A Novel Step Counter Supporting For Indoor Positioning Based On Inertial Measurement Unit

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***Abstract*—Step counter provides important information on various kinds of applications such as itinerary, exercise, health, etc. Especially, step counter is a very essential part for indoor positioning system in detecting exactly number of steps and supporting to find out the most suitable indoor position of people we want to track. In this paper, we proposed to develop a step counter system with high accuracy in comparison with the commercial applications. The proposed system is using the inertial measurement unit MPU9250 which consists of 3-DOF gyroscope and 3-DOF accelerometer; these sensors were calibrated carefully to avoid drift error. Furthermore, nRF24L01 wireless data transmitter/receiver is integrated for added convenience for users. After preprocessing, the recorded data are extracted from this IMU will be combined with step detection algorithm to find out the number of steps. The proposed algorithm was tested carefully with promising results of 96.5% in accuracy.**

Keywords*—Step counter, pedometer, indoor positioning, firefighter, firefighting and rescue, MPU9250.

I. INTRODUCTION

Walking and running are daily activities to monitor health, or go for work. There are a lot of publications about steps detection and steps counting in both researches and application software for health management and indoor positioning systems. As we know, the Global Positioning System (GPS) is not working reliable for indoor localization. Hence, there are several ways proposed for indoor positioning. Firstly, the systems are based on pre-installed sensor networks such as ultrasound beacon, wireless networks, imaging sensors, UWB, Doppler radar, etc [1]. These methods have highly positional accuracy, but it needs to prepare the environments and it is only suitable for several pre-prepared areas because these methods require having access points to transmit/receive signals in order to estimate the searching positions. These methods cannot apply to emergency situations like firefighting and rescue; soldier and police attack crimes, etc. Other types of indoor positioning systems do not require to prepare environments have been proposed, it uses portable sensors like inertial measurement unit (IMU), but the current limitations of these trends are low accuracy because of IMU errors.

In order to supporting Firefighters during firefighting and rescue process, the pre-installed sensor is not suitable because the access points may be destroyed by heat and flame of fire burning. Hence, the system may be broken before working.

Based on the above limitations, this paper proposed to develop of an efficient and high accuracy step counter system that is using low cost IMU and it does not depend on the environment in order to supporting for estimation the position of firefighters during working process.

II. METHODS

II.1. Hardware components

The prototype uses a computer with Microsoft® Windows® 7, 32 bits; Intel Core i5 - 3337U CPU @ 1.80 GHz; 4Gb of RAM. we also use IPhone 6, that installed Health App, Pedometer and Lenovo P780 was installed Pedometer – Step counter for comparison.

The hardware of our proposed device includes a micro controller unit (MCU), an IMU that consists of a 3-axis accelerometer for measure accelerations, 3-axis gyroscope for measure angle and 3-axis magnetometer; a nRF24L01 wireless data transmitter/receiver for PC, a SD card for saving data, a battery connection for main circuit. In the future, we will integrate Barometer sensor to determine the height of the wearing people in order to support for firefighters who are firefighting and rescue inside of a building.

II.2. System Architecture

The proposed system includes an IMU, SD card for storing data, an nRF24L01 to transmit/receive data between the device and computer, a micro unit controller (MCU). Furthermore, the system is also integrated a led to display state of the device and a button to turn on/ off the device.

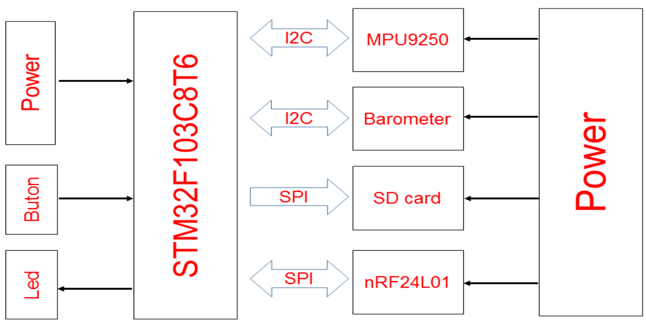


Fig 1. The architecture of the propose system

The accelerometer and gyroscope in IMU are used to measure acceleration and rotation of three axes Ax, Ay and Az.

II.3. Data collecting

The accelerometer is very essential in our proposed system in measuring acceleration in three axes Ax, Ay and Az. The reliability of data depends much on the calibration process. Hence, before measuring data, accelerometer is calibrated incredibly carefully. In this paper, we use accelerometer for measuring acceleration with sampling rate of 50 Hz and using I^2C (Inter-integrated Circuit) interface in the connection between IMU and MCU.

The accelerometer is mounted in the waist so that y-axis must parallel with Earth's gravity as in Fig. 2. The data receiving from the accelerometer is in the form of three-valued vectors of individual accelerations in the Ax, Ay and Az axes. The expected reading of the accelerometer would be approximately in [0, 1, 0] g (with g=9.81 m/s^2). Before applying step detection algorithm in detecting and count steps, the data are applied a preprocessing step to formulate the mean, orientation, and standard deviation.

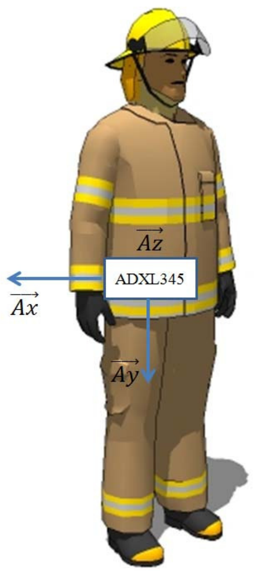
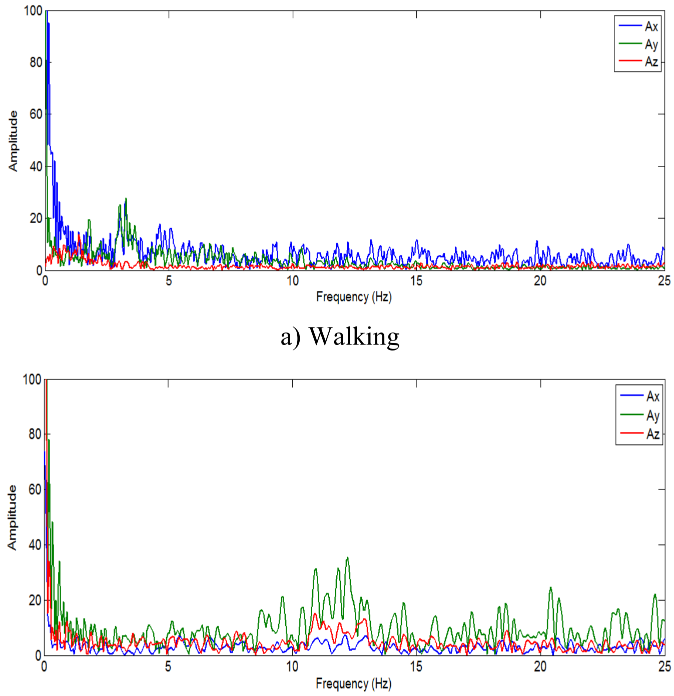


Fig 2. Position of the 3-DOF accelerometer in waist body

II.4. Filters

The frequencies of signal depend directly on moving speed of the legs, when the moving speed is increased; it means the rise of frequency [2]. The actions of firefighters during firefighting and rescue are very complicated. It includes walking, running, crawling and other activities. As can be seen from Fig. 3, when the velocity of user is increased, the frequency of step is also increased. The range of frequency of walking state is less than 5Hz, while the range of frequency of running state is greater than 8Hz. It is essential information for knowing state of the user in order to choose the suitable threshold for step detection.



a) Walking

c) Running

Fig 3. The relationship between moving speed (walking and running) and frequencies

In this paper, we do not use average filter for walking and running data because it is the cause of falsify signal in several cases. Hence, step counter may lose step detection; we only use a Kalman filter in MCU to reduce error of the device.

II. 5. Step detection algorithm

Based on information in Fig. 3 can be seen that, after the calibration IMU sensor and using Kalman filter in order to get the best recorded data, we will turn on the device to start recording data. The 3-DOF accelerometer will acquire accelerations in Ax, Ay and Az axes. After recording, we used Fast Fourier Transform (FFT) to transform data from time domain to frequency domain, and then we checked amplitude threshold and frequencies to estimate the state of firefighters (walking or running).

If the proposed algorithm detects firefighter is in running mode, the program in running mode will be executed. On running mode, the minipeakdistance is equal or greater than 4 while walking is equal or greater than 11 because the frequency of running is higher than walking. Then, we chose Threshold =0.981, this value is equal to gravity acceleration. If the difference between the peaks and Threshold is greater than 0.015 and 0.1 in running and walking states respectively, it will be confirmed a step. The reason in choosing 0.015 and 0.1 based on the experiment testing result to avoid the effects of vibration in gravity acceleration in steady state. (See Fig. 4 for more detail about step detection algorithm).

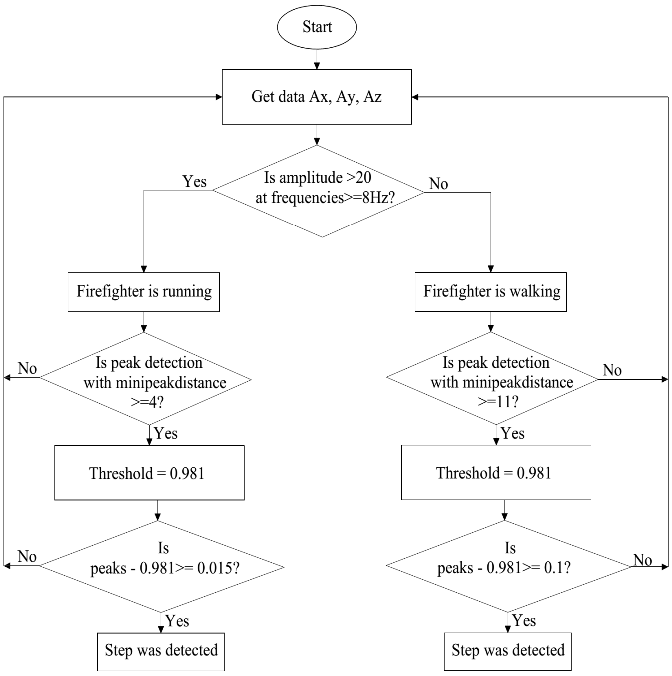


Fig 4. The step detection algorithm

III. THE EXPERIMENTAL RESULTS

3.1. The experimental setup

For the experimental testing, we tested our proposed algorithm on 6 sets and 6 male students, ages: 18-20, height: 1.72 – 1.78 m, weight: 65-78 kg who were random selected from University of Fire Fighting and Prevention (UFFP), Hanoi, Vietnam. The main reasons for choosing students at UFFP: they are Firefighters and they have knowledge, skills and they can take reliable data for test and evaluation process. The Fig. 5 is our proposed system and Fig. 6 is the volunteer, he is wearing our proposed system on the waist.

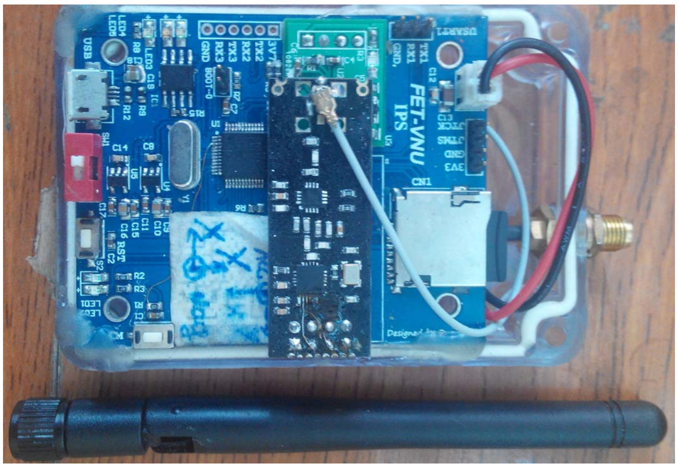


Fig 5. Our proposed system

Fig 6. A firefighter is wearing our proposed system

The experimental testing was executed both on our proposed system and Health, Pedometer applications installed on IPhone 6, Pedometer – Step counter was downloaded and installed on Lenovo P780 for comparison the performance of the proposed system with others commercial applications.

III.2. Testing process

A) Walking state

The volunteers used my proposed system for testing 12 forward steps with slow walking. Fig. 7 shows that our device can count exactly the number of steps. The simulation result was executed on Matlab software and displayed as Fig. 7 below:

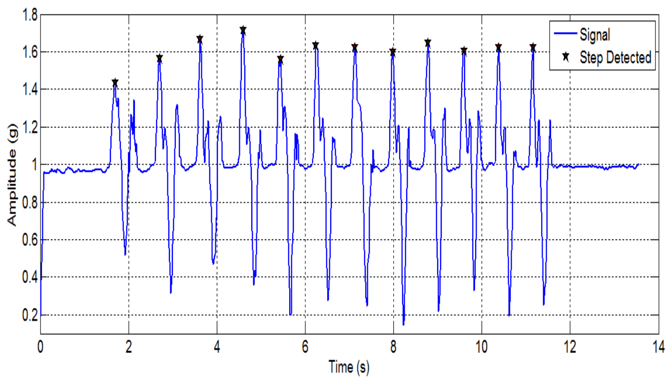


Fig 7. The result after executed 12 steps of slow walking

We also increased walking speed from slow to fast walking; it includes 7 steps in length and 5 steps in width. The model of the area for testing is a rectangular in Fig. 8.The Fig. 9 is the results of the testing process. It can be seen that, our proposed algorithm detected exactly the number of steps in total and the number of steps in each length and width of area testing model as well as.

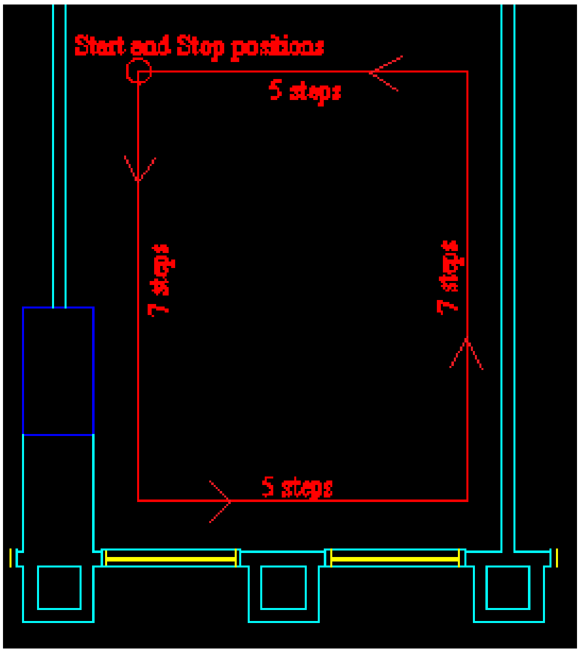


Fig 8. The model of the area for testing our propose algorithm (it is a rectangular, that includes 7 steps in length and 5 steps in width)

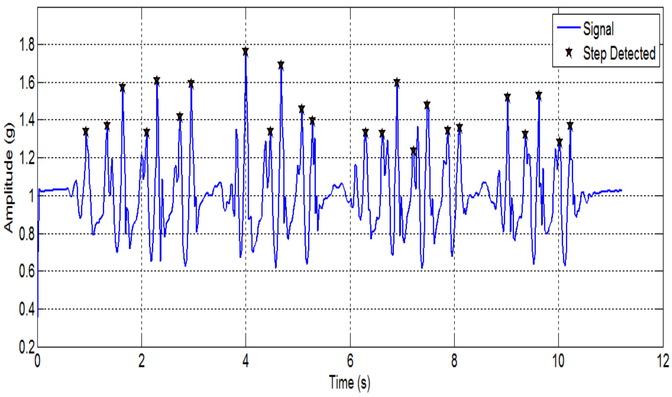


Fig 9. Results after executed 24 steps of fast walking

B) Running state

In running state, the movement speed is increased, we executed 53 steps of running, and then the proposed algorithm was applied on this data for step detection. In running state, our algorithm also detects the number of steps with high accuracy of 52 detected steps as in Fig.10.

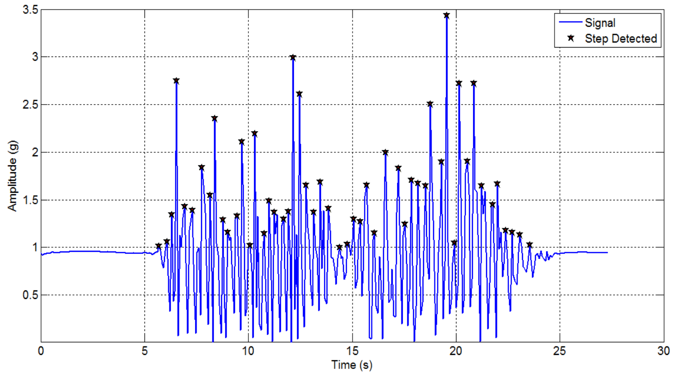


Fig 10. Step counting results after executed 53 steps in running state

III.3. Comparison with other commercial Applications

To evaluate the performance of the proposed algorithm, we compared our algorithm with some top applications like Health application of Apple installed on IPhone 6, pedometer – step counter on Play store installed on Lenovo P780 and Pedometer on Apple store installed on IPhone 6 in walking and running cases. We used four following factors: True positive (TP) factor to determine if a step executed and the device can detect it. False positive (FP) factor to determine if no step execution, but the system declared as a step; True negative (TN) factor to determine if a like – step event is declared correctly as no step executed. False negative (FN) factor to determine if a step executed, but the device cannot detect it.

After that, the sensitivity and the accuracy of the device can be evaluated by:

$$Sen = \frac{TP}{TP + FN} \quad (1)$$

$$Acc = \frac{TP + TN}{TP + TN + FP + FN} \quad (2)$$

In walking situation, we performed 82 steps in 10 times. On table 1, we only show the testing results of 5 times. Based on information from this table, we can see that Health App on IPhone 6 has good average results of 82.2/82 but the measurement results in each testing times are unstable without real-time response. The unstable phenomenal is the same with Pedometer – Step counter App installed on Lenovo P780.

In our proposed system, it was detected 81.4/82 steps in average, but the testing results at different times are quite stable (from 79 steps to 82 steps over 82 steps executed).

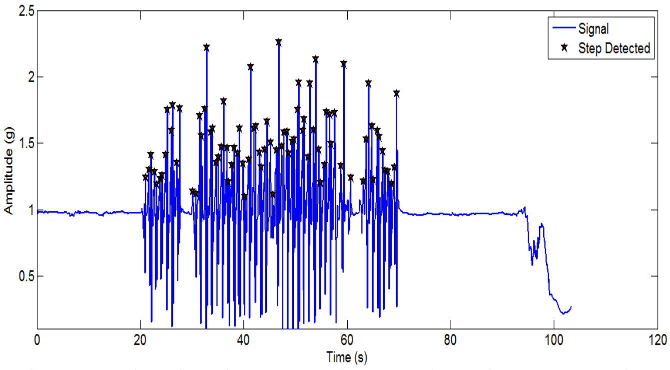


Fig 11. Step detection of our proposed system when volunteer executed 82 steps of walking

TABLE 1: COMPARISONS BETWEEN OUR PROPOSED SYSTEM WITH DIFFERENT COMMERCIAL APPLICATIONS ON THE 82 STEPS OF WALKING

Times	1	2	3	4	5	Average
Truth steps	82	82	82	82	82	82
Our proposed system	82	82	79	82	82	81.4
Health App on IPhone 6	79	83	79	85	85	82.2
Pedometer – Step counter App installed on Lenovo P780	82	76	82	84	77	80.2
Pedometer installed on IPhone 6	83	85	85	81	83	83.4

In running situation, the volunteers performed 107 steps in 10 times. The proposed algorithm detected the number of steps in running mode with very good accuracy; this performance is the same on Health app of IPhone (little difference). The Pedometer – Step counter App installed on Lenovo P780 and Pedometer installed on IPhone 6 are less stable than our proposed system and Health app.

TABLE 2: COMPARISONS BETWEEN OUR PROPOSED SYSTEM WITH DIFFERENT COMMERCIAL APPLICATIONS ON 107 STEPS OF RUNNING

Times	1	2	3	4	5	Average
Truth steps	107	107	107	107	107	107
Our proposed system	104	106	105	103	106	104.8
Health App on IPhone 6	109	107	111	108	109	108.8
Pedometer – Step counter App installed on Lenovo P780	99	104	105	101	106	103
Pedometer installed on IPhone 6	108	113	109	112	108	110

Based on the experiment testing results in Table 1, 2 and the formula (1) and (2), our proposed system detects exactly the number of steps with high sensitivity and accuracy of 97.4% and 96.5% respectively.

IV. CONCLUSION

In this paper, we have successfully developed a step counter with high accuracy. The MPU provides a good 3-DoF accelerometer for pedometer applications and taking advantage of its small, thin, low power supply. Furthermore, our proposed system can transfer data from our device to computer through the wireless network by using nRF24L01 wireless transmitter/receiver. In the future, we will base on recorded data to estimate length steps and orientation angle in combination with step counter to predict the positions of firefighter's on-duty.

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REFERENCES

[1] Jouni Rantakokko, Joakim Rydell, Peter Strömbäck, Peter Händel, Jonas Callmer, David Törnqvist, Fredrik Gustafsson, Magnus Jobs, Mathias Grudén, *"Accurate and reliable soldier and first responder indoor positioning: multisensor systems and cooperative localization"*, IEEE Wireless Communications, Vol18, Issue 2, April 2011, pp. 10 – 18.

[2] Qingchi Zeng, Biao Zhou, Changqiang Jing, Nammoon Kim and Youngok Kim, *"A Novel Step Counting Algorithm Based on Acceleration and Gravity Sensors of a Smart-Phone"*, International Journal of Smart Home, Vol. 9, No. 4 (2015), pp. 211-224.

[3] Z. Zhou, T. Chen, L. Xu, *"An Improved Dead Reckoning Algorithm for Indoor Positioning Based on Inertial Sensors"*, International Conference of Electrical, Automation and Mechanical Engineering (EAME 2015), pp. 369 – 371.

[4] Sampath Jayalath, Nimsiri Abhayasinghe, Iain Murray, *"A Gyroscope Based Accurate Pedometer Algorithm"*, 2013 International Conference on Indoor Positioning and Indoor Navigation, 28th -31stOctober 2013.

[5] RuiTerra, Lino Figueiredo, Ramiro Barbosa, Ricardo Anacleto, *"Traveled Distance Estimation Algorithm for Indoor Localization"*, Conferenceon Electronics, Telecommunications and Computers – CETC 2013, Procedia Technology 17 (2014) pp. 248 – 255.

[6] Ľubica Ilkovičová, Pavol Kajánek, Alojz Kopáčik, *"Pedestrian Indoor Positioning and Tracking using Smartphone Sensors, Step Detection and Map Matching Algorithm"*, International Symposium on Engineering Geodesy, 20–22 May 2016, Varaždin, Croatia, pp. 439 – 450.

[7] Pham Van Thanh, Tien-Anh Nguyen, Nghia Tran Duc, Nguyen Duc Anh, Tran Duc-Tan, *"Development of a Real Time Supported Program for Motorbike Drivers Using Smartphone Built-in Sensors"*, International Journal of Engineering and Technology (IJET), Apr-May 2017.

[8] Christian Koch, Matthias Neges, Markus König, Michael Abramovici, *"Online calibration of an IMU based step counter for AR based indoor navigation using visual natural markers"*, 2014 EG-ICE International Workshop on Intelligent Computing in Engineering ,January 2014.

[9] Soares-Miranda, L., Siscovick, D. S., Psaty, B. M., Longstreth, W. T., & Mozaffarian, D. (2015). Physical activity and risk of coronary heart disease and stroke in older adults: the Cardiovascular Health Study. *Circulation*, CIRCULATIONAHA-115.

[10] N. Chang, R. Rashidzadeh, M. Ahmadi. Robust indoor positioning using differential Wi-Fi access points. IEEE Transactions on Consumer Electronics. 56 (2010).

[11] H. Jeon, U. Jo, M. Jo, N. Kim, Y. Kim. An Adaptive AP Selection Scheme Based on RSS for Enhancing Positioning Accuracy. Wireless Personal Communications. 69 (2013).

[12] K. Yun, Y. Jo, N. Kim, U. Jo, S. Yang, Y. Kim. A Practical Indoor Position Estimation by Using a Laptop Computer Equipped With Sensors. International Journal of Smart Home. 7, 4 (2013).

[13] F. Scholkmann, J. Boss, M. Wolf. An Efficient Algorithm for Automatic Peak Detection in Noisy Periodic and Quasi-Periodic Signals. Algorithms. 5 (2012).

[14] Harsh Vathsangam ,My IMU estimation experience, 2010, https://sites.google.com/site/myimuestimationexperience/filters/complementary-filter

[15] Harsh Vathsangam, Complementary filter, 2010 .

[16] Arduino Uno R3, http://tae.vn/arduino-uno-r3

[17] Obvious, *Angle Measurement Using Gyro, Accelerometer, and Arduino*, Access to 9 am, March 21, 2017, http://www.instructables.com.

[18] Zhao, N. (2010). Full-featured pedometer design realized with 3-axis digital accelerometer. *Analog Dialogue*, *44*(06), 1-5.

[19] Datasheet Bluetooth HC06, http://hshop.vn/products/mach-thu-phat-bluetooth-hc-06-do-ra-chon-slave

[20] Xuan, Y., Zhao, Z., Fang, Z., Sun, F., Xu, Z., Du, L., & Wu, S. (2013). A gait cycle recognition based on the wireless inertial sensor network. *IERI Procedia*, *4*, 44-52.

[21] Mohammad Rawashdeh, *Arduino AND Bluetooth HC-05 connecting Easily*, Access to 9 am, March 22, 2017, http://www.instructables.com/id/Arduino-AND-Bluetooth-HC-05-Connecting-easily/

[22] N. Noury, P. Rumeau, A. Bourke, G. Laighin, J. Lundy, A proposal for the classification and evaluation of fall detectors, IRBM 29, pp. 340–349, (2008).