Laser-Based Settlement Measurement of Bridges for Improved Decision Making

PEER Lifelines Program

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Objectives & Features

We build a system to monitor the settlement of bridge foundations, and report wirelessly to decision makers. A successful project is one that has **sub-millimeter accuracy**, **battery life of 1+ years**, is able to take **daily measurements**, is **rugged for field** deployment, is **cost effective**, and is **easy to install**. Out of these specs, our team has established additional requirements for our system:

1) Ability to access current & stored data through website
2) Remote measurement request via website
3) Power supplied via lithium battery & PV panels

A laser module shines a beam onto a camera module. We assume no rotation of the camera, and will "blindly" measure a vertical displacement (see Fig 1).

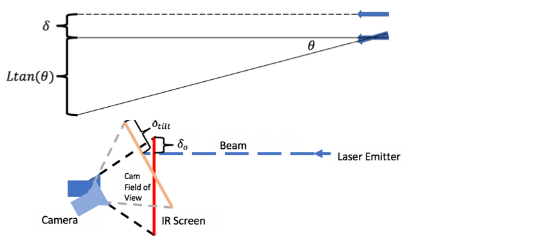
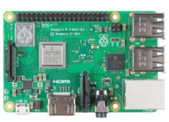


Fig 1: Effects of Tilt of Receiver or Emitter on Displacement Measurement

Hardware Components

We employ a Raspberry Pi and Arduino as our microcontrollers, with various sensors & modules for data collection & communications:



Raspberry Pi 3B+
ARM Cortex A53 processor: 64 bits, 1.4 GHz
1 GB SDRAM
Bluetooth 4.2 & Low Energy

Arduino UNO Rev3
ATMega328P microcontroller - 8 bits, 16 MHz
32 KB SRAM

Adafruit FONA
Cellular GSM breakout
2G SIM Card (TING)
"RING" interrupt

HM-10 BLE Module
UART Compatible

MMA8451 Accelerometer
3 axis, 14 bit, +/- 2,4,8 g

Raspberry Pi Cam V1.3
5 MP Camera

Crosshair Laser
Various strengths/power ratings

Approach & Implementation

To meet our objectives, we employ the architecture in Fig 2:

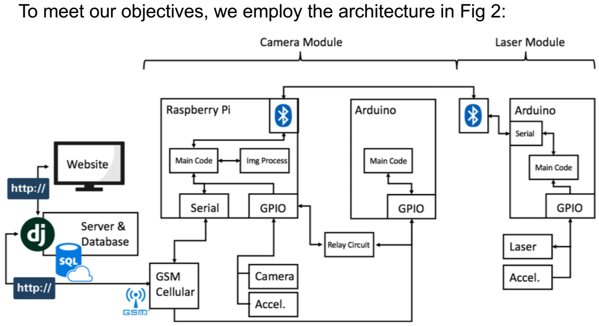


Fig 2: Overall System Architecture: Components and Communications

The cam module contains a RPi for high computation demands, and an Arduino, which turns the RPi on/off to conserve power upon a request received by the GSM module from the server.

The laser module includes an Arduino, which is perpetually on to ensure system responsiveness upon a measurement request.

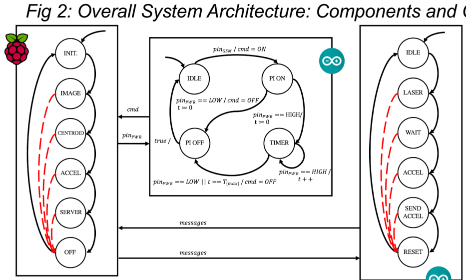


Fig 3: State Diagram for System Behavior

The two modules pass messages over BLE, and the RPi pushes data to the Django server over GSM using HTTP protocols. The Django server communicates with the website over HTTP.

In Fig 3, note that the RPi talks to its Arduino for power control, and to the Laser Arduino to coordinate measurement tasks. All timing is abstracted up to the server.

Computer Vision Algorithm

To achieve reliable submillimeter precision in determining the center of a crosshair beam, we developed a image processing and centroid estimation algorithm, as illustrated in Fig 4.

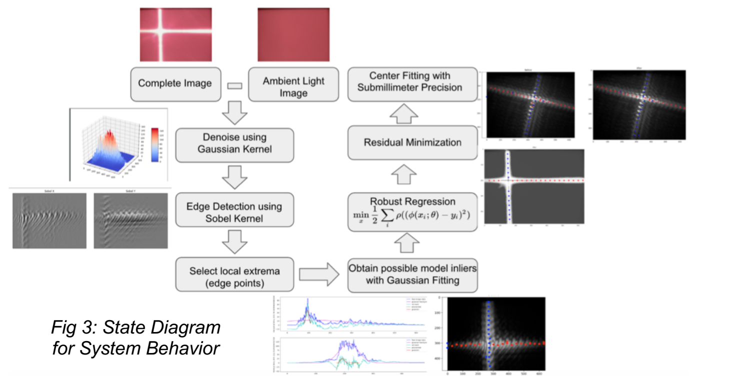


Fig 3: State Diagram for System Behavior

To reduce the impact noise & artifacts, we take two photos with every measurement (one with no laser beam), subtracting the baseline photo from the complete photo. Under ideal conditions, this algorithm achieves measurement error of 0.3 mm.

Calibration & Evaluation

The calibration value [inches/pixel] of our cam module is exclusively a function of its geometry. They are found by fixing the position of the beam, while shifting the camera module up/down. A simple linear regression of $\Delta Pixels/\Delta Elevation$ completes the calibration.

For a screen of **height 6", the resolution is 0.23 mm/pixel**. For a screen of **height 4.5", the resolution is 0.16 mm**

Additional evaluation was done by shaking test to evaluate system durability and accuracy, and different mounting configurations. A soil box was shaken to induce vertical settlement of a 6" diam. concrete cylinder. The laser module is mounted in a fixed reference frame, and the camera is mounted on top of the "pile." See Fig 4 and 5 for experimental set up.

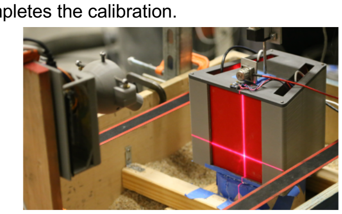


Fig 4: Device Mounting (Shake Table Test)

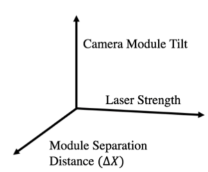


Fig 6: Lab Test Parameters

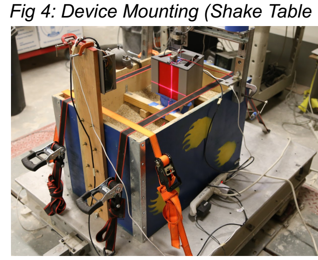


Fig 5: Soil Box Setup (Shake Table Test)

Subsequent Steps and Experiments

Preliminary tests lead to a new lab testing matrix, seen in Fig 6, which will explore 1) the limits of camera module tilt influence on the reading, 2) the influence of using a strong laser, 3) the limits of the distance separating the two modules, as well various intersections of the three, such as at what distance the computer vision algorithm fails, and a stronger laser is required.

As a proof of concept of the field deployment and wireless capabilities of our system, we anticipate deploying our final iteration across wooden foot-bridges on UC Berkeley campus (such as the one in Fig 7).

Fig 7: Foot Bridge, UC Berkeley

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