EVALUATION OF THE MEMS ACCELEROMETERS FOR WIRELESS MONITORING APPLICATIONS

Roman Berešík[1], Jozef Puttera[2]

ABSTRACT: The current advances in micro-mechanical systems (MEMS) and wireless sensor networks field show us new possible applications where these technologies could be used. These technologies have a huge potential for rapid and low cost installation in the areas where other sensor platforms could be hardly used. Typical applications are remote infrastructure monitoring, daily living activity monitoring, remote patient's health monitoring and remote surveillance systems as well. This paper deals with analysis and evaluation of the MEMS accelerometers used for event detection in particular areas as part of remote monitoring systems. For measurements, iMEMS 2-axis accelerometer ADXL202JE (Analog Devices) was used, as one of the sensors placed on the multi-sensor board MTS310CB (Crossbow). The measured data show potential of MEMS accelerometers to record events based on vibrations measurement and in conjunction with other sensors it can form complex event driven wireless surveillance (monitoring) systems. In conclusion, the outcomes of the experimental measurements are evaluated and also further research is outlined in the wireless sensor networks field.

Key words: iMEMS Accelerometers, MICAz, MTS310CB, CROSSBOW, ZigBee.

1. INTRODUCTION

Recently developed micro-electro-mechanical systems (MEMS), more exactly MEMS sensors and wireless sensor technologies have motivated many researchers in the field of MEMS sensor usage. There are many areas where these sensor systems could be applied such as vibrations and tilt measurements, structural health monitoring, patient's health monitoring, traffic vibration measurement and also event driven surveillance and monitoring systems. Properties of the MEMS based sensor systems in conjunction with low power wireless technology allow us to develop wireless sensor networks (WSN). The WSN technology has a potential to be used in the applications and areas where other sensor systems could be hardly exercised due to the environment, durability and sustainability. New aspects have to be considered in terms of the developing new algorithms for efficient power management, decentralized control within WSN in order to fully extort the WSN and MEMS sensors capabilities. Generally, wireless sensor networks integrate sensing, low power RF communication and computation elements into one platform, sensor motes. On-board computational unit allows sensor mote to process gathered data internally, if it is necessary, before transmitting it backwards to the gateway and subsequently to monitoring personal computer for further processing. Moreover, wireless sensors can be arranged into broad WSN such that they can communicate and collaborate with each other and gather data from particular area via on-board sensors. Wireless sensors have their own limitations which need to be determined. There are two main intrinsic restrictions of any wireless devices such as

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power source lifetime and the range over the gathered data can be reliably transmitted. These restrictions have significant impact on optimization of source codes. To overcome previously mentioned drawbacks, the special operation system TinyOS and component-based NesC programming language was created. This operational system and programming language is well suited for WSN and allows developing of a source code tailored for WSN in order to achieve energy efficient data transmission within the network.

2. SYSTEM DESIGN

To demonstrate ability of vibration and acceleration measurement by MEMS sensors, the basic sensing test bed was designed based on Crossbow technology. The sensor system consists of MIB520 working as gateway, MTS310CB multi-sensor board and two MICAz motes coupled with MIB520 and MTS310CB. For further processing and visualization of the measured data, a laptop equipped with databases and visualization software was used. The composition of the measurement system is shown in figure 1.

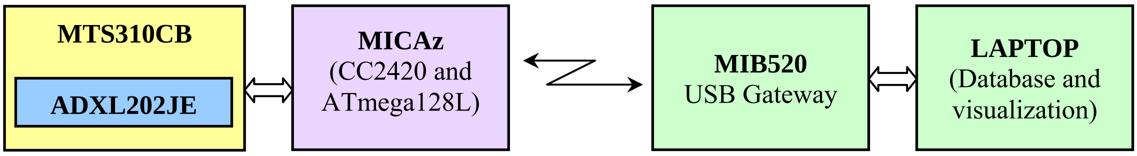

Figure 1 The basic arrangement of experimental measurement system

2.1. Hardware consideration

MICAz mote, shown in figure 2a, is a tiny embedded wireless measurement system designed specially for deeply embedded sensor networks. It consists of a 7.3728 MHz 8 bit ATMEL ATmega128L microprocessor, with 512kB of flash memory, 128kB of instruction memory and 4kB of data memory. The mote also consists of radio chip based on CC2420 (802.15.4 ZigBee). It operates in 2,4GHz ISM frequency band and has transmission capabilities of 250 kb/s data rate over a maximum range 100m. The ATmega128L and radio CC2420 (Texas Instruments) is fabricated as single processor board and can be configured to run sensor application (processing) and network-radio communication simultaneously.

a b c

Figure 2 Key components of wireless sensing system
a) MICAz, b) MIB520, c) MTS310CB

The gateway MIB520 (figure 2b) is used as receiver board in our measurement system. The MIB520 is responsible for receiving data packets from sensor, to rely data packets to laptop through USB port where the further data processing is executed. The

MTS310CB is a multi-sensor board equipped with a photo diode, thermistor (Panasonic ERT-J1VR103J), microphone, sounder, magnetic sensor (HMC1002) and finally iMEMS based accelerometer ADXL202JE developed by Analog Devices. The arrangement of the MTS310CB sensor board is shown in figure 2c. This flexible sensor board has variety of sensing modalities and can be used for variety applications including vehicle detection, low-performance seismic sensing, movement sensing, acoustic ranging and other applications. The ADXL202JE is low-cost and low-power two-dimensional accelerometers. It is capable to measure acceleration with full-scale range of -2g to +2g, both dynamic and static acceleration like gravity. Its essential technical specifications are shown in Table 1.

Table 1 Basic ADXL202JE technical parameters

Measurement range	± 2 g
Sensitivity (Duty Cycle per g), VDD=3V	11 %/g
Operating voltage range	3-5,25V
Supply current	0.6mA
Frequency respond – 3dB Bandwidth	6kHz
Noise performance – Noise density	200µg/√Hz rms
Temperature range	0-70˚C

The block diagram of the ADXL202JE is shown in figure 3. For a practical usage, only couples of external passive components are needed. These components set performance parameters and modes for measurements.

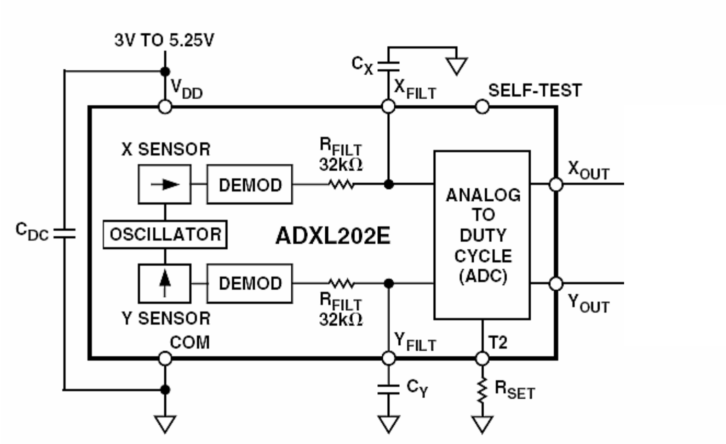

Figure 3 Block diagram of the ADXL202JE

The bandwidth of the accelerometer can be set by manipulating of the external capacitors values C_X and C_Y. The capacitors C_X, C_Y and resistors R_{FILT} implement low-pass filtering for antialiasing and noise reduction. The equation for the 3 dB bandwidth is expressed by following formula [6]

$$F_{-3dB} = \frac{1}{\left(2\pi\left(32k\Omega\right)\cdot C\left(x,y\right)\right)}. \quad (1)$$

In our case, the value of the capacitors C_X and C_Y is set to 100nF which means that the maximum bandwidth of the ADXL202JE accelerometers is 50Hz. The ADXL202JE noise level has characteristics of white Gaussian noise that contributes equally at all frequencies and its value is 200µg/√Hz. With the single pole roll-off characteristics, the typical noise of the ADXL202JE is determined by the following equations:

$$Noise(rms) = \left(200\mu g / \sqrt{Hz}\right)\left(\sqrt{BW.1,6}\right), \tag{2}$$

where: *BW* is bandwidth of accelerometer.

For 50Hz bandwidth, the rms noise is 1,8mg. Generally, output signals of accelerometer, which represent measured vibrations (movement), can have either digital or analog form. In our experiments, we used analog form of the output signals and the accelerometer provides instantaneous measurements of acceleration (vibration) caused by door movement in monitored area. The placement of the sensor in measured area is shown in figure 4.

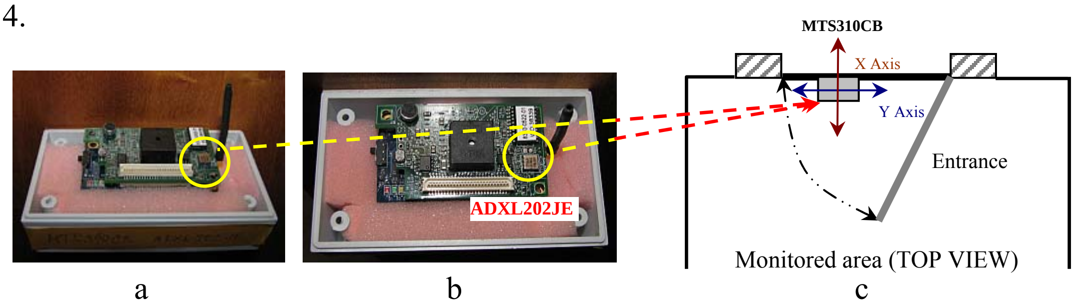

Figure 4 Simplified test bed for ADXL202JE
a), b) MTS310CB in case, c) representation of sensors placement

2.2. Software consideration

The MICAz motes run a TinyOS operating system and applications written in component-based program language called NesC. The NesC language which has C-like syntax is primarily intended for embedded sensor applications and supports concurrency models. In spite of the fact, that wireless sensor networks based on ZigBee protocol, are predetermined for multi sensor low-power applications, a single hop algorithm was chosen as essential algorithm for evaluation of the ADXL202JE abilities. The main goal was, to record door movement as signature that monitored area was violated. The multi hop algorithm will be used in perspective experiments. The measured values are sent via RF link toward to gateway MIB520, stored in PostgreSQL based database and visualized in MatLab. The value of the actual acceleration is measured by 10bit analog-digital converter ATmega128L, when timer overflows.

3. RESULTS

The figure 5 shows 350 samples of the measured acceleration data of both *x* and *y* axes during the violation of monitored area. The waveforms represent time dependencies of two independent acceleration values which characterize irregular, non-linear door movement proportional to applied force. In the graphs, the clear distinction between active and non active period can be distinguished. However, the magnitude of the values represents neither the activity level nor way how the area was violated. These values describe whether event happened or not. The values of *x* axis vary from -1,15g to 1,01g and for *y* axis vary from -0,74g to 0,18g. Looking at figure 5, every event has unique waveform character (shape). In the part A and B, differences among measured data of both accelerometer axes can be seen in terms of their magnitude and time dependences, even though that these data describe same events. The accelerometers axes can be described as vectors in space, with voltage values proportional to their magnitudes. To combine the measured values of *x* and *y* accelerometer axes into a single value, the better representation of the event signature can be achieved. The root-mean-square method for magnitude vector computation is used and it is given by following formula.

$$accel\_rms = \sqrt{accel\_x^2 + accel\_y^2}\ . \qquad (3)$$

Applying the formula (3) to the measured data, we get the output data waveform shown in figure 5, as acceleration rms values.

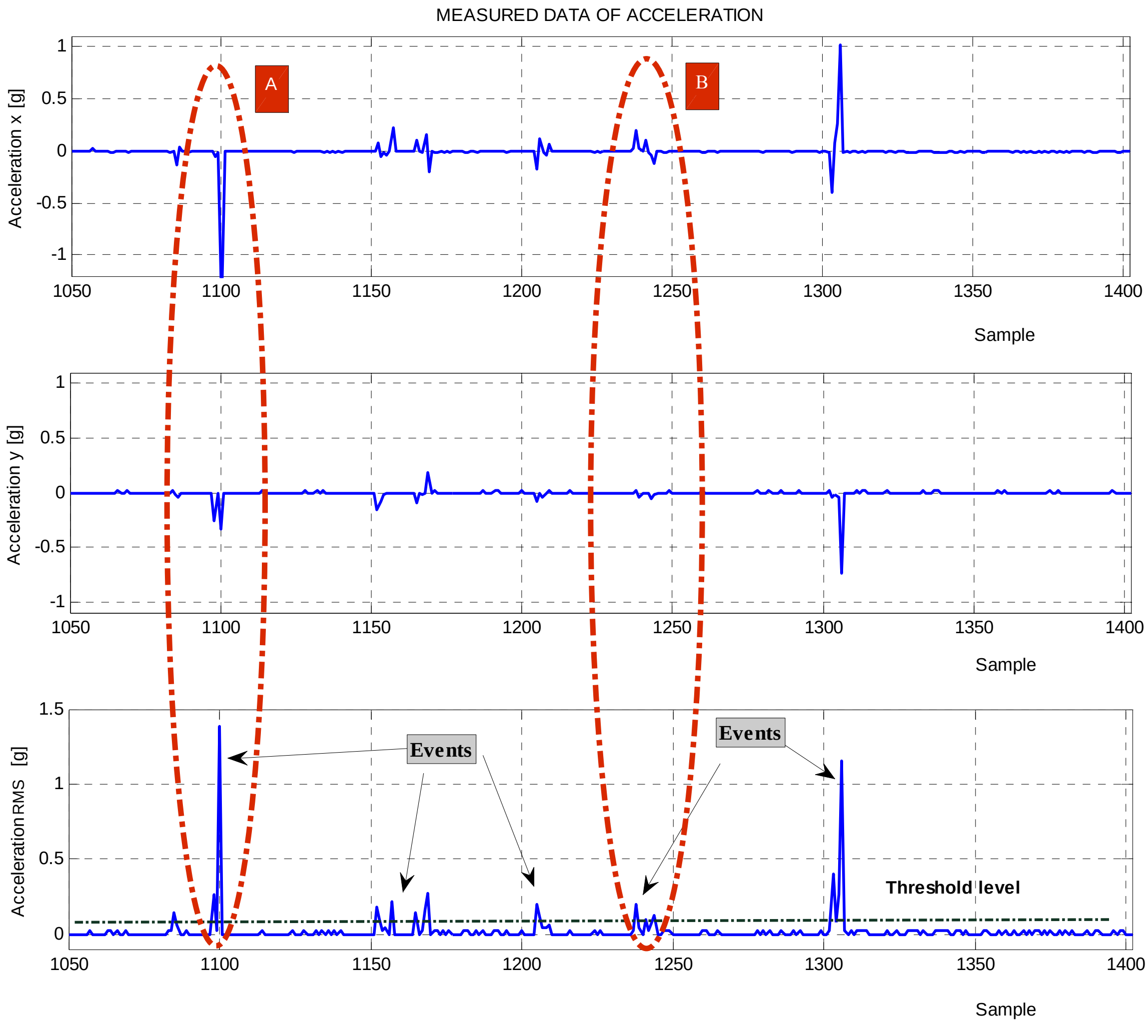

Figure 5 Waveforms of the measured acceleration data during a violation of monitored area

Experiments indicate that 1Hz sample rate is sufficient for this particular monitoring application in order to generate the trigger for driving other sensors in WSN, when signal magnitude exceeds threshold level. The key consideration which must be also taken into account in WSN is the power consumption. By comparison with environmental monitoring, vibration and movement measurements require the higher sample rate which subsequently increases power consumption of whole system.

4. CONCLUSION

The main goal of the conducted experiments was to analyze and evaluate of the iMEMS accelerometers ADXL202JE for monitoring applications. The preliminary experiment proved that the combination of MEMS accelerometers and wireless sensor technology are powerful technologies which are able to meet critical requirements in terms of compact size, low cost, high accuracy, low power consumption and flexibility for event driven sensor applications. Further research will deal with design of sensor board based on LIS3LV02DL accelerometer (STMicroelectronics) and source codes where threshold-based principle will be applied.

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