Micro-UAV Platforms for Structural Health Monitoring and Inspection

Usman Khan
Dept. of Electrical and Computer Engineering, Tufts University

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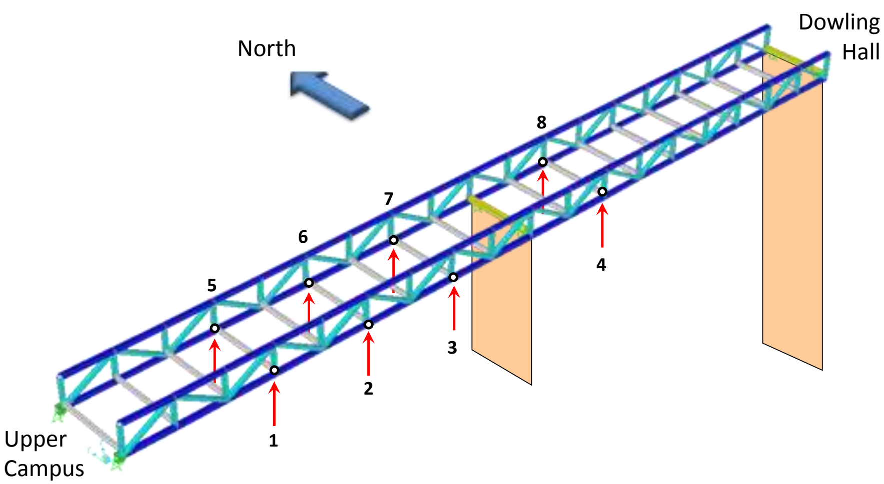
Tufts University School of Engineering

Dowling Hall Footbridge

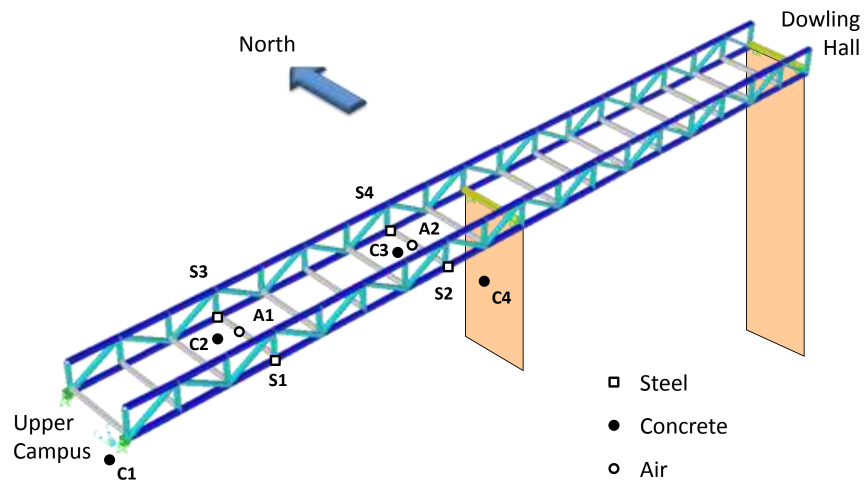
- Length: 44m, width: 3.7m
- 2 spans: supported by an abutment and 2 piers
- Steel frame, reinforced concrete heated deck

Monitoring System

- Eight accelerometers

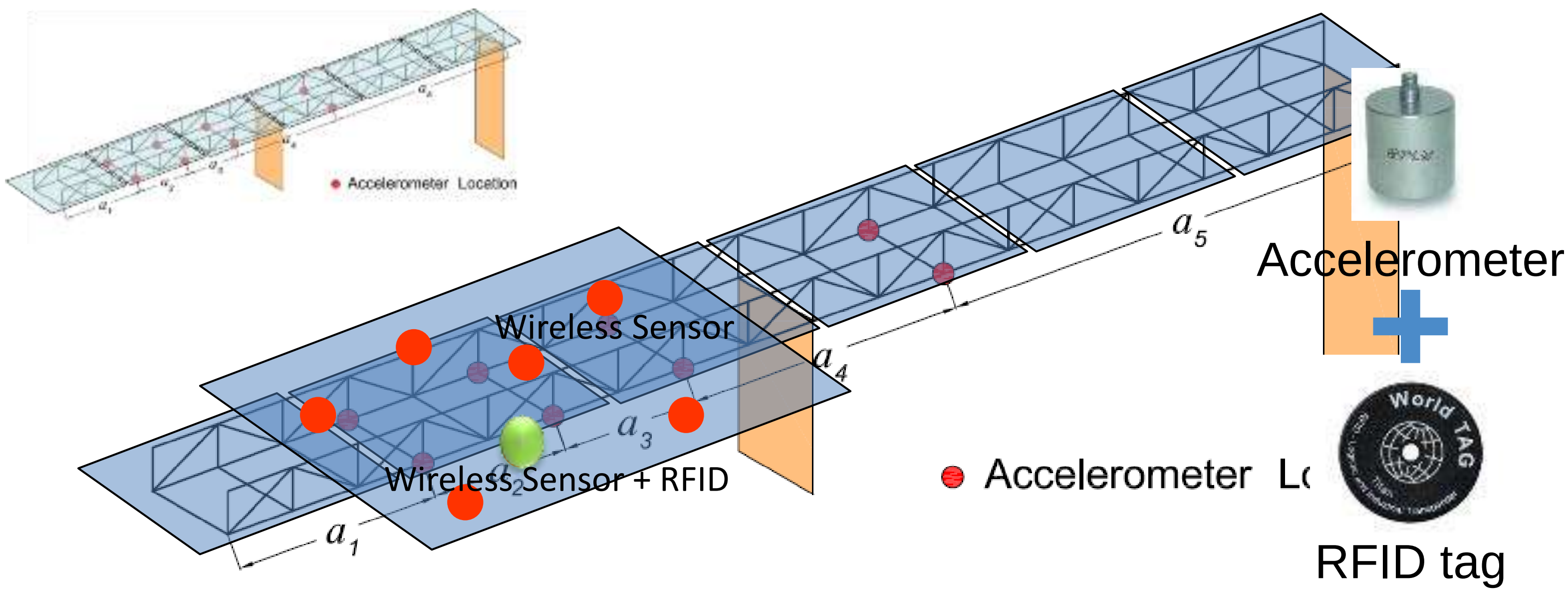


- Ten thermocouples



- Records 5-minute sample each hour or as triggered
- Data transfer via wireless bridge
- Automated modal identification based on hourly data

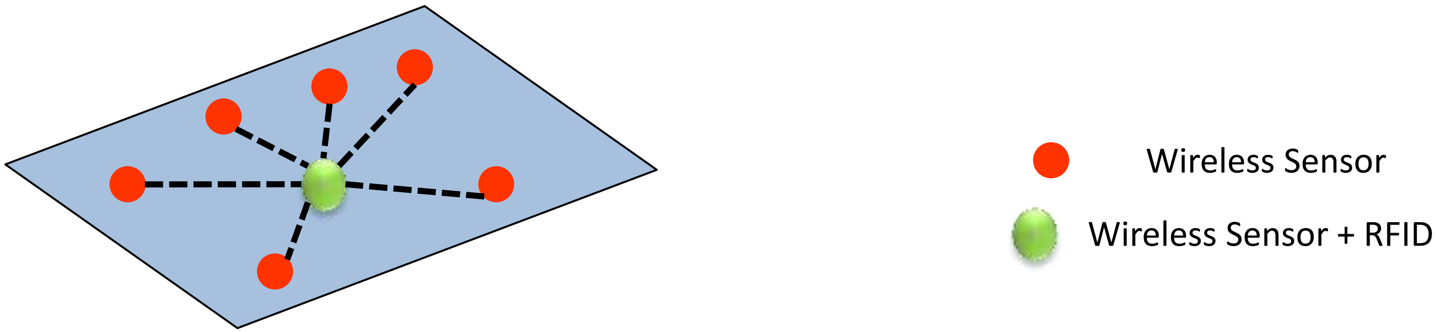
Proposed Approach: Wireless sensors



- Divide the bridge into distinct sub-structures
  - Instrument each component with several sensors
- Equip a local leader with an RFID tag

Proposed Aerial Approach: Low-power

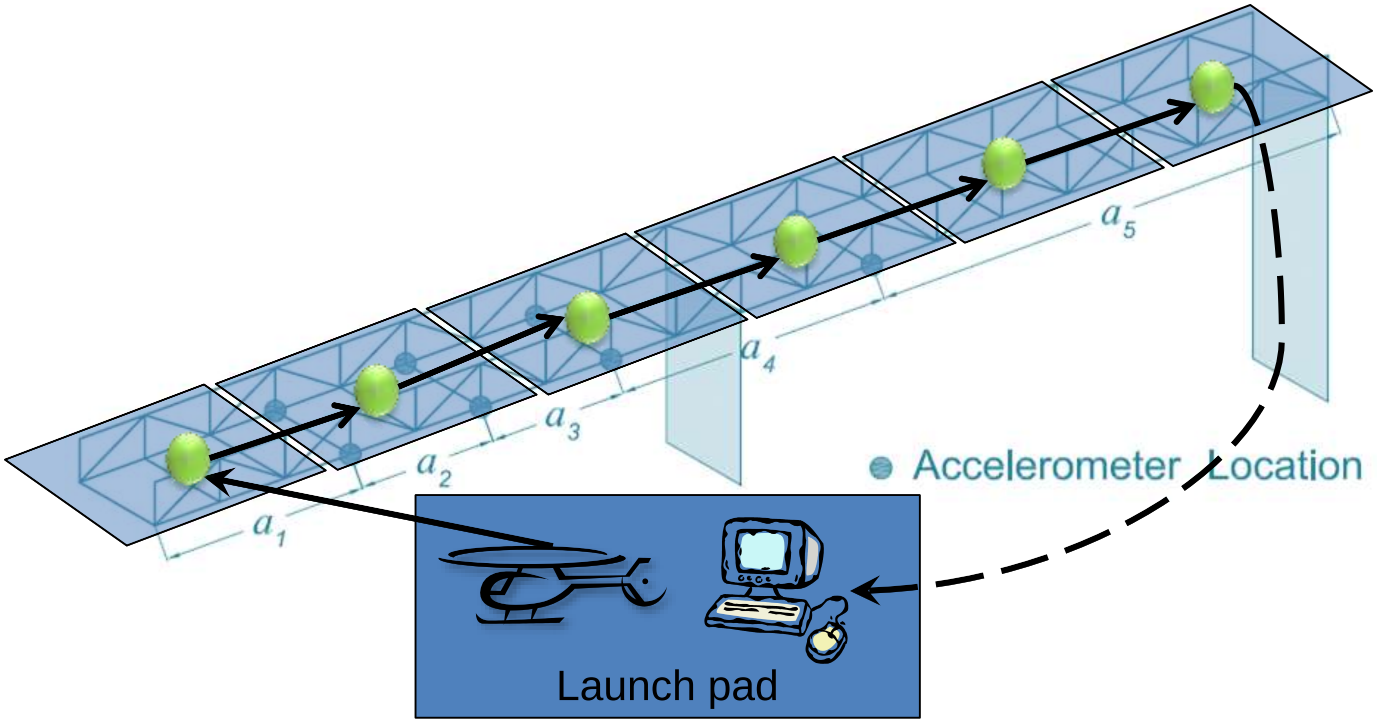
- Sub-structure dimensions ~3m-5m



- Each sensor
  - wakes up every X (=6hrs) and collects data for Y (=5mins)
  - computes a local feature (peak, amplitude of PSD) from time-series
  - transfers the features to **the local leader** over **short-distances**

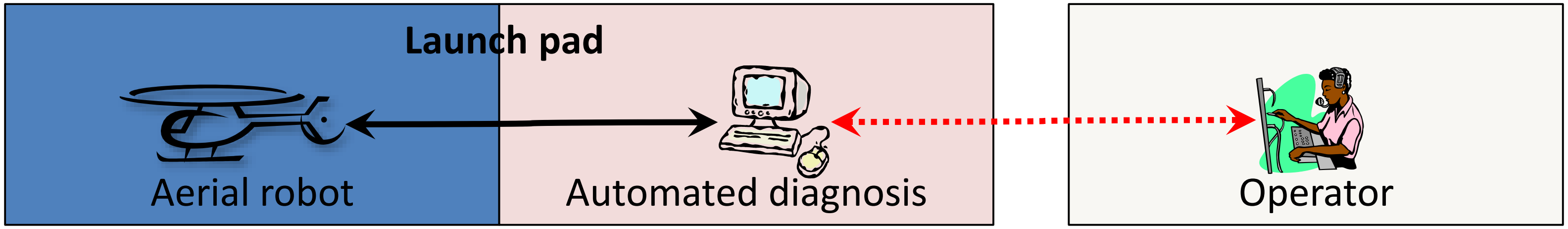
- At the end, the leader writes the relevant statistic on the RFID

Proposed Aerial Approach: Data collection



- Each sub-structure has a local leader with an RFID tag
- A quad-copter **self-navigates** to each RFID tag and collects data

A Practical Deployment



- Launch pad terminal issues instructions based on processed data
  - to the aerial robot
  - (warnings) to the operator

- Operator may also access the terminal to modify the instructions

- Instructions
  - Sensor programming, wake-up and data collection times/intervals
  - Key locations where to take **images**

Aerial Robot Prototype at Tufts

- AR.Drone quad-copters
  - $300, 12 minutes flight time
  - Available at toy stores

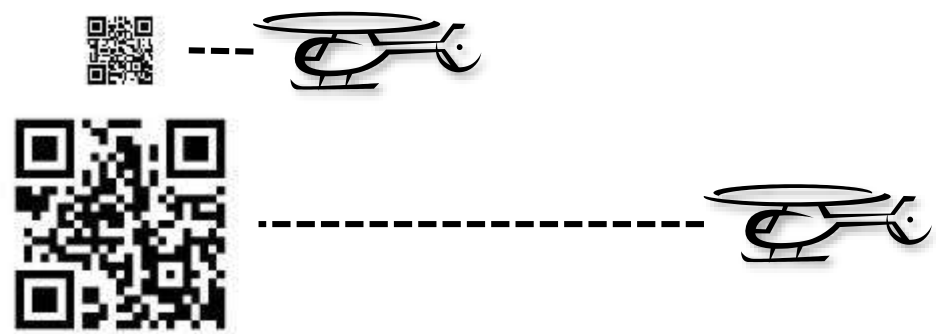
- RFID readers are mounted via a **microcontroller**
  - Arduino $33; Reader $50

- Quad-copters navigate to RFIDs
  - RFID tags $2.50

- Total cost ~$400 with 10 tags

Self-navigation

- Visual markers, QR codes
  - Varying sizes and shapes
  - Each code is distinct
- Larger size for long-range navigation
- Smaller size for use short-range navigation
  - close-in on the RFID tags



- Proof-of-concept demo:
  - http://www.youtube.com/watch?v=0AuF_Xj_Xms

Demos

- Proof-of-concept demo:
  - http://www.youtube.com/watch?v=0AuF_Xj_Xms
  - Demo from the bridge

- Target tracking

Proposed Aerial Approach: Key features

- Sensors only require power for
  - **short-range communication**
  - **intermittent sensing**
  - **low-order computation**

- Local leaders, in addition, require power to write RFID tags

- RFID tags **do not require power** to transmit data

- The quad-copter flushes the tag when the data is read so the local leader can subsequently flush its memory etc.

Proposed Aerial Approach: Key features

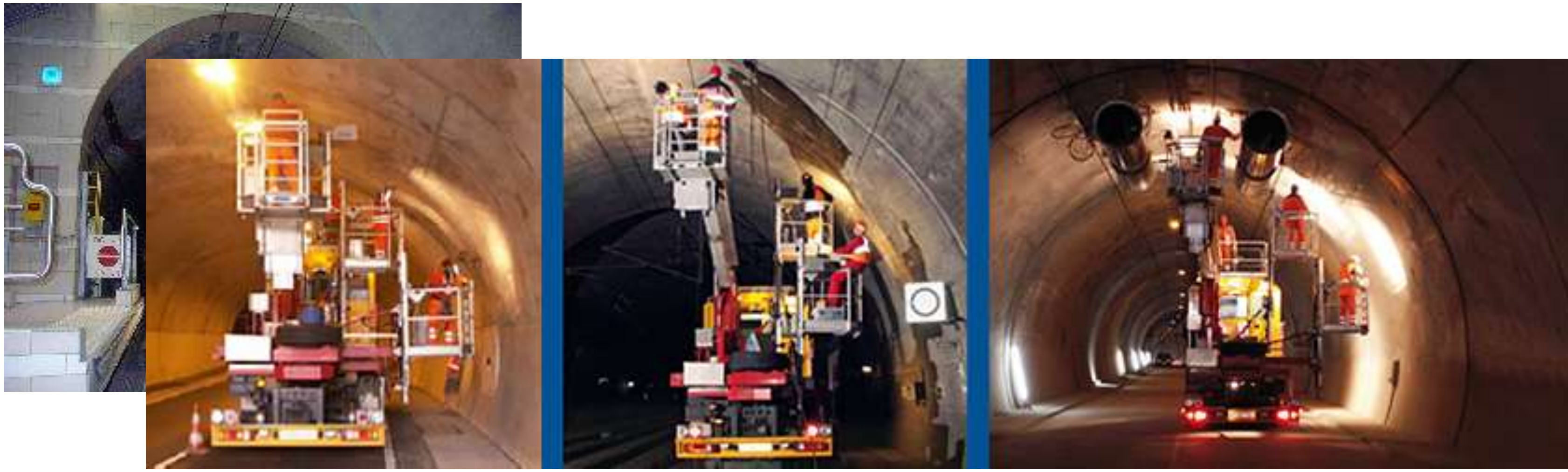
- The statistics computed by local leaders enable **sub-structure level** diagnosis

- This information will be fused with the image data from the aerial robots to localize damage at the structural component-level (joints, beams, columns)

Bridge/Tunnel Inspection

- **Visual inspection** is the primary method used to evaluate the condition of the majority of the nation's highway bridges
  - http://www.ndt-ed.org/AboutNDT/SelectedApplications/Bridge_Inspection/Bridge_Inspection.htm
- Texas DoT awarded $28 million contracts over 2007-2009
  - http://www.sao.state.tx.us/reports/report.aspx?reportnumber=10-017
- FY2012 budget for bridge inspection, $324 million per year
  - http://conferences.wsu.edu/forms/bridge/2011_pres/1A.pdf

Bridge/Tunnel Inspection



- Lane closures

- Proposed—self-navigating robots can automate inspection
  - Monitor paint flakes, corrosion, cracks, bearings, images of key structures
- Does not require any human intervention, lane closures
  - Periodically repeated at pre-specified intervals

Sensor Deployment

- Harsh unreachable environments

- An aerial robot self-navigates to locations of interest and deploys the sensor(s)

Proposed Aerial Approach: Data Analysis

- Image processing
- Pattern recognition

- Data-driven models
  - Subspace methods, clustering, support vector machines
  - Change point detection
  - Compressive sensing

- Decentralized (**at the quad-copter**) hypothesis testing
- Decentralized (**at the quad-copter**) estimation and learning
  - Decentralized PCA
  - Compute eigenvectors from geographically distributed data (matrix)

Summary

- Aerial monitoring and data collection features:
  - Low-power
  - Completely automated
  - Reprogrammable and reconfigurable sensing

- Applications
  - Inspection
  - Monitoring
  - Deployment