Introduction and Overall Plan

The purpose of this (very informal!) document is to provide the team with a proposed experimental test plan for the duration of this project. This will help each member plan research and deliverables for more efficient and integrated project execution. Comments and feedback are greatly appreciated and expected: it is intended to be a ‘working document’.

The overall goal of this project is to develop and prototype a system capable of providing relatively rapid structural health assessment of a large-scale structure after a transient damage-inducing event. A specific example that this project will focus on for demonstration purposes will be assessment of a bridge after an earthquake. To this end, we will progressively build up our experimental testbeds over the course of the project as we develop key components of this health monitoring system. Previously, we have classified the required components of this project into four main task areas, with the PI’s name(s) associated with each area, as appropriate:

I. Sensor Design, Characterization, Optimization, and Interrogation (Todd): We will explore and implement sensor modalities for both passive (peak-strain sensors) and active (piezoelectric sensor/actuators) detection of structural response. The communications will be built upon 'onloading' existing protocols such as RFID or Bluetooth. We will also consider establishing appropriate observability criteria with these sensor modalities, which involves damage detectability with regard to sensor placement and count. Finally, the sensors themselves will be designed to be interrogated by remote autonomous vehicles, such as a UAV.

II. Embedded Platform and Its Software Architecture (Gupta, Rosing): We have converged on Xscale platforms and identified two potential embodiments: the Intel DBPXA272 and the CalRadio 1.0 nodes. While the former has substantial computational capabilities, the latter provides flexible radio interfaces and then better able to integrate within the wireless networks. In this phase, we will develop an integrated software development platform that defines the necessary OS and programming infrastructure for porting SHM related applications. Using this platform, we will prototype porting of AR and ARX analysis that is currently done in the DIAMONDII software on the embedded platform and characterize the performance for these embedded applications with the goal to identify available processing and its roadmap for future in-situ data analysis;

III. Computational Model and Methods for SHM (Dasgupta): Using a Matlab infrastructure, we plan to explore two problems: (a) methods to support active probing of the sensors based on analysis of sensor data for identification of damage locations; (b) methods for outlier detection from the sensor data. In addition, this task will explore the following issues related to practical implementations for the SHM applications: (a) SHM algorithmic redesign to eliminate or minimize floating point operations; (b) methods to
perform automatic or assisted conversion of application code with floating point operations to integer only operations within specific error guarantees; (c) kernel based classification methods for rapid convergence of the structural analysis and damage prognosis from sampled data.

IV. Sensor network architecture and network level programming of the distributed SHM application (Gupta, Rosing): This task will bridge the gap from the architecture of the sensor nodes, local processing to its deployment in reduced or at-scale SHM applications. This requires defining the network architecture, model building with observability guarantees to enable SHM as well as programming interface that provides methods and tools for distribution of computations over the embedded nodes designed in II.

The next sections detail four testbeds that could be deployed with progress towards a final demonstration on the Coronado Bridge in San Diego at the conclusion of this project.

Phases 3 and 4: (Time period: now through Summer 2007)

The first structural testbed will be a metal lab-bench scale frame structure, similar to the one shown at the left of Figure 1. The structure is made up of two vertical bars (12" x 2" x 0.375") connected to a horizontal bar (22" x 2" x 0.375") by two angle brackets (2.5" x 2.5" x 0.25"). The vertical members are connected to an aluminum base plate (24" x 6" x 0.5") with two more angle brackets. An electromechanical shaker is attached to one of the vertical braces to provide dynamic load inputs to the structure. Damage may be simulated in two envisioned ways: (1) progressive loosening of one or more bolts and (2) providing large-scale transient impacts to one of the braces (such as with a hammer). Damage scenario (1) is a more progressive damage event that may not exactly match up with our long-term scenario on the Coronado Bridge (i.e., assessment after a triggering large event such as an earthquake, terrorist attack, etc.). Nonetheless, such a damage scenario is reversible and can be used to benchmark numerous components of a sensor design or even a network. Damage scenario (2) more realistically simulates the one-off

![Portal frame structure](image-url)
'triggering' type of damage events, and it would likely induce permanent deformation into the structure. The expected most realistic testing scenario would be to use the shaker to induce continuous simulated operational and environmental 'noise' into the structural response, and then impact the structure with a hammer to simulate a damage-inducing event.

In this phase the sub-tasks/deliverables will be (referenced by the broad task areas above):

(I.1) Obtain and evaluate peak-strain sensors in a performance metric experiment on the small frame testbed. Deliverable: evaluation report at 120 days
(I.2) Evaluate and update sensor design for interrogation by RFID tags and readers. Deliverable: evaluation report at 180 days
(I.3) Establish initial sensor optimization approach for observing peak strain patterns on the small frame testbed, including experimental verification. Deliverable: test report at 360 days
(II.1) Define architecture of SHM codes, including AR, ARX analysis codes, for use in the Xscale embedded systems. Deliverable: evaluation report at 120 days
(II.2) Simulate and compare performance of the SHM codes. Deliverable: simulation report at 120 days
(II.3) Identify the necessary OS services and port OS codes accordingly to the platform. Deliverable: software at 360 days
(III.1) Develop algorithms for active sensing and reconstruction of multivariate time series from sparse samples. Deliverable: report at 360 days
(IV.1) Define network and radio architecture for SHM application, including use of multiple radio interfaces. Deliverable: evaluation report at 180 days

Phase 5 (Time period: Fall 2007-Summer 2008) and Phase 6:

In this phase, a second, more complex structural testbed using Unistrut members will be deployed in the Powell Laboratories. This structure, 21.5 ft tall with a 10 ft by 10 ft footprint, was built for a previous project and can be reconstructed for the present project. Damage to this structure can be achieved by (1) loosening bolts; (2) attaching weights to the structure at key points for inertial load and exciting the structure laterally with a base excitation provided by a shaker table; (3) impacting the frame with a hammer; and/or (4) loading the frame with quasi-static hydraulic load actuators. This structure introduces more complexity into the testing by incorporating more environmental variability (less-controlled lab environment) and a significantly more extended footprint.

Near the end of Phase 5 (and possibly into the beginning of Phase 6), this project will utilize a field testbed at the Alamosa Canyon bridge near Truth-or-Consequences, NM (Figure 3). This bridge is a designated field test site by the New Mexico D.O.T., and the project members have control over the loading of the bridge, since it has been decommissioned from service. Damage can be applied to the bridge by cutting key members or by imposing impact damage. This structure is the first full-scale field testbed, and the project will demonstrate an initial prototype of the system components, including autonomous interrogation.
Sub-tasks and deliverables for Phase 5 will be enumerated later, after evaluation of performance on Phase 4.

The final testbed is the Coronado Bridge in San Diego, CA (Figure 4). The project will complete two demonstrations on the testbed. The first will be a full test of the hardware system performance, where the team will fly a UAV to interrogate a sensor array of peak strain sensors and active piezoelectric sensor/actuators. Since damage cannot be introduced into the Coronado Bridge, future tests will be conducted an a to-be-prescribed cycle where demonstration of the SHM evaluation algorithms will be conducted. The team will attempt to coordinate tests with the expected visual inspection
cycle(s) of the bridge to correlate algorithm performance with any observed bridge state changes.