DESIGN AND SIMULATION OF MEMS SENSORS WITH INBUILT GSM COMMUNICATION FOR SMART BUILDINGS

Chathuranga K.V.D.S.[1] Jayasinghe C.M.[2]

[1]Engineer, NANCO (Pvt) Ltd., Lot 14, Zone 1, Biyagama Export Processeing Zone, Walgama, Malwana, Sri Lanka.
E-mail: damiths@susnanotec.lk
Telephone: +94 11 4650519, Fax: +94 11 4741995

[2]Engineer, NANCO (Pvt) Ltd., Lot 14, Zone 1, Biyagama Export Processeing Zone, Walgama, Malwana, Sri Lanka.
E-mail: chiranthaj@susnanotec.lk
Telephone: +94 11 4650519, Fax: +94 11 4741995

Abstract: Use of MEMS based sensor in building automation is a trend in the present. This is because the inherent behavior of MEMS sensors are being very compact, low powered, sensitive and cheap methods of sensing biological and environmental activities in a smart building. This paper discusses about the use of MEMS based acceleration sensor and a pressure sensor coupled with an inbuilt GSM module in the building automation system, particularly the security applications. The writers have decided about the parameters for the needed sensors and designed the pressure sensor and the acceleration sensors for fabrication accordingly. The conceptual system hardware was tested using commercially available sensors and GSM modules. The applicability and the methods the integrated sensor system can be used for is also discussed. The case study is performed at the premises of The Sri Lankan Institute of Nanotechnology (SLINTEC). The paper contains the design parameters and the electronic systems design data and drawings. It is hoped that this data would be supportive to any person who would design or improve the proposed system.

Keywords: MEMS, Accelerometer, Pressure Sensors, Smart Buildings

1 Introduction

Resent technological advances have revolutionized the standards of living by making the lining environment smarter and interactive with the residents. Smart environments [1] tend to catch the attention of the people because it allows saving of energy, increase of health and security, lowering of maintenance cost and increase of comfort levels for humans.

When smart environments are concerned, smart buildings are the most talked about subject in the field. The essence of the smart building is comprised of advanced and integrated systems for building automation, life support and telecommunications systems. Use of new sensors and communication systems to built sensor networks for smart building installations are becoming more and more popular all over the world. The sensor networks are then connected to an integrated building management system which allows the tenants to manage the building. Fundamental reason for sensor networks is that by integrating the systems the building manager and tenants can do things that simply cannot be done with separate systems. When systems get integrated, communicate and data sharing is easy, provide more functionality and flexibility. In addition, intermigration allows information from one technology system to affect the actions of other systems. For example, if a smoke detector alarm is activated, the access control system changes to emergency mode; the heating, ventilation, and air conditioning systems adjust; the video surveillance camera changes so the affected area can be monitored; and so forth.[2]

Smart security systems are a predominant item in the smart building and management system. Modern homes use Micro Electro Mechanical devices in security systems, ventilation systems, and safety systems. MEMS are mostly used because of their small size and the low power consumption. It is also seen that the response time and the sensitivity is comparatively higher than mechanical only sensors.

In this paper, the use of MEMS acceleration sensors and pressure sensors in security application is presented. The sensor data is processes and sent through wireless communication network to the resident or the building management system. The proposed system can either be incorporated in to the building management system or can be used a separate security system. This separate system is ideal for a resident who does not have a building security system in their buildings but wish to incorporate additional security futures in to the environment they live in or work at.

The proposed system of sensors detects vibrations of floor or the sudden pressure drop inside the room when a person opens the door and enters the room. Then the system notifies to the resident that a human has entered the room. This type of system can be modified for the use for climate control or lighting control as with the system, it is easy to identify if a human has entered the room or not and it is easy to control the lighting of the rooms such as dimming or brightening the room as humans leaving or entering the room or the house. This will in return save the energy usage by the house. With a network of sensors such as these, it is possible to identify where the humans are at a given time. This kind of data would be ideal to model behavioral patterns of the residents in the building and utilize resources accordingly. An example would be to identify the pattern of bathroom usage of the residents. This data can be used to turn the water heater only at times when bathrooms are frequently used such as in the morning and at night.

The paper presents the design specifications and the designs of the sensors. The application circuits of the sensor module and the design specifications are published herewith. The GSM communication system and the software development are also addressed.

2 MEMS based sensor module with inbuilt GSM communication

The objectives of the project is to build a MEMS sensor unit having an acceleration sensor, a pressure sensor and a GSM unit and incorporate the sensor system in to a smart building security system to identify if a person has entered an unoccupied room (breach of security) and relay that information to a mobile phone via the GSM network.

The vibration due to motion of a person can be detected by using an MEMS accelerometer placed on the floor and near windows and entry points. A MEMS pressure sensor can be used for detecting the pressure changes caused by opening and closing of doors in a closed room. Pressure changes inside the room because the change in flow patterns when opening a door or window in a closed room. Because the two sensors are to be near an entry point, the sensors are to be compact and to be unnoticed, minimal number of wires is to come out from the unit. The system built is a single compact unit having a pressure sensor and an acceleration sensor unit. The only wires coming out were the power supply lines.

This system is activated only when the last person left the building. When the system is activated, the system does not expect to detect any movement inside the building, if it detects any movement it considers this as breach of security and immediately alarm the particular party using short message service (SMS).

Commercially available accelerometer and a pressure sensor with a microcontroller are used in the prototype designs to test the validity of the proposed system. A GSM modem is used as the communication equipment.

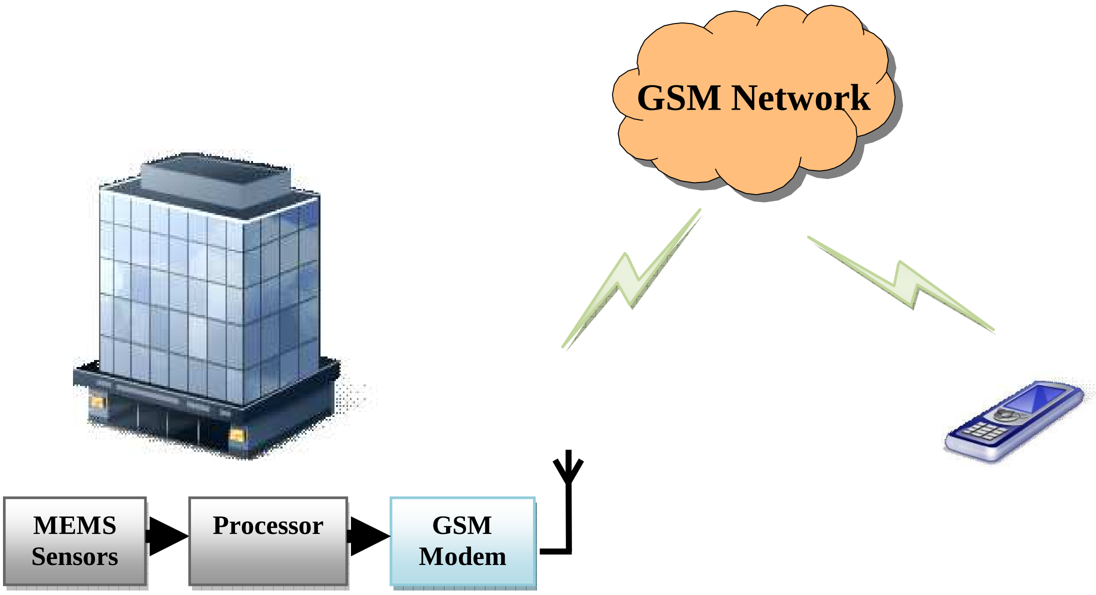

Fig. 1: Schematic diagram of the system

3 Design and Simulation of MEMS based sensors

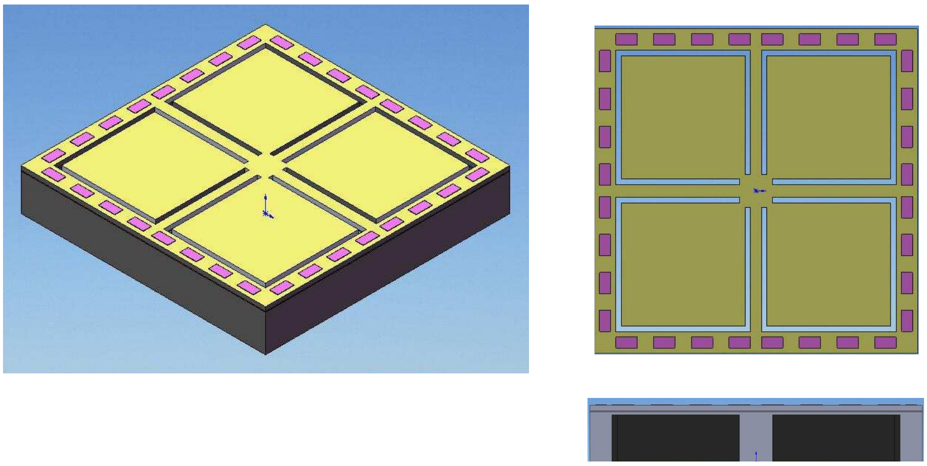

Fig. 2: 3D model of the proposed 3-axis acceleration sensing structure

3.1 Sensing Structure and Working Principle

The working principle of 3-axis acceleration sensor can be explained as follows; when the sensor is under the acceleration, the beam-structure has two kinds of important vibration modes that lead to form two deflection forms. Schematic drawings of deformed shapes of the beam structure are used to describe the working principle of the accelerometer. The first type shown in Fig. 3 (a) is caused by the X- or Y-component of acceleration (AX, Ay). In this case, seismic mass is being twisted around X or Y axes according to applied acceleration. The second type shown in Fig. 3 (b) is caused by the Z-component of the acceleration (Az). Az causes the seismic mass to move vertically up and down. These deflections of the beams as a result of the applied acceleration component on the sensor are generating strain on the crossbeam structure. Finally, stress variations on beam(s) surfaces are produced linearly as a consequence of the strain.

In p-type piezoresistors, the resistivity of diffused layers changes when subjected to strain. This phenomenon has been used as the sensing principle of the 3-axis accelerometer with integrated piezoresistors on a single crystal silicon crossbeam structure. The resistance variations of resistors could be converted into electrical signals by using imbalance of excited Wheatstone bridge circuits.

3.2 Structural analysis

The structural analysis of the sensing chip was done via two steps. Firstly, analytical analysis was done by classical elasticity theory for rough estimation of sensor dimensions based on the required ranges of acceleration, the piezoresistance effect of silicon, the non-buckling condition, and the necessary width of the beam for wiring. Secondly, this model was analyzed by a finite element method (FEM) to investigate more comprehensively the stress field in the structure, to determine the motion of the seismic mass, the resonant frequency of the structure and to refine the specifications of the beam dimensions. The finite element model of the sensing chip was numerically analyzed by using the commercially available ANSYS simulation software. The FEM model of the accelerometer is densely meshed in the beams to better resolve the stress distribution there. Element type, SOLID45 is used for the 3-D modeling of this solid structure. Firstly, the modal analysis was carried out to find the vibration modes of the sensor structure and resonant frequencies. Fig. 4 (a) and (b) show those vibration modes. Secondly, static analysis was performed to find out stress distribution and non buckling conditions of sensor structure. Fig. 4 (a) and (b) show the graphical representation of longitudinal stress distribution on the surface of X-oriented beam structure. Based on the stress distribution results obtained by FEM analysis and the classical elasticity theory, piezoresistors were placed to eliminate the cross-axis sensitivities, and to maximize the sensitivities to various components of acceleration.

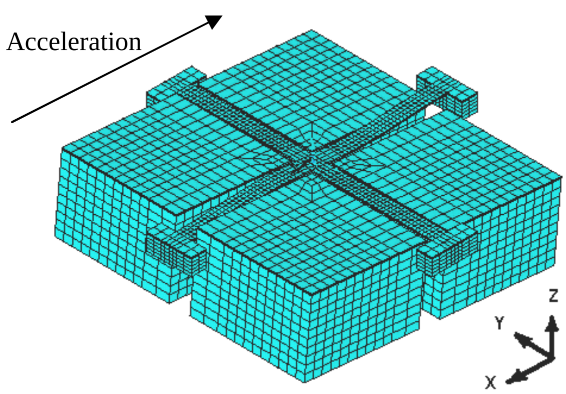

Fig. 3 (a): 1st vibration mode of the sensing structure

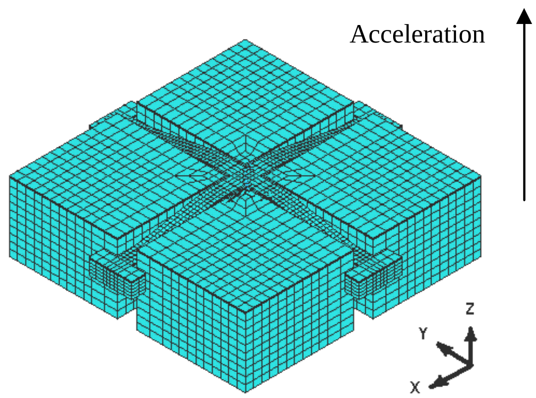

Fig. 3 (b): 2st vibration mode of the sensing structure

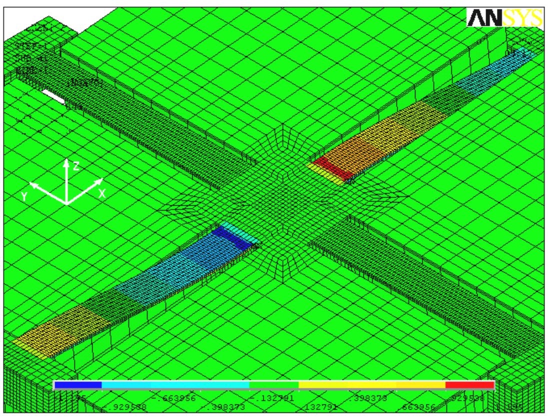

Fig. 4 (a): The stress distribution on surface of X-oriented beam structure under applied acceleration Ax

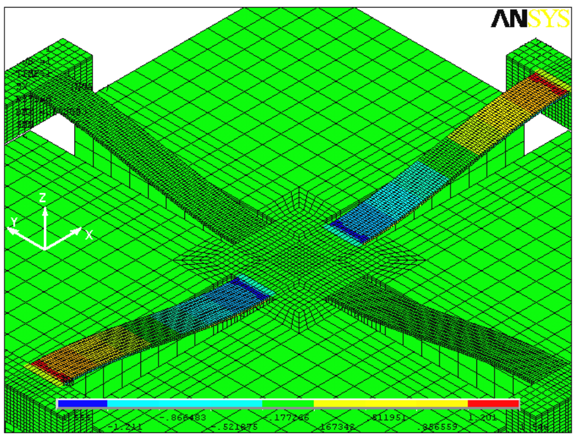

Fig. 4 (b): The stress distribution on surface of X-oriented beam structure under applied acceleration Az

3.3 Measurement Circuits

In most cases, Wheatstone bridges are being used for the measurement of resistance change of piezoresistors on sensors. Identical twelve p-type piezoresistors have been interconnected to form three Wheatstone bridge circuits on the beam structure. Induced voltage under the acceleration can be measured as the output of the sensor. [3]

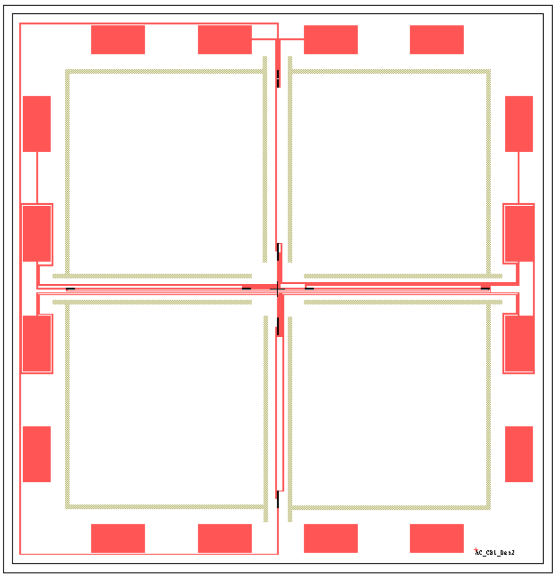

Fig. 5: Mask layout of the sensor (die chip area is 3mmx3mm)

3.4 MEMS Pressure Sensor

Design and Simulation procedure for the MEMS Pressure sensor was same as for the MEMS accelerometer.

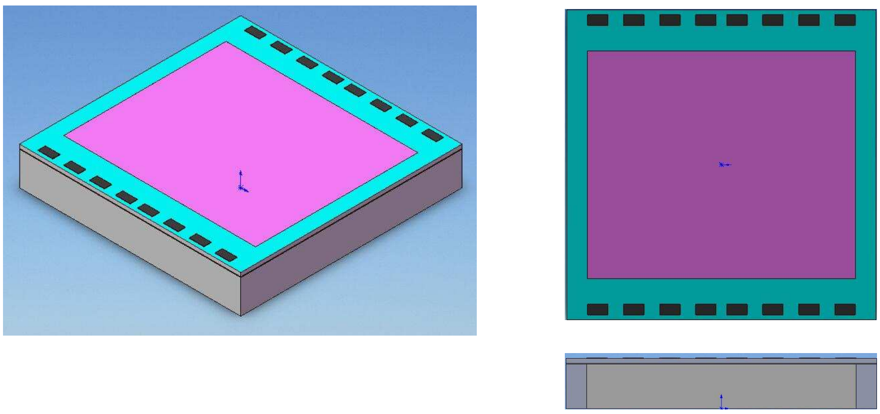

Fig. 6: 3D model of the proposed 3-axis Pressure sensing structure

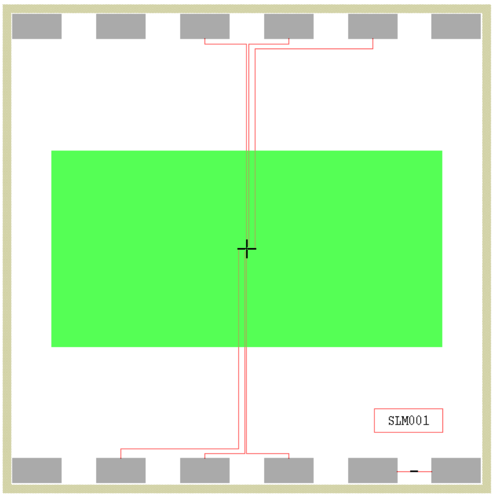

Fig. 7: Mask layout of the Pressure sensor (die chip area is 3mmx3mm*).*

4 Design

4.1 Sensing Mechanism for detecting the breach of security of the room

Vibration data are collected from an accelerometer, fixed on a tile or a plate and put beneath the carpet closer to a door or an entrance to the room. The system can be mounted such a way that it blends with the surroundings. This tile has one degree of freedom in the vertical direction. The amplitude of the tile is about 1mm. The pressure sensor opening is placed such a way that it will detect the pressure differences near the door. When a person walks near the place where the acceleration sensors are placed, they will pick up the vibration. Vibration waveforms can be filtered to identify if a person walked near the place. It also can produce the weight of the person and give characteristics of the persons walking pattern to a some degree of accuracy provided the use of three acceleration sensors near each other and comparing the three sensor data. However this data only is not sufficient to accurately state that a person has entered the room because the acceleration sensor picks up all the vibration signals near the vicinity of the sensor. In a building when a door or a window gets opened air inside the particular room move in a higher velocity, which causes a sudden pressure difference inside the room. This kind of action can be detected by placing a high sensitive pressure sensor inside the entrance. With the acceleration sensor data and the pressure sensor data processed at the same time, it can be concluded that a person has entered the room or passed near the room.

4.2 Electronic Circuit Design

The electronic circuit that was design for this application can be divided into the following major components,

I. MEMS Accelerometer
II. MEMS Pressure Sensor
III. Instrumentation amplifier for signal amplification
IV. Microcontroller with USB interface
V. Voltage regulator

RS232 Level convertor for GSM Modem

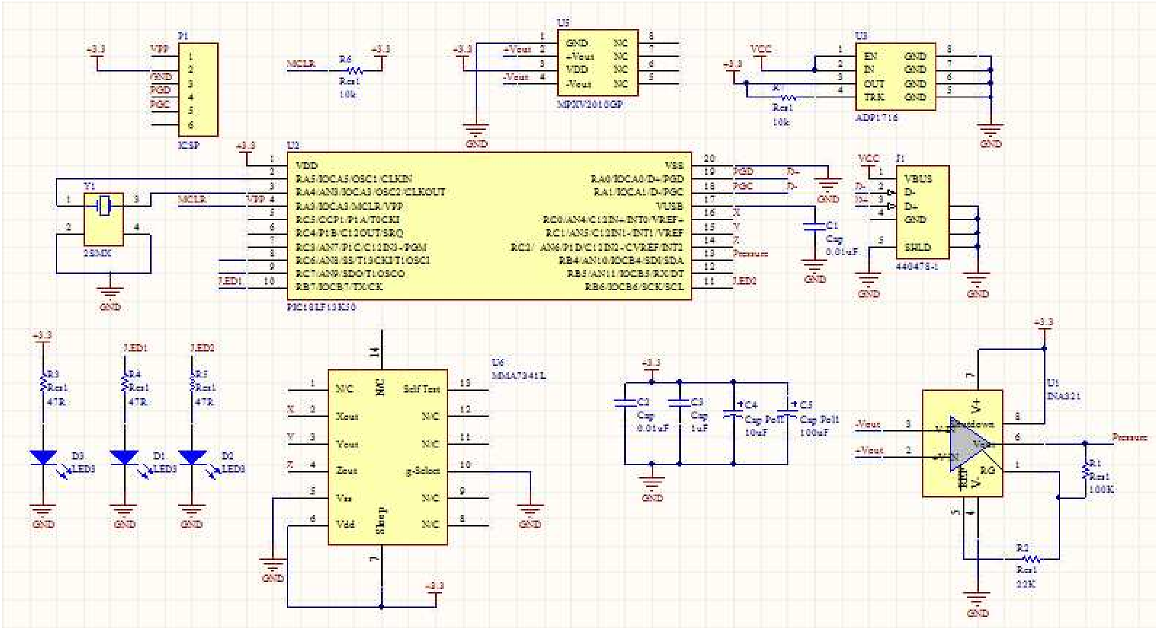

Fig. 8: Schematic diagram of the circuit

Both accelerometer and pressure sensor have very small output voltage value which is not sufficient for the Digital signal processing. Thus the signals had to be amplified. Instrumentation amplifier is used here for signal amplification. In this design we used an INA321 instrumentation amplifier (Texas Instruments) for signal amplification. Commercially available MMA7341 MEMS 3-axis accelerometer (Product of Freescale Corporation) is used for the acceleration sensor. It has a sensitivity of 3g. Commercially available MPXV2010GP MEMS Pressure sensor (Product of Freescale Corporation) is used. It has a sensitivity of 10kPa.

PIC18LF13K50 microcontroller is used for the signal processing. Analog to digital conversion is also performed using the built in analog to digital convertor. Since the GSM modem used in this design has the normal RS232 interface, for the RS232-TTL level conversion a MAX233 chip was used. The USB interface can be used to interface this system to a computer for further signal processing.

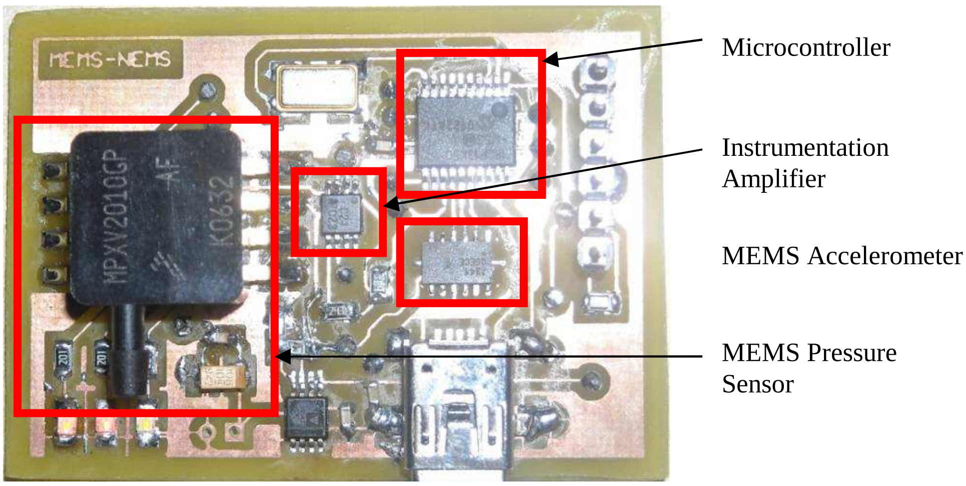

Fig. 9: Hardware circuit module (4.5cm×3.0cm)

4.3 Communication interface

Since GSM communication is very popular nowadays, it has been used to alert the user. SIEMENS mc35i GSM modem is used for the communication which has RS232 interface. Hayes "AT" commands are used to communicate with the modem through RS232. The Hayes command set is a specific command-language originally developed for the Hayes Smartmodem 300 baud modem in 1977. The command set consists of a series of short text strings which combine together to produce complete commands for operations such as dialing, hanging up, and changing the parameters of the connection. Most dialup modems follow the specifications of the Hayes command set. [4]

The following code describes a SMS send and setting up necessary configuration. The code is written in ANSI C language for PIC Microcontrollers.

```
printf("\rAT\r");
delay_ms(1200);
printf("\rAT+CPMS=\"ME\"\r");
delay_ms(1200);
printf("\rATE0\r"); //Disabling Echo feature
delay_ms(1200);
printf("\rAT+CMGF=1\r"); // Entering TEXT mode for SMS
delay_ms(1200);
printf("\rAT+CMGS=0712345678\r");  //send SMS to No 0712345678
delay_ms(2200);
printf ("Test1");
putc(26);
delay_ms(1200);
```

5 Conclusion

In this project we have developed a circuit incorporating a MEMS pressure sensor, an acceleration sensor and a GSM module for smart house security systems. The test codes and circuit designs are presented in this paper. The sensor module is having a compact design and can easily be used in security applications. It is wished that this research carried out would help future engineers to come up with solutions for smart building.

References

[1] Seth Holloway, Drew Stovall, and Christine Julien, What Users Want from Smart Environments.
[2] Jim Sinopoli, “Smart Buildings” ISBN 0-9786144-0-2 pages 3-4
[3] R.Amarsinghe, D.V.Dao, T.Toriyama, S.Sugiyama, “Design and Fabrication of Miniaturized Six-Degree of Freedom Piezoresistive Accelerometer” MEMS2005 Conference, pp. 351-354, 2005.
[4] http://en.wikipedia.org/wiki/Hayes_command_set, visited on 3rd August, 2010