Development of Virtual Stopwatch for Specific Sprint Monitoring Based on Wiimote's Accelerometer

Jediyanu Wigas Tu'u, Amar Vijai Nasrulloh, and Arfan Eko Fahrudin

***Abstract*—The commons method used to measure speed performance is by using a stopwatch. This method was so popular because its simplicity in running monitoring. Although stopwatch method is very effective, this conventional method can only measure speed in a limited measurement point. A research was conducted to develop tools which can measure running's speed sampling more than conventional stopwatch measurement did. By using accelerometer vibration characteristic combined with avirtual stopwatch, this tool can measure running's speed sampling up to step speed. From the testing result, this performance meter has accuracy 94.87% for average speed measurement and 88.06% for step speed measurement.**

***Index Terms*—accelerometer, wiimote, sprint, stopwatch.**

I. INTRODUCTION

Measurement of locomotors velocity is important in many sport analysis and human movement studies in general.Technology choices for linear velocity sensor include cable extension, magnetic induction, microwaves, optical or laser, piezoelectric, radar, or radio frequency, strain gauge, and ultrasonic sensors [1]. Even though these advance technology has already on the market, it is too expensive to be applied in many development countries. So, stopwatch is still popular tools to measure speed performance.

When focus on track sport, it is important to analyze the behavior of the runner in the different segments of the track to recognize the difficulties the runner has according to his abilities and physical contexture. This way, when the areas of decreasing or low speed are determined, the can be emphasized on a newly designed training program based on the results of the test [1].

The method used to measure speed from stopwatch is by using the equation of motion [2]. However, manual stopwatch measurement gives lack of accuracy. A timing gate can be used to improve measurement accuracy, but this method can only measure average speed, not speed performance. Using more timing gate to acquire speed performanceis not an efficient way.

There are several approach to measure speed performance, a Global Positioning System (GPS) or an accelerometer [3]. For long track measurement, GPS is a proper tool because it's main ability as position detector, but for short track measurement, GPS limited by its 3 meter accuracy [4]. So theoretically accelerometer is a proper tool for short track measurement by integrating accelerometer data to calculate speed.However, this is felt to be an unreliable method under normal circumstances due to errors accruing from the integration process [5]. Due to this error problem, a research to use another approach has been conducted. Previous studies by Neville [6] have shown that an accelerometer can detect stride which is characterized as a high acceleration value. With a virtual stopwatch combined with accelerometer stride detection, it is possible to measure speed by using the equation of motion without integrating it.

This paper describes the development of sprint performance measurement by the use of a virtual stopwatch from the wiimote's accelerometer.The software is developed by using open source technologies: Linux, Python and GTK (GIMP Toolkits).

II. MATERIALS AND METHODS

A. Motion

In two-dimensional (or three-dimensional) kinematics, everything is the same as in one-dimensional kinematics except that we must now use full vector notation rather than positive and negative signs to indicate the direction of motion. The average velocity of a particle during the time interval Δt as the displacement of the particle divided by the time interval [2]:

$$\mathbf{v} \equiv \lim_{\Delta t \to 0} \frac{\Delta \mathbf{r}}{\Delta t} \qquad (1)$$

Multiplying or dividing a vector quantity by a positive scalar quantity such as Δt changes only the magnitude of the vector, not its direction. Because displacement is a vector quantity and the time interval is a positive scalar quantity, we conclude that the average velocity is a vector quantity directed along Δr. Note that the average velocity between points is independent of the path taken. This is because average velocity isproportional to displacement, which depends only on the initial and final position vectors and not on thepath taken. As with one-dimensional motion, we conclude that if a particle starts its motion at some point and returns to this point via any path, its average velocity is zero for this trip because its displacement is zero [2]. The instantaneous

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Jediyanu Wigas Tu'u is with the Physics Instrumentation Laboratory, Physics Study Program, University of Lambung Mangkurat, Banjarbaru 70714 Indonesia (e-mail: wigas_alternation@yahoo.com).

Amar V. Nasrulloh is with the Physics Instrumentation Laboratory, Physics Study Program, University of Lambung Mangkurat, Banjarbaru 70714 Indonesia (e-mail: amarvijai@gmail.com).

Arfan E. Fahrudin is with the Physics Instrumentation Laboratory, Physics Study Program, University of Lambung Mangkurat, Banjarbaru 70714 Indonesia (e-mail: arfan.eko@gmail.com).

velocity v is defined as the limit of the average velocity Δr/Δt as Δt approaches zero [2]:

$$\mathbf{v} \equiv \lim_{\Delta t \to 0} \frac{\Delta \mathbf{r}}{\Delta t} = \frac{d\mathbf{r}}{dt} \quad (2)$$

B. Peak Detection

The detection of signals in the presence of noise plays an integral role in a great number of applications. For example, it is used in communication systems in the detection of signals such as radio or television broadcasts and differentiating them from noise, in medicine with the detection of an ECG signal, and more[7]. The accelerometer signals show considerable difference in morphology and amplitude among the individuals.Accelerometer signals have previously been shown to be useful for step detection[8].

C. Wiimote

The Nintendo Wii remote, or Wiimote, is a handheld device resembling a television remote, but in addition to buttons, it contains a 3-axis accelerometer, a high-resolution high-speed IR camera, a speaker, a vibration motor, and wireless Bluetooth connectivity. This technology makes the Wii remote one of the most sophisticated PC-compatible input devices available today; together with the game console's market success, it's also one of most common. At a relatively inexpensive price, the Wii remote is an impressively cost-effective and capable platform for exploring interaction research. Software applications developed for it have the additional advantage of being readily usable by millions of individuals around the world who already own the hardware [9].

Although the Wii remote's official specifications are unpublished, the global hacking community has collectively reverse-engineered a significant portion of the technical information regarding its internal workings. Because many low-level details are available online and, furthermore, are likely to be refined and updated as more information is uncovered, the following descriptions of each major Wii re-mote component represent only higher-level details relevant to building custom applications [9].

D. Accelerometer

An accelerometer is an electromechanical device that measures acceleration forces. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic – caused by moving or vibrating the accelerometer. There are many types of accelerometer developed. The vast majority is based on piezoelectric crystals, but they are too big and too clumsy. People tried to develop something smaller, that could increase applicability and started searching in the field of microelectronics. They developed MEMS (Micro electromechanical systems) accelerometers[10]. Micro machined accelerometers are a highly enabling technology with a huge commercial potential. It provides lower power, compact and robust sensing. Multiple sensors are often combined to provide multi-axis sensing and more accurate data[11].

The provider of wiimote's motion sensing capability is an ADXL330 manufactured by Analog Device. The ADXL300 is a three axis accelerometer. The product measures acceleration with a minimum full-scale range of +/- 3 g. It can measure the static acceleration resulting from motion, shock, or vibration[12].As an integrated part of wiimote, it has 8 bits per axis, and a 100 Hz update rate [9].

Accelerometer features have been used successfully for classification of human activities, both offline[13] and in real-time[14]. Using a variety of simple features from accelerometer, barometer, and microphone input, Lester et al were able to classify distinct human activities with high accuracy. Consolvo et al used real-time classification of human activities to provide rapid-feedback health monitoring for a fitness application [15].

E. Bluetooth

Bluetooth is a way for devices to wirelessly communicate over short distances. Wireless communication has been around since the late nineteenth century, and has taken form in radio, infrared, television, and more recently 802.11. What distinguishes Bluetooth is its special attention to short-distance communication, usually less than 30 ft. Both hardware and software are affected by this special attention [16].

F. Comparison

The development of speed performance meter by using accelerometer began when the popularity of the accelerometer itself increased.Several commercial performance meter had already on the market, including NIKE+ from Nike [18] and then followed by miCoach from Adidas [21]. Both of these products have a sensor attached to a shoe and then send the data to the handheld device. A validity study of the Nike+ device during walking and running done by Kane [20] showed that the Nike+ device overestimated the speed of level walking at 55 m x min (-1) by 20%, underestimated the speed of level walking at 107 m x min (-1) by 12%, but closely estimated the speed of level walking at 82 m x min (-1), and level running at all speeds ($p<0.05$). Then he concluded that the Nike+ in-shoe device provided reasonable estimates of speed and distance. Unfortunately, the price for these commercial system are relatively expensive because the algorithm and signal processing complexity [19].

When compared with commercial system and other development [18, 19, 20, 21], this sprint performance is more economical and simpler. The usage of wiimote and the software development based on open source technology clearly reduce the cost.

G. Design Process

The aim of this research is to develop a sprint performance meter by using another approach of accelerometermeasurement. A Simplified hardware set up for acquiring data is shown in Figure 1.

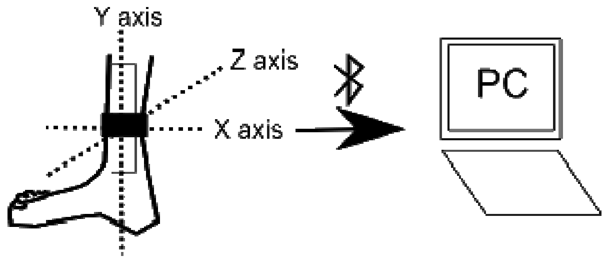

Fig. 1.The simplified design of the device. The wiimote is attached to leg and the accelerometer data is send simultaneously via Bluetooth communication.

Theoretically, the equation of motion used for acquiring speed from acceleration is [2]:

$$\mathbf{v} = \mathbf{v}_i + \mathbf{a}(t_f - t_i) \quad (3)$$

The variable $v_i$is initial velocity. The variable t_i is initial time and The variable t_f is final time. But as described in introduction, applying this equation to accelerometer data will cause integration error due to accelerometer sensitivity to small acceleration. Also, gravity acceleration make accelerometer always give non zero values. Soin this research, another equation of motion is used [2]:

$$\begin{aligned} \mathbf{v} &= \mathbf{v}_1 + \mathbf{v}_2 + \mathbf{v}_3 + \ldots + \mathbf{v}_n \\ &= \frac{\mathbf{x}_1 - \mathbf{x}_0}{t_1 - t_0} + \frac{\mathbf{x}_2 - \mathbf{x}_1}{t_2 - t_1} + \frac{\mathbf{x}_2 - \mathbf{x}_1}{t_2 - t_1} + \ldots + \frac{\mathbf{x}_{n+1} - \mathbf{x}_n}{t_{n+1} - t_n} \quad (4) \\ &= \sum_{n=0}^{m} \frac{\mathbf{x}_{n+1} - \mathbf{x}_n}{t_{n+1} - t_n}; n = 0,1,2,3\ldots \end{aligned}$$

Variables t_{n+1} and $t_n$are time interval between stride of every stride/step occured. Variables x_{n+1} and x_n are the average distance of stride length. This equation is used for calculating speed of every step.

Before applying the equation, an algorithm is developed to acquire data of stride, length, time interval. To detect stride from accelerometer data, peak detection algorithm is used [17]. Figure 2 provides flowchart diagram of signal detection algorithm to detect stride. After extracting stride data, the track distance is divided by total of stride which is obtained from stride data to get average stride length value. This value is equal to time intervalin equation 4. With all of this calculation, the running speed performance of a runner will be acquired. Threshold value is a constant value acquired from an experimentthat a vibration value from a running step is always more than 15 m/s^2.

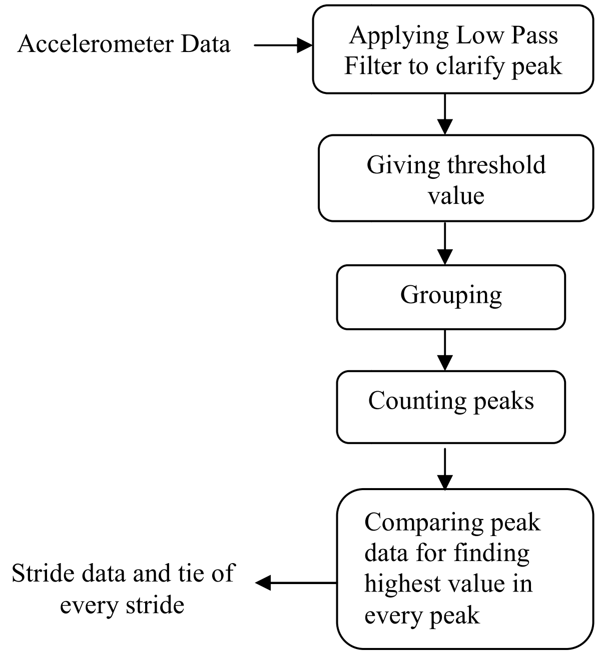

Fig.2. Methodology to detect stride from acceleration data by using peak detection algorithm.

H.Evaluation Set Up

The tools evaluation is done by measuring speed data from 5 measurement points in 20 m sprint track. The measurement points are set at 4 m, 8 m, 12 m, 16 m, 20 m. Speed data is acquiring together with conventional stopwatch.

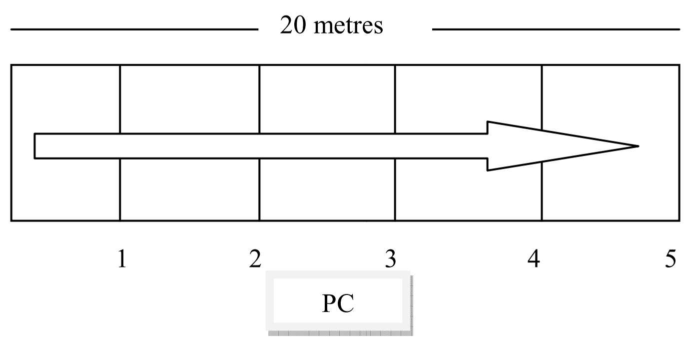

Fig.2. The 20 meters sprint track and 5 measurement points

III. RESULTS

As describe above, acceleration data which acquired from wiimote must be processed by a low pass filter to get cleaner signal data. A low pass filter prevents false stride detection because spontaneous vibration caused by stride makes some extreme value that raise another peak which is not the real stride signal. Jonathon Neville [6] describes that a low pass filter of 9 Hz is applied since 0.9 Hz is significantly slower than the minimum stride frequency. But in this research, a 0.9 Hz filter still not make the step signal cleaner. So 0.09 Hz which is smaller than 0.9 Hz is applied. The filtering process of a 0.09 Hz low pass filter is shown in Figure 3. The first plot shows unfiltered signal which contains extreme value after peak signal. The second plot shows filtered signal. The filter had removed noise and extreme value. The last plot shows the signal comparison between filtered and unfiltered signal.

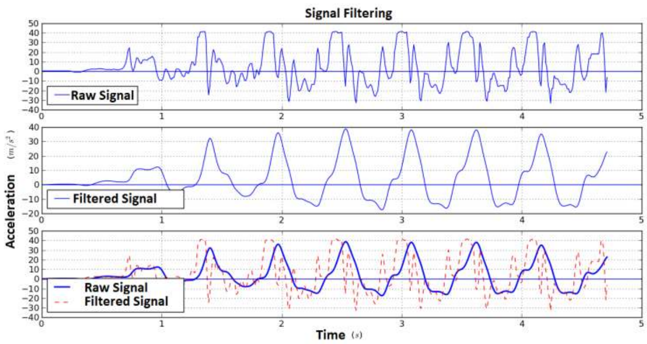

Fig. 3. Time domain representation for filtering process

The implementation of peak detection algorithm has successfullydetected runner's stride. Figure 4 shows the algorithm processing for detecting stride. Red dots indicate groups of stride which is detected after giving threshold value. At the peak, there are numbers of strides sequences. After the number of strides and time intervals acquired, the software processed the raw data to obtain speed performance and then visualized it.

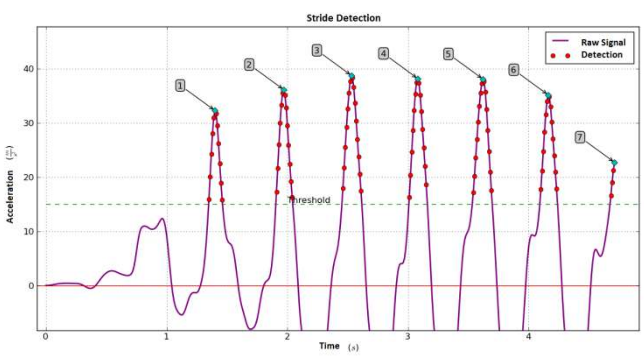

Fig. 4. Data visualization of stride detection by using peak detection algorithm

The result of development is a complete speed performance software analysis as shown in Figure 5. The software had implemented the algorithm for measuring perfomance. This software has several capabilities: real time stopwatch, data acquiring, data testing, and data analysis. The Graphical User Interface shows real time raw and acceleration values from accelerometer to show the measurement. For evaluating the speed performance meter, this tool is tested to measure speed in 20 meters sprint. Result of the speed performance which is analyzed by the software is shown in Figure 6.

Before the device is ready to acquire data, the wiimote must be paired with the PC. The Connect button in Figure 5 is used to pair with the wiimote. When button is pressed, button 1 and 2 in wiimote also must be pressed so the wiimote can be discovered. To disconnect the wiimote, just press Disconnect button. After pairing the wiimote with the PC, Raw and Acceleration data would show the current value of the wiimote in real time. In this state, the speed performance meter is ready for the measurement. Start, Stop, Reset buttons in the Figure 5 are used to start, stop, and reset the virtual stopwatch, but the buttons will not record the data until the Recording Data checkbox is checked. If all of measurement procedures are done, The "Harry Plotter" button will analysis the data and visualized it. Figure 3, 4, 6 is visualized by using this analysis button.

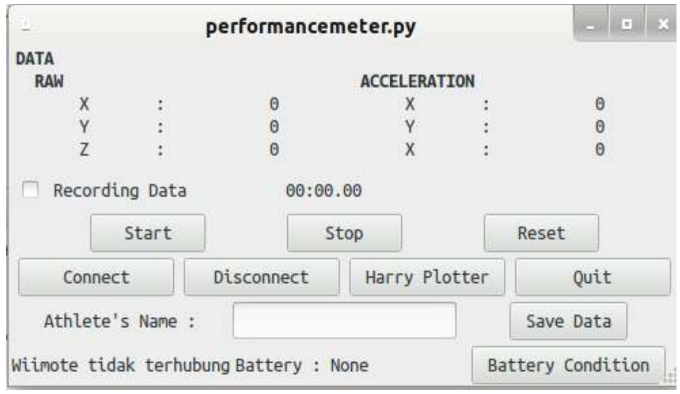

Fig.5.The Graphical User Interface of speed performance meter software for acquiring, recording, and analyzing wiimote's data.

From the Figure 4, the data visualization showed that the total steps are 7 steps. So in the Figure 6, there is 7 point of speed performance within 20 meters. The calculation of every step speed is presented in Table I.

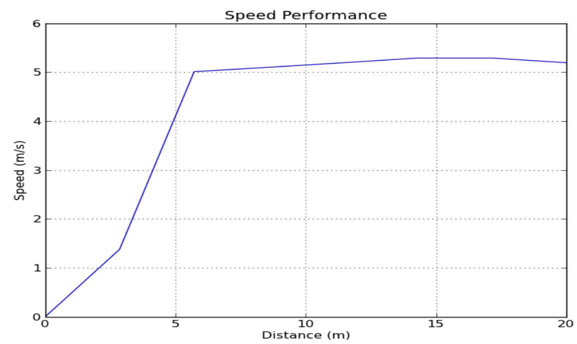

Fig. 6. Visualization of speed performance data

Table I and II shows the comparison between the virtual stopwatch and conventional stopwatch speed measurement. From this comparison, the sprint performance meter has more sampling values than the conventional stopwatch. Total data are equivalent with sprint step in 20 m. The complete comparison between virtual and conventional stopwatch visualized in Fig. 7.

TABLE I
RUNNING PERFORMANCE USING WIIMOTE/VIRTUAL STOPWATCH

Time (s)	Distance (m)	Speed (m/s)
0.00	0.00	0.00
1.40	2.86	2.04
1.97	5.71	5.01
2.53	8.57	5.19
3.08	11.43	5.19
3.62	14.29	5.29
4.16	17.14	5.29
4.71	20.00	5.29

[a]s = second,m = meter.

TABLE II
RUNNING PERFORMANCE USING STOPWATCH

Time (s)	Distance (m)	Speed (m/s)
0.00	0.00	0.00
1.43	4.00	2.80
2.34	8.00	4.40
3.26	12.00	4.35
3.97	16.00	5.63
4.72	20.00	5.33

[a]s = second,m = meter.

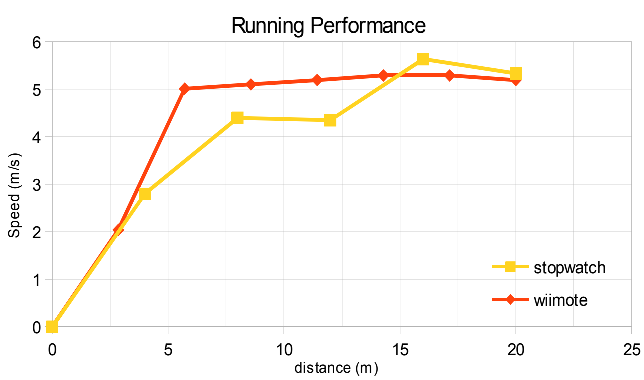

Fig. 8.Visual comparison of running performance between conventional and virtual stopwatch (wiimote).

IV. CONCLUSION

This paper shows that the development of speed performance meter by using peak detection algorithm can measure speed performance. The performance meter can be used to develop runner speed stability in certain running tracks.

Speed performance meter that had developed by using stride detection is using the same equation which used by conventional stopwatch. Nevertheless, the stride utilization as a natural stopwatch marker allows more speed data sampling than the conventional stopwatch did. From the testing result, this performance meter has accuracy 94.87% for average speed measurement and 88.06% for step speed measurement.

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Jediyanu Wigas Tu'u was born in Bandung, West Java, in 1988. He received an undergraduate degree in Physics (2012) from the University of Lambung Mangkurat (Unlam) Banjarbaru Indonesia. His current research interests are Sport Engineering, Biomedical Engineering, and Open Source Technologies.

Amar Vijai Nasrulloh was born in Surabaya, in 1978. He received an undergraduate degree in Physics (2004) from Institut Teknologi Sepuluh Nopember (ITS) and a graduate degree in Electrical Engineering (2010) specialty in biomedical engineering program from Institut Teknologi Bandung (ITB), Indonesia. He received the Academic Achievement Directorate General Higher Education (DIKTI) Scholarship (BPPS) for his graduate degree. In 2005, he joined the Physics Study Program of Lambung Mangkurat University as a lecturer. Currently he is member of HFI(Indonesian Physical Society). He becomes a member of IEEE in 2011. His current research interests are Video Processing, Imaging and Image Processing, Biomechanics and medical Instrumentation.

Arfan Eko Fahrudin was born in Kediri, in 1979. . He received an undergraduate degree in Physics (2004) from Institut Teknologi Sepuluh Nopember (ITS) and a graduate degree in Electrical Engineering (2010) from University of Gadjah Mada (UGM), Indonesia. In 2005, he joined the Physics Study Program of Lambung Mangkurat University as a lecturer. He received the Academic Achievement Directorate General Higher Education (DIKTI) Scholarship (BPPS) for his graduate degree. Currently he is member of HFI (Indonesian Physical Society). His current research interests are Image Processing, Pattern Recognition and Medical Instrumentation.