IMTC 2004 – Instrumentation and Measurement
Technology Conference
Como, Italy, 18 - 20 May 2004

A 3-Axis Acceleration Sensor Data Acquisition Instrument System

Johnson A. Asumadu[1], Vernen La Belle[1], Ryan Od'Neal[1], and G. Adam Covington[1]
[1]Electrical and Computer Engineering Department, B-224 Parkview Campus, 4601 Campus Dr., Electrical and Computer Engineering Dept., Western Michigan University, Kalamazoo, MI 49008, TEL: (269) 276–3147, FAX: (269) 276-3151, johnson.asumadu@wmich.edu

Abstract *- It is not always possible to wire a 3-axis rotating sensor on a rotating drum directly to data acquisition equipment in an experiment or in testing industrial equipment. A special 3-axis motion sensor subsystem mounted onto a rotating drum is indirectly coupled to data acquisition system by broadband amplitude modulation (AM) radio signals. The sensor subsystem consists of one 2-axis accelerometer circuit in the x-y plane, one 2-axis accelerometer circuit in the z-plane, and two z-axis gravity switches, The sensor subsystem is self-contained and hermetically sealed. The sensor subsystems send 3-axis motions to a computer-based data acquisition equipment using the broadband AM radio signals. The computer then calculates the acceleration, the vibrations of bucket, and position of the sensors. The computer, using a graphical unit interface, then shows the position and rotation of the drum. The program for the sensor subsystems utilizes interrupts that allow the sensor subsystems to interpret and send data quickly. The software and the sensor subsystems are portable and can be integrated into other applications or expanded.*

Keywords *- Accelerometer, 3-axis, A/D-D/A and Data Acquisition, Sensor, AM Radio, Gravity Switches, Remote Measurements, Autonomous Sensing and Measurement Systems.*

I. INTRODUCTION

It is not always possible to wire sensors directly to data acquisition equipment when the sensors are to be located on a rotating member and in very hostile environmental - very high temperature, volatile liquids, and high humidity. For example, in testing washing machines the sensor and data acquisition equipment may be subjected to oil and water spray. The sensors are used to obtain (*i*) the acceleration, (*ii*) the forces (vibrations) on the rotating drum, and (*iii*) the vertical position (tilt) of the rotating drum. The information obtain from the monitoring sensors is used to improve quality of washing machines and to lower cost.

Currently, in testing rotating buckets in the washing machine industry, there are several methods of interfacing the sensors to the data acquisition equipment as found for example at Whirlpool, Inc. In one method the sensors are directly coupled to the data acquisition equipment. This method works well for sensors that do not move often or move less than 360 degrees. Another method of coupling sensors to the data acquisition equipment is through slip rings. The slip rings allow the sensors to travel in circles relative to the data acquisition equipment. This method is expensive, and the sensors and the slip rings are subject to damage from slip-ring commutations, and from oil and water spray. These two methods of data acquisition are not suitable for use in hostile environments where the probability of damage is high. Other commercial solutions to this problem do exist but are very costly and proprietary. Coupling this with the possibility of damage to the sensor and the data acquisition equipment, the other commercial solutions are also not very attractive [1] – [2].

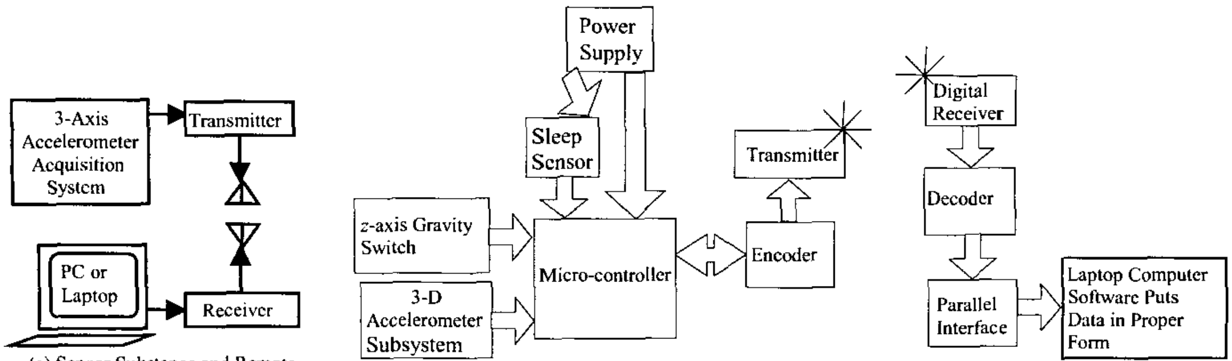
The purpose of this paper is to address the data acquisition needs for a specific sensor subsystems used in testing washing machines in industry such as the ones found at Global Laundry Controls. A hermetically sealed 3-Axis sensor subsystem has been built using two monolithic acceleration sensor ICs and gravity switches. The sensor subsystem sends 3-axis motion information to a computer-based data acquisition system by means of AM radio signals. The method may be extended to other remote data acquisition needs. Because the sensors are indirectly couple to the data acquisition equipment, the data acquisition system is protected from water spray, oil, and vibrations. There are no wires to be twisted off or damaged while running tests. The receiving unit/acquisition can be located as far as 300 feet away. The solution is inexpensive, reproducible, nonproprietary, and is expandable to other sensors. Assembly language was used to program the MCU and Visual Basic was used to program the data acquisitions and graphical unit interface (GUI) systems.

II. METHODOLOGY

A. Acceleration Sensor

The Fig. 1(a) shows a simplified functional block diagram of the sensor subsystem and the remote data acquisition system. The design behind the instrument system consists of two main areas: sending unit block (transmitter) and receiving unit block (receiver). The transmitter consists of two 2-axis accelerometers, two gravity switches, a micro-controller, an encoder, and an AM transmitter (see Fig. 1(b)). The receiver consists of an AM receiver, a decoder, and laptop/PC as shown in Fig. 1(c).

The 2-axis accelerometer is ADXL250 [3] – [6] built by Analog Devices and it is capable of measuring accelerations in two orthogonal axes on a single monolithic chip. An axis of the ADXL250 can measure a maximum of $\pm$50g (g = 9.8 m/s^2). The ADXL250 measures acceleration through the use of differential capacitor sensor composed of fixed plates and moving plates attached to a beam as shown in Fig. 2 (a). Accelerating the chip causes the movement of the beam. The movement of the beam changes the differential capacitances,



(a) Sensor Substance and Remote Data Acquisition System

(b) Transmission Unit Block Diagram

(c) Receiving Unit Block Diagram

Fig. 1 Functional Block Diagram

which is measured by an on chip circuitry. The accelerometer has all the circuitry needed to drive the sensor. Each axis of the ADXL250 outputs static and dynamic accelerations along the two orthogonal axes parallel to the face of the chip as shown in Fig. 2(b). It has a temperature range of -40°C to +85°C (industrial grade), and its output is directly measured in digital form and therefore no glue logic is required. The update cycle of the ADXL250 [7] can be adjusted from 0.5 ms to 10 ms. The bandwidth of the accelerometer is set from 0.01 Hz to 5 KHz; some accelerators have higher bandwidth.

The output voltage of the accelerometer v_{out} (for any of the axes) is a function of both the acceleration *dv/dt* input and the power of supply voltage applied $v_{applied}$ is given by [7].

$$v_{out} = \frac{v_{applied}}{2} - \left(Sensitivity \times \frac{v_{applied}}{5V} \times \frac{dv}{dt} \right) \quad (1)$$

The output voltage of the ADXL250 along an axis is nominally 2.5 V at 0 g and moves to an output voltage of 5 V at 50 g. Along the same axis the acceleration in opposite direction moves to an output voltage of 0 V at -50 g. The output amplifier circuitry provides a normal output scale factor (sensitivity) of 38 mV/g.

Consider the cantilever shown in Fig. 2(c). Suppose the cantilever acceleration is a_{cc} when a mass *m* is suspended at the end *l* (from support) of the cantilever. It can be shown that the deflection θ of the cantilever is given by

$$\theta = \sin^{-1}\left(\frac{a_{cc} g}{l(2\pi f)^2} \right) \quad (2)$$

where *f* is the frequency setting of the accelerometer. The deflection angle of the drum during rotation can, therefore, be computed by finding the difference θ_{diff} between the deflections in the *x*-axis θ_x and *y*-axis θ_y ($\theta_{diff} = \theta_x - \theta_y$).

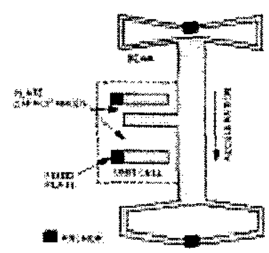


Fig. 2(a) Simplified view of ADXL250 On-chip Sensors

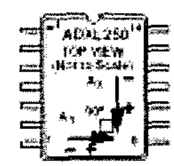


Fig. 2(b) ADXL250 Axes Direction

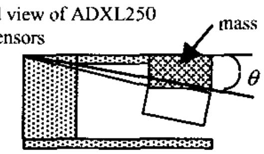


Fig. 2(c) Mass on a Cantilever

B. Implementation

The sensor subsystem two ADXL250's are mounted 90° apart as shown in Fig. 3(a). One ADXL250 is mounted in the *x-y* horizontal plane and the other one is mounted in the vertical position to act as the *z*-axis. The direction of each axis is illustrated in Fig. 3.

The *x*-axis component part of the vertically mounted ADXL250 is not connected (ignored). In this way, the horizontally mounted ADXL250 provided the *x*-axis and *y*-axis, and the vertically mounted ADXL250 provided the *z*-axis acceleration. By using this approach a 3-Axis Accelerometer is obtained by using two ADXL250s. The three outputs (*x* and *y* axes accelerations from the horizontal ADXL250, and *z* axis acceleration from the vertical ADXL250) [8] are directly fed to a micro-controller. The output voltage from each of the three axes is in a form of an

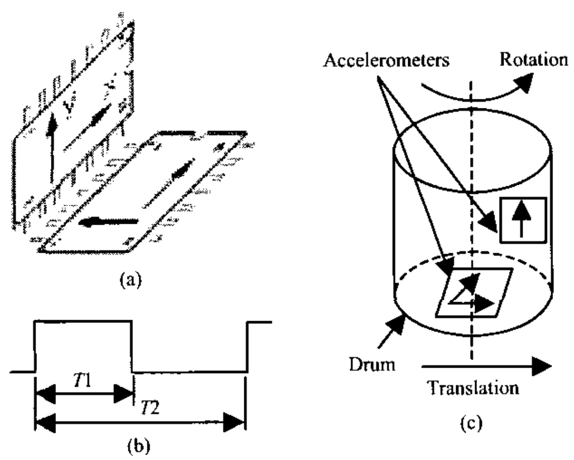


Fig. 3 Accelerometers Mounted on Drum

analog voltage pulse with a certain period as shown in Fig. 3(b). The duty cycle (ratio of pulse width to period) of the output voltage pulse is proportional to acceleration. The acceleration A_g on each axis is obtained by modifying equation (1), and it is given by the following equation:

$$A_g = \left(\frac{\frac{T1}{T2} - \frac{1}{2}}{0.04} \right) \qquad (3)$$

where $T1$ is the output voltage pulse duration of the accelerometer and $T2$ is the period. The period $T2$ is adjustable from 0.5 ms to 10 ms by an external resistor R_{SET} and given by

$$T2 = \frac{R_{SET}}{125M\Omega} \qquad (4)$$

The output pulse duration can directly be measured by a micro-controller counter without the need for an A/D converter or glue logic.

The accelerometers are mounted carefully to avoid errors. Fig 3(c) shows how two accelerometer PCBs are mounted onto a rotating drum; one is mounted in the x-y (horizontal) position and the other is mounted in the z-axis (vertical) position. The outputs of the ADXL250 and the z-axis gravity switches are fed directly to a 68HC11 micro-controller [9] – [13] on an Axiom Evaluation Board used for prototyping. The 68HC11 directly measures the acceleration by counting the duration of T1 (see Fig. 3(b)). The 68HC11 converts all data into serial form and feeds the data to the encoder HT640. 434A). When the serial data is received by the AM RF receiver (RWS-434), the serial data is sent to the decoder format which is transmitted by the AM RF transmitter (TWS HT648. The encoder converts and encodes the data into a serial. The decoded data is latched to the laptop/PC. The transmitter/receiver pair is able to process 350 data sets per second or the equivalent of 8-bit packets for 5 channels. A packet consists of 3 bits for protocol and 5 bits of data.

III. RESULTS

The results logged using the set of data from the indirect method were very good. The speed and tilt (deflection) angle of the rotating drum were obtained. Figure 4 shows the computer graphical interface reconstruction of the acceleration and speed of the rotating drum. The Fig. 4 shows the representation of the rotation in the x-y-z plane. As the speed of rotation increases, the effect was towards the formation of more complete circle.

The maximum acceleration occurred on the x- and y- axes while the minimum acceleration was along the z-axis. The output drive from the ADXL250 was less than 100 μA. The raw output from the accelerometer when digitized is summarized in Table I.

Table I Raw Digital Output

g-force	Voltage (V)	ADXL250 Output
- 50 g	0	\$00 = 00000000
0 g	2.5	\$80 = 10000000
+ 50 g	5	\$FF = 11111111
100 g / 255 = 0.39 g per count		

In computing the tilt (deflection) angle, it was necessary to use the acceleration in the x-axis because these angles were very small. Even though the tilt (deflection) angle of the rotating drum could but calculated using (2) (with l = radius of drum), the twist angles cannot be shown using a computer graphical interface because the deflections were negligible.

IV. CONCLUSION

It is clear that in using dual-axis accelerometer sensors the real time motion analysis of a rotating drum is possible. It is possible to have miniature devices for measurements of signals from milli-gs down into the micro-gs. One of the best sensors (based on the capacitance) for the detection of the very small displacement, tilt (twist), dynamic acceleration (e.g. vibration), and static acceleration (e.g. gravity) is the ADXL250 (or the family of ADXL sensors by Analog Devices). However, the higher performance obtained using the ADXL250 is at a cost. Two 2-axis accelerometers were used to create a 3-axis accelerometer (a 3-axis accelerometer is more expensive than a 2-axis accelerometer). The data from the accelerometers are fed directly into a micro-controller without the need for an A/D converter or glue logic. Using a small number of electronics components, a couple of adjustments, and very simple code in assembly language and Visual Basic, it is possible to track acceleration in three axis.

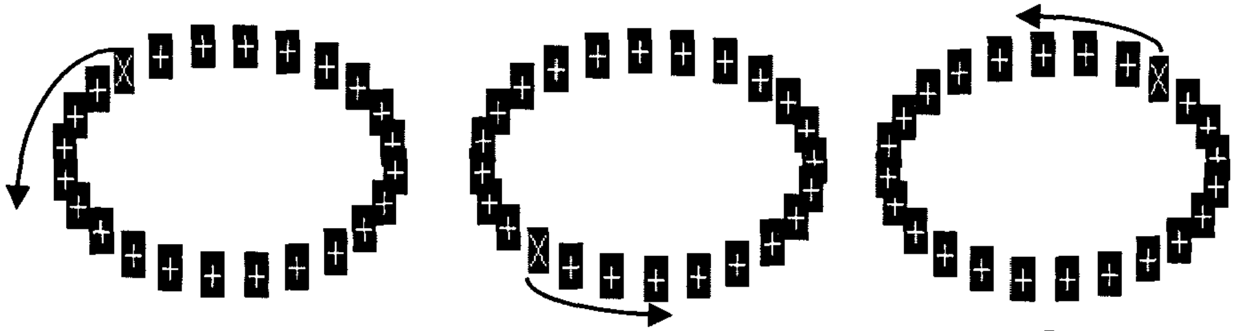


Fig. 4 Anti-clockwise Rotation in the X-Y-Z Plane

REFERENCES

[1] www.uspto.gov/web/offices/ac/ido/ptdl/step7.html

[2] http://www.uspto.gov/patft/index.html

[3] W. Kuehnel and S. Sherman, "A Surface Micromachined Silicon Accelerometer With On-chip Detection Circuitry," *Sensors and Actuators A*, vol. 45, no. 1, pp. 7-16, 1994.

[4] W. Yun, R. Howe, and P. Gray, "Surface Micromachined, Digitally Force-balanced Accelerometer With Integrated CMOS Detection Circuitry," *Proc. of the IEEE Solid-State Sensor and Actuator Workshop* '92, p. 126, 1992.

[5] R. Nasby, J. Sniegowski, J. Smith, S. Montague, C. Barron, W. Eaton, P. McWhorter, D. Hetherington, C. Apblett, and J. Fleming, "Application of Chemical-mechanical Polishing to Planarization of Surface-micromachined Devices," *Proc. Solid-State Sensor and Actuator Workshop*, pp. 48-53 (1996).

[6] J. Sniegowski and E. Garcia, "Surface-micromachined Geartrains Driven by an On-chip Electrostatic Microengine," *IEEE Electron Device Letters*, vol. 17, no. 7, p. 366 (1996).

[7] http://www.datasheetcatalog.com/datasheet/A/ADXL250.shtml

[8] W. Clark, R. Howe, and R. Horowitz, "Z-axis Vibratory Rate Gyroscope," *Micromachining Workshop III: Technology and Applications*, Sept. 1996. Juneau

[9] Scott Edwards, "*Programming and Customizing the Basic Stamp Compute*r", McGraw Hill, 1998, pp. 128-129.

[10] Basic Micros', "*Atom User's Guide*", Basic Micro Inc., Revision 2.3, 2002.

[11] Parallax's', "*Basic Stamp II User manual*", Parallax Inc., Revision .94.

[12] Parallax's', "*Student Guide to Industrial Control*", Parallax Inc., V1.1.

[13] M68HC11 Microcontrollers, "*M68HC11 Reference Manual*", Motorola Inc., Revision 6, 2002.