Intelligent Ground Vibration and Building Management System

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***Abstract*-Preemptive systems are systems that help in prediction of potential and possible future damages. Such pre emptive systems find its application in many areas ranging from small industries to infrastructure like bridges, buildings and historical moments. At present structural damage of building may cause significant losses of life and various properties at different places. So a low cost. low power, tilt measurement systems and ground vibration monitoring designed with a three axis MEMS accelerometer and a PIC 16F877A micro controller. The MEMS accelerometer detects the angle shift of the building from its original position, when the inclination of the building exceeds its pre determined threshold limit. A notification message will be send to the concern authority of Government personnel and to the owner of the building through GSM modem. Additionally automatic detection for LPG gas inside the building is proposed as safety measurement and an automation system to save the human lives from disaster.**

Keywords – Accelerometer, Vibration, MEMS, PIC 16F877A microcontroller, Tilt measurement systems.

I.INTRODUCTION

Analyzing stability of the building is a needed measurement process in building. Periodic monitoring of the structural damage will save the human lives in a better way [5]. Tilt measurement system is a device used to measure the tilt angle of the carrier to horizontal plane, which is widely used in attitude measurement fields such as MUAV, robot, motorcar, ship, building and so on.

With the development of MEMS Technology, the MEMS accelerometer becomes the good choice to design the micro tilt measurement system for its low power and low cost. The accelerometer can be used for tilt measurement because of its measurement principle [2-3].

This paper designs a low cost, fast response tilt measurement system. The work focuses on 3aspects.one is sticking the 3 axis accelerometer on beams or pillars of the building and to estimate the angle shift of the building. The accelerometer senses the angle shift of the building which is the difference between static acceleration and acceleration due to gravity. The next is using PIC16F877A microcontroller to process data and to determine Whether the inclination exceeds the pre determined threshold to send notification message to the concerned authority. The last aspect is determining leakage of LPG gas inside the building to save human lives from disaster.

The remainder of this follows. In section II, we will briefly introduce the measuring principle and the structure of the tilt measurement system. In section III we will describe the hardware design of the system. In section IV we will show how to compensate the error of the accelerometer with temperature. In section V experimental results are proposed to demonstrate the performance of the tilt measurement system proposed.

II. MEASURING PRINCIPLE AND SYSTEM STRUCTURE

A. MEASURING PRINCIPLE

Tilt is a static measurement. The force of gravity is used as input to determine the orientation of the beam calculating the degree of tilt. The accelerometer will experience acceleration in the range from -1g to +1g through 180° of tilt.

$$1g = -9.8m/s^2$$

B. 0 G OFFSET CALIBRATIONS

Accuracy and repeatability is a general concern for nearly all accelerometer applications. The accuracy of the tilt measurement can be improved by using a 0g offset calibration technique to compensate for offset errors. Even though the offset is trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and direction. This results in offset calibration.

C. GROUND VIBRATION

As population density increases, Construction operations, including blasting and pile driving, expose ever larger numbers of nearby facilities and individuals are perceived to be intolerable levels of ground vibrations. Ground vibrations are a significant factor when considering highway construction activities such as pile driving and rock blasting operations. These activities create the potential for real damage to surrounding building structures and facilities, as well as a perceived damage from human sensitivities to detectable yet non-damaging ground motions. Hence photos and video surveys, vibration level, crack monitoring and survey of elevations, vibration monitoring equipment are the requirements of vibration monitoring plan.

D. MEASURING TILT USING A 3 AXIS ACCELEROMETER

In order to define the angles of the accelerometer in three dimensions the pitch, roll and theta are sensed using all three outputs of the accelerometer. Pitch (ρ) is defined as the angle of the X-axis relative to ground. Roll (ϕ) is defined as the angle of the Y-axis relative to the ground. Theta (θ) is the angle of the Z axis relative to gravity [4].

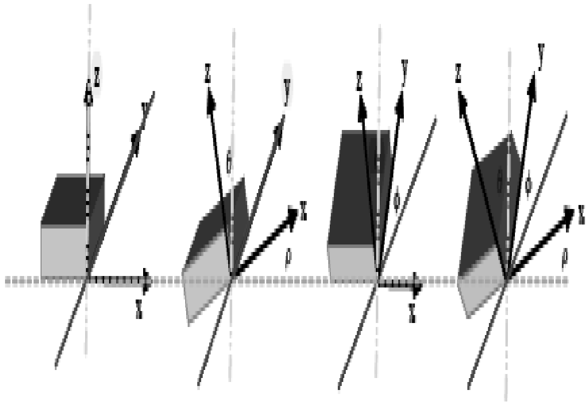

Fig.1.Three axis for measuring tilt

$$\rho = \arctan\left(\frac{A_X}{\sqrt{A_Y^2+A_Z^2}}\right) \quad \ldots \quad (1)$$

$$\varphi = \arctan\left(\frac{A_Y}{\sqrt{A_X^2+A_Z^2}}\right) \quad \ldots \quad (2)$$

$$\theta = \arctan\left(\frac{\sqrt{A_X^2+A_Y^2}}{A_Z}\right) \quad \ldots \quad (3)$$

$$\sqrt{A_X^2 + A_Y^2 + A_Z^2} = 1g \quad \ldots \quad (4)$$

Now the acceleration due to gravity on the X-axis, Y-axis and Z-axis are combined.

III. HARDWARE CIRCUIT

A. BLOCK DIAGRAM OF TILT MEASUREMENT SYSTEM AND GAS LEAKAGE DETECTION

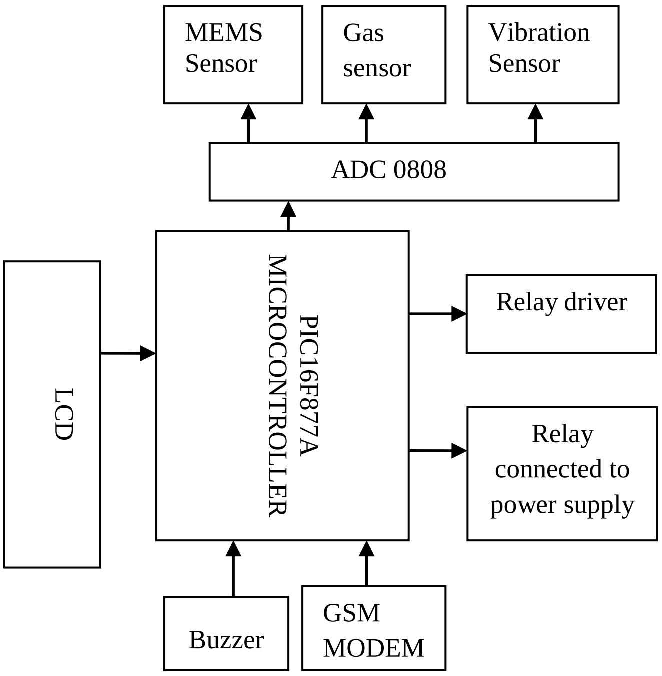

Fig.2.Block diagram of tilt measurement system and leakage detection

The microcontroller block is the heart of the system. It controls all the sensors and other modules. The MEMS sensor (MMA8451Q) and gas level sensor (MQ-6) were interfaced with microcontroller through the ADC0808. The MEMS Sensor MMA8451Q (3 axis accelerometer) calculates the tilt that is angle shift of the building based on the difference between the static acceleration and the acceleration due to gravity, using a micro-electro-mechanical system (MEMS)-based accelerometer. It gets the value from the sensor and converts it to the binary or digital respected value. The GSM module block is the communication block which sends the SMS to the real world if anything goes wrong. The buzzer is an indicating device which is used here to indicate the leakage of gas. The reed relay is connected with the relay driver which is in contact with the microcontroller. If the LPG leakage is detected, the relay will turn off the power supply of the building [6]. All the outputs and the indications were displayed through the LCD display.

B. 3 AXIS ACCELEROMETER SELECTION AND ITS PERIPHERAL CIRCUIT

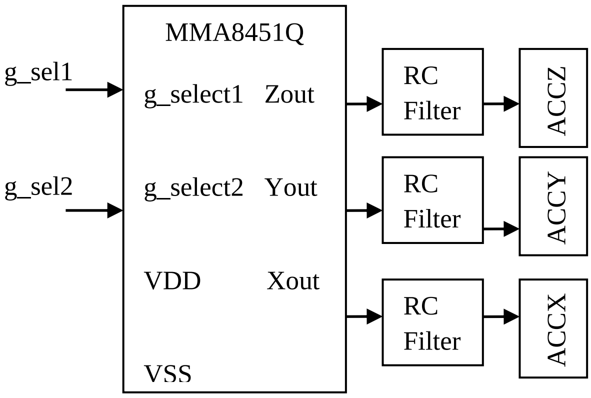

Fig.3.peripheral circuit of 3 axis accelerometer

A 3-Axis accelerometer MMA8451Q is used in this system. The MMA8451Q low cost capacitive micro machined accelerometer from Free scale features analog output-select which allows for the selection among four sensitivities (2g/4g/8g).As shown in fig.3 the peripheral circuit of MMA8451Q is simple for its using the MEMS technology, which only includes RC low pass filters and the power filter for reducing clock noise and the power noise.

C. MICROCONTROLLER SELECTION

PIC 16F877A microcontroller is used in this tilt measurement and gas leakage detection system. It is a RISC (Reduced instruction set computer) CPU and has 35 single word instructions. It uses an 8-bit data bus. The registers in the PIC chip are also 8 bits wide. Read and write operations of PIC microcontroller uses decimal numbers between 0 and 255.Its operating speed is DC-10MHZ clock input.

Program memory is 1KB.It has 40 pins and six ports namely PORT A, PORT B, PORT C, PORT D, PORT E.Among these ports PORT B, PORT C and PORT D Contains 8 pins, where PORT A contains 6-pins and PORT E contains 3 pins. Each port can be configured as input or output by setting TRIS (Tri state register) as logic 1 or logic 0. It has universal asynchronous receiver transmitter, two analog comparators, 10 bit 8 channel analog to digital converter, serial peripheral interface, 8/16 bit timer/counter, brown detection circuitry and it is self programmable under software control. Data retention is less than 40 years. It has 100000 erase/write cycles.

D. VIBRATION SENSOR

Vibration sensor used here is innometer 4150.The InnoMeter 4150-3 is designed for the measurement of vibrations on buildings according to Structural Health Monitoring.Vibrations from heavy building activities, traffic, machine operation or also detonations affect existing building stock. The InnoMeter 4150-3 measures these vibrations, evaluates them according to the standard immediately and can inform about the occurred vibrations at any time.This is a triaxial vibration sensor which is positioned at the building.A signal converter type InnoBeamer, transmit vibration signals transmitted to the controller to take necessary actions.

IV. ERROR COMPENSATION

Capacitive accelerometer with a simple structure, high sensitivity, good dynamic response, anti over loading large, high temperature, radiation and strong vibration, such as adaptable harsh conditions, a series of advantages such as cheap. At present, however, capacitive accelerometer sensor temperature characteristics affect its measurement accuracy is one of the important factors. Therefore, in order to enhance the capacitive acceleration sensor stability and reliability of qualitative, the temperature must be compensated.

Measurement errors of the MEMS accelerometer are derived from manufacturing process, installing method and external environment. The alignment error of the system can be negligible for the 3-axis MMA8451Q is stuck on a high-precision aluminum hexahedron. Because MMA8451Q is sensitive to the temperature, the drift error of the system with the temperature needs to be compensated. Because the nonlinearity of MMA8451Q is less than 1% FSO, the model of MMA8451Q will be given by [3]:

$$a = \frac{(y - K_0)}{K_1} \qquad \ldots \qquad (5)$$

where K_0 is the zero-g offset of MMA7260, K_1 is the scale factor of MMA8451Q, y is the output voltage of MMA8451Q and a is the corresponding acceleration Magnitude. The relationships between K_i (i=0, 1) and the operation temperature is given by

$$K_0 = K_{00} + K_{01}\,T$$
$$K_1 = K_{10} + K_{11}\,T \qquad \ldots \qquad (6)$$

Where T is the operation temperature of the 3-axis accelerometer and Kij(i,j=0,1) are parameters to be determined. In order to obtain the correct acceleration magnitude, the zero-g offset K_0 and the scale factor K_1 must be revised according to the current operation temperature. By the tilt measurement system being put in the temperature box, the temperature model of the accelerometer ranging from 5ºC to 45ºC is obtained with the following steps, which may be acceptable for common tilt measurement applications.

1) Calibrate the temperature sensor in PIC16F877A Because the temperature sensor outputs the voltage Magnitude which is proportional to the operation temperature, the linear relation can be gained by processing data from the temperature sensor with the least-square linear fitting while the operation temperature is 5 ºC, 15 ºC ,25 ºC ,35 ºC and 45 ºC respectively.

2) Make the sensitive axis of the accelerometer perpendicular to the gravity vector, acquire data from the accelerometer while the operation temperature is 5 ºC ,15 ºC , 25 ºC , 35 ºC and 45 ºC respectively and

process the data with the least-square linear fitting. Then K_{00} and K_{01} in (6) are gained.

3) Make the sensitive axis of the accelerometer in the same direction of the gravity vector and do the experiment like step 2). Then K_{10} and K_{11} in (6) are gained.

After the parameters $Kij(i,j=0,1)$ are obtained in the Off-line way, they are written into the Flash of microcontroller and will be used for calculating the zero-g offset K_0 and the scale factor K_1 according the operation temperature in Section V.

V. ALGORITHM

In order to improve measurement accuracy of the system, data acquired from MMA8451Q should be processed. Firstly although outputs of MMA8451Q have been filtered with RC filters, the layout and the routing of the circuit will have great impact upon the effect of filtering noise. So the over-sampling filter and FIR filter are used to reduce the noise of this system farther. Secondly the drift error with the temperature needs to be compensated. So a global variable "filter_flag", the default value of which is zero, is defined in the software. If filter_flag=1, filtering is over, or else filtering is running.Realization steps of the algorithm proposed is as follow, with which the effective tilt angles of the carrier are calculated [1].

1) Initialize the system.

2) Read the filtering flag from the memory and wait until filtering is over, that is filter_flag=1.

3) Read parameters Kij (i, j=0, 1) saved in Flash and Calculate the zero-g offset $K0$ and the scale factor $K1$ according to the current operation temperature from the temperature sensor embedded in PIC 16F877A with (6).

4) Read the filtered data which is acquired from MMA8451Q and transform the voltage magnitude into the acceleration magnitude with (5).

5) Calculate the tilt angles of the carrier and go to step 2).Moreover in order to update the tilt angles at the speed of 100 Hz, interrupt service routines are designed in this system. A/D is started every other 10ms in Timer routine. Data transmission between the peripheral device and the tilt measurement system is realized in SPI routine and in UART routine.

Table.1.Measurement range for various angles

Theoretical Value/°		Measurement Value/°		Error/°	
Pitch	Roll	Pitch	Roll	Pitch	Roll
0	0	0.13	0.03	-0.13	-0.03
0	15	0.14	15.22	-0.14	-0.22
0	30	0.17	30.41	-0.17	-0.41
0	45	0.25	45.24	-0.25	-0.24
0	60	0.29	59.97	-0.29	0.03
15	0	15.44	0.04	-0.44	-0.04
30	0	30.62	0.04	-0.62	-0.04
45	0	45.75	0.02	-0.75	-0.02
90	0	90.77	0.15	-0.77	-0.15

VI. RESULTS

Measurement accuracy of the tilt measurement system tested and it was done on a three-axis turntable which can be rotated through 360° around x axis, y axis and z axis respectively. Change the pitch angle ρ and the roll angle φ respectively through controlling the three-axis turntable and acquire tilt measurement outputs of the system in every attitude (average 1000 samples). The measurement results and the indications of the three-axis turntable are listed in TABLE 1, which shows the measurement error of the system is less than 1°. The system is acceptable for common applications the measurement range of which is from - 90° to + 90°. This tilt measurement system designed will be used in buildings to periodically monitor the structural damage of the building.

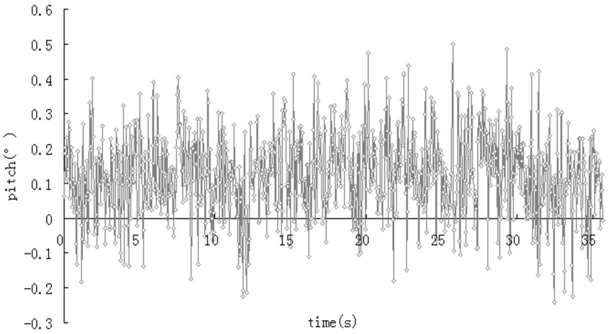

Fig.4.Outputs of the tilt measurement system

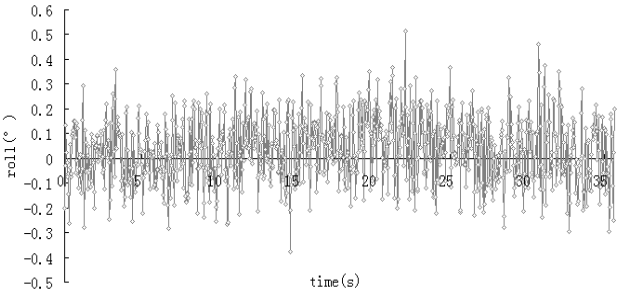

Fig.5.Outputs of the tilt measurement system

VII. CONCLUSION

In this paper we have proposed development of the tilt measurement, ground vibration monitoring and gas leakage detection system. By a PIC16F877A microcontroller is used, the power consumption is reduced and the speed of processing the system is much higher. According to the information collected for temperature with the help of microcontroller, the drift error of the accelerometer with the temperature is also compensated. The results show the effectiveness of the proposed scheme for the tilt measurement system, the measurement error is less than 1° and the leakage of gas detected and human lives saved from the disaster.

VIII. REFERENCES

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