TerpInspectors: A Semi-autonomous Mobile Network for Infrastructure Inspection

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In the last 5 years alone there were at least 74 major bridge collapses reported worldwide, which resulted in more than 300 deaths, numerous injured, costly material losses and major prolonged disruptions to traffic in busy cities and vital roadways. The tragic collapse of the I-35W Mississippi River bridge in 2007 is a stark reminder that these catastrophes can still affect the U.S. as well. According to the U.S. Department of Transportation (Federal Highway Administration)[1], the United States has 605,102 bridges of which 64% are 30 years or older and 11% are structurally deficient. As various technical reports indicated, the Mississippi River bridge had structural problems and monitoring had been recommended since 2001. Existing monitoring systems produce various time series measurements that are sufficient to keep track of wear and tear figures, such as structural stress ranges, stress cycles and fatigue life. However, structural failure and potential collapse is often preceded by fractures, buckling (of load-bearing components), or pitting corrosion, that can be identified visually when they are found. In fact, the following counsel is given in a 2001 report[2]: ''Recommendations are made for focused visual inspection". 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. The current procedures for visual diagnostics are conducted by inspectors who may not have easy access to critical sections of the structure or availability to conduct frequent evaluations. This is specially the case in long and complex suspension bridges or when load-bearing and critical sections are unreachable due to the configuration of the structure.

Big challenge: In order to guarantee cost-effective and routine detailed examination of all structurally deficient bridges, it is important to investigate new methodologies and principles to create systems to aid inspectors in the visual examination of load bearing parts.

Our team proposes the creation of a new mobile sensor network system to aid a human surveyor in remotely and routinely inspecting areas such as a girder assemblage, joints, piers, welds, rivets, support cables and decks of complex bridges (e.g., suspension bridges). The following is a list of the main components of the proposed system: i) Battery-operated mobile robots capable of moving within complex bridge structures with integrated wireless networking capabilities, a small camera and processing capabilities. ii) Base stations tasked with high-level coordination of the mobile robots and placed along the bridge. They will also be used for data-storage and transmission to a data center, and have an interface that may be remote or operated locally by the user. iii) Battery-operated low power beacons installed in the bridge's structure for localization. (Resensys has ample experience using these devices whose expected battery life exceeds 20 years). We will also deploy and test our system in conjunction with existing fixed nodes developed by Resensys that provide other measurements that can complement the information obtained from the collected images.

The creation of such new CPS systems, subject to provable performance guarantees (to satisfy safety codes), will require fundamental research in algorithms, performance evaluation and hardware to address the following challenges: i) Devise new locomotion principles to support mobility within steel and concrete girder structures. ii) Build a network of small robots capable of executing certain basic primitives that require cooperative behavior, such as forming a cluster of several robots around a pre-specified robot or location. Semi-autonomous coordination of a group of robots will require a feasibility analysis and distributed strategies that guarantee omniscience of the localization within group. iii) Design an information collection scheme capable of coping with the adverse effects that steel and concrete impose on the communication (and hence coordination) among the robots within enclosed structures. These challenges can be addressed using new ideas that extend the state of the art of disruption tolerant networks by incorporating prior information on the bridge structure and the schedule of tasks which governs the mobility of the robots.

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[1]See http://www.fhwa.dot.gov/bridge/structyr.cfm

[2]H. M. O'Connell, R. J. Dexter, and P. M. Bergson. Fatigue evaluation of the deck truss of bridge 9340. Technical report, Minnesota Department of Transportation, 2001, page 5.