Wireless Capacitor Sensing for Structural Health Monitor

AHM Zahirul Alam, *Member, IAENG*, Noor Syamira Asyiqin Amir Hassan, Nurul Arfah Che Mustapha, Md Rafiqul Islam, Sheroz Khan and Muhammad Abu Eusuf

Abstract— **Structural health monitoring (SHM) is a method of localizing damage in infrastructures regarding structural strain, vibration or movements due to external contributing factors which mainly occur as a result of natural disasters. The need to analyze such occurrences can prevent potential damage of massive scale. A sensing system with high sensitivity is needed for reliable structural health monitoring. A capacitive sensing circuit is designed using off-the-self-components and transmit data wirelessly using XBee. The circuit can detect small changes of capacitance variation due to structure vibration.**

Index Terms— **Capacitor sensor, Instrument Amplifier, Structural health monitor, Wireless monitor**

I. Introduction

Civil structures involve the meticulous construction of buildings, roads, bridges and tunnels regarding design and maintenance to prolong the lifetime of such structures. Often, these structures as well as its integrity also define a country's socioeconomic well-being. The larger the structure, the harder it is to monitor its structural health and the more expensive it is to keep it under constant maintenance. Natural disasters such as earthquake, typhoon and landslides are major contributing factors to the decline in structural life expectancy. This increases the demand for a thorough implementation of the structural health monitoring system as tragic incidents such as collapsed bridges and cracked structures have a direct relationship to public safety. If neglected, it can lead to huge amounts of casualties apart from causing a country's economy to suffer.

The ultimate aspect of damage analysis and localization in infrastructures can be made by diagnosing the structural deviation from its original and optimal performance [1]. From henceforth, the analysis as to how much deviation has occurred and what type of action that needs to be taken can immediately follow with great regards to the safety of the structure. Over time, researchers have conducted the study of suitable materials that can be used to manufacture accurate sensing abilities. The SHM systems as it usually involve the monitoring of massive infrastructures almost simultaneously. Apart from that, it is also important to comprehend and interpret the type of data that is captured by the SHM systems. Vibration and inclination measurements are examples of data that can be captured by sensors and are vital in SHM systems.

Sensors used in SHM systems should be appropriately and strategically placed over a structural system while data acquisition is needed to monitor receiving signals. Sensors that are high in sensitivity allows the collection of more accurate data. This means that even the subtlest changes can be recorded and monitored. Immediate action can be taken in response to any detection that might lead to negative outcomes. Needless to say, the method to achieve reliable data collection is essential for an SHM system to function efficiently.

Moreover, a wide range of sensors is used to analyze key factors affecting structural integrity. These sensors monitor parameters such as movement and strain of structures. Currently, there are different types of sensors such as electrical resistance, vibrating wire sensors and distributed sensors. These sensors help to detect even the smallest movements that are almost impossible to detect with the naked eye. Additionally, these sensors are used within methods that range from traditional strain monitoring techniques such as fiber optics, acoustics and ultrasonic to more sophisticated techniques such as 3D laser scanning and digital imaging techniques.

In recent years, there has been an increase in interest in the use of wireless networks for many SHM systems due to the presently ever-evolving technological era [2-4]. The applications of such wireless networks are associated with several challenges that need to be taken into consideration upon implication. Such issues that need to be taken into consideration concern the cost of maintenance and the sensing reliability of the system. This is due to the fact that the implementation of a guided system includes high costs of installation and is an industrially arduous work, including

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AHM Zahirul Alam is with the Department of Electrical and Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: zahirulalam@iium.edu.my).

Noor Syamira Asyiqin Amir Hassan is with the Department of Electrical and Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: syamira.amir@gmail.com).

Nurul Arfah Che Mustapha is with the Department of Electrical and Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: nurularfah@yahoo.com).

Md Rafiqul Islam is with the Department of Electrical and Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: rafiq@iium.edu.my).

Sheroz Khan is with the Department of Electrical and Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: sheroz@iium.edu.my).

Muhammad Abu Eusuf is with the Department of Civil Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia (e-mail: abueusuf@iium.edu.my).

the need for frequent maintenance and inspection. More than that, if a guided system is used instead of a wireless network, this cost will increase significantly over massive structures. Hence, the demand for a wireless network gives the industry an opportunity to decrease costs in many aspects and is a distinguishable advantage to many.

A design of a wireless capacitive sensing circuit for structural health monitor are presented.

II. Design

The block diagram of the wireless structural health monitoring system is shown in Fig. 1. It consists of a capacitance sensor for detecting any changes in structure which can be measured by the changes in the capacitance. The changes of capacitance are reflected in terms of voltage. The voltage is capturing and monitoring through Arduino microcontroller. The data is transmitted/receive via Xbee.

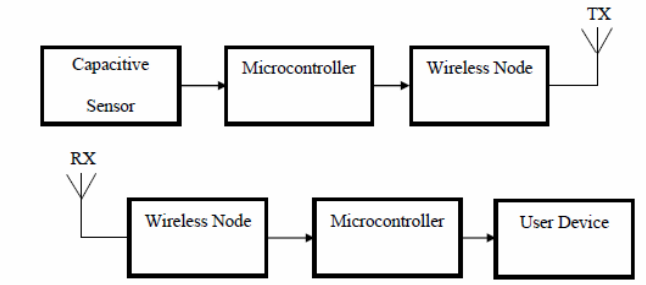

Fig. 1. Block diagram of the structural health monitoring system.

The circuit diagram of the capacitor sensor network is shown in Fig. 2. The circuit consists of a reference capacitance, C1 and a sensing capacitance C3. The sensing capacitance is designed using two parallel copper plate of dimension 10 cm × 10 cm separated a gap. The measured value of capacitance is 170 pF. The reference capacitance is chosen to be equal to the sensing capacitance value as 170 pF. The first part of the circuit of Fig. 2 act as a differential sensing amplifier using operational amplifiers followed by Schottky rectifier with RC filter. The outputs of the two diode rectifiers are then fed into an instrumentation amplifier which senses the differential change of these two outputs as expressed in equation (1) [5]. The non-inverting terminals of both the Op-Amps are shorted and connected to a reference voltage which is act as a reference voltage of ADC of Arduino input.

$$V_{diff} = \pm \frac{\Delta C}{C_f} \cdot \alpha \cdot V_{amp} \tag{1}$$

Where α is the attenuation of the diode rectifier and V_{amp} is the amplitude of the input voltage applied to the sensing amplifiers.

The output of the differential amplifier is given by

$$V_{out} = G \cdot V_{diff} \tag{2}$$

Where G is the differential amplifier gain which can be controlled by the resistance R5. The MCP6004 Op-Amps, DN5711 Schottky diodes and AD 623 instrumentations are used for the circuit shown in Fig. 2. Arduino UNO is used as an ADC to measure the instrument amplifier output voltage and the Arduino is attached to XBee module to transmit the data. Another Xbee is connected to the personal computer to receive data as indicated in the block diagram of Fig. 1. The complete implementation of the circuit is shown in Fig. 3.

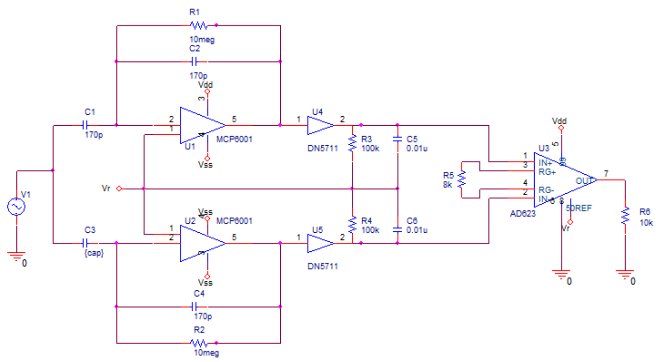

Fig. 2. Capacitive sensing circuit.

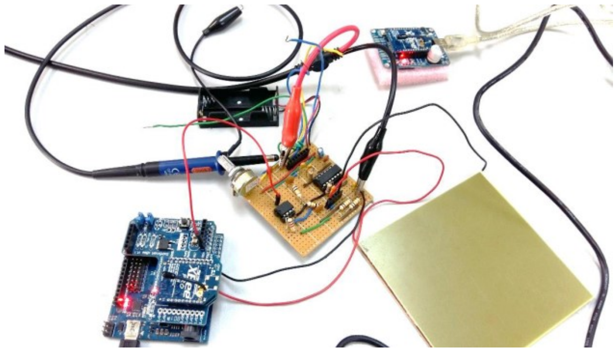

Fig. 3. Complete implementation of the sensing circuit.

III. Result and Discussion

The reference capacitance is varied from 170 pF to 200 pF with the vibration. As vibration occurs in the structural body causes to vary the distance between parallel plate capacitance. Simulation has been done using PSpice simulator to observe the behavior of the output of the instrumentation amplifier. The output voltage of the instrument amplifier with the variation of the sensing capacitance is shown in Fig. 4. It is observed that the output voltage is 1.5 V, which is equal to the reference voltage when the sensing capacitor value is 170 pF which is equal to the reference capacitance. The output voltage decreases as the value of the sensing capacitance increases. The output voltage of the instrumentation amplifier can be increased by interchanging the reference capacitor, C1 and the sensing capacitor C3. The effect of the interchanging capacitances is shown in Fig. 5.

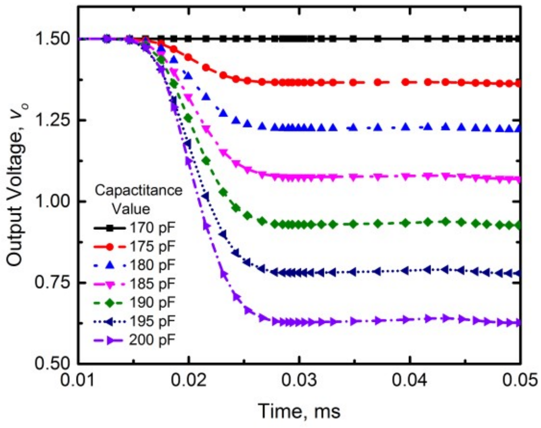

Fig. 4. Instrument amplifier output voltage with the variation of the sensing capacitor.

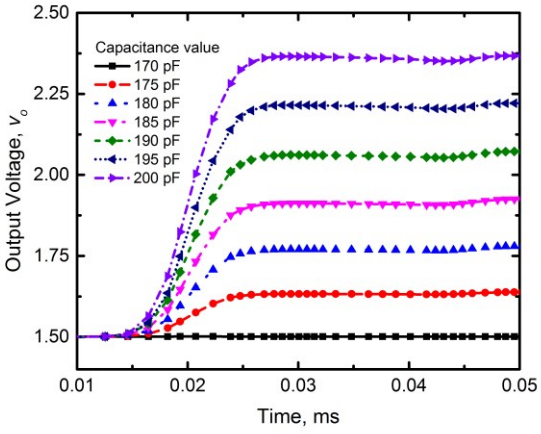

Fig. 5. Instrument amplifier output voltage with the variation of the sensing capacitor by interchanging sensing and reference capacitor.

Figure 6 shows the variation of the output voltage of the instrument amplifier with the changes of the sensing capacitance on the reference capacitance. It shows that the output voltage increases or decreases linearly with the changes of the capacitance depending on the position of the sensing capacitor as predicted by Eqn. 1. It is observed that the output voltage changes at the rate of 25 mV with the change of 1 pf capacitance for the differential amplifier gain, G of 13.5.

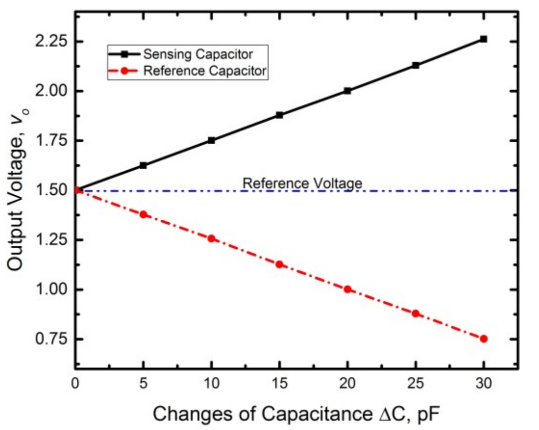

Fig. 6. Instrument amplifier output voltage with the changes of capacitances.

The output of the instrument amplifier is fed to the ADC pin of Arduino with Xbee. Arduino is properly configured to read the exact voltage of the amplifier and transmit data by Xbee. The other receiver Xbee also configured properly to receive data. It is found that the Xbee received proper data corresponding to the sending data.

IV. CONCLUSION

A simple capacitive based structural health monitoring system has been proposed. The circuit can measure a very small capacitance changes. The proposed circuit can give an output of 25 mv for every pf changes. The measured data can easily transmit using Arduino microcontroller based system. Xbee is successfully used for wireless data transmission. Many sensor nodes are required for monitor a large structure.

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