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# COMPARISON OF FEASIBILITY OF RISK MONITORING IN BUILDINGS IN TWO WIRELESS SENSOR NETWORK: MICA MOTE AND MEMS

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**Abstract:-** In this paper feasibility of risk monitoring of buildings in two wireless sensor network is presented, firstly by using MICA Mote and then by MEMS. Also, it will be verified that the MEMS sensors are superior as it provides high quality sensor data and no data loss as compared to MICA Mote. In order to assess earthquakes the structures is monitored firstly by using a smart sensor based on the Berkeley Mote platform. The Mote has on-board microprocessor and ready-made wireless communication capabilities. In this paper, the performance of the Mote is investigated through shaking table tests employing a two-story steel structure. The feasibility of risk monitoring for buildings is also discussed. In building monitoring using MEMS, a low power wireless network employing capacitive MEMS which is custom-developed, 3D accelerated sensor and a low power readout ASIC is used at the sensor nodes. After the earthquake, the plastic hinge activation of structure is being measured using MEM sensor either periodically or on demand by the base station. During an earthquake the accelerometers are used to measure the seismic response of the structure. The seismic response is recorded by the accelerometer based on the local acceleration data and remote triggering from the base station. The base station is based on acceleration data from multiple sensors across the structure. In a 800 MHz band, a low power architecture had been implemented over an 802.15.4 MAC.

**Keywords-** MICA Mote, Microelectromechanical System or MEMS, ASIC, remote monitoring, wireless sensor network.

## I. INTRODUCTION

The MICA (Fig.1) Mote have been developed by researchers at the University of California, Berkeley [7]. It is an open hardware and open software platform for smart sensing and consists of plug-in sensor boards, processor, transceiver, and attached AA battery pack.



Fig1: MICA

However, in MEMS in order for the installation of a permanently installed sensing system in buildings to be economically viable [1], the following conditions must be fulfilled:

□ The sensor modules must be wireless to reduce installation costs by eliminating the need for installation of large amounts of cabling.

□ The sensors must require low amount of maintenance, which implies that they must operate for a long time without battery replacement, and therefore have low power consumption.

□ The sensors must be low cost, which can be accomplished by sensors that can be mass produced such as MEMS sensors.

The capability of MEMS and wireless networking for monitoring civil structures is well documented [2][3][4].

The sensor system realized in the paper as described in this paper addresses all of the above requirements.

## II. ARCHITECTURE FOR MONITORING SYSTEM USING MICA

### A. Shaking table test by MICA

The application software, which was developed by the Open Systems Laboratory, the University of Illinois at Urbana-Champaign, was installed to the MICA. It runs on the TinyOS version 1.0 and has a re-try function for sending the information to the base station from each MICA2. Shaking table tests were conducted to investigate the performance of the MICA. Fig. 2 shows the two story test structure considered with elasto-plastic beams and columns. They are made with aluminum for columns and beams. The MICA and a reference accelerometer were attached to the top and base of the test structure as shown in Fig. 3.

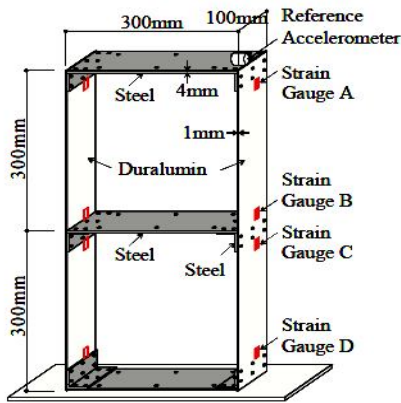
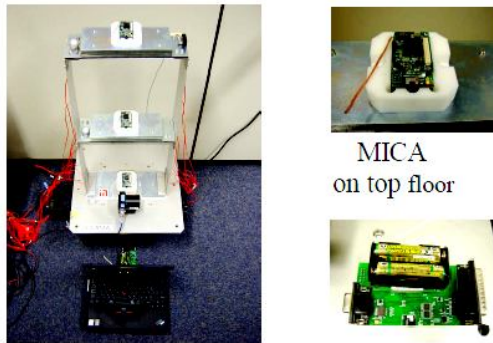


Fig2: Tet structure



Test structure and PC with base station

Base station

Fig3: Tet structure setup

**B. Sensor board**

A variety of sensor boards for the MICA are available. A MTS310 Sensor Board manufactured by Crossbow Technology, Inc. [6], which was used in this research, has acceleration, magnetic, light, temperature, and acoustic sensors, as well as a sounder as shown in Fig. 4. Other sensor boards can be designed and manufactured freely for specific purposes. The “Tadeo sensor board” which is equipped with a high-sensitivity acceleration sensor has developed and tested for civil engineering applications [8].

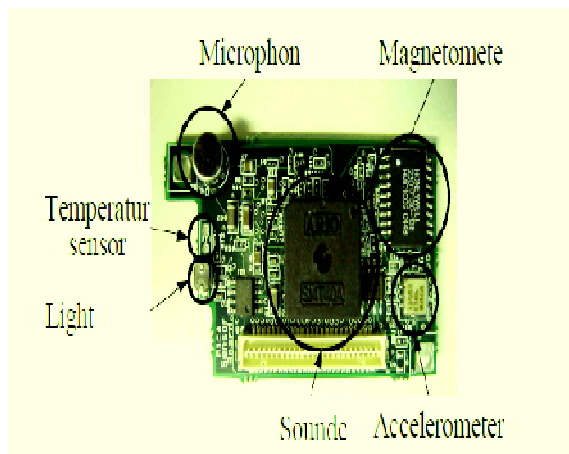


Fig4: M3S310 Sensor board

**III. ARCHITECTURE FOR MONITORING SYSTEM USING MEMS**

*A. Network Architecture*

The monitoring system consists of two types of modules: strain sensing modules and acceleration sensing modules. They are placed in the building as shown in Fig.5. The strain sensor modules are mounted at the lowest level of the building, to estimate the vertical column loads and to measure the settlement and plastic hinge activation of the building after an earthquake. Horizontal acceleration is measured by two 3D acceleration sensing modules (where only the two horizontal axes are really required) at each level during an earthquake, allowing analysis of the seismic response of the whole structure. A typical 7-story, 24-column building requires approx. 72 strain sensors (3 per column) and 14 accelerometer modules (2 per floor).

The data obtained by the sensor system is wirelessly transmitted to a nearby base station using a line of sight link with a range of >1km. The line of sight link uses directional antennas to improve the link budget, but not so directional that alignment is required, which could pose a problem during seismic events.

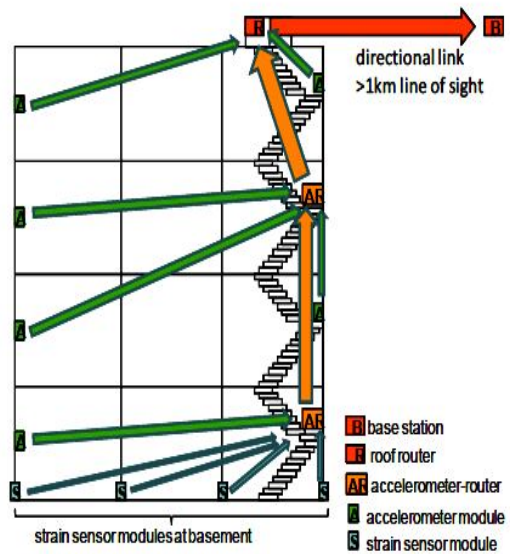


Fig5: Network architecture

In order to form a robust wireless link from all modules, including the strain sensor modules at the basement of the building, towards the receiver base station, a multi-hop network architecture is used as shown in Fig. 5. On the roof of the building a dedicated router module (without sensor) is placed to forward the data between the sensor network and the receiver base station. Some accelerometer modules on intermediate floors can be configured as additional intermediate routers when required to obtain a robust link from all sensor modules in the building towards the roof router module. As shown on Fig. 5, it is recommended to place the router modules in

or close to the stairwell for improved vertical floor-to-floor propagation through the building. For lowest power consumption in the sensor modules, the network is implemented using indirect data transfer using polling on top of a standard 802.15.4 MAC.

**B. Micro-electro-mechanical System (MEMS)**

Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move as in Fig. 6.

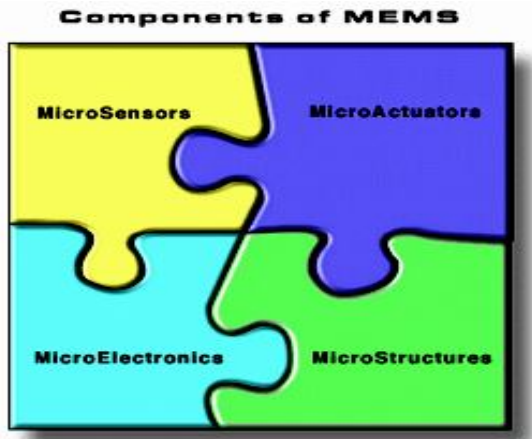


Fig6: Components of MEM

The MEMS strain sensor is a longitudinal comb finger capacitor. Fabrication procedure of strain sensor starts with a SOI wafer with a 500µm thick handle, 50µm thick fingers and 2µm thick oxide layer with 400 fingers in the sensor and it has a sensitivity of 0.133fF/µε. It consists of 2 transverse comb finger structures for the X and Y axis and a pendulating one for the Z axis. It was fabricated with a surface micromachined process from a 85µm thick SOI wafer. It has 78 fingers with a total sensitivity of. Sensitivity-bandwidth-linearity in all three axes, is the major tradeoff in the design of accelerometer. The readout ASIC is packaged together with all the three accelerometers i.e. X, Y and Z into a system-in-a-package and then mounted onto the printed circuit board as can be seen on Fig 8.

**C. Strain sensing front-end module**

The MEMS strain sensor is packaged together with the readout ASIC into a special front-end strain sensing module which is embedded inside the reinforced concrete onto the reinforcing bar, preferably prior to the pouring of the concrete. As shown in Fig. 7, the sensor is mounted on a polyimide carrier which in turn is glued onto the reinforcing bar. A variant of this package exists in which the carrier is thin steel, which offers the additional possibility for welding the carrier to the reinforcing bar. The module is molded in PDMS silicone to protect the components from the environment during installation and pouring of concrete, while remaining a mechanically compliant package to avoid distorting the strain sensor measurement. This front-end strain sensing module is connected to the rest of the module through a small 4-wire cable with a maximum length of 1.5m.

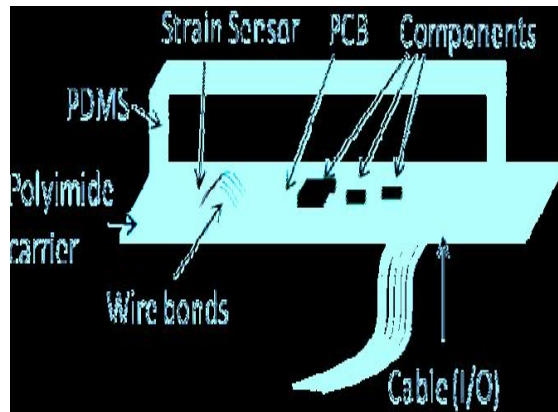


Fig7: Strain sensor front end module

**D. Accelerometer Module**

Both the accelerometer and strain sensing variants of the module use the same core components. For installation into the building these components are placed into a standard off-the-shelf plastic casing that can be conveniently mounted on the floor, wall or ceiling using screws, and offering access for sporadic battery replacement if needed.

The core components are:

- 1) A custom-developed low power capacitive sensor readout ASIC [5].
- 2) A low power 16-bit successive-approximation analog-to-digital converter (Analog Devices AD7683).
- 3) A low power microcontroller (TI MSP430) to control the sensor data acquisition and temporarily store the data in a 64Kx16bit SRAM memory (Cypress CY62126).
- 4) A low power wireless IEEE 802.15.4-compatible module (Atmel ATZB-900) operating in the 900MHz band.
- 5) A custom patch antenna was designed for the modules. Its shape and radiation pattern is optimized for wall-, floor- and ceiling-mounting in the building.
- 6) The modules are powered by a an 8.5Ah C-cell long



operating life primary Lithium Thionyl Chloride battery (Tadiran SL-2770), suitable for 10 to 25 years of operation



Fig8: Packaged accelerometer module with axes

E. Measurement initiation

1) Accelerometer modules

The main trigger for the recording of an acceleration measurement is the detection of the start of an earthquake. The detection is done using a distributed earthquake detection mechanism as shown in Fig. 9. When the output of the builtin accelerometer in a selected number of monitoring nodes exceeds a certain minimum threshold, during a certain minimum time, these monitoring nodes provide alerts to the station. The base station software will decide based on the number of monitoring nodes providing alerts whether to wake up the entire network of acceleration sensing nodes over the radio. The monitoring nodes are selected based on their location and amount of environmental noise. Ground-level nodes may be suitable candidates, provided they are sufficiently far removed from disturbance sources such as heavy traffic. The selection of monitoring nodes can be done dynamically from the base station. This allows for example to disable the monitoring function on nodes that report unusually high numbers of false alarms. To that purpose, the hardware and software of the monitoring nodes are identical to that of the non-monitoring nodes. The monitoring function is an optional function which can be enabled or disabled during operation by the base station. After the nodes have been woken up the recorded data is read out by the base station which sequentially requests the data of each sensor module.

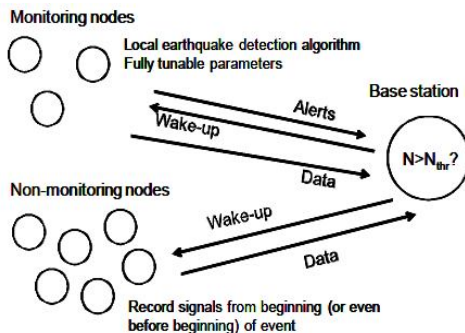


Fig9: Network earthquake wake-up procedure

2) Strain sensor modules

The main measurement scenario for the strain sensor is a periodic readout. Samples are taken at a configurable sample between 10 seconds and 18 hours. The strain sensor modules use a radio polling interval of 60 seconds. This also allows manual wake-up functionality from the base station, again useful for monitoring and testability reasons. Unlike for the accelerometers, in the case of the strain sensors the sensor and read-out ASIC can be entirely shut down between measurements. This results in a lower power consumption and longer battery life. Since a typical building requires many more strain sensors than accelerometer modules, it is useful for the strain sensors to have the longest battery service life.

IV. RESULTS

A. MICA (Free Vibration Test Results)

Free vibration tests of structure in Fig. 2 were conducted. Fig. 10 shows measured accelerations at the top of test structure A using both the reference accelerometer and the MICA. Accelerations from the MICA were sent wirelessly to the base station, which was attached to the notebook PC (see Fig. 3). The sensitivity of the accelerometer on the MTS310 Sensor Board is not sufficient for accurate measurement of small amplitudes [8]. Additionally, some of data were lost during the test because of wireless communication problems such as packet collisions. The maximum rate of data loss was 30 percent.

B. MEMS (Power consumption Results)

Fig. 11 shows the measured power consumption in the sensor modules for strain sensor and accelerometer modules and how it is broken down according to the different components of the system. The total average power consumption is 0.274mW for the strain sensor modules and 1.73mW for the accelerometer modules. With the abovementioned C-cell size battery this implies a battery life of 12 years for the strain sensor modules and 2 years for the accelerometer modules.

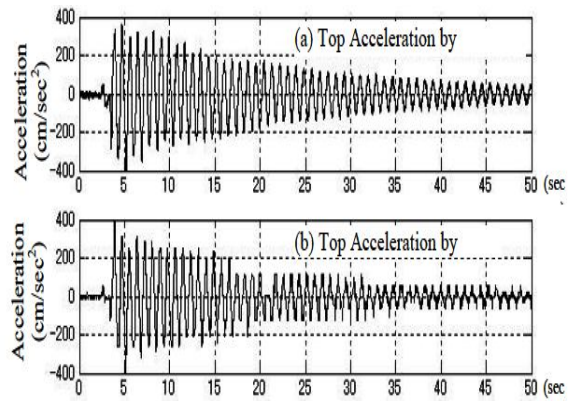


Fig10: Free vibration test results

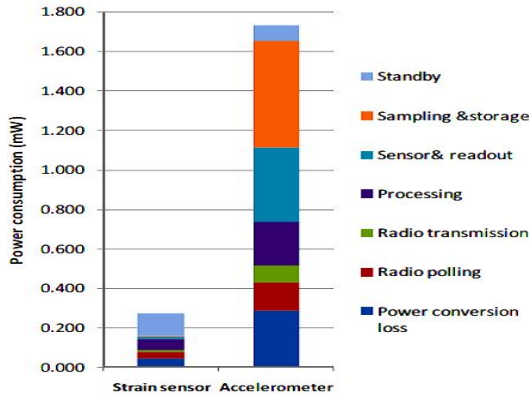


Fig11: Sensor module power consumption result

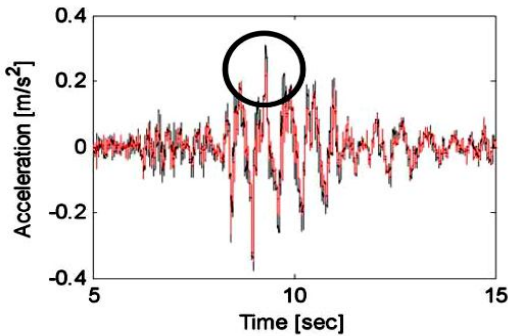


Fig12: Wireless sensor module acceleration signal output on full scale model with simulated earthquake and comparison to reference accelerometer

**V. CONCLUSION**

The feasibility of risk monitoring for buildings using the smart sensors was discussed, and the performance of the MICA Mote as a wireless sensor was tested. The sensitivity of the accelerometer on the MTS310 Sensor board is not sufficient for accurate measurement of small amplitudes. Additionally, some of data were lost during the test because of wireless communication problems such as packet collisions. These results were shown by the free vibration test results of MICA. Further research on more effective modes of communication that facilitate no data loss is needed to achieve a wireless sensor network for building risk monitoring.

The presented wireless system for building monitoring using MEM Stakes advantage of the unique features of custom-developed MEMS sensors and read-out ASIC combined with an optimized network and module architecture, to realize a solution which offers long battery lifetime and potentially low cost in manufacturing, installation and maintenance, while providing high-quality sensor data at the right time.

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