Cyber-Physical System for Bridge Lifecycle Monitoring

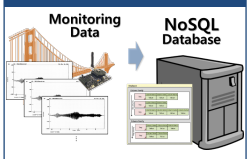
Seongwoon Jeong[1)], Ray Hou[2)], Jerome P. Lynch[2)], Hoon Sohn[3)] and Kincho H. Law[1)]
[1)]*Stanford University,* [2)]*University of Michigan,* [3)]*Korea Advanced Institute of Science & Technology*

Introduction

The goal of this research project is to develop a scalable cyber-physical system (CPS) framework for the integration of physical and computational systems for bridge lifecycle monitoring. Bridge monitoring involves several independent but isolated components. Sharing of information and software modules across different systems is limited. Information sharing and system integration would facilitate meaningful use of data, thereby enhancing bridge operation and maintenance and public safety. This project focuses on the development of a scalable cloud-based cyberinfrastructure platform for managing, sharing and utilizing sensor data and bridge information. The cloud-based platform comprises of virtual machines, distributed database and web servers. Distributed database built on a peer-to-peer architecture enables scalable and fault-tolerant data management on a cloud computing environment. Platform-neutral web services are designed in compliant with the Representational State Transfer (REST) design, and enable access to the cloud resources via a standard web protocol. For data interoperability, a bridge information modeling (BrIM) schema for bridge monitoring applications is defined. Furthermore, CPS applications, including data-driven sensor data reconstruction module, data integration module, and web/mobile user interfaces, are developed to facilitate the utilization of bridge monitoring data.

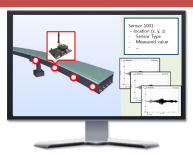
Research Objective

Cloud based Bridge Sensing Data Management



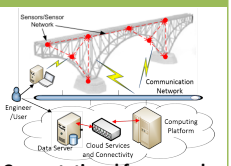
NoSQL database technologies to facilitate managing bridge monitoring data

Integrated Technology of Sensing Data and BrIM



Ontology and data schema for sensor information and bridge information model (BrIM)

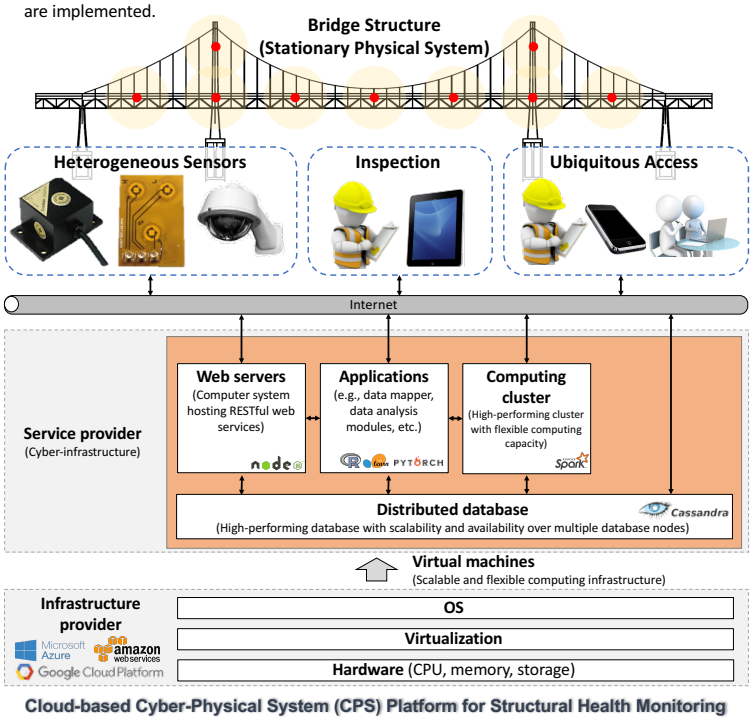
Framework for Lifecycle Bridge Management



Computational framework to support bridge management and lifecycle assessment analysis.

Cloud-based Cyberinfrastructure Platform

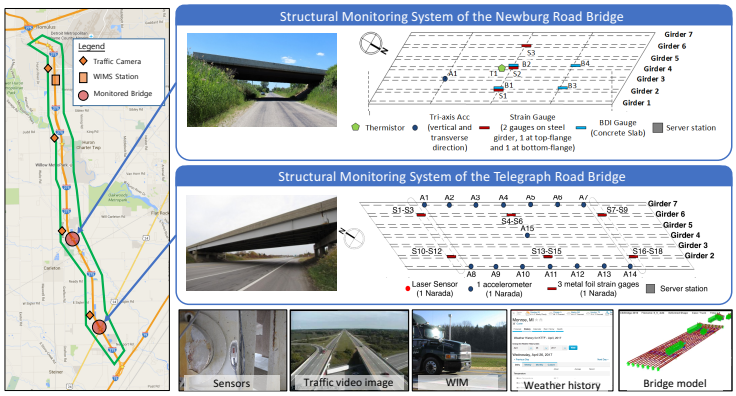
- Cloud-based virtual machines (VMs) are utilized to implement Cyberinfrastructure platform.
- A distributed NoSQL database is deployed to manage sensor data and bridge information over multiple cloud VMs. Specifically, Apache Cassandra database is employed to guarantee partitioning tolerance and database availability.
- A BrIM schema is developed to support data interoperability applications. The BrIM schema includes data entities for the description of bridge geometric models, engineering models and sensor information.
- Web servers are employed to host RESTful web services that expose resources to clients via Hypertext Transfer Protocol (HTTP). Web services for storing and retrieving bridge monitoring data are implemented.



Cloud-based Cyber-Physical System (CPS) Platform for Structural Health Monitoring

Test-bed: I-275 Highway Corridor

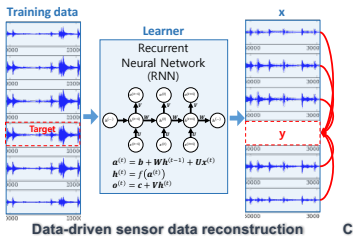
- Telegraph Road Bridge: 60 sensors (accelerometers, strain gauges and thermistors)
- Newburg Road Bridge: 12 sensors (accelerometers, strain gauges and thermistors)
- The sensor networks acquire data for a one-minute duration every two-hours.
- Sampling rate: 200Hz (accelerometer), 100Hz (strain gauge and thermistor)
- Traffic video images from the traffic monitoring system of the Michigan Department of Transportation (MDOT) is collected.
- WIM data, weather history, sensor metadata and bridge models are also managed.



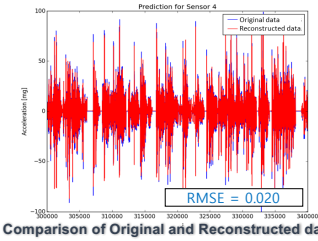
CPS Applications

1. Data-driven Sensor Data Reconstruction

- Extracting meaningful information from sensor data is of critical importance to support data-driven decision-making for bridge management. Recurrent Neural Network is employed to build a prediction model for sensor data reconstruction. Result shows that the proposed approach can reconstruct sensor data with high precision. The approach can be used for cross validation of sensor data and detecting structural anomalies.



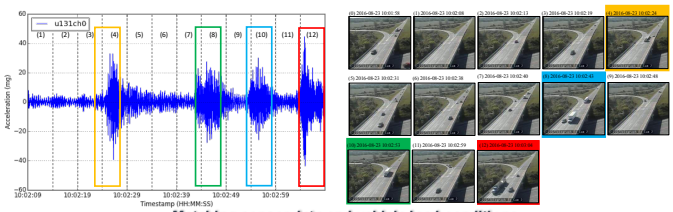
Data-driven sensor data reconstruction



Comparison of Original and Reconstructed data

2. Sensor and Traffic Data Integration

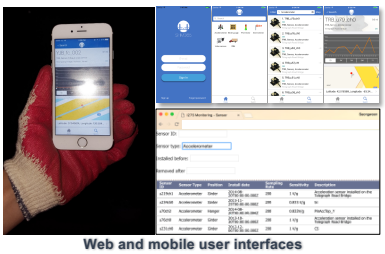
- To identify input vehicle load applied to bridge structure, vehicle detection module is created. Traffic monitoring photos and sensor data are synchronized. Background subtraction is applied to detect size and location of vehicle from photos.



Matching sensor data and vehicle load conditions

3. Web/Mobile User Interfaces

- Web and mobile interfaces are developed to facilitate ubiquitous access to bridge monitoring information.
- Web interface supports retrieval of sensor list, sensor data, traffic video images and bridge models.
- Mobile user interface built upon iOS supports retrieval of sensor list, sensor information and sensor data.



Web and mobile user interfaces

Acknowledgement

This research is supported by the US National Science Foundation (NSF), Grant No. ECCS-1446330. This research is also supported by a supplemental Grant No. 13SCIPA01 from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport (MOLIT) of Korea government and Korea Agency for Infrastructure Technology Advancement (KAIA). The research team at Stanford University would like to thank Prof. Jerome Lynch of University of Michigan for the sensor instrumentation effort on the I-275 Highway Corridor.