Gait Identification Using Kalman Fusion of Accelerometer and Gyroscope

P. Sutyasadi[1]

Abstract— These days health is becoming important investment for every one. Along with the fast development of technology, many common diseases are seemed appearing to accompany it. This research is part of development of medical instrumentation that may help people from common daily health problems. An instrument for gait identification is constructed by using a two axis accelerometer and a one axis gyroscope. Both gyroscope and accelerometer can be used in determining tilt angle as in this case is the each particular gait position. However, they have their own drawbacks. Gyroscope is fast in determining the tilt angle, but it has drift in its output. In other hand, accelerometer has drift free output but it performs badly in transient state due to noises. By using Kalman filter both of the output signals will be fused to get the best estimate of the gait position. These sensors will be placed on the leg and thigh of the patient. While the patient walks or runs on a thread mill, gait information is generated and logged. Furthermore, graphs of the gait identification result will be served to ease a medical specialist or a physician to analyst the data. Experiment of the research shows sample of typical gait for normal people. Positions of the gait along the time examination are identified, and these can be used to determine any abnormalities that may found on further patient inspection.

Keywords— accelerometer, gait, gyroscope, kalman

1. INTRODUCTION

Gait analysis system is used to get real time display of some one's gait like joint angles, footfall information and temporal measurement [1]. A gait cycle is defined as a period starting with an initial sole to ground contact and lasting up to the moment when the contact is repeated with the same sole [2].

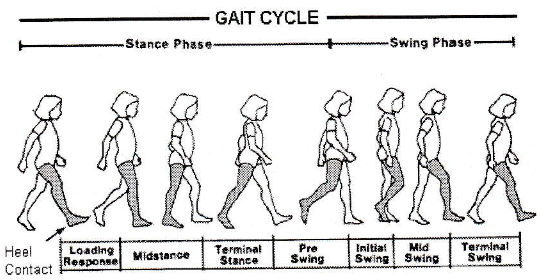

Fig.1. Diagram of the gait phases characteristic fornormal walking [2]

Several test for gait analysis often done by using video computerized motion analysis, a walking track force platform system, and multi channel dynamic electromyography [3]. Kinematic analysis revealed motion abnormalities of dynamic kinematic joint angle. As an example, an ambulation pattern confirmed that the patient was avoiding loading to the left low back region. The left side was a bit painful so the patient leaning away from that side.

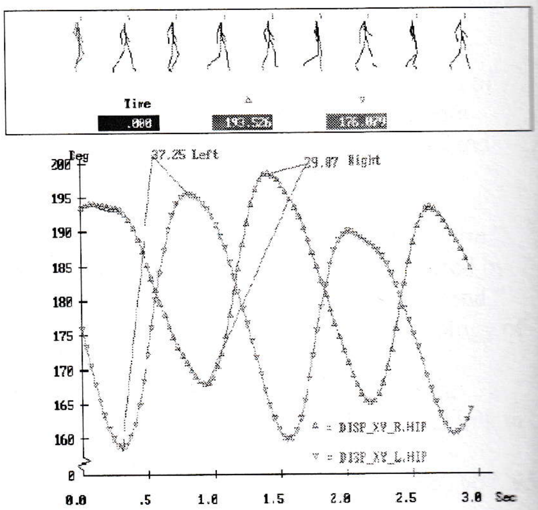

Fig.2. Dynamic Range of Motion Right Hip vs. Left Hip [3]

Clinical gait analysis can be performed in specialized laboratory with the three methods mentioned above. This method gives accurate result. Previously, the diagnostic depends on the physician knowledge and experience only that sometimes gives subjective, no reliable, and valueless result [4]. By using an accelerometer, a practical and low cost method of gait analysis is possible to conduct. Beside that, accelerometer also has been used for monitoring a range of different movements such as sit to stand transfer, postural sway, and falls [5].

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2. METHODOLOGY

2.1 Sensor system

The gait analysis is done by measuring the angle of the patient's leg and thigh while the patient walks in a treadmill. An accelerometer and a gyroscope will be used to measure the angle. An accelerometer is a meter that measures acceleration. Both of dynamic or static acceleration will be measured by the accelerometer. Earth gravity is a static acceleration. Therefore, it will be detected also by the accelerometer. Accelerometer able to detect the gravity, so it can detect the orientation of the patient's joint and angles. Gyroscope is a device that able to measure rate angle. Output of the gyro needs to be integrated to get angle value. Nonetheless, the output being integrated is contained with noise, so the final result is drifted due to the noise integration along the time process. Even an accelerometer able to directly measure the angle, its output is so noisy in transient time. Both of gyro and accelerometer output need to be fused by using Kalman Filter algorithm to get the best estimate angle[6]. Gyro reading needs to be corrected by the accelerometer, and the drawback of accelerometer in transient time needs to be compensated by the gyroscope[7].

Accelerometer and gyroscope being used in this experiment is Combo IMU sensor ADXL203 and ADXRS610 from Sparkfun. The detail picture of the combo IMU sensor accelerometer and gyroscope is shown in Figure 3.

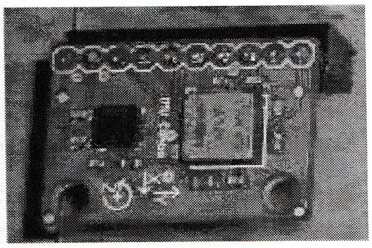


Fig.3. Accelerometer and gyroscope module

Over all of the system block diagram is shown on Figure 4. Accelerometer and gyroscope send their data and then fused by using Kalman Filter algorithm that is written in a microcontroller. The microcontroller will output the estimated angle value. This angle value then will be sent to the PC where the data will be processed and reported in form of graph. By analyzing this graph a physician can do the investigation.

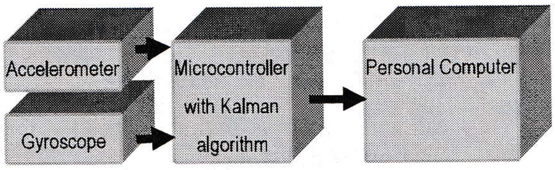


Fig.4. Block Diagram of gait data logger

2.2. Electronic circuit

The microcontroller being used is Arduino Board with ATMEGA328 chip.

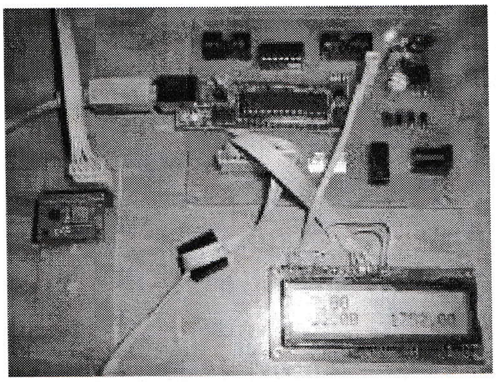


Fig.5. Electronic part for the overall gait data logger

Output signal from the accelerometer and gyroscope are connected to the Arduino analog input. The Kalman algorithm runs in this microcontroller in 50ms cycle time, it means the estimated angle is updated every 50ms. To investigate the gait, tilt sensor will be placed on the patient's leg. By record the position angle produced by the sensors while the patient walk, the gait information will be acquired. Detailed placement of the sensors on the patient's body is shown in Figure 6.

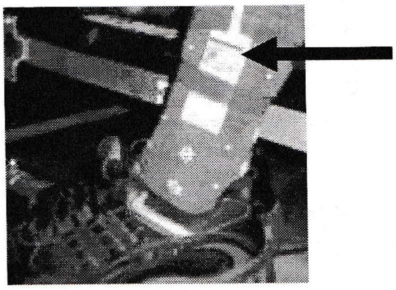


Fig. 6. Sensor Placement

2.3 Kalman filter

The goal of Kalman filter is to estimates the correct states of the system in the presence of disturbances and measurement noise. This is done by minimizing the mean squared error between the actual and estimated data.

The kalman algorithm works in two steps:

1. The first step the algorithm predicts the state estimates forward in time. The estimate from this first step is called the 'a priori' state estimate.
2. The next step is to get feedback from the sensors and then update the 'a priori' state estimates with the feedback from the sensors. The updated state estimate is called the 'a posteriori' state estimate.

The kalman filter goes through this cycle of predicting the state estimate and updating the state estimate with the measurement obtained from the sensors. The ongoing cycle of the algorithm is shown below:

Fig.7. The ongoing cycle of the Kalman filter algorithm

Steps on fusion the gyro and accelerometer using Kalman filter:

1. Define the update rate dt. This is how often the state is updated with gyro rate measurements.
2. Define the measurement covariance noise R
3. Define the process covariance noise Q
4. Define the covariance matrix update
   a. P_{k+1}^{-} += Pdot * dt
   b. Pdot = $A*P_k + P_k*A' + Q$
5. Define the estimated state update
   a. $angle^{-}$ += g * dt
   b. g = gyro_measurement – gyro_bias
6. Define the Kalman Gain.
   $K = P_{k+1}^{-} * C^T * (C * P_{k+1}^{-} * C^T + R)^{-1}$
7. Update the covariance matrix.
   $P_{k+1} = (I - K * C) * P_{k+1}^{-}$
8. Update the state estimate.
   X += K * (angle_accel._meas – angle)

Result of the Kalman Fussion is depend on some predefined parameters such as the measurement and process covariance matrices. To get the best estimation of the angle or gait, some experiment with those matrices are conducted. The noisy signal is came from the accelerometer only and the smooth one is output from Kalman Filter. In this case, signal from the accelerometer will be used as the reference and Kalman Filter output signal will be the signal being diagnosed. Q is the process noise covariance matrix. If the Q value of the accelerometer is smaller than the Q on gyroscopes, that indicates the system rely on the accelerometer more than on the gyroscope. Below are some experiment result by varying the Qa (accelerometer) and Qg (gyroscope).

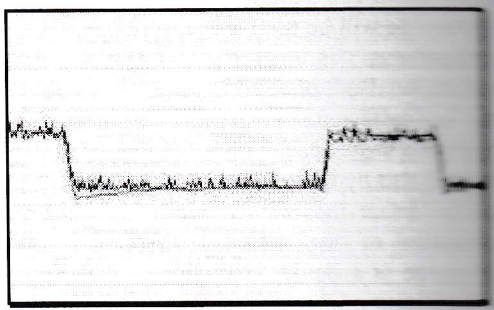


Fig.8. With Qa = 0.001and Qg = 0.00003

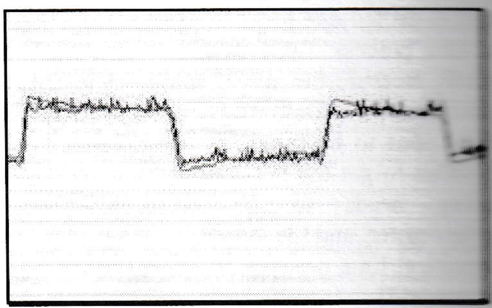


Fig.9. With Qa = 0.00001 dan Qg = 0.001

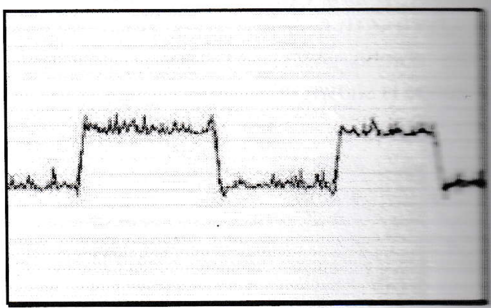


Fig.10. With Qa = 0.3 and Qg = 0.1

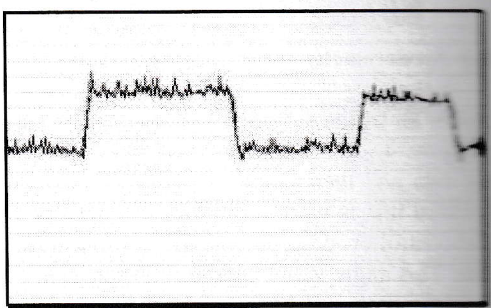


Fig.11. With Qa = 0.1 and Qg = 0.3

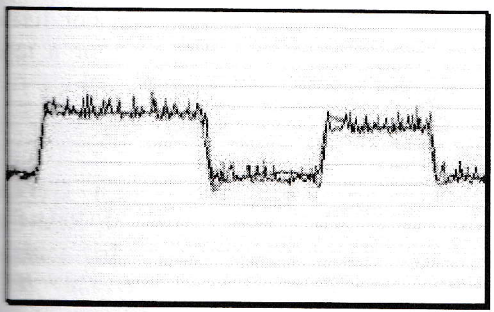


Fig.12. With Qa = 0.001 and Qg = 0.003

From Figure 8 and Figure 9 can be seen that it is better to have Qa smaller than the Qg because it has smaller overshoot and smaller settling time. If the initial value is to big, the output is still a bit noisy, like shown on Figure 10 and Figure 11. The best result like shown on Figure 12 is taken with Qa = 0.001 and Qg = 0.003. R is the measurement noise covariance matrix. If R big, that means the measurement process contain a lot of noise.

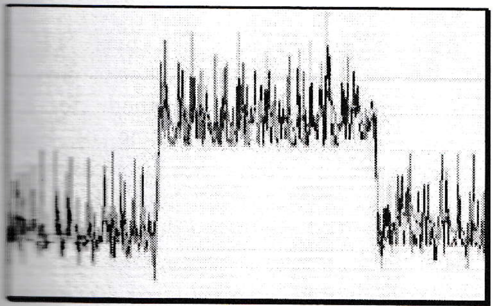


Fig.13. With R = 0.003

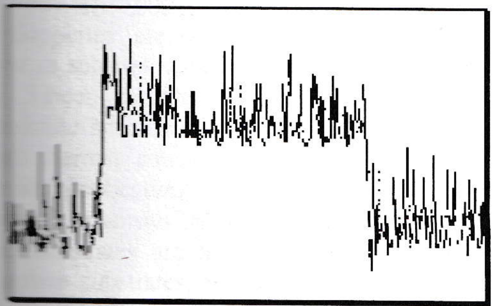


Fig.14. With R = 0.3

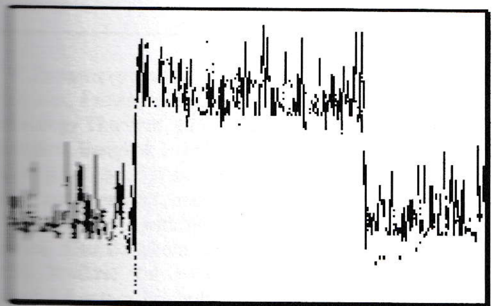


Fig.15. With R = 30

Figure 14 shows that R = 0.3 gives the best output response. Small R indicates that the measurement noise is assumed to be small. The output signal will closely follow the accelerometer measurement with a lot of noise. If the R matrix is big, it tells the system that the measurement process contain a lot of noise which are need to be eliminate. It will cause the output signal become smooth but low in response speed like shown in Figure 15.

3. RESULT AND DISCUSSION

The test is separated in two experiments. The first experiment is to test the gait recording instrument on a normal patient walk slowly, walk fast, and run. The second experiment is to test a patient with an injured leg or knee walking on a treadmill.

Fig.16. Graph of gait for patient walk slowly.

Fig.17. Graph of gait for patient walk fast.

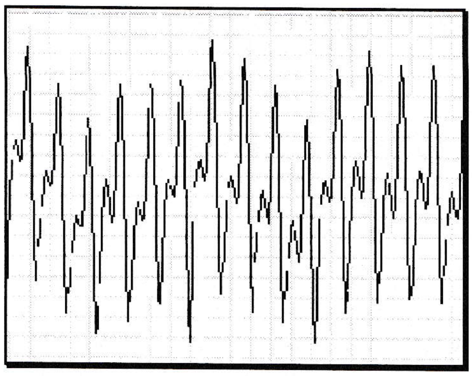
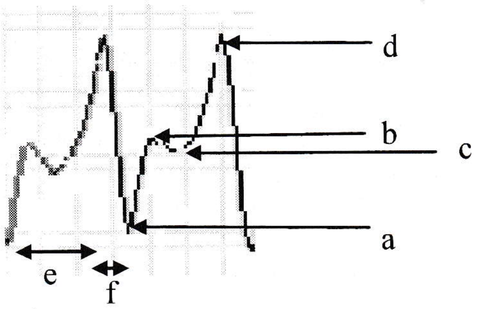


Fig.18. Graph of gait for patient run



Where:

a : Terminal stance
b : Pre swing
c : Initial swing
d : Terminal swing
e : Swing Phase
f : Stance Phase

Fig.19. Graph of gait phases for normal walking

Figure 16, Figure 17 and Figure 18 show that there are similar pattern during the walking or running process. Difference that may appear just in the frequency of the output waves. Frequency on running is higher than on walk fast, there fore walk fast has higher frequency than on walk slow. However, all of the graph have a complete pattern of a gait cycle along the stance and swing phases. Figure 19 shows a complete pattern of gait phase.

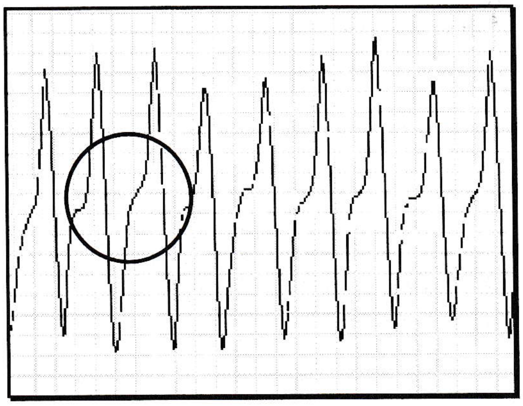


Fig.20. Patient walks slowly with knee injury.

Figure 20 from the second experiment shows that the pattern has deformed wave compared with the normal gait graph. It happens on the pre swing and initial swing phase. This type of pattern will appear when the patient does not bend the knee normally on the swing phase. This may happen when the patient has some kind of knee injury.

4. CONCLUSIONS

Gait identification system is finally constructed by using an inertial measurement unit (IMU) sensor which is consist of accelerometer and gyroscope. In purpose to achieve the best signal characteristic, both of the sensors were fused using Kalman Filter. The tool can be used to log gait data of patient that walk in a treadmill and convert it into an easy to read graph. Furthermore, a physician can examine it. This system is only able to detect two axis movements. For further work, need to improve the system for a multi channel three axis gait identification tool.

5. REFERENCES

[1] Rogers, B., Dunn F., Walden G., and Eidelberg E. 1991. A Low Cost, Real time Gait Analysis System. In *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Vol. 13, No. 5, 1991

[2] Mijailovic N., Gavrilovic M., and Rafajlovic S. 2009. Gait Phases Recognition from Accelerrations and Ground Reaction Forces: Application of Neural Networks. In *Teltor Journal*, Vol. 1, No. 1.

[3] Back Pathology - Positive History http://www.arielnet.com/Main/adw-60.html. Last accessed: 20 July 2010

[4] George I.Z., John N.A. Gait Analysis and Automatic Gait Event Identification Using Accelerometers.

[5] Mathie M.J., Coster A.C.F., Lovell N.H. and Celler B.G. 2004. Accelerometry: providing an Integrated, Practical methode for Long Term, Ambulatory monitoring of Human Movement. In *Physiological Measurement*, Institute of Physical Publishing, UK.

[6] D.Simon. 2001. Kalman Filtering, *Embedded System Programming vol 14, no 6. pp. 72-79.*

[7] E. W. Bollinger. *Low Cost Gyro Accelerometer Combo Sensor.* Retrieved September 2006, from Dallas Personal Robotic Group Web site: http://www.dprg.org/projects/2003-01a/

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