MARYLAND ROBOTICS CENTER
THE INSTITUTE FOR SYSTEMS RESEARCH

THE DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

CPS: Synergy: Collaborative Research: Designing semi-autonomous networks of miniature robots for inspection of bridges and other large infrastructures

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Objectives

Visual identification of structural flaws is quite valuable not only to predict an imminent collapse of a bridge, but also to determine effective precautionary measures and repairs.

In this project, we will pursue a three-year basic research program to establish new design and performance analysis principles, and technologies for the creation of a semi-autonomous network of small mobile robots to aid visual inspection of civil infrastructure. This network will aid a human surveyor to remotely and routinely inspect structure areas such as a typical girder assemblage that supports the decks of a suspension bridge. Methods to be used: The goals mentioned above will be addressed via a multidisciplinary basic research effort in hardware, algorithm design and performance analysis. In order to achieve this goal, our team includes one researcher (CTO of Resensys LLC) in the area of bridge monitoring, and 3 faculty from 2 departments. Our team's expertise covers all the key basic research areas of the project.

Importance of Bridge Monitoring

Visual identification of structural flaws is quite valuable not only to predict an imminent bridge collapse, but also to determine effective precautionary measures and repairs.

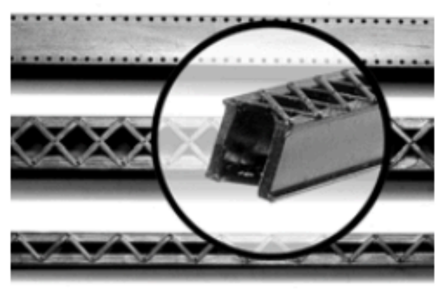
(a) Bending of a metal plate that was detected prior to the collapse.

(b) Fracture that was later found to be a major cause of the collapse.

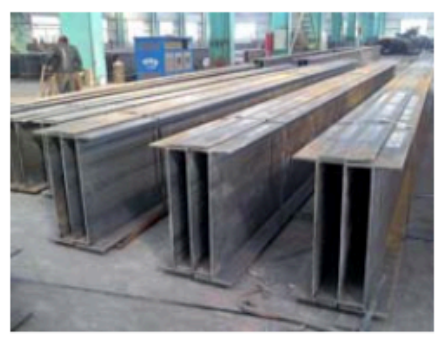
Structural flaws of I-35W bridge

Problem Formulation

We will pursue a three-year basic research program to establish new design and performance analysis principles, and technologies for the creation of a semi-autonomous network of small robots to aid visual inspection of civil infrastructure. The main idea is to use such a network to aid a human surveyor in remotely and routinely inspecting structure areas such as a typical girder assemblage that supports the decks of a suspension bridge.



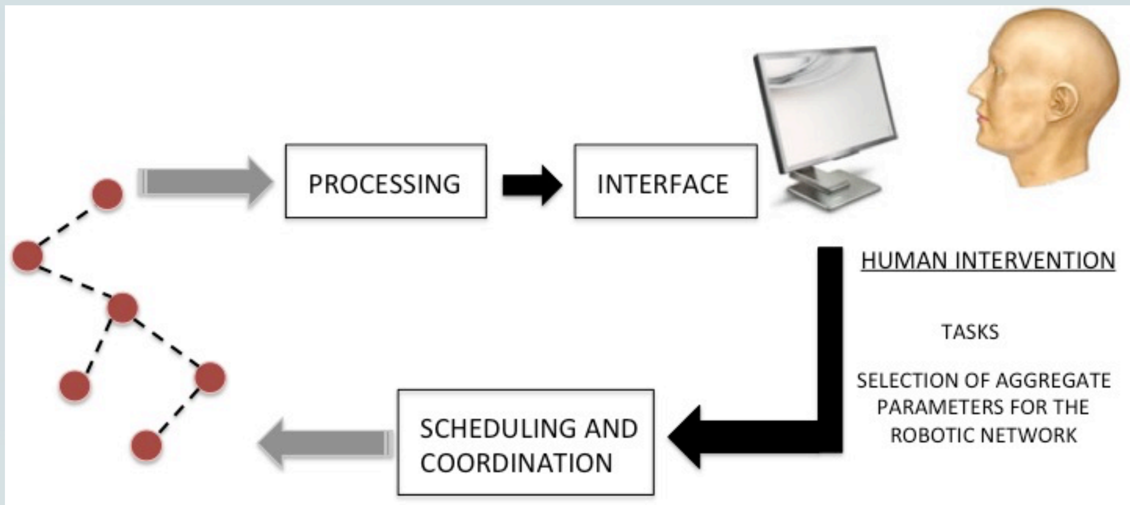
(a) Example of an old open girder.



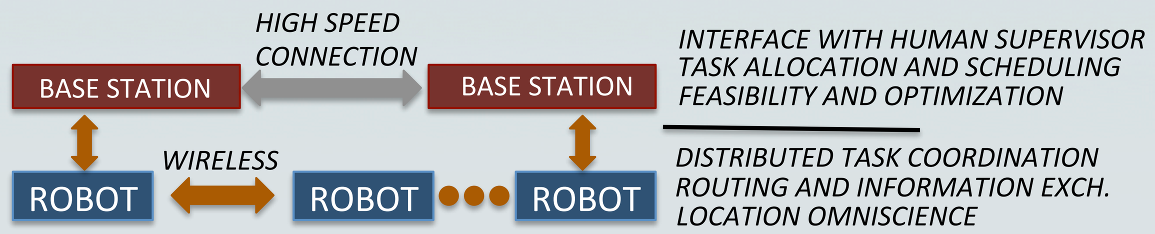
(b) Modern closed girder.

(c) Girder assemblage.

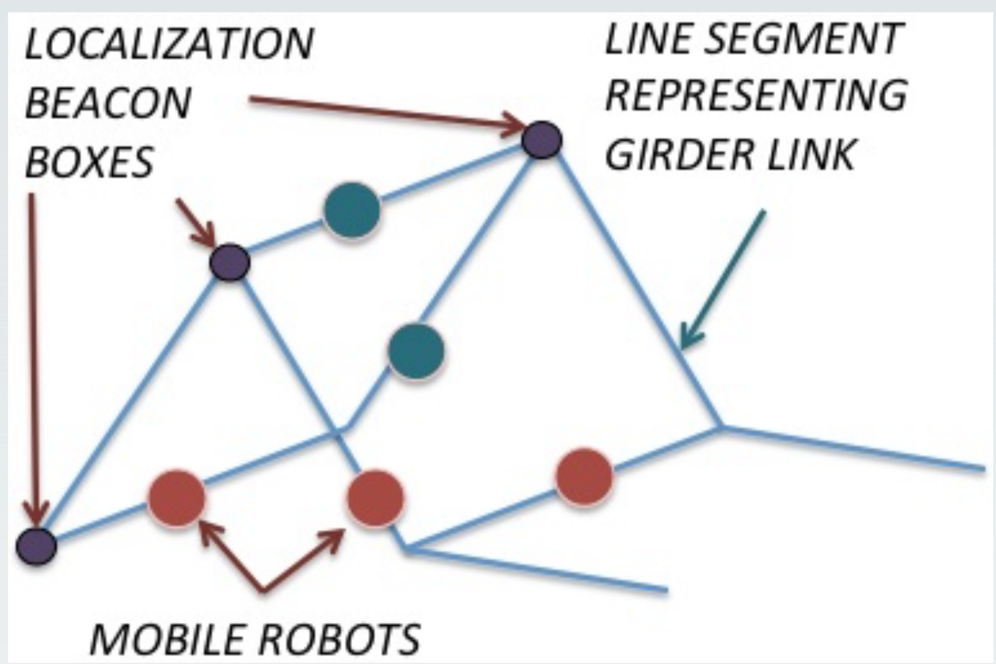
System Description:



The role of the proposed network of small robots is to acquire sensory information, such as images, and send it to the base stations for processing and feature extraction. The network is mobile and semi-autonomous, and it will have self-organizing capabilities to carry out the inspection tasks.



Networked coordination, team decision and information collection:



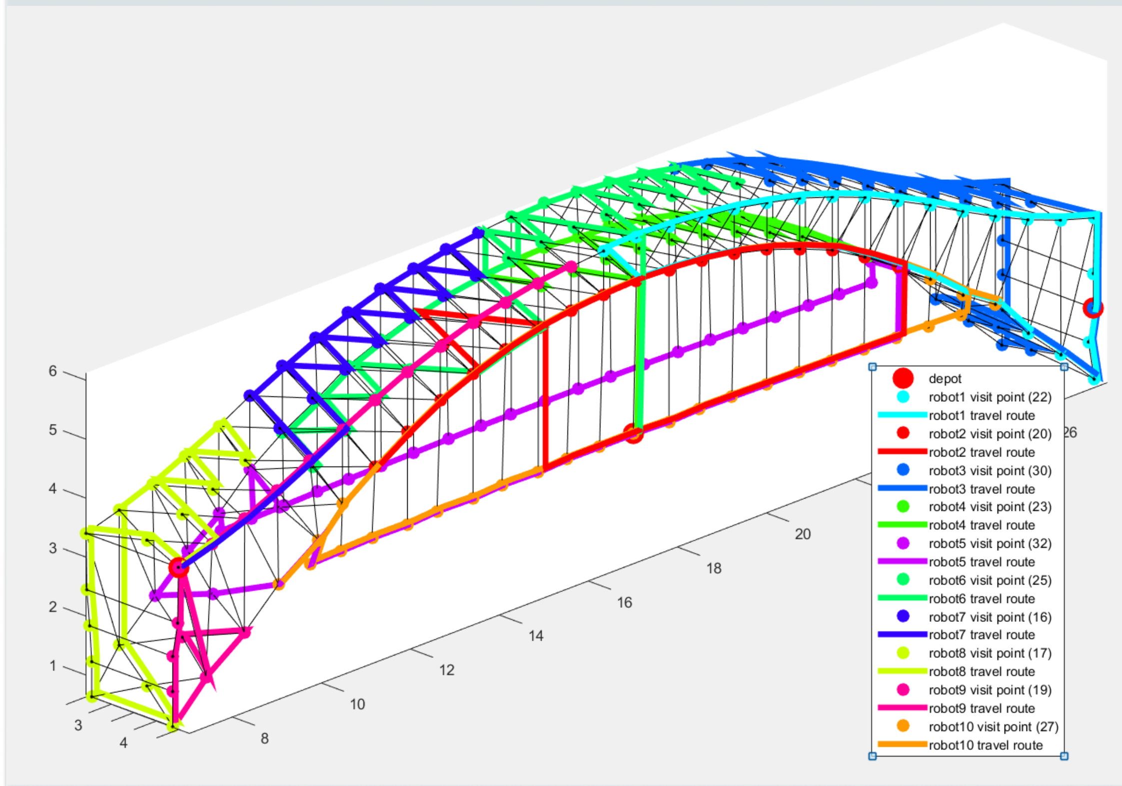
The system will be designed to execute a group survey mission, for which the user specifies an area to be surveyed, number of robots assigned, duration and which measurements should be collected (vibration, tilt, temperature) in addition to still images. The following are the mission steps that must be executed to accomplish the mission:

1. The robots will first follow the precompute schedule to inspect the bridge.
2. If something unexpected occur, for instance, robot failure or cost greatly exceed the precompute estimation, the robots will communicate with base station and other robots to modify the schedule.
3. The robots will report back to BSs when done.

Task Scheduling for Human-Assisted Inspection Systems

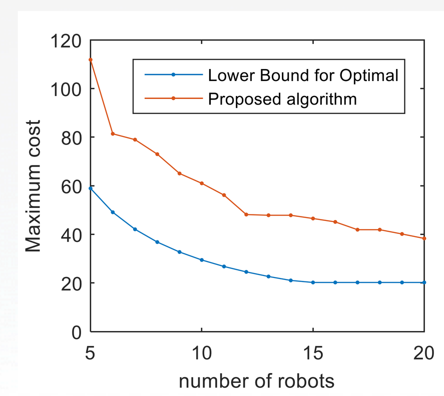
We formulated a new class of problems in which a human operator assists a semi-autonomous inspection system. New tasks arrive to a queue (according to a statistical model), which are eventually assigned to a human operator who can service them within a fixed time interval, with a certain probability that depends on the workload level. We adopt a model in which the workload level is likely to increase when a new task is assigned and is expected to decrease after a rest period. We investigate policies to decide when to assign a new task to the operator or allow for a rest period, such as to maximize the rate at which tasks are successfully completed. We show that given any policy that depends on the queue length and workload state, there is another policy whose performance is no worse that assigns tasks based solely on a threshold on the workload state. Analysis and design of optimal policies can be greatly simplified by considering the aforementioned class of threshold policies. We also have preliminary results for the case in which there are two types of tasks and similar considerations on operator workload.

Path Planning for Inspection



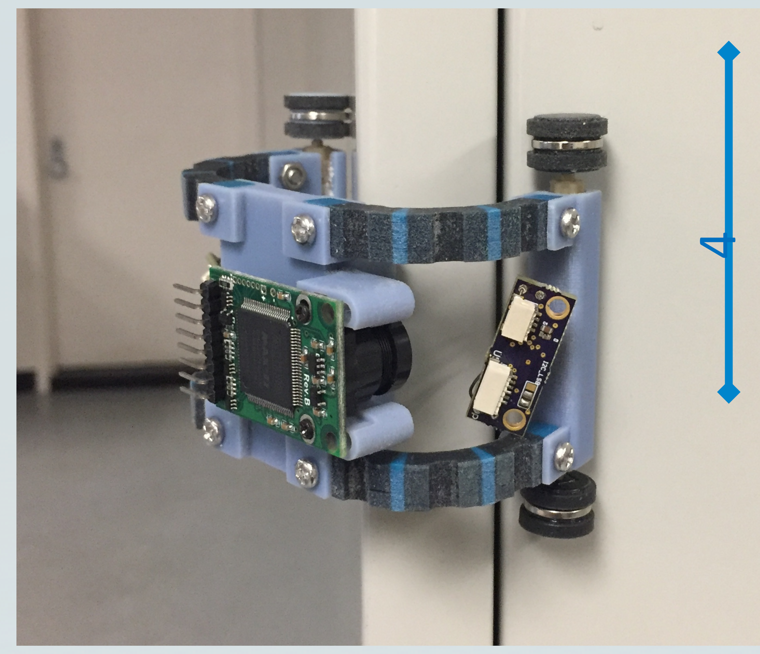
We studied the problem of planning the deployments of (mobile) robots for bridge inspection. The robots are assumed to be initially stationed at multiple depots placed throughout the bridge. The problem is formulated as a min-max cycle cover problem in which the vertex set consists of the sites to be inspected and robot depots, and the weight of an edge captures either (i) the amount of time needed to travel from one end vertex to the other vertex or (ii) the necessary energy consumption for the travel. In the first case, the objective function is the total inspection time, whereas in the latter case, it is the maximum energy consumption among the deployed robots. We proposed a novel approximation algorithm with approximation ratio of $5+\varepsilon$, where $0<\varepsilon<1$. In addition, the computational complexity of the proposed algorithm is shown to be $O(n^2+2^{d-1}(\log(n)+\log(1/\varepsilon))$, where n is the number of vertices and d is the number of depots.

The numerical results (to the right) demonstrate that the maximum cost of the proposed algorithm is at most 2.5 times the lower bound for the optimal value.

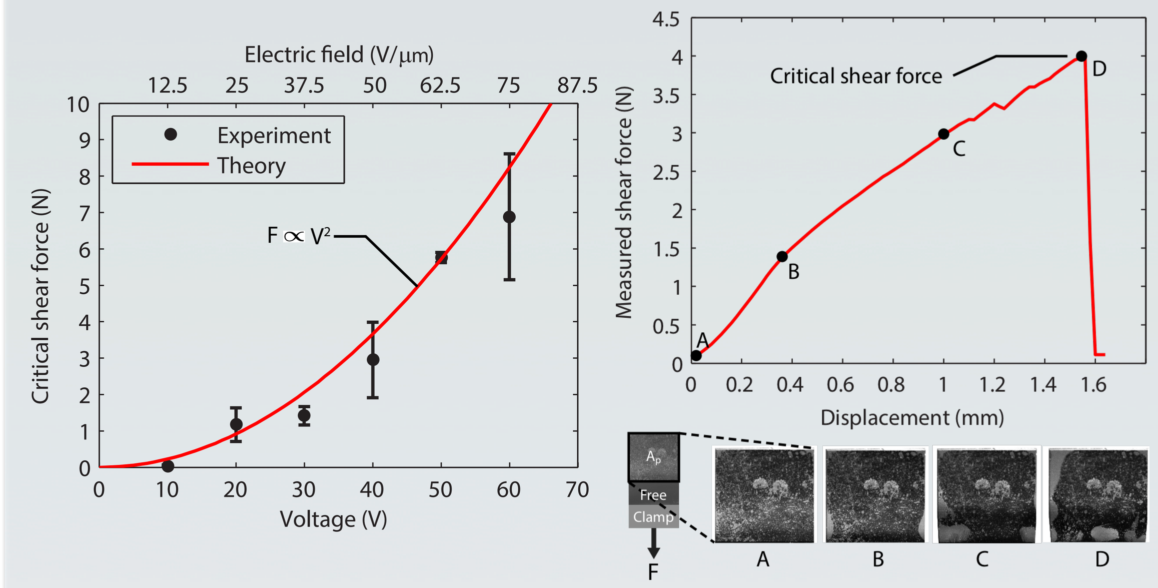


Locomotion:

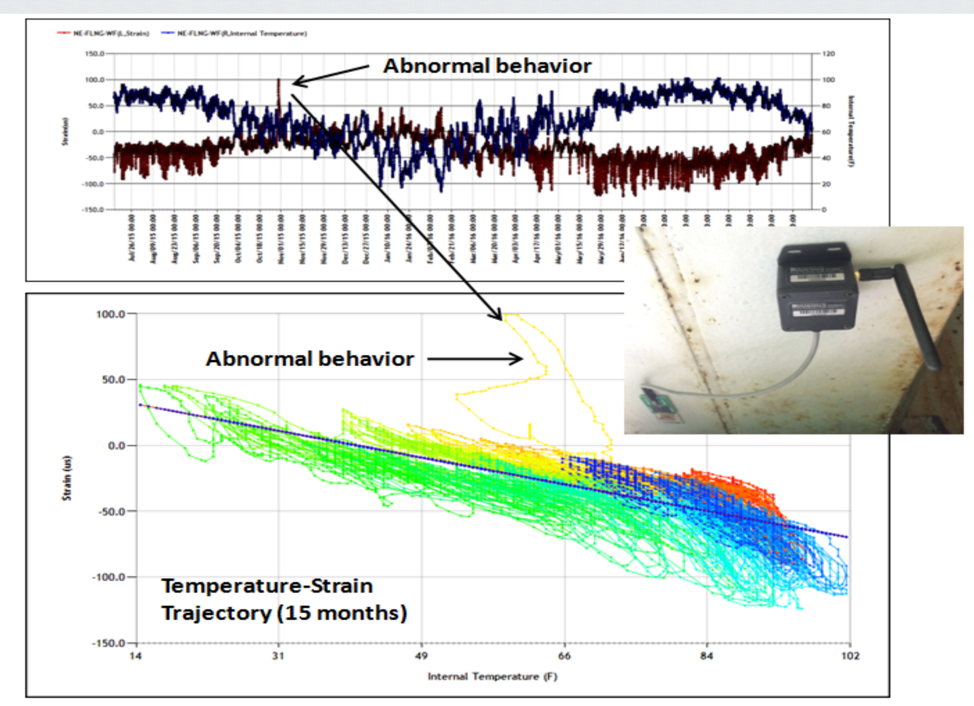
New robots have been designed; these are small (e.g. deck of cards size) and utilize compliant legs with adhesive wheels/legs. The robot shown below includes a camera, ARM microcontroller, 802.15.4 radio, a 3D printed chassis composed of multiple materials (printed on Objet Connex), and magnetic wheels (to be replaced by electroadhesives).



Work on electroadhesives that adhere to both steel and concrete has focused on developing a model to predict adhesion and understand failure in fabricated low-voltage electroadhesives. The plots shown are for 50 mm² area of adhesive.



Application Scenario:



15-month strain(blue) Temperature(red) from a highway bridge element

The picture in the graph shows a wireless SenSpot on a highway bridge girder. The top graph shows a 15-month strain and temperature from a girder of a highway bridge. An abnormal strain increase was observed in the last week of October 2015.
The malfunction is more visible if temperature-strain trajectory in lower graph. Such detection will be further inspected by dispatched robots to locations where an issue was detected.