Accelerometer Based Real-Time Remote Detection and Monitoring of Hand Motion

J. Pang, I. Singh

Abstract—**Real-time hand motion capture by using one triaxial accelerometer provides useful information about an individual's daily activity and it is also useful for the development of gesture-based customer devices. With the fast growth of integrated circuit technology, the small size iMEMS digital accelerometers are available on market. The digital triaxial accelerometer influenced on gravitation holds the output data for each axis in its data registers. This paper presents one design system by using wearable triaxial digital accelerometer ADXL345 for hand motion sensing and using RCM3365 board as web server. The system collects real-time 3-axis data on users, and it supports remote monitoring of hand motion through internet. It is also capable of storing data into Excel sheets on remote PC for post-processing. The proposed system has wide potential applications including learning, game, navigation, sports medicine, health-care, and so on.**

Index Terms—**Digital accelerometer, web server, remote monitoring, hand motion, real-time**

I. Introduction

THERE have been reports of accelerometers being used by researchers to detect people standing, walking and falling [1], to measure tremor [2] of patients and so on. With the fast progress in the integrated circuit technology, the small and lightweight accelerometers become available. The sensor miniaturization has stimulated great interests among researchers for developing wearable sensor systems [3], [4] to detect and monitor activities of body gestures [5]. However, most developed systems are limited by the amount of memory and hardware resources contained in low-power microcontrollers.

One option to solve above problem is to use wireless sensor platforms to transfer data to local computers. For such systems, short battery life is a big concern for long-time accelerometer data collection. In this paper, we presents our new solution of using ADXL345 from Analog Devices [6] to detect hand motion, and RCM3365 board [7] from Digi International Inc. as web server for long-term hand motion monitoring in real-time. This also adds convenient feature for remote monitoring.

iMEMS is an integrated micro-electromechanical system. The small size iMEMS accelerometer such as ADXL345 has advantage of low cost and low power consumption. Especially, with integrated on-chip Analog-to-Digital Converter (ADC), ADXL345 provides convenient interface with other digital portable systems. Moreover, it not only supports either a SPI or I2C digital interface, but also offers high resolution measurement.

For remote accelerometer data monitoring, RCM 3365 module is chosen in this work. RCM 3365 module has one 8-bit Rabbit 3000 microprocessor which runs on maximum clock frequency of 44.2 MHz. It has low electromagnetic interference (EMI). It contains mass Flash, SRAM resources, and 10/100 Base-T Ethernet connectivity to support Local Area Network (LAN) and Internet-enabled applications. In addition, it supports Dynamic C which is C-friendly instruction set for fast and efficient development of complex systems.

The rest of the paper consists of several parts. Part 2 shows the system architecture. Part 3 describes ADXL345 accelerometer internal architecture and output angle calculation. Part 4 explains the net based hand motion detection procedures. Part 5 illustrates the hand motion detection results. At last, part 6 gives conclusion.

II. System Architecture

The architecture of the net based accelerometer design for hand motion detection system is shown in Fig. 1. ADXL345 is high resolution 3-axis digital accelerometer. When hand moves, the accelerator detects movements. The RCM3365 serves as WEB server. The data on the webpage is collected into the Excel database.

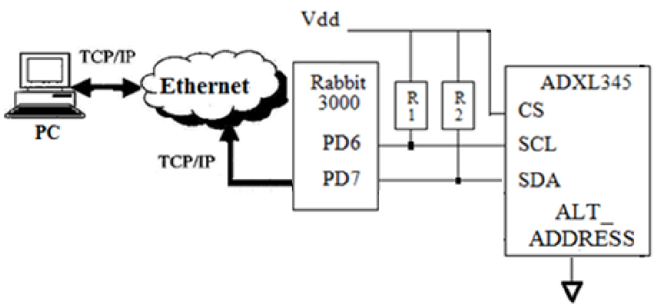

Fig. 1. Accelerometer design for hand motion detection system block diagram

In Fig. 1, two 2K ohm resistors R1 and R2 are used to connect the clock signal (SCL) and the data signal (SDA) with power supply Vdd. The PD6 and PD7 pins of Rabbit are connected with SCL and SDA of ADXL345 respectively. PD6 and PD7 are default pins of Rabbit 3000 to be used for I2C communication. Chip select (CS) pin of

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ADXL345 is connected with Vdd. This indicates ADXL345 chip will communicate with other devices through I^2C interface instead of through SPI interface. ALT_ADDRESS pin is connected with ground. The value of Vdd is 3.3 V in this design.

III. ADXL345 ACCELEROMETER

The accelerometer ADXL345 is based on polysilicon surface-micromachined structure suspended by springs built on a silicon wafer. Differential capacitors measure the deflections of the structure. The built-in 13-bit ADC converts the analog sensing signal into digital format. The filtered digital results are available to both control logic block, interrupt logic block and an on-chip first-in first-out (FIFO) memory. The FIFO block can store up to 32 sample sets of X, Y, and Z data. The INT1 and INT2 are two programmable interrupt pins. The serial I/O block provides serial clock, serial data I/O, and serial address signals for serial communication with external Master device. The orientation diagram of ADXL345 is shown below.

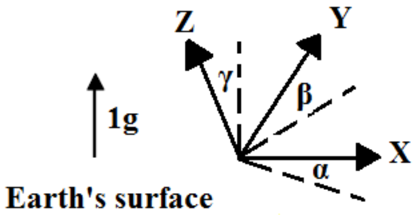

Fig. 2. Accelerometer orientation diagram

In Fig. 2, α and β are tilt angles of the accelerometer X-axis and Y-axis relative to the ground. γ is the angle of the accelerometer Z-axis relative to gravity. For ADXL345, the initial positions of X-axis and Y-axis are in a 0 *g* field, and Z-axis is in the 1 *g* field of gravity. ADXL345 output Ax, Ay and Az values. Its X-axis, Y-axis and Z-axis tilt angles can be calculated according to the following equations.

$$\sin(\alpha * \pi / 180) = Ax / \sqrt{Ax^2 + Ay^2 + Az^2} \quad (1)$$

$$\sin(\beta * \pi / 180) = Ay / \sqrt{Ax^2 + Ay^2 + Az^2} \quad (2)$$

$$\cos(\gamma * \pi / 180) = Az / \sqrt{Ax^2 + Ay^2 + Az^2} \quad (3)$$

$$\alpha = \tan^{-1}(Ax / \sqrt{Ay^2 + Az^2}) * 180 / \pi \quad (4)$$

$$\beta = \tan^{-1}(Ay / \sqrt{Ax^2 + Az^2}) * 180 / \pi \quad (5)$$

$$\gamma = \tan^{-1}(\sqrt{Ay^2 + Ax^2} / Az) * 180 / \pi \quad (6)$$

The ADXL345 does not output data from 0^o to 360^o. Instead, the angle varies from 0^o to 90^o in the first quadrant, then from 90^o to 0^o in the second quadrant, from 0^o to -90^o in the third quadrant and from -90^o to 0^o in the fourth quadrant for X-axis and Y-axis. For Z-axis, the angle varies from 0^o to 90^o in the first quadrant, from -90^o to 0^o in the second quadrant, from 0^o to -90^o in the third quadrant, from 90^o to 0^o in the fourth quadrant. As a result, the formulas listed in the following table are used to generate output angles from 0^o to 360^o.

TABLE I
ADXL345 ANGLE CORRECTION

A	β	γ	Angle Correction		
>0	>0	>0	αf=α	βf=β	γf=γ
>0	>0	<0	αf=180-α	βf=180-β	γf=180+γ
>0	<0	>0	αf=α	βf=360+β	γf=γ
>0	<0	<0	αf=180-α	βf=180-β	γf=180+γ
<0	>0	>0	αf=360+α	βf=β	γf=γ
<0	>0	<0	αf=180-α	βf=180-β	γf=180-γ
<0	<0	>0	αf=360+α	βf=360+β	γf=360-γ
<0	<0	<0	αf=180-α	βf=180-β	γf=180+γ

IV. HAND MOTION DETECTION

Fig. 3 shows the hardware system used in the net-based hand motion detection system. One wireless router NETGEAR is used to interface RCM3365 with internet. RCM3365 serves as web server. And ADXL345 is attached with wearable strings. RCM3365 communicates with ADXL345 through I^2C interface.

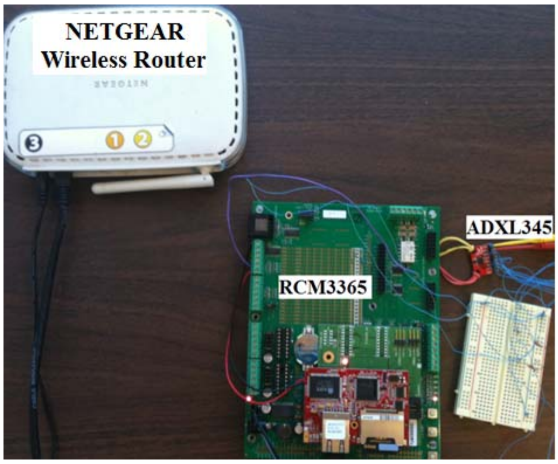

Fig. 3. Net based accelerometer design for hand motion detection hardware system

In Fig. 4, one user wears ADXL345 accelerometer on top of his hand. The accelerometer is tilted to the right facing up. PC is used to display accelerometer X-axis, Y-axis and Z-axis tilting angles on the designed webpage.

Fig. 4. Hand motion test with wearable accelerometer tilted right and facing up

I^2C serial communication protocol is used for accelerometer data collection. Rabbit 3000 processor serves as Master device, and ADXL345 serves as Slave device. In this design, only single mode write and single mode read are used. To write to the slave device ADXL345 in I^2C single write mode, Rabbbit 3000 processor needs to perform the following steps:

1) Send the START sequence.
2) Send the I^2C Address of the ADXL345 device and set the R/W bit to low.
3) Send address of the ADXL345 internal register to be written.
4) Send the data byte.
5) Send the STOP sequence.

On the other hand, in order to read data from the slave deviceADXL345 in I^2C single read mode, Rabbbit 3000 processor performs the following steps:

1) Send the start sequence.
2) Send the I^2C address of the ADXL345 device and set the R/W bit to low.
3) Send the internal address of the ADXL345 register to be read.
4) Send the START sequence again.
5) Send the address of the ADXL345 device and set the R/W bit to high.
6) Read data from the slave device ADXL345.
7) Send the STOP sequence.

This design used LA5000 logic analyzer to measure I^2C signals generated by hardware. LA5000 is PC-based logic analyzer. It communicates with PC through USB port. It offers high speed clock rates, deep buffers, and also easy data management.

The measured I^2C clock signal in this design is displayed in Fig. 3. It is 26 us. So the I^2C clock frequency is about 38.46 KHz.

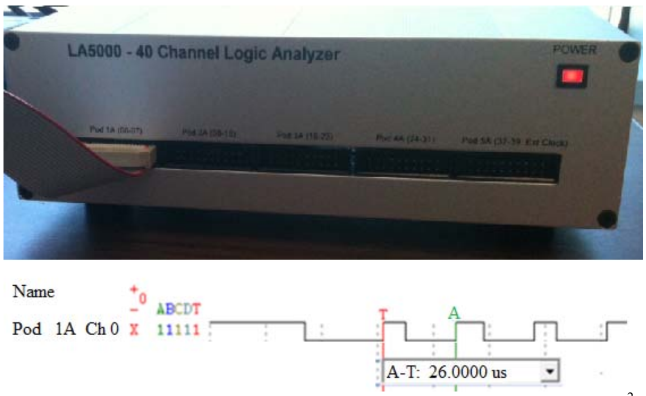

Fig. 5. PC-based logic analyzer LA5000 and measured waveform of I^2C clock signal

The ADXL345 is attached to the top of the user hand. Its Y-axis is parallel to the arm pointing outwards and its X-axis is perpendicular to the arm. When the hand rotates, the ADXL345 X-axis output angle changes. Six different hand positions were tested successfully based on conditions listed in the following table.

TABLE II
SIX DIFFERENT HAND POSITIONS

X-axis Output Angle	Hand Positions
$\alpha f > 350$ or $\alpha f < 10$	Hand is in straight up position
$10 < \alpha f < 90$	Hand is in left-titled facing up position
$90 < \alpha f < 170$	Hand is in left-titled facing down position
$170 < \alpha f < 190$	Hand is in upside down position
$190 < \alpha f < 270$	Hand is in right-titled facing down position
$270 < \alpha f < 350$	Hand is in right-titled facing up position

Similarly, in case user hand moves either backward or forward, the angle between Y-axis and ADXL345 changes. Such changes can be used to differentiate if hand moves forward or backward.

Moreover, combining output angles of αf, βf, and γf together, the designer can detect more complicated hand motions.

The following steps are used by the Rabbit 3000 microprocessor to detect hand motion described in the above algorithm.

1) Write ADXL345 internal registers such as BW_Rate, Power_CTL and Data_Format registers by using I^2C single write mode to set up ADXL345 data output rate, normal power mode and right-justified data format.
2) Use sock_init() to initiate the TCP engine and use http_init() to start web server.
3) Next, the following tasks are done in a loop:
   - Read ADXL345 X-axis, Y-axis, and Z-axis data by using I^2C single read mode.
   - Calculate related hand motion angles and detect hand positions.
   - Using one median filter of size 3 to remove spikes from accelerometer data.
   - Update web variables.
4) C# program runs on a remote PC to capture real-time accelerometer data on internet and store them in Excel sheets.

V. RESULTS

Results for hand motion tests with both wearable accelerometer straight up case and tilted right and facing up case are used in this section for discussion. Fig. 6 shows accelerometer in straight up position and Fig. 7 shows web page display.

Fig. 6. Hand motion test with wearable accelerometer straight up

The IP Address of the wireless router NETGEAR is 192.168.1.1. The IP address of the RCM3365 kit is configured accordingly in Fig. 7 as 192.168.1.100 to work properly on the LAN. The webpage displays correct hand position detection in real-time. The webpage can also be

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designed to display 50 triaxial accelerometer output angles on one page in real-time and then get updated. The number of samples to be displayed on one page is configurable.

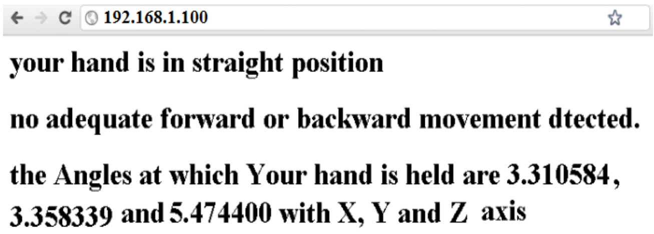

Fig. 7. Web page display for hand motion test with wearable accelerometer straight up

Because C# program runs on a remote PC to capture real-time accelerometer data on internet, it stores data in Excel sheets on the remote PC. Sample Excel sheet results are shown in Fig. 8. "E" column represents X-axis tilted angle, "F" column represents Y-axis tilted angle, and "G" column represents Z-axis tilted angle. Each Excel sheet collects 50 samples and also generates angle plot automatically as shown in Fig. 9. New Excel sheets are generated when 50 news samples are available.

E	F	G
273.6256	1.574417	86.74665
274.2878	1.338136	86.10285
274.2878	1.338136	86.10285
274.2878	1.338136	86.10285
274.2878	1.338136	86.10285
274.2878	1.338136	86.10285
274.2878	1.338136	86.10285
272.8025	1.116601	87.43955
274.1426	1.343359	86.08802
272.8025	1.116601	87.43955

Fig. 8. Samples of accelerometer data stored in Excel sheet

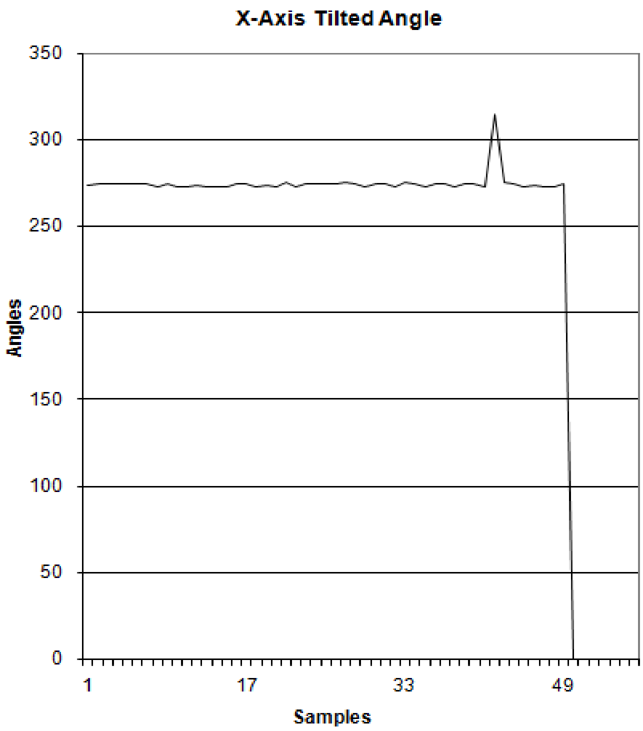

Fig. 7. Accelerometer X-axis titled angle plot for hand motion test with wearable accelerometer tilted right and facing up

The X-axis tilted angle plot shown in Fig. 7 indicates that collected samples satisfies the relationship specified in Table II. The hand motion with wearable accelerometer tilted right and facing up can be successfully detected.

The designed algorithm described in this paper is easy to implement in real-time. The presented several hand motion positions are useful in many real-world applications and customer electronic desvices. In this paper, The formulas we developed in Table II for hand motion detection are based on our experiments. Each hand positioncovers relatively wide angle range. The high-resoltion ADXL345 satisfies our system need quite well. As a result, the small sensor erros are not big concerns. The hand motion detection of 6 presented position shown in Table II, also hand moving forward, and hand moving backward can be detected in real-time succesfully with nearly 100% detection rate.

For more accurate accelerometer angle detection, more complicated algorithms need to be designed. At the same time, the tradeoff between the algorithm complexity and the real-time accelerometer tilted angle detection needs to be considered.

VI. Conclusion

The paper presents how to remotely monitor hand motion in real-time. The proposed system architecture is flexible for fast development of embedded accelerometer system with net interface features. Experiments show that our system is well suited for hand motion detection in multiple directions. ADXL345 accelerometer supports high resolution. Also because our proposed algorithm covers relatively wide angle range for each hand motion position, it is not sensitive to small sensor erros.

More accurate accelerometer angle detection requires more complicated algorithms to process accerlerometer data. At the same time, the tradeoff between the algorithm complexity and the real-time angle detection needs to be considered.

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