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Vibration Monitoring Using MEMS Digital Accelerometer with ATmega and LabVIEW Interface for Space Application

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***Abstract*— The launch of space craft generates extreme conditions, such as vibrations and acoustics that can affect the launch pad, space craft, and their payloads. These vibrations produced by machinery are vital indicators of machine health. Vibration analysis is used as a tool to determine a machine's condition and the specific cause and location of problems, expediting repairs and minimizing costs. Low cost vibration monitoring devices can be used in sounding rockets, nano-satellites and such low cost space applications. This paper explains the algorithm to extract vibration data over I^{2}C interface from ADXL345, which is a MEMS based accelerometer works on differential capacitance working principle. The sensor digital output will give the error free data even in noisy conditions. ATmega microcontroller is used to read the data from the sensor and send to LabVIEW software running on the computer which will extract and display the data from the serial port in real time.**

Index Terms*— *Digital output accelerometer; I^{2}C; LabVIEW; Space application; ATmega microcontroller; MEMS; Vibration measurement

I. INTRODUCTION

The recent advances in embedded system technologies such as Micro-Electro Mechanical Systems (MEMS) sensors hold a great promise for the future of vibration measurement based condition monitoring which is a much cheaper alternative. It has built-in signal conditioning unit as well. There are number of research studies going on about the MEMS accelerometers construction and the measurement principle. MEMS have been proposed for a number of space applications, as lighter and smaller replacement parts or as entire new systems [2,3,4,5] or as a means to provide affordable redundancy. Most MEMS devices currently under development for specific space applications are not intended for picosatellites, simply because most satellites currently have masses larger than 100 kg. However pico and nanosatellites are the main users in space of MEMS parts. Pico and nanosatellites are also the main users in space of COTS components such as microcontrollers, batteries, etc. Since the development budget of these small satellites often precludes using standard space grade components.

In this paper a method is developed for extracting vibration signals and analyse its performance for space applications. Here we use ADXL345 vibration MEMS based digital sensor [6] with capability to sense vibration of 16g in both SPI (Serial Peripheral Interface) and I^{2}C digital output with 16-bit data. It is a complete 3-axis acceleration measurement system with a selectable measurement range of ±2 *g*, ±4 *g*, ±8 *g*, or ±16 *g*. It measures both dynamic acceleration resulting from motion or shock and static acceleration, such as gravity, that allows the device to be used as a tilt sensor.

Microchip ATmega16 [7] is used to read the SPI data from the sensor. For this a 32 bit command is sent to the sensor and the response for the 3 sensing channels will be received, which is then sent to the serial port of a computer through CP2102. IAR Embedded workbench for AVR is used to compile and AVR Dude GUI is use to burn the hex code to ATmega controller. National Instruments graphical programming tool LabVIEW is used to read the I^{2}C response from the ATmega through the CP2102 serial port of the computer. The algorithm developed will extract and convert the tri-axis vibration data from I^{2}C response. LabVIEW is also used as graphical user interface to display and plot the real time vibration resultant output.

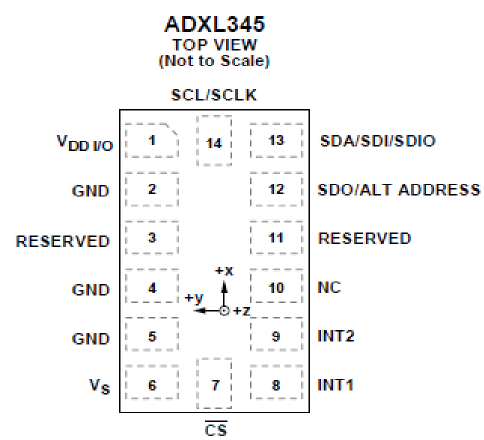


Fig. 1. Top View of ADXL345

II. SYSTEM DESCRIPTION

A. Digital MEMS Vibration Sensor

The ADXL345 is a small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I^2C digital interface. The sensor is a polysilicon surface-micro machined structure built on top of a silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against forces due to applied acceleration. Deflection of the structure is measured using differential capacitors that consist of independent fixed plates and plates attached to the moving

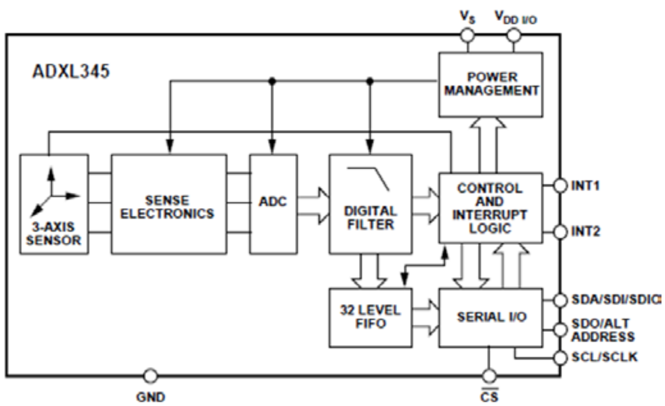
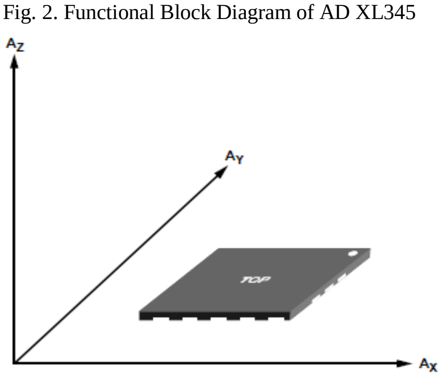


Fig. 2. Functional Block Diagram of AD XL345



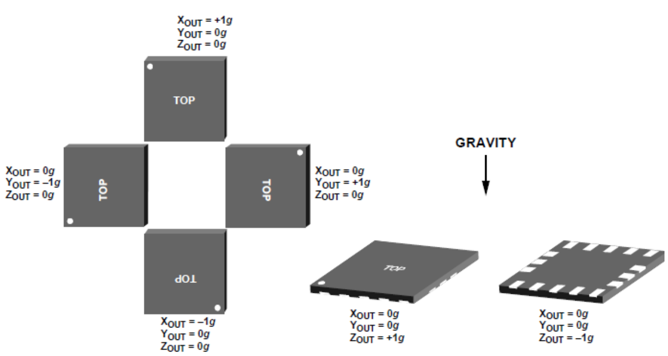


Fig. 3. Orientation towards gravity

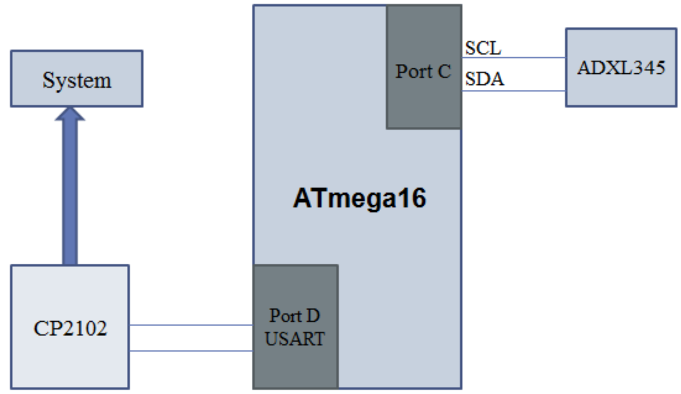


Fig. 4 . Hardware Inter Connection

mass. Acceleration deflects the proof mass and unbalances the differential capacitor, resulting in a sensor output whose amplitude is proportional to acceleration.

The 7-bit I^2C address for the device is 0x53, followed by the Read/Write bit. The user can select an alternate I^2C address by connecting the SDO/ALT ADDRESS pin to the VDD I/O pin. The 7- bit I^2C address for the configuration is 0x1D, followed by the Read/Write bit. Sometimes it is important to confirm the validity of a communication sequence before going to the next design stage. This can be done by reading the DEVID register (Address 0x00). It is a read only register that contains 0xE5. If the data read from DEVID is not 0xE5, it is the indication that either the physical connection or command sequence is incorrect.

The DATA_READY interrupt signal indicates that 3-axis of acceleration data is updated in the data registers. It is latched high when new data is ready. (The interrupt can be configured to be latched from low-to-high through the DATA_FORMAT register. Refer to the ADXL345 data sheet for details.) Use the low-to-high transition to trigger action on an interrupt service routine. Data is read from the DATAX0, DATAX1, DATAY0, DATAY1, DATAZ0, and DATAZ1 registers. To ensure data coherency, it is recommended that multibyte reads are used to retrieve data from the ADXL345.

The data format of the ADXL345 is 16 bits. Once acceleration data is acquired from data registers, the user must reconstruct the data. DATAX0 is the low byte register for X-axis acceleration and DATAX1 is the high byte register. In 13-bit mode, the upper 4 bits are sign bits as shown in figure 5. ADXL345 uses twos complement data format. When in 13-bit mode, 1 LSB represents about 3.9 m*g*.

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
SIGN	SIGN	SIGN	SIGN	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0

DATAX1 DATAY1 DATAZ1 (D15–D8) — DATAX0 DATAY0 DATAZ0 (D7–D0)

Fig 5. Data Construction of ADXL345

B. ATmega Micro Controller

Interfacing of ADXL345 is done using ATmega16. The TWI (Two Wire Interface) or I^2C protocol allows the systems designer to interconnect up to 128 different devices using only two bi-directional bus lines, one for clock (SCL) and one for data (SDA). The only external hardware needed to implement the bus is a single pull up resistor for each of the TWI bus lines. All devices connected to the bus have individual addresses, and mechanisms for resolving bus contention are inherent in the TWI protocol. CP2102 is used to interface PIC and computer serial port.

C. LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications.

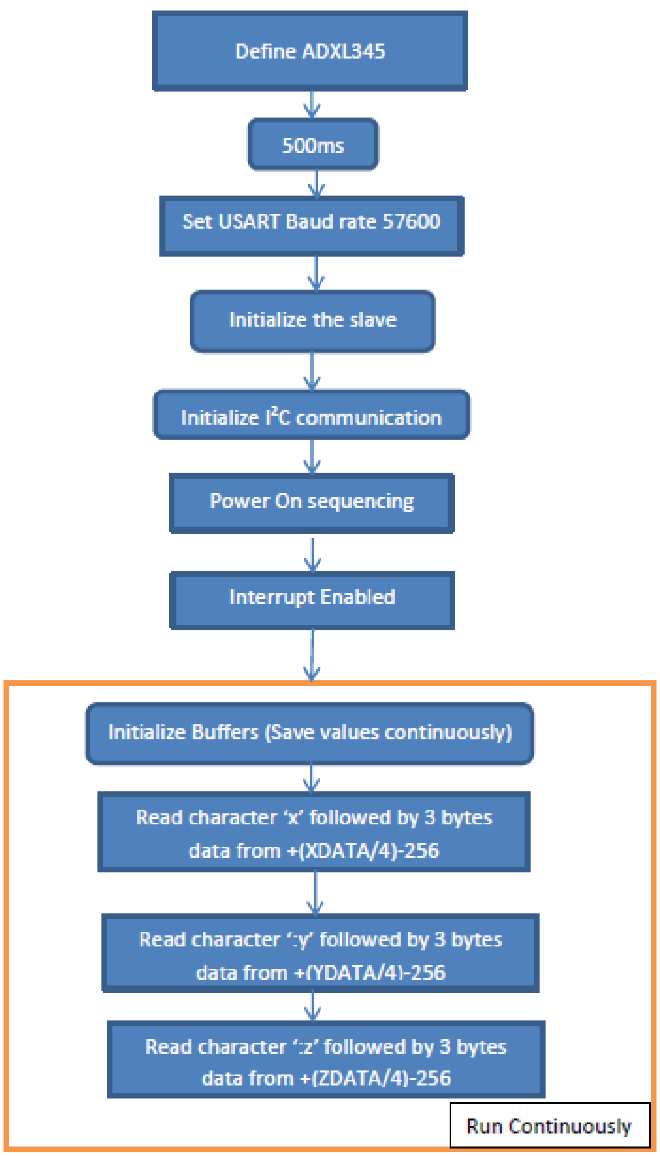


Fig. 6. Flow chart for ATmega I^2C Communication with ADXL345

ADXL345 3-channel bit streams is taken to LabVIEW code via ATmega16 and the necessary signal processing is done to extract the resultant vibration output which is explained in detail in section III. The software continuously monitors resultant 'g' and its power spectrum in real time.

III. SOFTWARE DESCRIPTION

Program for ATmega16 was written in IAR Embedded workbench for AVR. The hex code is burned to ATmega using AVR Dude GUI burner.In order to program ATmega16 for I^2C Communication, we have to define the communication mode and USART configurations to communicate with computer serial port. The sensor requires start up delay and recommended start up command sequences for the proper functioning. The baud rate for communication is set as 57600. The required commands for calibrating the values in XDATA, YDATA, ZDATA registers and reading them out to computer serial port are given. Output from ATmega16 will be in the format-- x3bytes XDATA: y3bytesYDATA: z3bytesZDATA: these values are given to LabVIEW code for extracting resultant 'g' value corresponding to the hex values.

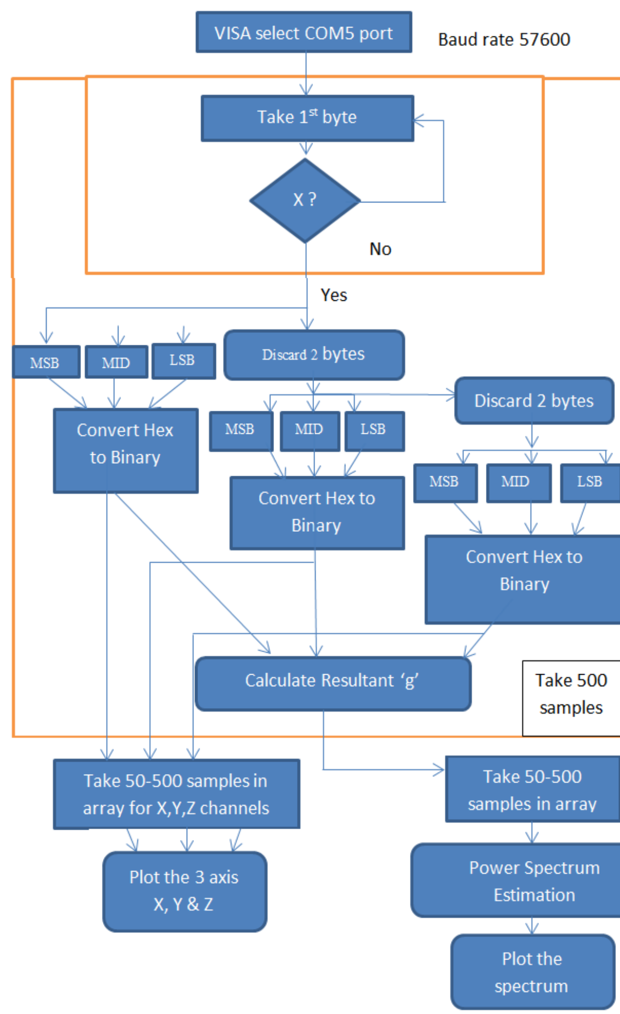


Fig. 7. Flow chart for Simulation in LabVIEW

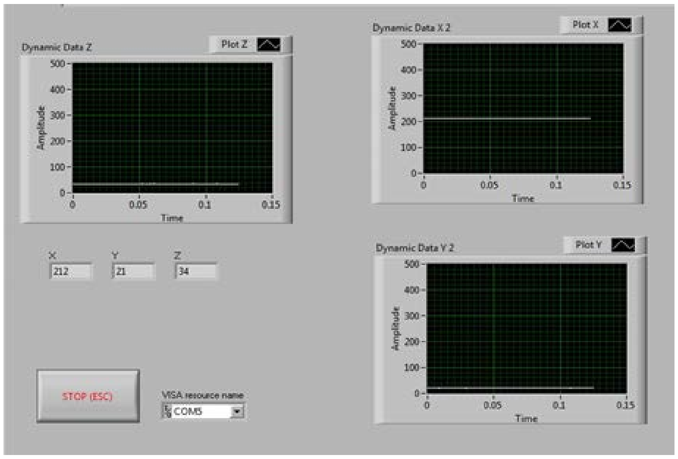


Fig 8. LabView output of ADXL345 with no vibration input

The vibration output power spectrum of a fault motor may show a number of peaks in its power spectrum here and there. Also by setting threshold in this vibration signal necessary control signals can also be generated. These control signals can be used to drive the actuators to correct the improper functioning of machines.

IV. RESULTS AND DISCUSSIONS

The proposed method is simulated using LabVIEW software and the result displayed on the front panel is shown in figure 8. Figure 8 shows LabVIEW output with no vibration input, where we got output as,

X=212

Y=21

Z=34.

The resultant vibration value for this is given by the equation

$$R = \sqrt{X^2 + Y^2 + Z^2} \quad (1)$$

and we get the resultant as 216. For 1g input the output is 256 LSB (given in dtasheet). Therefore resultant in terms of g value is R/256 which gives 0.85g.

Since the sensor was kept on Earth surface a value below 1g has to be sensed. And perfect 1g output we obtained for all the three axis after ensuring perfect horizontal orientation.

Figure 9. shows the LabVIEW output of ADXL345 when mounded on DC geared motor of 3600rpm. We can see a dominant peak in its resultant g power spectrum between 30-60 Hz. The output shows only 1 dominant peak which implies the motor is working perfect.

The vibration sensor has used to detect a faulty motor. The power spectrum of such motors shows numerous peaks throughout the frequency range. Also the wavelet transform of the time domain signal of one of the dominant axis clearly shows a number of spikes showing unwanted vibrations in it as shown in figure 10. The output is calibrated to get amplitude in ‘g’. By doing this extra processing we can easily sense mechanical failures than can happen to machines.

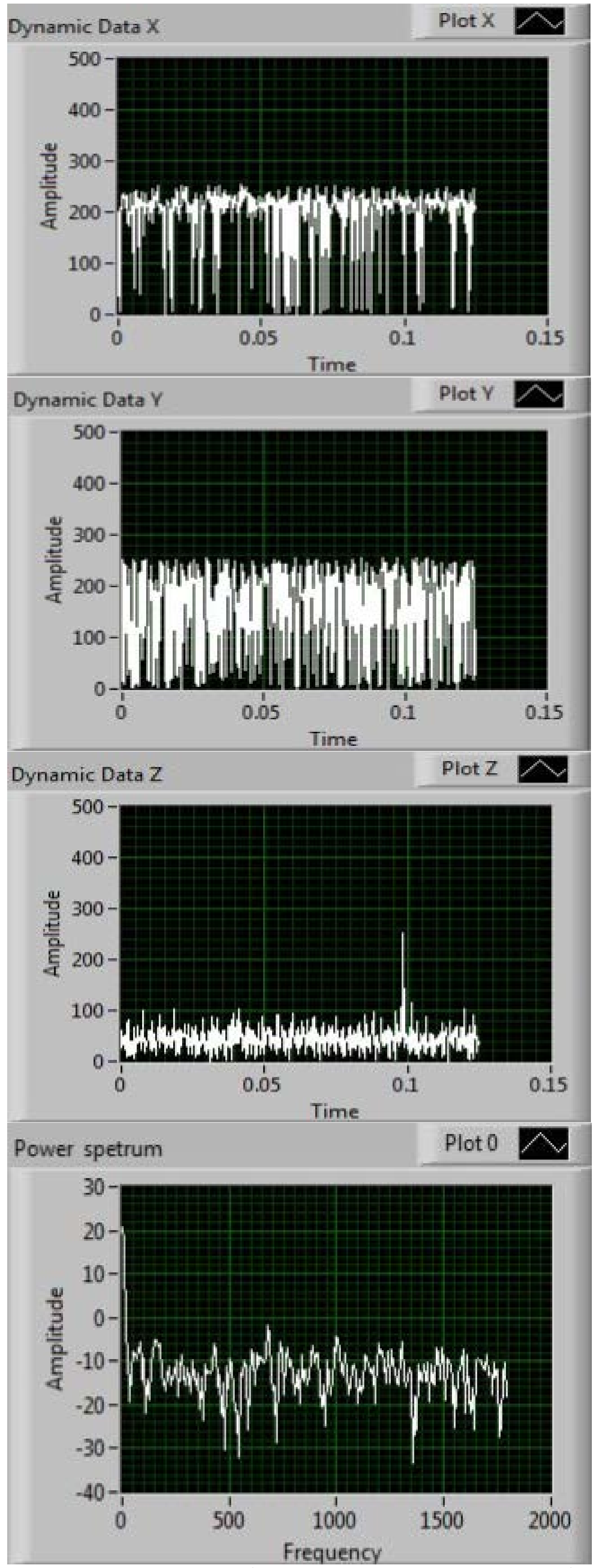


Fig. 9. LabVIEW output of ADXL345 when mounded on a motor of 3600rpm

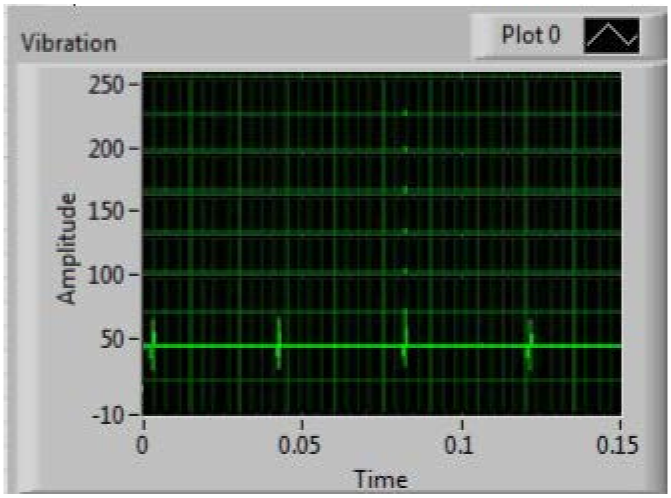


Fig. 10. Wavelet transform of vibration from a faulty motor

The sensor has high resolution advantage compared to the conventional piezoelectric and analog MEMS sensors and output of this sensor is insensitive to external noise. This is very compact in size with very low power consumption. Due to these unique features ADXL345 accelerometer is suitable for low cost space application and the method proposed in this paper can be used to read and extract the data from the sensor.

The sensor can be used in the launch vehicles as a redundant vibration sensor and the algorithm developed can be implemented using DSP and interfaced to Telemetry system. It is very suitable for experimental low cost flights.

V. CONCLUSION

The digital MEMS sensor ADXL345 consistently monitored different vibration signals with good accuracy. It can help in the miniaturization of various types of monitoring systems and this size reduction can result in decreased power consumption and overall system cost. Further comparative study of the sensor with existing vibration sensor for space application has to be done as its high resolution and compact size is very desirable for low cost space applications such as sounding rockets, nano-satellites etc.

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