Design and Implementation of a Low-Cost Wireless Platform for Remote Bridge Health Monitoring

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Abstract-- In this work a low cost Arduino based Bridge health monitoring system is proposed. This uses Web Server with IP connectivity for accessing accelerometer readings. Statistical signal processing of readings obtained from sensors involve intensive calculations. As a result processors that support large data size and high duty cycles are required for data assessment. Internet of things (IoT) helps in integrating data from various sensors located at different geographical location and leveraging it to a high computing machine at Base station. Arduino, an open source hardware platform reads vibration data from an accelerometer and transmits this information on web based Application Programming Interface (API). The IoT has been used to connect the accelerometer to the internet thereby enabling the computation and analysis of real time data at base station.

Keywords-- Arduino, API, IoT, Bridge Health Monitoring, Structural Health Monitoring.

I. INTRODUCTION

Bridge Health Monitoring is a process of monitoring various characteristics of a structure that determine the damages and aging of the bridges. There has been an incorporation of variety of sensor networks, both wired and wireless, for detecting statistical patterns of stress and strain that pertain to the structural health. Vibration based health monitoring systems to detect the damage of bridges are one of the most explored approach so far.

However, incorporation of sensor, data conditioning, data processing and analysis of results at the bridge sites has high computational requirements like large memory and powerful processing capability. Implementing bridge health monitoring (BHM) by integrating sensor networks is not a new concept [1-2]. Traditional approaches consist of conventional piezoelectric accelerometers hardwired to data acquisition boards in a personal computer. These data acquisition systems collect structural vibration data from various locations in the structure for analysis. Sometimes it may take several weeks to install a large scale wired data acquisition system as it may often turn out to be too expensive [3]. The downside of using such systems includes:

1. High cost of installation and disturbance to the regular operation of the structure as the wires having to run all over the structure.
2. High equipment cost.
3. Cost of maintenance.

Due to the drawbacks of the wired structural health monitoring (SHM) system, health monitoring with wireless sensor networks (WSNs) is becoming popular. The WSN based SHM system uses wireless communication for exchange of information between the sensors and also with the server as shown in Figure 1.
The WSN-based SHM, as shown in figure 1, offers various advantages. Firstly, the cumbersome process of maintaining and installing the cables is reduced. Secondly, the onboard controller helps in efficient distribution of data processing. Moreover, the WSN system helps in scalability of the network by which it becomes easy to add or remove sensors after initial installation [4].

Wireless sensor networks are becoming extremely popular for SHM systems implemented on Bridges. The ZigBee is extensively used for short distance Code Division Multiple Access (CDMA) based mobile phone network that are used for long distance communication. Modules like u-node (ubiquitous node) that combine sensor and ZigBee are used for health monitoring [5]. The multi-functional wireless bridge monitoring system uses accelerometers, strain transducers, and temperature sensors, for concurrently monitoring various parameters of the bridge. This kind of system combines hybrid sensing capabilities for economic, low maintenance and short-term dynamic measurement along with advance hardware functionality [6].

Although wireless systems offer many advantages, they have a limited life span of batteries. As a result, high costs are incurred for battery replacement especially for remote locations like bridges. Alternative sources of energy like solar energy are widely used. However, they become incompetent where sensors need to be installed at places with low light intensities [7]. Wind and Vibration energy are also harvested for powering of the systems in SHM [8-9].

A novel wireless sensor system that harvests vibrations in the bridge structure created by passing traffic, which is converted into usable electrical energy by means of a linear electromagnetic generator, is studied by previous researchers [10]. The system is capable of harvesting up to 12.5 MW of power in the resonant mode with the frequency of excitation at 3.1 Hz. A magnetic shape memory alloy-based self-powered sensor system for structural health monitoring of highway bridges has been proposed by previous researchers that consists of an energy harvesting material, power conditioning circuitry, a sensor, an analog-to-digital converter, and a wireless transmitter [11]. The system uses NiMnCoIn magnetic shape memory alloy (MSMA) that converts mechanical vibrations into electrical energy.

However, SHM wireless systems have stringent requirement for time synchronization accuracy, scalability and reliability. Therefore, a wireless system for identifying the system conditions under different environmental load condition is used by previous researchers [12]. When tested for time synchronization a reduced spatial jitter of 125 ns which is far below the 120 μs required for high-precision acquisition systems is observed. To this end, in this paper we present a low cost and flexible structural health monitoring system using a web server, with IP connectivity for remotely accessing accelerometer vibration data using Google spreadsheet. The proposed system offers a novel communication protocol to monitor vibration data of bridges and thereby determining the health of the bridges.
The Google application script was used to access data from web server and log data onto the Google spreadsheet as described in Section 1. In Section 2, the proposed system architecture and its features were briefly described while Section 3 outlines the system implementation for the structural health monitoring. Finally, the conclusions of the research study are presented in Section 4.

II. PROPOSED SYSTEM AND ARCHITECTURE

A. Features of the Proposed System

In order to address the mentioned issues of leveraging high computation and analysis to the base, we designed and implemented a novel, stand-alone, flexible and low cost structural health monitoring system using IoT. The system consists of a web-server based Ad fruit Wi-Fi Module, hardware interface modules, and Google Spreadsheet. This system allows authorized people to remotely monitor real time accelerometer values from anywhere using internet.

B. Description of Proposed Architecture

This section describes the proposed architecture and design of flexible and low cost structural health monitoring system. The architecture is divided into two parts: site location and remote locations as shown in Figure 1. Remote locations represent authorized users who can access the Google spreadsheet from their PC using the Internet. The site location consists of a Wi-Fi router, an Arduino with Wi-Fi module and an accelerometer. An accelerometer connected to Arduino senses the vibration of the bridge. The data obtained from the accelerometer are pushed onto the Google spreadsheet in real time. The received data is processed at the destination computer with high processing capability. A Wi-Fi module connected to an Arduino is used to develop a standard communication with the external world.

III. DESIGN AND IMPLEMENTATION OF THE SYSTEM

In this section we introduce the hardware and software platform employed in the design and implementation of the Bridge Health Monitoring system.

A. Hardware:

For proof of the concept, low cost and off the shelf electronics hardware is used for the setup. The overall implementation diagram is illustrated in Figure 2.
B. Software:
Software of the proposed architecture is divided into two parts: Server Web service and Arduino. To successfully communicate between remote user and accelerometer the configuration stage layers have been implemented on the Arduino Uno.

The Adafruit_CC3000.h libraries are used to receive data on Arduino Uno and create output messages in JavaScript Object Notation (JSON) format. Figure 3 shows the flowchart of connection establishment between the Arduino Uno and the Internet.

![Image](image_url)

**Figure 3 Algorithm and flow chart for interface of accelerometer and Internet of Things**

As described in Figure 3, the accelerometer is connected to the internet via Adafruit Wi-Fi Device which has a built-in TCP/IP stack with a “BSD socket” interface. We have implemented software to connect it to remote user. The Health Monitoring system first enters the configuration state during which the Wi-Fi Module establishes connection with the Wi-Fi network using an IP address that is dynamic in nature via Dynamic Host Configuration.

C. Application framework:
The access to Web services has to be easy, direct, open and interoperable.

That is, the provided communication means and programming interfaces (APIs) shall be easy to implement on every platform and developing environment. The most open and interoperable way to provide access to remote services is to utilize Web services. Therefore, in our approach we have used web service utilizing standard operation such as GET requests that return JavaScript Object Notation (JSON) responses to communicate between the remote user and web server. JSON is a lightweight data-interchange format. For example, to send accelerometer data, a HTTPS GET request is sent to the server as illustrated in Figure 4.
Google App script is a scripting option used to write the script and this can be accessed from web service. Google spreadsheets allow the data access via JSON feed natively. However, since Arduino can’t handle HTTPS, a pushing box API is used to run as GET request link from Arduino to run the Google script. Figure 5 shows the flow chart for sequence of actions required to access data on Google spreadsheet.

D. Implementation:

For the proof of concept accelerometer was fitted on the beam (cracked and intact) of 22.5 x 2.625 x 3.5 inch with rubber boots which provides cushion to the beam during vibration as shown in Figure 6 (a).

As shown in Figure 6 (a), the vibrations in x, y, z directions were read by accelerometer for the cracked and un-cracked beam and were pushed to the Google spreadsheet. The Fast Fourier transform, that involves computations of large stream of data, was performed at the receiver Computer. The vibration response of the beam was obtained from which the 1st natural frequency response of the cross section of beam was obtained as shown in Figure 6 (b).
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\[ \omega_n = \frac{1}{2\pi} \sqrt{\frac{2k}{3m}} \] ...............(1)

Where,
\( m = \) mass of concrete specimen (17.94 lb)
\( k = \) stiffness of the beam (19.1 x 10^6 psi)

Using equation 1, the natural frequency was obtained to be 52.81 Hz. From the theoretical and experimental natural frequencies it can be observed that the experimental frequency was 0.35% higher than the theoretical natural frequency for the same specimen. Hence, the frequencies obtained from experimental analysis was in acceptable limit and can be used for obtaining natural frequencies and has potential in using structural health monitoring of the bridges.

IV. CONCLUSION

In this paper, an Arduino based a low cost and flexible BHM using IoT is proposed and implemented. The proposed architecture utilizes API to run as GET request link from Arduino to run the Google script between the remote user and the site devices. An Adafruit Wi-Fi Shield is used to access the Wi-Fi network at site. In future a GSM based shield using mobile cellular networks such as 3G or 4G - LTE can be used to access the system. A network of accelerometers can be fitted on bridges and Arduino based BHM system can be used to collect the real time data. This data can be further processed at Data Centers and assessment of structural integrity of bridges can be done. The resulting output can help in detecting structural damage that affects the performance of a structure.

REFERENCES