Bioengineering Research

A Portable Motion Sensor to Measure the Movements of Runners for Biomechanics Analysis

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Abstract

Learning the activities of professional runners has always been very important for researchers because it leads to learning their movements by amateurs. Therefore, learning and recording movements accurately help to learn amateurs. In this paper, a portable system to record the obtained data of runners is presented. The presented system consists of an accelerometer and gyroscope sensor, a Bluetooth module as well as a processor that the data of three-dimensional angular velocity and linear acceleration sensors are read and recorded with the help of the small processor. This data is then stored in the processor and then sent to a Bluetooth module through the UART protocol. The data are sent to a personal computer for recording and simulation. The data are read using Matlab software and then illustrated. The results show that this system measures motion parameters for runners and can be calculated steps of movement. Additionally, the outcome result can be compared with professional runners by the amateurs for learning. The presented system is very small and inexpensive that can be easily used to record the activities among amateurs and improve their movements.

Received: 28 October 2020, **Accepted**: 18 December 2020
DOI: 10.22034/jbr.2020.253869.1036
Keywords: Motion sensor, runners, biomechanics analysis

1. Introduction

Scientific evidence suggests that the risk of diseases caused by sedentary lifestyles significantly reduce in people who are physically active and in good physical condition [1]. Regular physical activity and good physical fitness improves health and disease prevention and can be part of the treatment of diseases [2-3]. In recent years, there has been a growing trend in the tendency to monitor the physiological function of the body between the medical community and the sports community during the daily activities of individuals [4]. In addition to making these tools available to the public at large, many media advertisements take place in this area. Also, the relatively low costs of some devices make the use of a variety of wearable monitoring devices equipped with electronic sensors popular in sport [5]. Examples of these devices include pedometers, accelerometers, heart rate monitors, ECG monitors. In addition to assessing physiological factors, these tools allow players, coaches, physicians, and clubs to monitor an athlete's movements, detect pressure, and control

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biometric markers to maximize athlete performance and reduce injury. Control of these variables allows detecting the occurrence of biomechanical fatigue in the athlete early. As a result, it is possible to prevent player injuries in training and competitions with timely interventions. It is also possible to make changes in the player's training program to bring the player to his best performance [6].

Electronic devices have been gradually developed to measure physical activity in the world in the last decade based on the technologies created in the field of sensors and processors [7]. First, the devices were marketed as mechanical pedometers. Gradually, due to low sensitivity and errors, a one-axis accelerometer sensor was used, but these sensors were also unable to record the body's acceleration in three axes [8]. Recently, three-axis accelerometer sensors have been used to measure physical activity due to their high accuracy and durability. These devices are considered a suitable alternative to the old methods of recording physical activity. So far, from simple pedometers and motion meters to advanced physical activity recording devices that use accelerometer sensors have been introduced to the market. Research shows that an accelerometer is directly related to energy expenditure during physical activity [9].

Pedometers are the simplest and most common means used to measure body movements. Whenever the acceleration of the vertical motion exceeds the threshold defined for the device, it is recorded in the form of a "step" in the device. Many health programs aim to reach a certain number of steps per day to encourage people to do physical activity [10]. One of the most common results of using pedometers is to increase the amount of physical activity during the day and is often used as the first step to measure the level of fitness and daily activity of people. Although the accuracy of using pedometers in counting routine steps has been accepted, their use in competitive sports is not accurate enough and these devices do not have the ability to accurately measure the movements of the athlete and determine the amount of energy consumed [11].

The use of accelerometers in sports is more popular because it provides the athlete with access to more advanced performance information and gives them the ability to make changes to his training pattern. These devices often consist of two parts that are sensitive to mechanical changes. Also, it contains a microchip that interprets the data from this physical sensor [12]. Besides, recent advances in technology in the field of microelectromechanical systems have allowed the production of sensors that, despite their tiny volumes, are capable of detecting motion in all directions [13]. Another advantage of accelerometers is the ability to calculate the amount of energy consumed. Determining the amount of energy consumed is one of the essential factors in determining the intensity of activity. In addition to movement information, these devices can provide physiological data such as heart rate, calories consumed, sleep pattern, number of steps, and so on [6], [14]. In the field of professional sports, accelerometers give much more accurate information about the athlete's movements. The use of accelerometers in football has led to the identification of different physical needs and pressures in different football positions [13].

The global positioning system (GPS) is one of the alternative tools for determining the position of the athlete instead of accelerometers. GPS devices need to transmit data from multiple GPS satellites orbiting the earth. GPS satellite information that is all obtained from different GPS receivers, is matched to determine the speed and position of the receiver [15]. With the development of GPS systems in team sports and the adding of a reference receiver on the earth in recent years, many wearable receivers are used by players, the amount of time error of satellite data has decreased, and accuracy measurements have improved to one meter. These wearable devices provide data about distance traveled, number of steps, speed, calories burned, altitude, instantaneous velocity, and so on. Most importantly, by transferring this data to a central receiver and storage of information, it is possible to evaluate players instantly, long-term, and changes in performance [16]. The tools that determine the body's physiological response to exercise are also foremost in promoting athletic performance and preventing sports injuries [17]. Heart rate is one of the useful indicators in identifying physiological adaptations and intensity of player effort. The basis of most of these devices is the use of a wearable sensor around the chest and the transmission of information to a display system (often a wrist device) using wireless [17-18]. New systems have begun to use eye sensors around the wrist or fingertips to detect heart rate. Although it is easier to use ocular sensors, it has been shown that chest sensors are much more accurate at accurately detecting heart rate, especially at high beats, as well as during movement [19]. Heart rate monitoring tools are often used as an important tool in determining the intensity of exercise and activity, because there is a direct and linear relationship between heart rate and VO2 (is measured in milliliters of oxygen consumed in one minute, per kilogram of body weight (mL/kg/min)), especially at intensities below the maximum. On the other hand, there is such a relationship with energy consumption. Therefore, using this tool is the most common method of determining the intensity of exercise performed [20].

In this paper, a system for measuring the linear acceleration and angular velocity of runners is developed. The system uses a 3D accelerometer sensor and a 3D gyroscope, a processor, and also a Bluetooth module. With the help of the processor, the data of this acceleration sensor is read through the I2C protocol. This data is then sent to the Bluetooth module via the serial protocol. This Bluetooth module sends USB data to a personal computer so that the variations in accelerometer and gyroscope can be seen on the laptop and used for training purposes.

2. Material and Method

The presented system measures angular velocity and linear acceleration and is very small and portable. The developed system comprises a motion sensor (MPU-6050), a processor (Atmega 8), and a Bluetooth module. More data is described in detail. The system is supplied by a 3.7V, 230mAh lightweight lithium polymer battery. The MPU-6050, Bluetooth module and Atmega 8 have very low power consumption, very cheap prices, and are widely used in the market.

2.1. The motion sensor

The project uses a sensor that benefit a 3D accelerometer and a 3D gyroscope. This is the first 6-axis sensor produced in the world, which was manufactured and marketed by Invensense in the United States at the end of 2010. This sensor has low power consumption, so low prices, and very high performance in consumer electronic devices such as tablets, smartphones. The sensor is a system in SiP packaging that combines two chips. The size of this sensor is miniature (1.4 x 4 mm), which makes it suitable for use in any circuit, even tiny circuits [21].

The MPU-6050 communicates with the processor via the I2C serial interface and sends all its information to the processor through this interface. The sensor also has an auxiliary I2C serial interface through which it can communicate with other external sensors and read data throughout this interface with the help of MPU-6050 [21].

A digital motion processor is placed inside the MPU-6050 to remove the processing of motion calculation algorithms from the main processor. This motion processor captures and processes accelerometer, gyroscope, and compass data and even other external sensors such as pressure sensors, whose information is read through the I2c auxiliary series, at any time. As a result, the accelerometer, gyroscope, and compass data are read from the processor registers or placed in FIFO buffers [21].

This digital motion processor has access to the MPU output pins to generate interrupts. The main purpose of the digital processor is to reduce processing power and eliminate extra time from the main processor. Because motion processing algorithms are intricated algorithms (these algorithms run at speeds above 200 Hz). To cover motion, a processor alone cannot record precise movements, so a digital motion processor is used alongside the main processor [21].

2.2. The processor

As previously mentioned, in the developed system an Atmega 8, an AVR processor is used. The number of pins of the Atmega 8 microcontroller for SMD is 32 pins. From this number of bases, two pins are utilized for micro supplying, which are bases number 3 and 4. Also, two other pins are used to communicate the serial protocol or UART with the Bluetooth module. These two bases are 30 and 31 of the microcontroller and are called Tx and Rx. Also, two pins are used to connect to the I2C protocol. These two pins are numbers 27 and 28, which are called SDA and SCL.

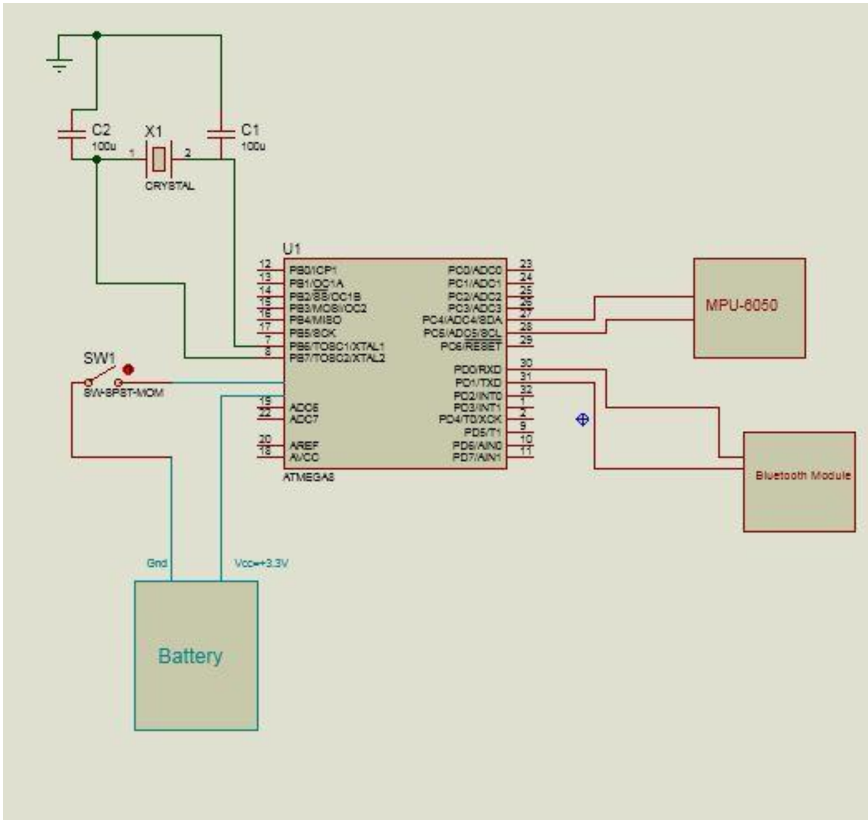

Figure 1: Schematic of a circuit built to monitor hand angle velocity

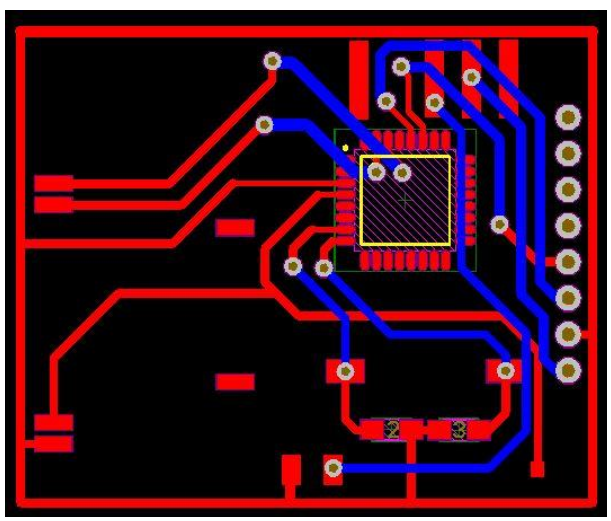

Figure 2: PCB designed in Altium Designer software

Two other pins were employed to connect to the crystal, which is pins 7 and 8 and are called XTAL1 and XTAL2. To program the microcontroller, 6 pins of SCK, MOSI, MISO, Reset, VCC, GND are used which are the number of 17, 15, 16, 29, 4, and 3 pins, respectively [22].

2.3. Bluetooth Module

The HC-05 Bluetooth Module is a Bluetooth serial module. This module is used to convert the serial port to Bluetooth. In other words, using this module, it can create a virtual serial connection (wirelessly) between the proposed devices and a personal computer via Bluetooth. The schematic of the developed system in

Figure 3: the developed system for measuring acceleration and angular rate of runners.

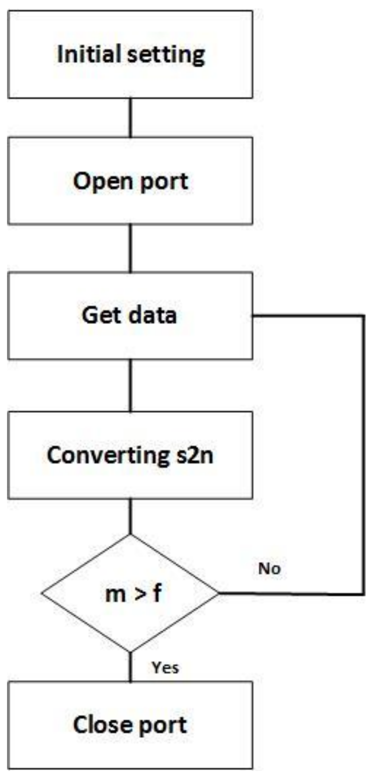

Figure 4: The proposed algorithm for the recording of the developed sensor in Matlab

Proteus software is shown in Figure 1. The Proteus library was used for this schematic [23].

With the help of the above schematic, the connections between the different parts are found and drawn it in the Altium Designer software. The printed circuit board (PCB) file of the circuit, which is drawn in Altium Designer software, is in the form of Figure 2. As Figure 2 shows, the red lines correspond to the top layer, and the blue lines correspond to the bottom layer. Therefore, this two-layer circuit is designed to have less volume and less noise for the circuit. After designing the circuit, it is given to a circuit manufacturing company to place the schematic on the printed circuit fiber. After that, the components are mounted on this circuit by soldering system and the circuit after this the soldering system is as follows.

Other circuit components include crystals. The crystal is for regulating the external frequency of the microcontroller circuit, which is 8 MHz, and is connected with two 22 picofarad capacitors to eliminate noise. Finally, the AVR microcontroller reads and stores the sensor data via the I2c protocol. It then sends this data to the Bluetooth module via the serial protocol. The data is sent to personal computer through this module and is displayed there. The final circuit is made as shown in Figure 3.

2.4. Getting data in Matlab

First, all the programs and charts are closed and also deleted all the variables. Then the command window is clear. Next, the final number of sampling samples (m) is selected. In the next section, the serial port was configured and the baud rate is set on 9600 bit per second while the port for reading information is *Com13*. Then the port is opened by *fopen(s)* command. Then in an iteration loop, first the accelerometer data is read from the port using the *fgets* command. Since data is a string, it is mandatory to convert the string to a number. So the *str2num* command was used and put the data in a variable. Then, this data is divided on 16384 to get the amount of acceleration in terms of gravity acceleration. This value is obtained from the datasheet of MPU-6050. Finally, the port is closed with the *fclose* command and the data was displayed with the *plot* command. The variable of n also shows the number of samples at each iteration. All of the proposed algorithms are shown in Figure 4.

3. Results & Discussions

The developed senor is tested in different situations as follow:

3.1. Stability test

First, to test the stability of the presented sensor, it is mounted on one place motionless for a long time, and its data is recorded. This test is performed for the purpose that accelerometer sensors have a large number of deviations over time. According to Figure 5, which was performed for 10,000 samples in 285 seconds, the stability of the system is acceptable. So the system can be used for tests.

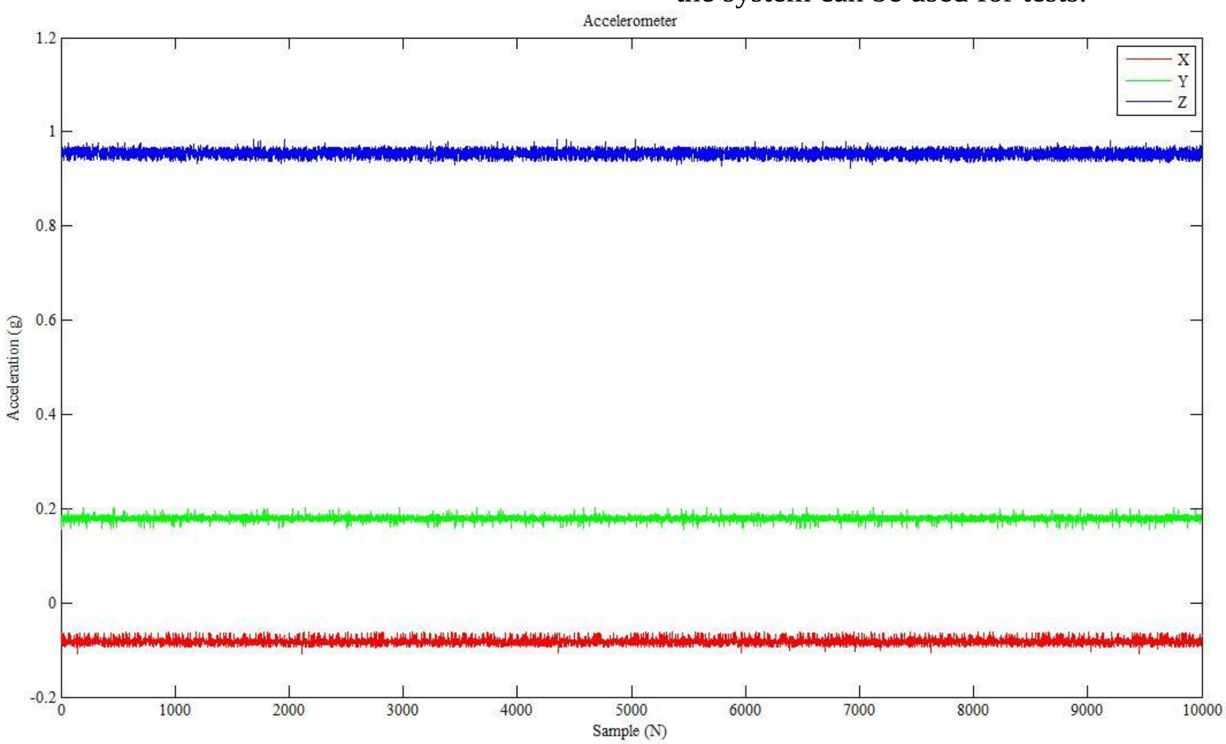

Figure 5: Sensor output test made in idle mode

The variance from the obtained data is taken during this period, and the values for the three axes X, Y, and Z are as follows:

X=0.00003282
Y=0.00002084
Z = 0.00006118

Which are miniature. Therefore, being stable for the system is acceptable. Also, the mean values of the accelerations obtained from Figure 5 during this period are as follows:

X=-0.0824
Y=0.1790
Z = 0.9541

3.2. Walking

In this test, a volunteer is asked to walk at a normal speed in 30 seconds. The obtained data is recorded and shown in Figure 6.

Like Figure 6, the linear accelerations obtained from the three accelerometers along the three axes of length, width, and height. As can be illustrated, it is obtained that these movements are linear rhythmic acceleration, and the volunteer moves with a certain rhythm.

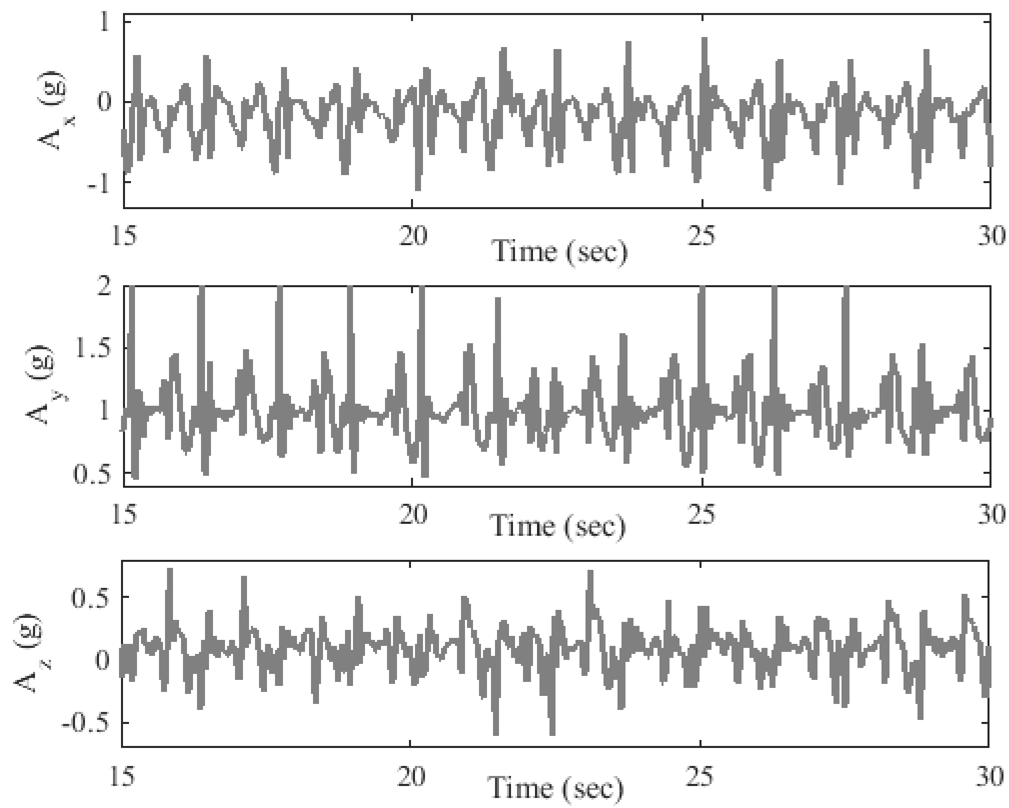

Figure 6: Linear acceleration test for ordinary running

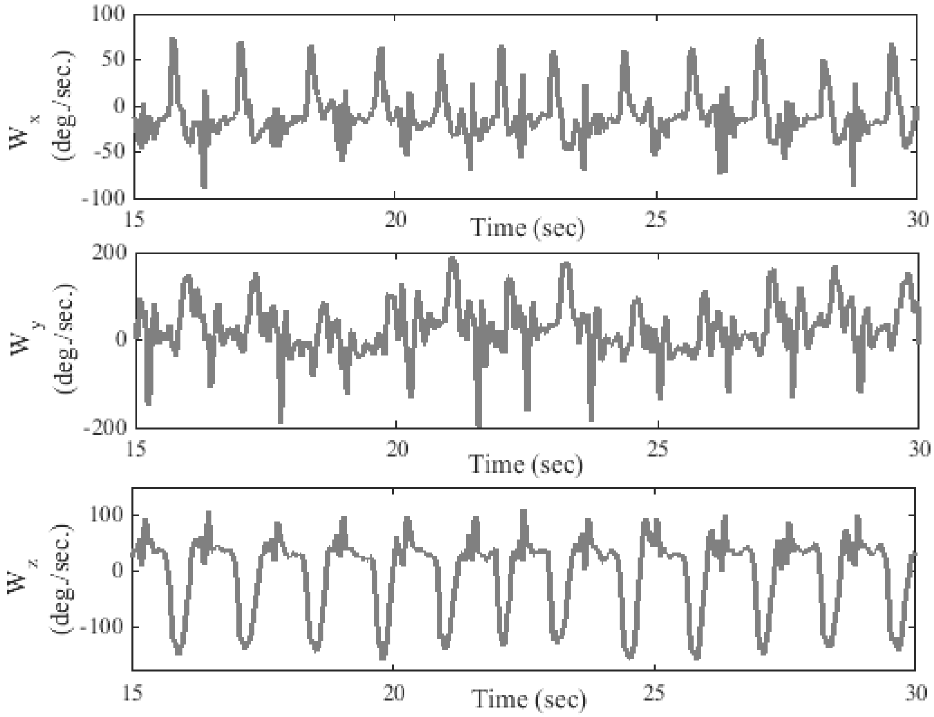

Figure 7: Angular velocity for normal running

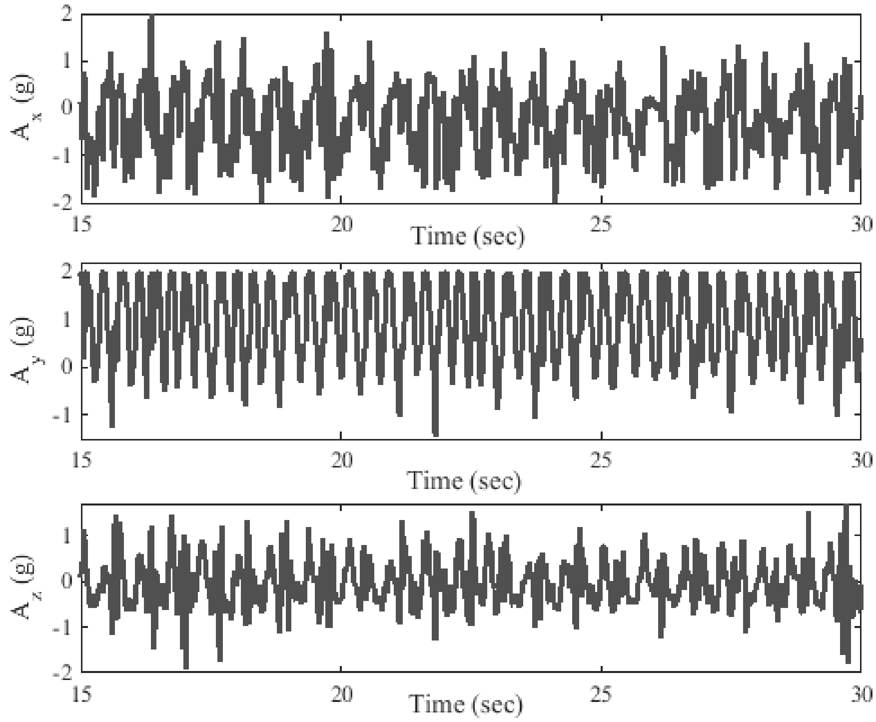

Figure 8: Linear acceleration for fast running

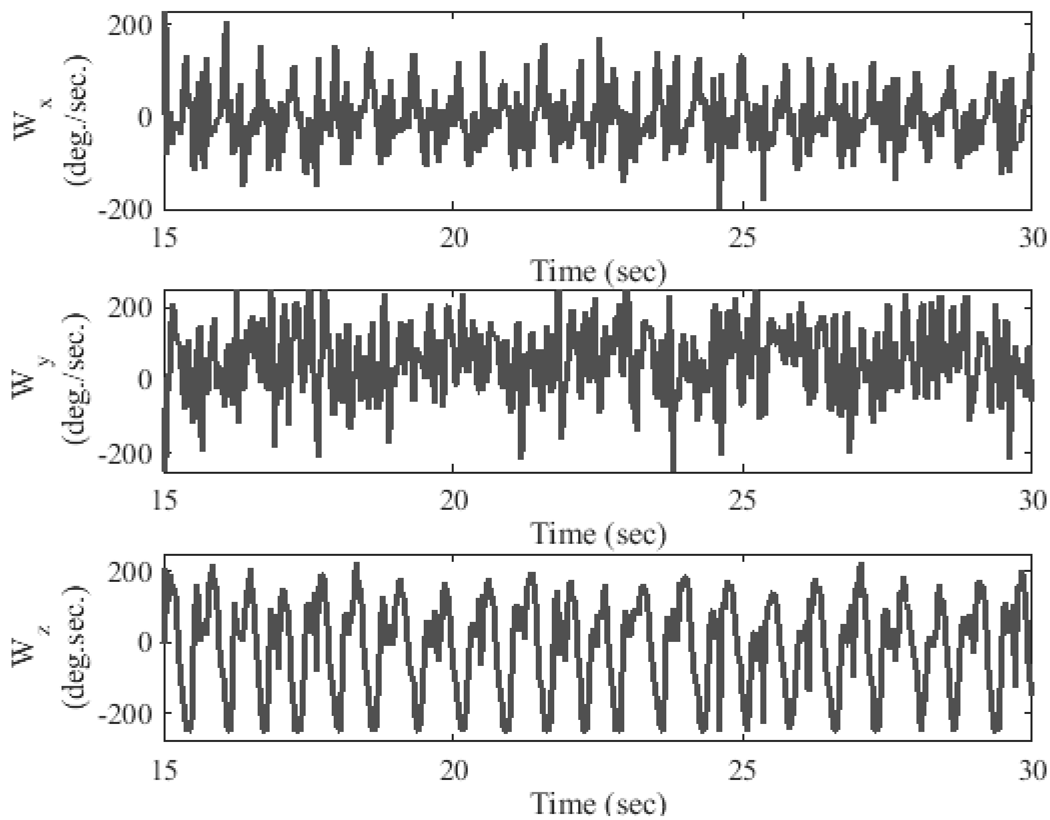

Figure 9: Angular velocity for fast running

In the next Figure, the angular velocity of movement is measured using a gyroscope. Like the accelerometer, this output indicates that the movement is a rhythmic movement and that the volunteer is running slowly. Also, from these diagrams in Figures 6 and 7, it is possible to identify the athletes' steps and compare the output conditions of linear acceleration and angular velocity in three dimensions with the amount of data of professional runners and try to move in their direction. Moreover, the volunteer walks 24 times in 30 seconds.

3.3. Fast running

In the next test, the candidate is asked to move faster, and the results obtained from the system are as Figures 8 and 9. The tests are performed in 30 seconds by the volunteer. Figure 8 shows the linear acceleration of the runner in the direction of the three axes. As can be seen, the output movement is rhythmic. The steps of the individual are known and the linear accelerations of the volunteer movement can be extracted from the moment at any time. This plot has a higher frequency compared to the linear acceleration of a runner at a slow speed.

Figure 9 shows the angular velocity of the volunteer that is running fast. As Figure 9 shows, the frequency of the volunteer's velocity angle is higher than before (slow running), so that the volunteer has taken 44 steps in 30 seconds. Also, the output data shows the steps and the angular velocity in three dimensions.

The obtained result of Figure 6-9 demonstrates that the angular velocity around the Z-axis, as well as the linear acceleration around the y-axis, is the best result for analysis and comparison. Because all outputs are shown more clearly than other outputs.

In the end, as mentioned earlier, by knowing and recording these accelerations, it can be saved credible data for learning professional activities. Now, if this data is stored, and compared to the values of a professional runner, the performance of volunteers can improve over time. For this purpose, it is enough to put the diagram together and comparing the angular velocity and linear acceleration of the two movements.

4. Conclusions

In this paper, a motion measurement system that is portable and can be easily charged was developed to calculate the motion parameters of runners. The system consists of a 3D accelerometer and a 3D gyroscope as well as a Bluetooth module that is was used to send data. The results showed that this system measures angular velocity and linear acceleration with excellent accuracy. Besides, the number of runner steps can be discerned from these results. Finally, with important motion parameters, amateur runners can improve their behavior and use the proposed system for training purposes.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

Acknowledgments

No applicable.

References

[1] Jaloli, M., Fathi, M., Mohammadi, S.M. and Abbasi Kesbi, R., 2019. A Proposed Algorithm for the Detection of Thyroid Cancer based on Image Processing. *Journal of Bioengineering Research*, *1*(3), pp.7-14.

[2] Burchfield, T.R. and Venkatesan, S., 2007, June. Accelerometer-based human abnormal movement detection in wireless sensor networks. In *Proceedings of the 1st ACM SIGMOBILE international workshop on Systems and networking support for healthcare and assisted living environments* (pp. 67-69). ACM.

[3] Fathi, Mohammad, Mohammadreza Nemati, Seyed Mohsen Mohammadi, and Reza Abbasi-Kesbi. "A machine learning approach based on SVM for classification of liver diseases." *Biomedical Engineering: Applications, Basis and Communications* 32, no. 03 (2020): 2050018.

[4] Ravi, N., Dandekar, N., Mysore, P. and Littman, M.L., 2005, July. Activity recognition from accelerometer data. In *Aaai* (Vol. 5, No. 2005, pp. 1541-1546).

[5] Abbasi-Kesbi, Reza, Hamidreza Memarzadeh-Tehran, and M. Jamal Deen. "Technique to estimate human reaction time based on visual perception." *Healthcare technology letters* 4, no. 2 (2017): 73-77.

[6] Gafurov, D., Snekkenes, E. and Bours, P., 2007, June. Gait authentication and identification using wearable accelerometer sensor. In *2007 IEEE workshop on automatic identification advanced technologies* (pp. 220-225). IEEE.

[7] Abbasi-Kesbi, Reza, and Alireza Nikfarjam. "A miniature sensor system for precise hand position monitoring." *IEEE Sensors Journal* 18, no. 6 (2018): 2577-2584.

[8] Larnder, C.I. and Larade, B., 2019. On the determination of accelerometer positions within host devices. *American Journal of Physics*, *87*(2), pp.130-135.

[9] Abbasi-Kesbi, Reza, Alireza Nikfarjam, and Hamidreza Memarzadeh-Tehran. "A patient-centric sensory system for in-home rehabilitation." *IEEE Sensors Journal* 17, no. 2 (2016): 524-533.

[10] Ahmadian, M. and Jafari, K., 2019. A Graphene-Based Wide-Band MEMS Accelerometer Sensor Dependent on Wavelength Modulation. *IEEE Sensors Journal*.

[11] Abbasi-Kesbi, Reza, Atefeh Valipour, and Khadije Imani. "Cardiorespiratory system monitoring using a developed acoustic sensor." *Healthcare technology letters* 5, no. 1 (2018): 7-12.

[12] Tadi, Mojtaba Jafari, Tero Koivisto, Mikko Pänkäälä, and Ari Paasio. "Accelerometer-based method for extracting respiratory and cardiac gating information for dual gating during nuclear medicine imaging." *Journal of Biomedical Imaging* 2014 (2014): 6.

[13] Najafi, M., Valipour, A., and Mohammadi, S.M., 2020. Developing an In-expensive Device for Measuring the Pressure of Children's Soles, *Journal of Bioengineering Research*, *accepted*.

[14] Haescher, Marian, Denys JC Matthies, John Trimpop, and Bodo Urban. "A study on measuring heart-and respiration-rate via wrist-worn accelerometer-based seismocardiography (SCG) in comparison to commonly applied technologies." In *Proceedings of the 2nd international Workshop on Sensor-based Activity Recognition and Interaction*, p. 2. ACM, 2015.

[15] Kuang, Da, Willy Bertiger, Shailen D. Desai, Bruce J. Haines, and Dah-Ning Yuan. "Observed geocenter motion from precise orbit determination of GRACE satellites using GPS tracking and accelerometer data." *Journal of Geodesy* 93, no. 10 (2019): 1835-1844.

[16] Abbasi-Kesbi, Reza, Zahra Asadi, and Alireza Nikfarjam. "Developing a wireless sensor network based on a

proposed algorithm for healthcare purposes." *Biomedical Engineering Letters* 10, no. 1 (2020): 163-170.

[17] Michael, S. and Sommer, R., 2019, July. Efficient Design and Layout of Capacitive 3D Accelerometer. In *2019 16th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD)* (pp. 225-228). IEEE.

[18] Su, Y.S. and Twu, S.H., 2019, April. A Real Time Fall Detection System Using Tri-Axial Accelerometer and Clinometer Based on Smart Phones. In *International Conference on Biomedical and Health Informatics* (pp. 129-137). Springer, Cham.

[19] Abbasi-Kesbi, Reza, Alireza Nikfarjam, and Ardalan Akhavan Hezaveh. "Developed wearable miniature sensor to diagnose initial perturbations of cardiorespiratory system." *Healthcare technology letters* 5, no. 6 (2018): 231-235.

[20] Chung, W.Y., Lee, Y.D. and Jung, S.J., 2008, August. A wireless sensor network compatible wearable u-healthcare monitoring system using integrated ECG, accelerometer and SpO 2. In *2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (pp. 1529-1532). IEEE.

[21] https://invensense.tdk.com/

[22] https://www.microchip.com/wwwproducts/en/ATmega8

[23] https://components101.com/wireless/hc-05-bluetooth-module