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Design and Development of Accelerometer Based System for Motion Analysis

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***Abstract*— In this paper, accelerometer based system for motion analysis is designed and developed which is able to monitor the improvement of the patient's health. In this paper, a tri-axial accelerometer is used to acquire the signal in three different axes from the subject's body and then signal acquisition is done by using microcontroller. After signal acquisition, this data is sent to the laptop/PC using wireless transmission RF module XB24. To make this system wearable and compact, printed circuit board is designed and the output of this system is shown in MATLAB.**

***Keywords*— Motion Analysis, ADXL335 Accelerometer, AVR Microcontroller, RF module XB24, Printed Circuit Board, Arduino, X-CTU, MATLAB**

I. INTRODUCTION

Motion analysis plays a very important role in medical field like in physiotherapy. It is a field of wide interest which is used to enable the assessment of large variety of variables related to the quality of life [1]. Physiotherapy is a branch of rehabilitative medicine which is aimed at helping patients maintain, recover or improve their physical abilities. So we can say that physiotherapy is the treatment of any disease, pain or injury by physical means. The physiotherapist keeps notes on the patient's progress, carries out periodic examinations, and adapts treatment along the way as required. The proposed system can be helpful for the physiotherapist to see the improvement in the patient's health. As we know that the physiotherapist evaluates the results of rehabilitation by only watching the patient. Every physiotherapist evaluates the progress of the patient and gives his own results that mean different conclusions come from different physicians and these results can be totally different [2]. Thus the evaluation of patient's progress leads confusion. The other problem is that patients can't monitor their progress independently without physiotherapy because they do not have any feedback from therapy process. So to overcome from this problem, this system is designed and implemented which is wearable and comfortable with the long battery life. By using this system in the rehabilitation process, we can improve the results of evaluation and make the rehabilitation process more efficient. The size of this system is compact that's why patient can wear it easily [3].

In this paper, accelerometer based system for motion analysis is designed and developed. The related work is explained first followed by hardware design and software design. Experimental Results and Conclusion is explained in the end of the paper.

II. RELATED WORK

As we know that science and new techniques strongly influence the world of medical field nowadays [3]. In order to analyze the patient's improvement, various setups and devices have been developed. Many of these devices were based on video analysis, while others made direct measurement and signal is captured through awkward setups which are very much uncomfortable for the patients and thus physician can't analyze the improvement of patient's health accurately [3]. For motion analysis, there are two methods. The first method is contact type method in which motion analysis is done by using accelerometer. In this method, the device is connected to the subject's body and then calculations of kinematic parameters have done. The second method is non-contact type method which is also called "Video Analysis Method". In this method, motion analysis is done by using high speed camera. This method is time consuming because analysis can only be done offline. The cost of the camera which is used in video analysis is high. On the other hand, contact type method gives the more accurate result and the cost is low as compared to the non-contact method.

There are different types of accelerometers used for motion analysis. The first accelerometer used for motion analysis is Piezoresistive accelerometer. It consists of sensing element which has a seismic mass and cantilever beam. The motion of the seismic mass generated due to acceleration, can be detected by piezoresisters in the cantilever beam and seismic mass. In this, accelerometer is connected to the Wheatstone bridge which produces voltage proportional to the acceleration. This accelerometer is simple and it is of low cost which can measure static acceleration but the major drawbacks of this accelerometer are the temperature sensitive drift and the low levels of output of signals. The second accelerometer is Piezoelectric accelerometer in which sensing element bends

because of applied acceleration and causes displacement in the seismic mass. This gives an output voltage which is proportional to the acceleration. This accelerometer gives accurate result and its response is linear. It has large dynamic range and noise is very small. But the disadvantage is that it can't measure static acceleration. The third accelerometer is MEMS accelerometer capacitive based sensor. In this accelerometer, the change in capacitance is measured. A small mass is mounted on tiny lever which causes lever to move when it is accelerated and thus it changes the capacitor which converts this capacitance into a voltage [4]. This voltage is directly proportional to the acceleration. MEMS accelerometer has low cost, less weight, smaller size and it has not temperature sensitive drift. It measures the static and dynamic acceleration. After comparing all above accelerometers, we have concluded that motion analysis using MEMS accelerometer is better than other two accelerometers because of its low cost, less weight, less size and its accuracy. In the proposed method, MEMS accelerometer is used because we have to make portable and compact device which can be easily worn by patients.

III. HARDWARE DESIGN

Accelerometer based system for motion analysis consists of ADXL335 accelerometer, Microcontroller, RF Module XB24 (zigbee) and printed circuit board designing. A block diagram of the wearable system is shown in Fig 1.

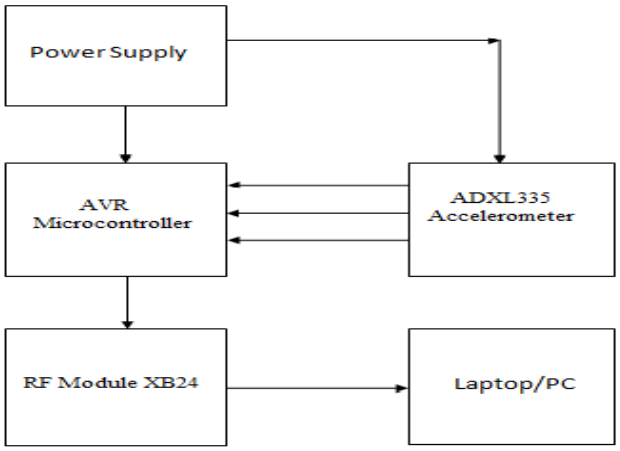

Fig. 1. Block Diagram of Accelerometer Based System for Motion Analysis

A. ADXL335 Accelerometer

ADXL335 accelerometer is the tri-axial accelerometer which measures the acceleration in three axes that is X-axis, Y-axis and Z-axis. It is a smaller, lighter and cheaper than traditional accelerometers It has in-built signal conditioning circuit. It measures static and dynamic acceleration with a minimum full-scale range of ±3g [5]. ADXL335 accelerometer and the pin diagram of ADXL335 accelerometer are shown in Fig 2 and Fig 3 respectively. In this paper, five pins are used that are Xout, Yout and Zout for the output in X, Y and Z axes respectively, Vcc (3.3V) for power supply and GND for ground.

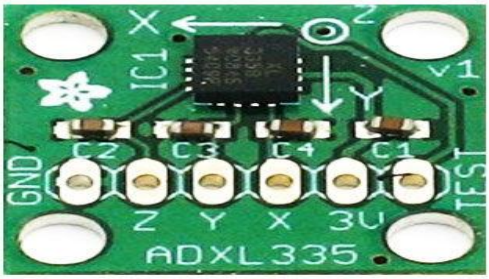

Fig. 2. ADXL335 Accelerometer

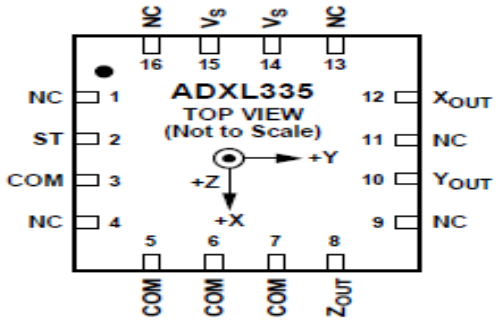

Fig. 3. Pin Diagram of ADXL335 Accelerometer

1) Calibration of ADXL335 Accelerometer: A characteristics graph of ADXL335 accelerometer is shown in Fig 4.

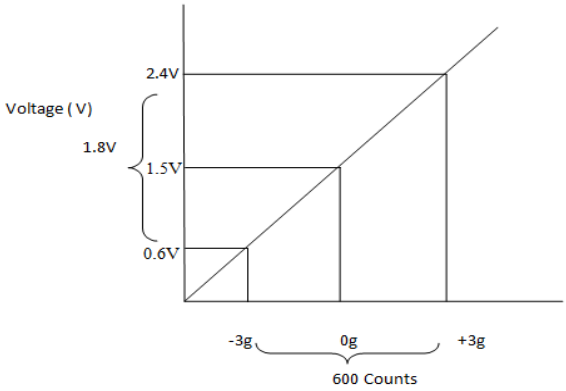

Fig. 4. Characteristics of Accelerometer

a) Calculation of Output Voltage: From the datasheet of ADXL335 accelerometer, output voltage at 0g (V_0) is 1.5 V. Equation (1) and equation (2) is used to calculate the maximum and minimun output voltage respectively.

$$V_{max} = V_0 + \text{Sensitivity at } +3g \quad (1)$$

$$V_{max} = 1.5V + 900mV = 2.4V$$

$$V_{min} = V_0 + \text{Sensitivity at } (-3g) \quad (2)$$

Vmin= 1.5V--900mV = 0.6V

Where Vmax is maximum output voltage and Vmin is minimum output voltage. So the voltage range is 0.6V-2.4V and the difference between maximum and minimum voltage is 1.8V. It has ±3g range which means it has total 6g span and 600 counts is in microcontroller. These 600 counts have to come between 0.6V-2.4V.

b) Calculation of Vref for Analog to Digital Converter: For 600 counts, voltage per step has to be found. The difference between maximum and minimum voltage is 1.8V. Equation (3) is used to calculate the voltage per step.

Voltage per step= Vmax-Vmin/600 (3)
Voltage per step= 1.8/600= 0.003V/step=3mv/step

In this paper, 10bit microcontroller is used which means $2^n - 1 = 2^{10} - 1 = 1023$ where n= 10. Equation (4) is used to calculate the Vref as reference voltage.

Vref = Voltage per step×1023= 3.069V (4)

c) Calculation of Counts for Different "g's": At 0g when no acceleration, Count= 1023×Vin/Vref = 1023×1.5/3.069= 500. If we get count greater than 500 say 730 then we subtract this from 500 and get the output in g like 730-500= 230 which means 2.30g. If we get count less than 500 say 440 then we get the g in negative,440-500= -60 means -0.60g. Here "g" is the gravitational acceleration that is equal to the 9.8 m/s^2.

B. AVR Microcontroller

AVR microcontroller is high performance and low Power AVR 8-Bit microcontroller. In this paper, ATmega328 microcontroller is used. It has three ports that is Port B, Port C and Port D and has 256 general purpose registers [6]. It has in-system self-programmable flash program memory, programmable serial USART and Master/Slave SPI serial interface. It has 8-channel 10-bit ADC. The supply voltage is 2.7V-5V.

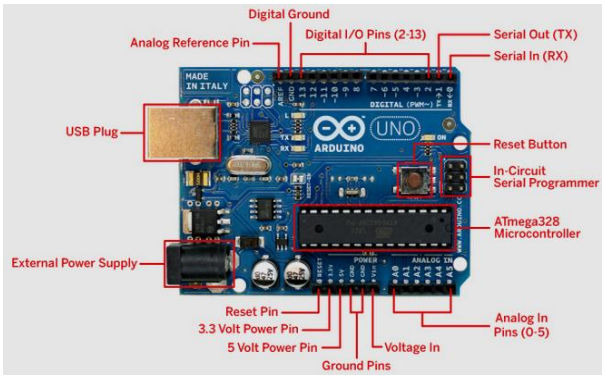

Fig. 5. Arduino UNO Board

In this paper, Arduino Uno microcontroller board is used as shown in Fig 5. This is cheaper in price than many available boards on the market and Free Arduino software available at the official website. It is smaller in size than many other versions. In this paper, 8 data bits, 1 start bit, 1 stop bit and none parity is used. The baud rate is 9600. The pin diagram of ATmega328 is shown in Fig 6.

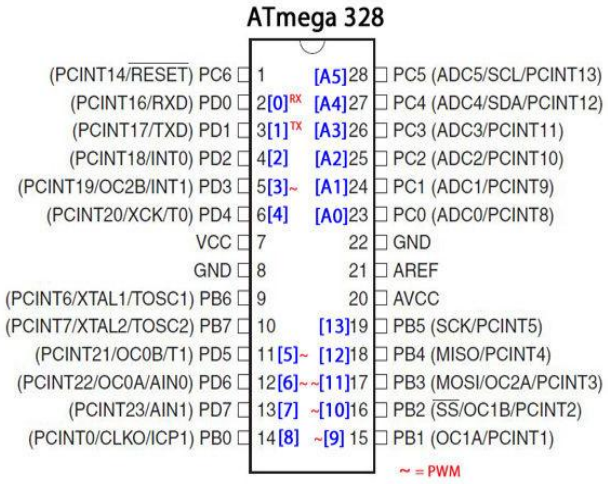

Fig. 6. ATmega328 Pin Diagram

C. RF Module XB24(Zigbee)

XB24 (Zigbee) is high level communication protocol. It is used to create personal area networks built from small, low-power digital radios. Zigbee is a low-cost, low-power, wireless mesh network standard. It is based on an IEEE 802.15.4 standard which specifies the physical layer and media access control for low-rate wireless personal area networks. Zigbee network uses coordinator, router and end devices to communicate [7]. It can transmit data over long distances by passing data through intermediate devices and creates a mesh network. This is simpler and less expensive than other wireless personal area networks such as Bluetooth or wi-fi. The RF module XB24 is shown in Fig 7.

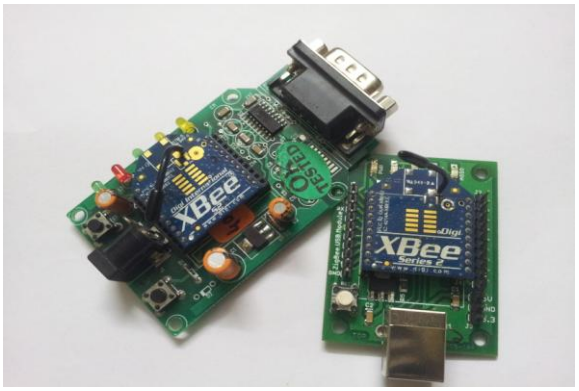

Fig. 7. RF Module XB24 (Zigbee)

In this paper, four pins are used in zigbee that are Vcc (3.3V) for power supply, Tx for transmission of data, Rx for receiving of data and GND for ground. A pin configuration of RF module XB24 is shown in Fig 8.

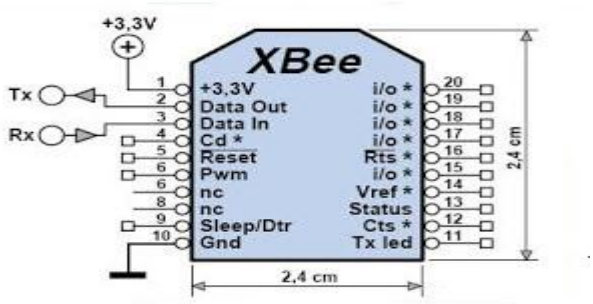

Fig. 8. RF Module XB24 (Zigbee) Pin Configuration

D. Designing of Printed Circuit Board

To make system compact and portable, printed circuit board (PCB) is designed. PCB layout is designed by using Proteus 8 Professional (8.1 Version) software. After making PCB layout, PCB plate is drilled by using drilling machine and then etching process is done. Etching is the process in which firstly we use oil paint to paint the routing connections and keep it for dry. After drying the plate, this plate is kept into the ferric chloride solution to remove the copper and when copper is removed then this plate is washed using clean water and plate is wiped by clean cloth. Lastly, oil paint is removed by using paper cutter and then soldering of the components is done. In this paper, epoxy fiber glass is used for PCB plate designing.

IV. SOFTWARE USED

A. Arduino Software

Arduino software is used for writing and burning of program into the microcontroller. It is open source software which can be used by anyone at free of cost. In this software, direct commands are available which are used for initialization of register, ADC, analog input and digital output [8]. To program microcontroller, firstly program is written in embedded "C" and converted into Hex file which is then burn into the flash memory of microcontroller. In this paper, Arduino 1.0.6 version is used.

B. X-CTU

X-CTU is used for testing and configuring the zigbees. This software is easy to use and allows users to test the radio modems in the actual environment with just a computer and the items included with the radio modems.

C. MATLAB

MATLAB program is written for the purpose of obtaining the data from the serial port that the Arduino microcontroller sends in real time and plotting graphs of accelerometer data [9]. For reading the data from the external device, some in-built commands in the MATLAB are used. To create serial port object, serial (PC serial port, the baud rate, number of data bits) command is used. To open the serial port object and to connect the PC to the external device for serial communication, fopen command is used. To read/write data from the external device and to send data in binary format to the external device, fread/fwrite command is used. fclose is used to close the serial communication between MATLAB and external device. In this paper, MATLAB R2014a version is used for displaying the output.

V. EXPERIMENTAL RESULTS

After designing and developing the device for motion analysis, it is attached to the subject's body parts like hands or legs [10]. When subject starts the motion like walking, jumping, running etc, this system plotted the graphs between the gravitational acceleration and the time in three different axes that is X axis, Y axis and Z axis. The final accelerometer based system for motion analysis is designed and implemented as shown in Fig 9 which is operated by 9V battery.

Fig. 9. Accelerometer Based System for Motion Analysis

When subject does not move like he is taking rest, then linear graphs are plotted as shown in Fig 10. At this condition, the value of gravitational acceleration comes in the range of ±1.5g.

When subject starts to move slowly due to some physical activity like walking, it gives the output in all three axes which is shown in Fig 11. At this condition, the value of gravitational acceleration comes in the range of ±2g. From this figure, we can observe that subject is moving slowly because variations in the X, Y and Z axis are small.

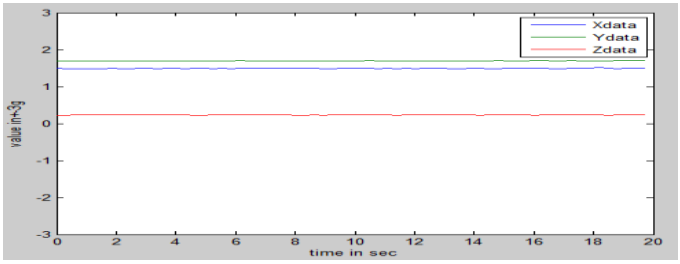

Fig. 10. Output of the System when subject does not move

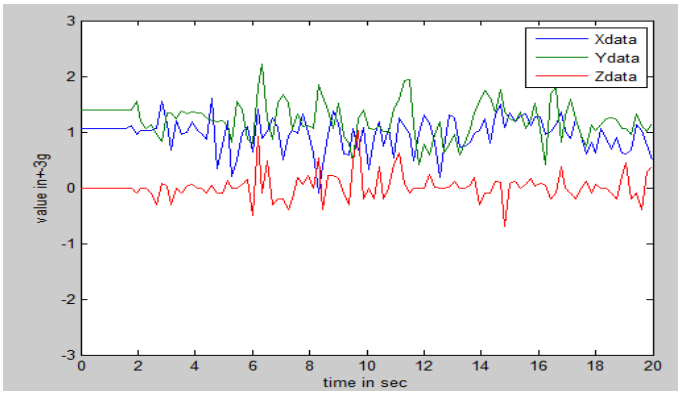

Fig. 11. Output of the System when subject starts to move slowly

When subject starts to move fast due to some physical activities like jumping and running, it gives the output in three axes which is shown in Fig.12. The value of gravitational acceleration at this condition comes in the range of ±3g. From this figure, we can analyze that subject is moving fast because we get large variations in the X, Y and Z axis.

In this way, we can say that this system gives the accurate result in the range of ±3g. By analyzing these graphs, physiotherapist can see and evaluate the improvement in the patient.

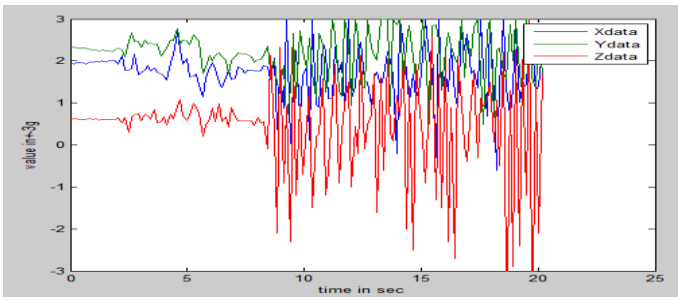

Fig. 12. Output of the system when subject starts to move fastly

VI. CONCLUSION

In this way, accelerometer based system for motion analysis is designed and implemented. This system is wearable and compact with the long battery life. The aim of this paper is not only to detect the motion but also to make the cost effective system. This system is capable of giving the accurate data of the subject's motion which is helpful for the physician to analyze to see the recovery of the patient. This device can also be used in the different sports which are related to the motion of the subject like running, javeline discus throw, swimming etc.

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