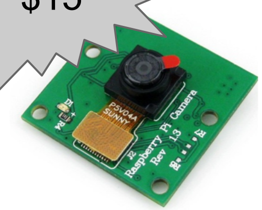
Raspberry Pi 3B+

$80



Adafruit FONA GSM Cellular Board

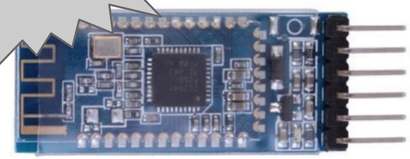
$15



Raspberry Pi Camera v1.3

Laser Module

$10



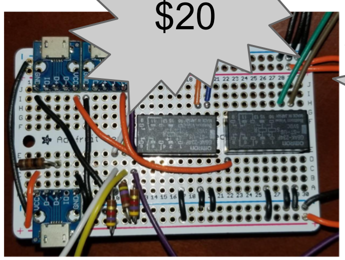
HM-10 Bluetooth Low Energy Transmitter/Receiver

$50

100 mW cross-hair laser

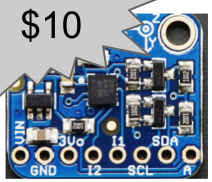
Both Modules

$20



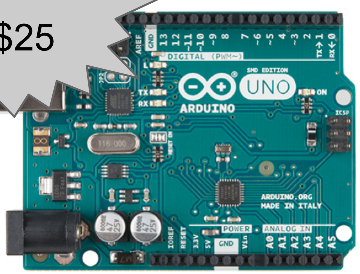
Custom-made relay circuit board

$10



MMA8451 Triple-Axis Digital Accelerometer

$25



Arduino UNO Rev3

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Embedded System Design

An embedded system “tied” hardware together to implement the system architecture.

Features:

- Asynchronous code between Camera & Laser modules ensures correct **BLE communication between modules**
- Robust operation ensured by **error catching of runtime errors**, resulting in **non-fatal program execution**
- Data not transmitted to the server over 2G is **saved and transmitted** the next time a measurement is taken

Power Consumption

Average power consumption of the camera module is: ~4 Ah/day → 2 x 10W solar panels, which generate ~15 Ah over 3 days** + 12 Ah battery	The average power consumption of the laser module is ~1.5 Ah/day → 1 x 10W solar panel needed * + 12 Ah battery

**Assumes 5 hours of peak-sun every day, with average power generation of 0.5 A @ 5V*

→ In worst case, camera module lasts ~3 days, laser module lasts ~7 days

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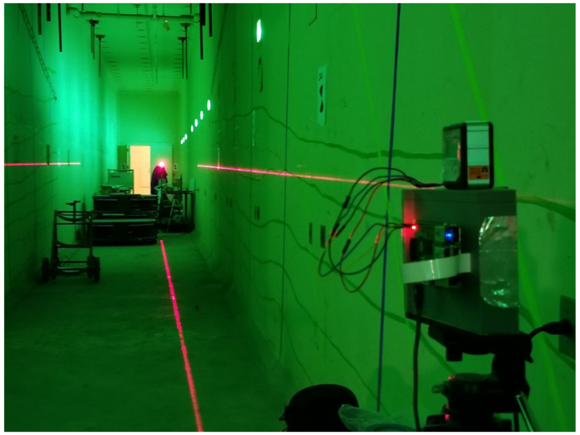
Lab Tests

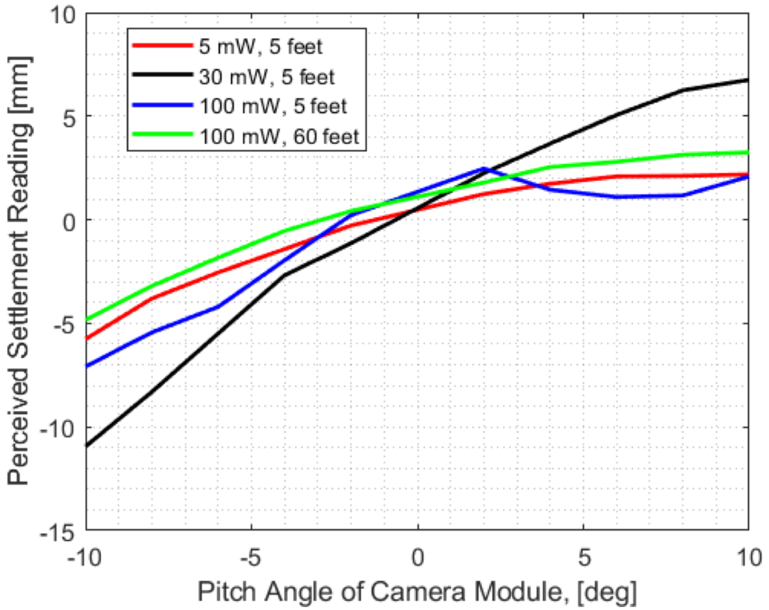
Controlled lab tests were performed to verify the accuracy of the prototype.

Realized the following conclusions:

1) **Submillimeter precision was achieved** *given specific laser and camera settings* **at 60 feet**
2) **Camera tilt** contribution to displacement measurement **is nontrivial**



Lab setup: 3D printed camera enclosure on tripod



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Outdoor Enclosure Design

Hardware housed in a commercially-made utility box. The box has a NEMA 3R rating, which guarantees the following:

1. Protects the components from the ingress of **solid objects**, such as fingers and falling dirt
2. Adds protection against the ingress of **dripping and splashing water, rain, sleet, and snow**
3. Will be **undamaged by ice forming** on the enclosure

Custom mounting fixtures cut from sheet acrylic to mount hardware within the utility boxes

Camera Module

Laser Module

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Field Testing

Camera unit

Laser unit

Measurement in progress

Solar Panel Mountings

Field Testing

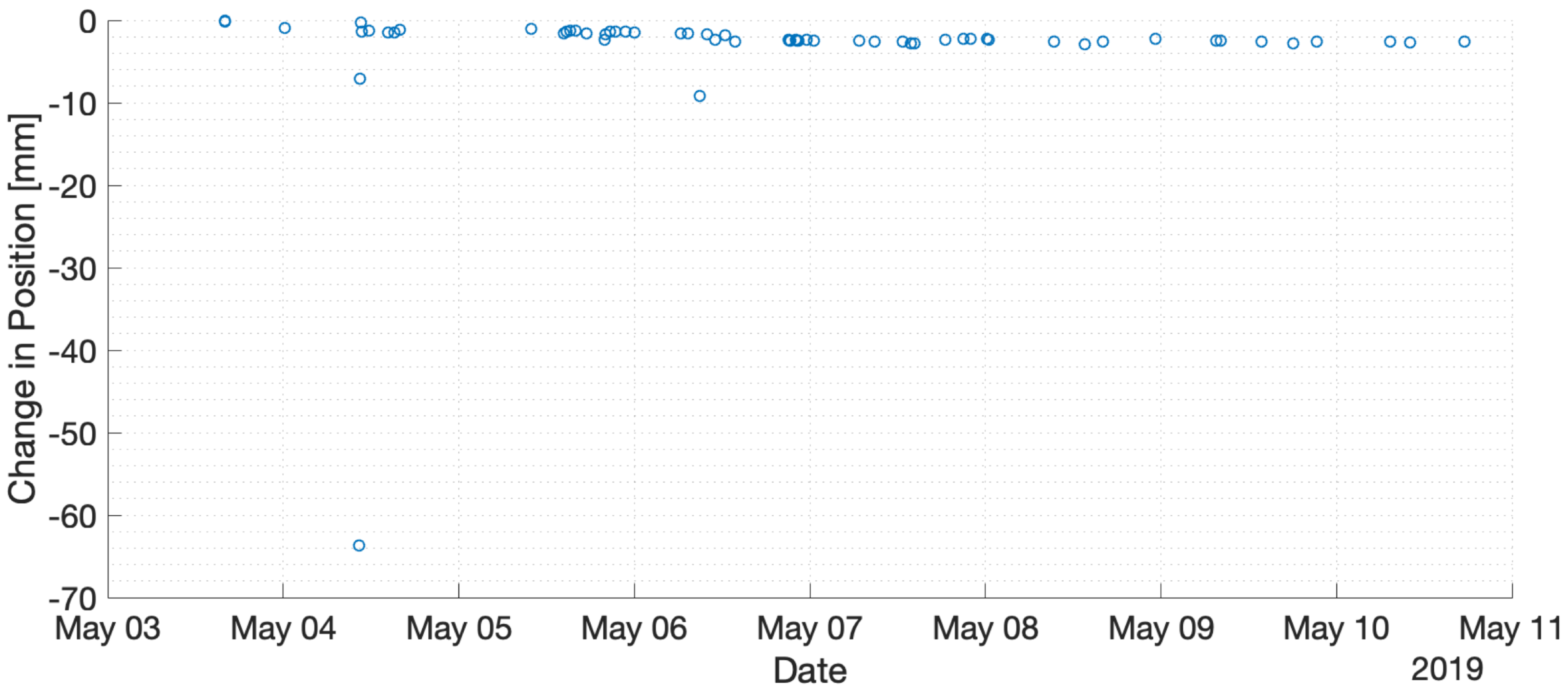
This system was deployed for a week.

Limitations:

- **Data transmission** over 2G **impeded** by vegetation and installation location relative to bridge

- Transient **light disturbances** on the camera screen were filtered out, but **not steady-state disturbances**, e.g. reflections of the laser beam on the screen, direct sunlight on screen

Field Testing



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Next Steps

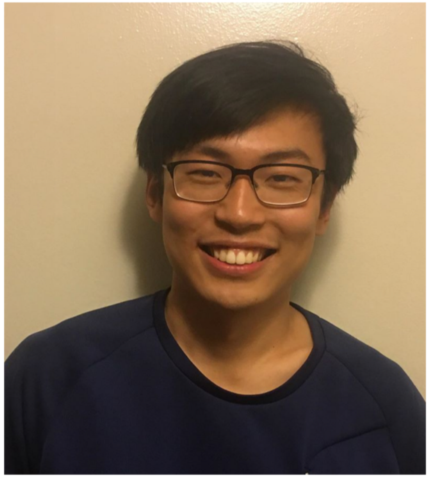
Prototype Improvements

- Reduce power consumption
- Extend inter-module range
- Improve remote communication (2G)
- Add more user accessibility features
- Reduce hardware form-factor

Long-Term Directions

- Investigate ambient light impacts on image feature extraction
- Explore other laser options (e.g. 4 dots, instead of a cross-hair)
- Incorporate tilt data more effectively (e.g. correct displacement measurement with tilt readings)

UG/GR Team



Albert Qu

UG: Computer Science & Cognitive Science, B.A. 2020

Computer vision & website/server

Henry Teng

Civil Engineering, UC Berkeley, B.S 2017, M.S. 2019

Embedded system design & implementation, Testing & Deployment

Wyeth Binder

Civil Engineering, UC Berkeley, B.S. 2019

Enclosure design & fabrication, Testing & Deployment

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