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Technical Research

Designing a new wearable and Wireless Inertial Measurement Unit for the physical activity monitoring

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ABSTRACT

Physical activity monitoring is important to record all the daily physical activities for the purpose of fitness and health. This motive caused a tremendous progress in the wearable technologies. Current project encompasses 9 degree of freedom inertial sensor (triaxial accelerometer, gyroscope, and magnetometer) with Wi-Fi communication in a very small wearable data logger integrated with a web server. It is applicable as on-body sensor network for more intricate activity recognition applications. Inertial sensor data measured and transferred to either a custom designed web server in online mode or stored in a MicroSD memory card in the offline mode. Wearable data logger with 18×30×30 mm (W×L×H) and 20 gram weight designed and produced. The system was tested at 200 Hz during online mode and acceptable precision and noise ascertained. Current device provided movement recording with wireless communication in small size and low cost to be applicable in the health and fitness applications.

Keywords: Data Logger, Inertial sensor, Wi-Fi, Fitness.

Introduction

Sufficient and regular physical activity is very crucial to improve and maintain an individual's health and fitness. Quantification of the activities in training and exercise is an essential component in the fitness coaching [1]. Hence, it is important to monitor daily physical activities. With advancement in the wearable technological tools the envisioned physical activity monitoring system is feasible. In this regard, new technological advances in wearable sensors and wireless communication provided opportunity to design a low cost, smart, small size, and lightweight health monitoring system [2]. Therefore, the focus of this project was on the development of new approaches for the physical activity monitoring and its intensity estimation.

Wearable technologies offered an exciting opportunity for human centered research [3]. Recent advances in miniature inertial sensors and wireless connections fostered a remarkable growth of interest for human motion analysis and tracking in real life and their extensive applications in: health care, sport, elderly and child support, automation in smart homes, research, etc. Author was developed a portable inertial physical activity monitoring data logger using only triaxial accelerometer [1]. The limitation of this type of data loggers is solely related to the measurement range of the accelerometer and lack of angular rotation measurement as well as the interference of the rotational movements on the linear acceleration recorded by the accelerometer. Therefore, in this project a 9-axis Inertial Measurement Unit (IMU) was used which is consist of a triaxial accelerometer, triaxial angular rate sensor (gyroscope) and a triaxial magnetometer (compass) to address the challenge of creating a robust physical activity monitoring systems for broad range of physical activities and intensities.

Material and Methods

Hardware Setup

A selectable measurement range and sampling rate IMU (The MPU-9255) integrated a 3-axis micro-electro-mechanical system (MEMS) accelerometer, a 3-axis MEMS gyroscope, and a 3-axis magneto-inductive magnetometer sensor with a temperature sensor from InvenSense Inc. (San Jose, CA). The IMU sensor fuses information obtained from linear acceleration (g), angular rate (˚/sec), magnetic field (μT) in order to calculate orientation and trajectory. The IMU sensor uses three 16-bit analog-to-digital converters (ADCs) for digitizing the angular rate outputs, three 16-bit ADCs for digitizing the accelerometer outputs, and three

16-bit ADCs for digitizing the magnetometer outputs. For precision tracking of both fast and slow motions, programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000 °/sec, programmable accelerometer full-scale range of ±2g, ±4g, ±8g, and ±16 g, and a magnetometer full-scale range of ±4800 μT controlled by the data logger microcontroller. Other features include programmable digital filters, a precision clock with 1% drift from - 40°C to 85°C, an embedded temperature sensor, and programmable interrupts. The device enables to use either I^2C or SPI ports and operates in 2.4V to 3.6 V. In this project a 32 bit high speed microcontroller was programmed and connected to the MPU-9255 by using the SPI port at 20 MHZ.
The backbone of the system was Wi-Fi communication between each data logger with the server. For this purpose ESP8266 was used and programmed as a client to communicate with a web server. To enable this data logger to apply as a wearable device, a Lithium polymer battery (3.7 v, 440 mAh) was implemented and a battery charger chip was used to supervise the battery voltage and charging. A high-efficiency step-up DC-DC converter was mounted on the board to regulate the battery voltage at 3.3 v. The ESP8266 has no flash memory, therefore a 32 Mbit flash memory implemented in this data logger and a MicroSD card socket was mounted and connected to ESP8266 SPI port for offline data storage in FAT32 format on a 2GB MicroSD card.

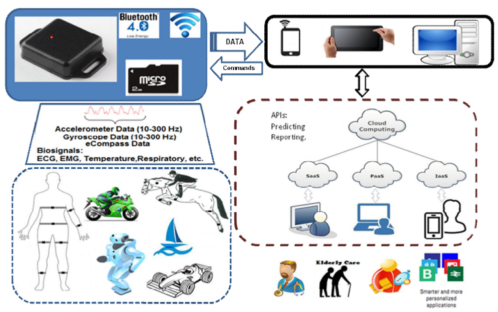

Figure 1. **Data logger and its applications.**

The placement of the data logger is shown in Figure 1, which was fixed to the body so that they did not restrict normal movements of the subjects.

Calibration

The IMU system always affected by drifts and offsets. In order to correct the measurements, a calibration process is very crucial. Bias, noise, and scale-factor errors, including linearity, have a notable impact on systems that use MEMS gyroscopes and accelerometers for angle and displacement measurements. Generally, a common goal of calibration is to narrow the error distribution of a sensor. A linear-compensation approach, which addresses first-order bias and scale-factor errors, will suffice for reaching less-than-1% composite errors.

Measure the average of the MEMS-gyroscope output while holding the device in a constant position is a simple method for estimating bias errors. Measurement of scale-factor errors using a servo-motor device, which employs an optical encoder for precise angular rate control, is a choice method.

The IMU has three accelerometer/gyroscope, and magnetometer sensitive axes perpendicular to the chip. The magnitude of the acceleration was calculated as follows, where XYZ is the acceleration vector magnitude, *X* the component of linear acceleration as measured along the *X*-axis, Y the component of linear acceleration as measured along the *Y*-axis, and *Z* the component of linear acceleration as measured along the *Z*-axis.

$$XYZ = \sqrt{X^2 + Y^2 + Z^2} \qquad (1)$$

Root mean square error (RMSE)
The root mean square error (RMSE) was used to analyze the average difference between the signals. If the value of the RMSE was small, then the signals were close to each other in time domain.
The RMSE value was calculated using acceleration signal for each axis; vertical (X), lateral (Y), anterior/posterior (Z), and resultant (XYZ).

$$X_{RMSE}=\sqrt{\frac{(X_1{}^2+..+X_N{}^2)}{N}}$$

$$Y_{RMSE}=\sqrt{\frac{(Y_1{}^2\ +..+Y_N{}^2)}{N}} \qquad (2)$$

$$Z_{RMSE}=\sqrt{\frac{(Z_1{}^2+..+Z_N{}^2)}{N}}$$

After calibration with the factory setting, a dynamic validation method has been used to adjust the gyroscopes [4].

Software

Firmware of the Data Logger

Firmware is the most important part of the data logger and its main functions are: (1) manage the peripherals in order to guarantee an accurate and stable sampling frequency; (2) supervise the correct operation of communications with the web server using Wi-Fi, and using serial and JTAG port for debugging; (3) control the processes to store the inertial data captured before transfer it to a peripheral; and (4) converting raw data to calibrated information from IMU by the firmware. Therefore, a specific firmware has been developed in C^{++}. Wi-Fi router SSID and password was used for the communication with Internet and connecting to the web server.

Web server

In order to sense, store, analyze, track, recognize human movements and predict activities and orientations, efforts have made to create a web server program. Initial web server shown in the Figure 3 programmed to communicate with the data logger and demonstrate nine channel data (e.g. acceleration, rotation and magnetic sensor). The aim for the software engine is application in simple to intricate multidisciplinary applications such as: fitness, calorie counting/fat burning, professional sport engineering, high scale, efficient human and animal movement analysis, activity recognition, monitoring, gaming, simulation and control, posture/fall detection, as well as disabled, elderly or child care, etc.

Results

Data Logger Hardware

The current data logger has been designed to record three dimensional dynamic movements based on multi sensor locations to monitor physical activity in different intensity levels. Each data logger designed to act as a client located on a limb (e.g. wrist, trunk, leg, etc.) and sending data to the web server or storing data on a MicroSD card during offline mode. A selective measurement range (±2-±18g) triaxial accelerometer, gyroscope (±250-±2000 º/s), triaxial magnetometer in ±4800μT from IMU applied in the data logger to measure human body linear accelerations and rotations as well as orientation of the earth geomagnetic field. A low power ESP8266 built-in Cadence Tensilica L106 32-bit RISC microprocessor from Tensilica Xtensa, running at 80 MHz integrated with IEEE 802.11 b/g/n Wi-Fi, SPI, I^2C, and UART ports, ADC and 16 GPIO pins. Data logger builds by a 32 MBit serial flash memory (W25Q32FV) from Winbond. A high-efficiency, step-up DC-DC converters and a Miniature Single-Cell, Li-Ion, Li-Polymer battery Charge Management Controller implemented in this data logger. Eagle PCB design software from Autodesk Inc. was used to design PCB. Final prototype PCB size was 30×18 mm in double-layer board to accommodate in a small plastic box. The final data logger weight powered by a 370 mAh- 3.7 v Lithium polymer battery is 20 gram.

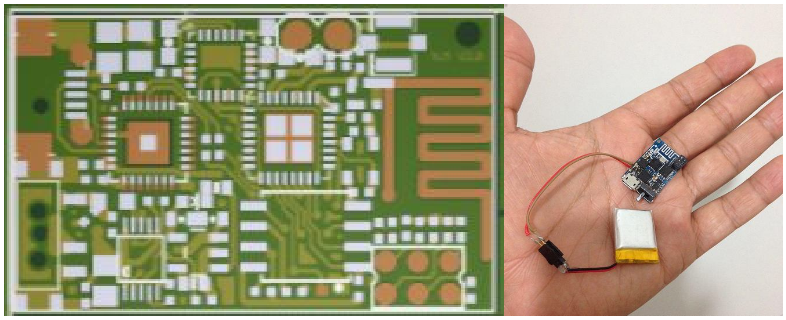

Figure 2. Data Logger.

Data streaming

Data steaming was tested on the web server. Maximum data streaming speed was 1000 Hz and for the smooth data charting data was presented in a line chart at 50 Hz.

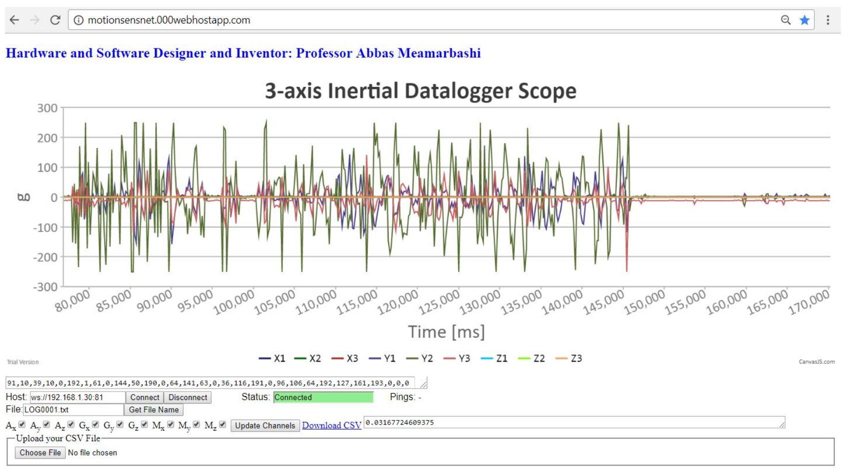

Figure 3. Webserver Data streaming.

In this stage, data can be downloaded as a Comma-Separated Values (CSV) file. Other features of the web server are communicating with any client IP and activate/deactivate each data channel for data streaming. It was programmed to send commands, sensor calibration data to the data logger and receive latest file name to store data on the MicroSD card and calibrated data for the data streaming.

Calibration

Calculate the gyroscope bias-offset-correction factor by averaging the first 3 seconds of data. The initial calibration was performed on the IMU sensor relies on information provided in the data sheet. At any acceleration, according to sensor features, offsets of 100 mg (mili-gravity) can appear in any axis, non-linearity is 3% of the full scale, and change the sensitivity due to temperature is 0.025%/°C. The gyroscope has a non-linearity of less than 1% of the full scale. It has a thermal drift about 10% near the limits of the operating temperature and mechanical intrinsic frequencies. However, the temperature variation in the common applications are between 15-40 °C, therefore thermal drift is considerably low. The magnetometer has a cross-axis sensitivity of ±0.2% FS/Gauss, sensitivity to the temperature of −3,100 ppm/°C and an offset of ±10 ppm/°C. The magnetometer has a linearity error of 0.8% FS, hysteresis error of 0.15% FS and a repeatability error of 0.11% FS.

Data processing and Validation

With a completed prototype, the functionality of the system was first validated. In the first validation experiment, the prototype unit is fixed with three screws on a static cubic surface and recorded the acceleration data from the IMU accelerometer after 3 minutes data streaming on the web server. The gyroscope was calibrated by the factory setting and then validated by fixing to the Biodex Isokinetic Dynamometer lever arm in each axis at 200 Hz and up to 500 °/s during 10 repetitions [4].

Test-retest reliability was very high for the dynamic test in three axes (r values ranging from .89 to .95). Test–retest experiments showed that the offset and the sensitivity of the accelerometer were equal for each measurement direction and remained constant on three measurement days.

Table 1. Results of the IMU Testing at 200 Hz

Sensor	Root Mean Square Error (RMSE)	SD
Accelerometer	8 mg-rms	0.083
Magnetometer	0.1 °/s-rms	0.090

Discussion

In the current study a light and small data logger with broad range 9-axis IMU with a large capacity MicroSD card with a web server developed for short term physical activities. In contrast with existing low range accelerometer data loggers in the market, this product has the advantages of having selective acceleration, angular sensor, and magnetometer range in three axes with small size and very affordable price. It acts as a sensor package node attachable to the limbs to record three dimensional movements and rotations in multi locations. This sensor node applied because wrist, waist, or any single limb may not always be the most suitable placement. This system is able to measure and record the physical activities and distinguish the amplitude and frequency ranges of dynamic human body movements for the health and fitness applications.
Current project presented efforts on the development of a high speed physical activity monitoring system to be applicable in the field of health and fitness. Wi-Fi communication and its web server is the most prominent feature of the system for the global physical activity monitoring.

Conclusion

The design, development and implementation of an advanced wireless, precise, and low cost system for the measurement, recording and real-time transmission of kinematic 9DOF IMU data presented in this article. Initial testing and its web server data communication provided unique opportunity for the health and fitness physical activity monitoring. The IMU of the system provided selectable range measurement for most of the physical activities [5] with acceptable precision. Further attempts required to develop more sophisticated online and cloud-based activity recognition after human trials. Moreover, enormous applications of this system expected in navigation systems [6], robotics, gaming, etc.

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References

1. Meamarbashi, A., *Quantification of exercise performance intensity during walking and running by three-dimensional accelerometry.* Sports Technology, 2013; **6**(1): 2-9.
2. Abidoye, A.P., et al., *Using wearable sensors for remote healthcare monitoring system.* Journal of Sensor Technology, 2011; **1**(2): 22-28.
3. James, D., *Wearable Technology in sport, a convergence of trends.* Journal of Advanced Sport Technology, 2017; **1**(1): 1-4.
4. Meamarbashi, A., *A novel inertial technique to measure very high linear and rotational movements in sports, part I: The hardware.* Journal of Applied Sciences, 2009; **9**(9): 1746-1751.
5. Yu, H., S. Cang, and Y. Wang. *A review of sensor selection, sensor devices and sensor deployment for wearable sensor-based human activity recognition systems.* in *10th International Conference on Software, Knowledge, Information Management & Applications (SKIMA).* 2016. Chengdu, China.
6. Hamidi, H. and A. Valizadeh, *Improvement of Navigation Accuracy using Tightly Coupled Kalman Filter.* International Journal of Engineering-Transactions B: Applications, 2017; **30**(2): 215-223.

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