International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 6, August - 2012

Energy Based Athletes' Performance Assessment

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Abstract: **Several athletic events such as sprint, hurdles, marathon running etc, require performance evaluation for improving athletes' efficiency, for which certain parameters that can be wirelessly measured as and when the athletic events are happening, are discussed here. On-field techniques of measurement of athletes' performance are limited to calculation of the best time and a few methods conducted in the laboratory environment involve testing of athletic ability measured by Vo2max functions on a treadmill. Characterizing performance parameters that affect the end result of time in track events requires assessment of the total and axial energy efficiency that leads to best time outcome. In this paper we analyze running activities such as a 30m dash by making use of inexpensive accelerometers and biomechanical signal processing techniques to create a methodology to take into account parameters other than lap time in running events for analyzing the performance of the athlete. Shimmer research's wireless accelerometer sensors were used to analyze 30m dash events. The concept of kinetic energy is implemented in a sports science scenario and a first of its kind analysis of athletes from the Indian subcontinent is conducted. A unique technique based on Hilbert Huang Transform (HHT) is proposed as a High Pass Filter (HPF). After the filtering two performance parameters i.e., kinetic energy/ power in watts and Energy Spectral Density (ESD) are determined. This study aims to create an inexpensive and efficient performance analysis technique to overcome the several drawbacks of popularly used Opto-kinetic motion analysis systems.**

Keywords: Energy Spectral Density (ESD), Hilbert Huang Transform (HHT), Opto-kinetic motion analysis systems.

I. INTRODUCTION

Sports scientists monitoring the energy usage of elite athletes during training rely predominately on athlete self-monitoring augmented by monitored training sessions and traditional physiological measures such as heart rate and blood lactate concentration. Self-monitoring relies on the athlete recording their activities in a diary [1] and using a reference table to estimate energy expenditure [2]. Estimating athlete energy use during competition in field sports can be labor intensive and involves video monitoring and manual activity categorization. The availability of microelectronics devices and micro-electromechanical systems (MEMS), particularly accelerometers provides an alternative, noninvasive method of automatic monitoring activity.

In the last decade there has been a growing interest in the assessment of daily physical activity using electronic accelerometers [3, 4, & 5]. These motion sensors register accelerations and decelerations of the body and, in this way, provide an objective and direct measure of the frequency and intensity of movements during physical activity. Data from studies on gait analysis and ergonomics have demonstrated a linear relationship between the integral of the absolute value of body acceleration and oxygen consumption or energy expenditure [6, 7, 8, & 9], initiating the development of accelerometers to estimate energy expenditure during physical activity.

The purpose of this study was to establish methods for the estimating of energy use of athletes' in training and competition. Shimmer wireless accelerometer were chosen as the sensor platform because they are unobtrusive, have wide bandwidth, and can provide information pertaining to various activities of interest such as walking, running, etc.

In this paper, we analyze the 30m dash track training event to determine parameters of Energy Spectral Density (ESD) and kinetic energy of the athlete. The 30m dash was chosen to determine the ability of the athlete to accelerate within short distances and reach maximum speed within the finish line. The 30m dash event is a popular training exercise where the athlete is asked to run the distance in shortest time as possible.

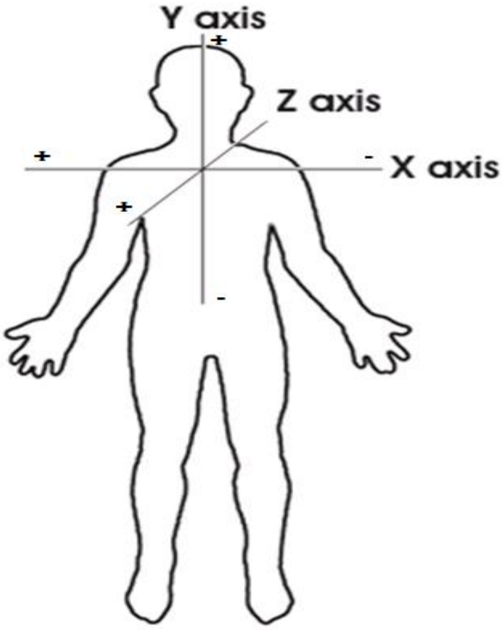
II. METHODOLOGY

A. Subjects

Six subjects (4 males, 2 female; mean±sd age = 24±5 years), who all gave written consent, participated in the trial. Detailed instructions were given to the subjects and they were asked to refrain from alcohol and any kind of medication twenty four hours prior to the experiment.

B. Procedure

Prior to data collection, subjects were given a practice trial to become familiar with the task to be performed in the experiment. In this experiment, the subjects were instructed to run a 30-mt dash with his maximum speed. The 30m dash was chosen to determine the ability of the athlete to accelerate within short distances and reach maximum speed within the finish line. A wireless tri-axial accelerometer was placed at the sacrum which is the CG (center of gravity) of the body. Figure 1 (a) shows the three axis of the accelerometer with respect to the player figure 1 (b) shows the accelerometer worn by the player at the CG. The three axes of accelerometer align with the player's body in such a way that acceleration in the x channel correspond to movement in the mediolateral axis, accelerations in the y channel correspond to movement in the Superior-inferior axis and accelerations in the z channel correspond to movement in the anteroposterior axis.



(a)

(b)

Fig.1: (a) A visual representation of the location of accelerometer. (b) Shows the accelerometer worn by the player at the CG

C. Data Acquisition

The readings were taken using Shimmer wireless tri-axial accelerometer at 50 Hz sampling rate. The data was recorded in Log mode, where the data is stored in inbuilt memory card. These data was later transferred to the computer using software provided by Shimmer research.

III. DATA ANALYSIS

Analysis of the collected data occurred in several distinctive phases as the information was assimilated. Initial processing involved removal of orientation signal from the acceleration signal. Second phase involved filtering the acceleration data using Hilbert Huang Transform (HHT). The final analysis involved identification of assessment parameters i.e., kinetic energy/ power in watts and Energy Spectral Density (ESD).

The accelerometer data extracted was filtered with a low pass filter of 0.9 Hz since 0.9Hz is significantly slower than the minimum stride frequency. Therefore the resulting signal for each axis of the data represented the orientation of the sensor. The orientation signal was then subtracted from the original signal to remove any effects due to the player's angle.

A. Hilbert Huang Transform

The acceleration data obtained is non-stationary in nature, i.e. their frequency changes w .r .t time. So we propose a technique called Hilbert Huang Transform by N. E. Huang [10] presented a new and powerful method for the analysis of the nonlinear and non-stationary time series data. The method is composed of two parts, Empirical Mode Decomposition (EMD) and Hilbert Transform (HT).

In this paper we use EMD to decompose the acceleration signal into smaller into its smaller intrinsic mode function (IMF). Since IMF is of prime importance for the present investigations, a brief overview of their details is discussed in the current section.

An IMF is a function which satisfies two important properties: (i) In the whole data set, the number of extremes and the number of zero-crossings must either be equal or differ at most by one. (ii) At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero. A process called 'sifting' is then applied to the raw signal $X(t)$ to extract all its IMF's. In sifting process, between each successive pair of zero crossings, a local extremum in the test data is first identified. Following this, all the local maximas are connected using cubic spline line forming the *upper envelope* and the local minima by a cubic spline line form the *lower envelope*.

The mean $m_1(t)$ of these envelopes is calculated and the difference between the mean and the data is obtained as the first component $h_1(t)$ given as

$$h_1(t) = X(t) - m_1(t) \qquad (1)$$

In the subsequent sifting process the signal $h_1(t)$ is treated as the proto IMF and in the next step it is treated as data.

$$h_{11}(t) = h_1(t) - m_{11}(t) \qquad (2)$$

After k sifting steps, the k^{th} component is obtained as

$$h_{1k}(t) = h_{1(k-1)}(t) - m_{1k}(t) \qquad (3)$$

The component is then designated as the first IMF $c_1(t)$ of the data if it satisfies the two conditions of the IMF as discussed in the earlier paragraph. If both the conditions are satisfied, the first IMF is obtained as

$$c_1(t) = h_{1k}(t) \qquad (4)$$

$c_1(t)$ is then separated from the data to get the residue $r_1(t)$

$$r_1(t) = X(t) - c_1(t) \qquad (5)$$

In all the following steps, the residue signal is treated as the data signal and equations (1) to (5) are applied to obtain the subsequent IMFs.

This sifting procedure leads to obtain a series of subsequent residue signals of the main data signal. The said process terminates when the residue signal becomes a monotonic function from which no more IMFs can be extracted.

The signals are separated in the decreasing order of frequencies by applying EMD. For the present analysis signals below 20 Hz are required, therefore the high frequency components are subtracted from the signals. First 2-3 IMFs contain high frequency components, these IMFs are eliminated and the signal is reconstructed with the remaining IMFs.

B. Energy Expenditure

Integrals of the absolute value of accelerometer output from x, y, and z directions were obtained, resulting in the variables IAAx, IAAy, and IAAz. The sum of these variables was calculated to get IAAtot. To test the hypothesis of a quadratic relationship between the integral of absolute accelerometer output and EEact, the computed variables were squared (IAAX2, IAAy2, IAA/, and IAAtot). The magnitude of the total acceleration vector was obtained by squaring the output from each accelerometer and extracting the square root of the sum of these values. Next, the integral of the magnitude of the acceleration vector (IAV) was computed. This variable was squared to obtain IAV2. The last processing method involved the estimation of kinetic energy (KEx, KEy, KEz, KEtot) and power (P) due to the rate of change of total kinetic energy at the point of attachment of the TA. These variables are directly related to the metabolic energy cost of movement and might be used to describe the relationship between metabolic (EEact) and mechanical (acceleration) phenomena during physical activity. As accelerometers measure linear accelerations, only kinetic energy due to translational motion could be calculated from accelerometer output. Acceleration signals were integrated over time, resulting in instantaneous velocity. The signals thus obtained were squared and multiplied by 1/2mb with mb representing the subject's body mass, to calculate instantaneous kinetic energy curves for each rneasurement direction. Summation of these curves resulted in total kinetic energy.

C. Energy Spectral Density (ESD)

ESD is the total energy of the signal represented in spectrum. ESD of all three axes is determined. Figure 2 indicates Energy Spectral Density (ESD) of one subject whose magnitude of the energy along z-axis i.e. forward direction is maximum. Energy along y axis is minimum as there is minimum movement along y axis. This indicates that the athlete is not wasting his energy in unnecessary movement, which shows his running technique is right.
Figure 3 indicates the flow chart of the methodology used.

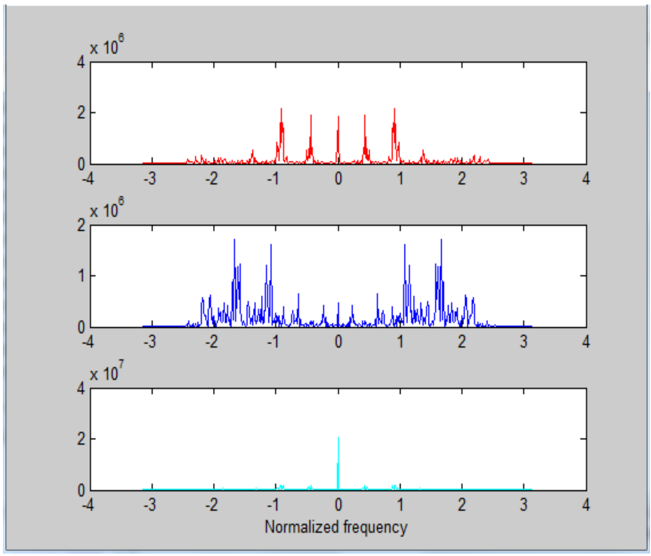


Fig 2: Energy Spectral Density Along X, Y and Z Axes

IV. RESULTS AND DISCUSSION

The acceleration data recorded are ADC values which should be converted to m/s^2 .Once the data is converted to m/s^2 it represents the acceleration data in m/s^2 for which a MATLAB code was written, Figure 4 shows acceleration data in three axes, where pink color represents acceleration in z- axis, red color represents acceleration in x- axis and blue color represents acceleration in y – axis.

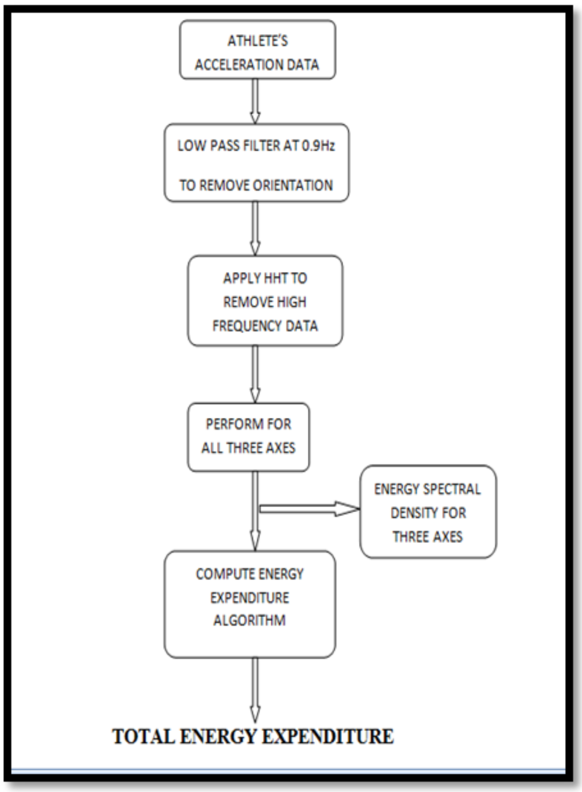


Fig 3: Flowchart of Methodology

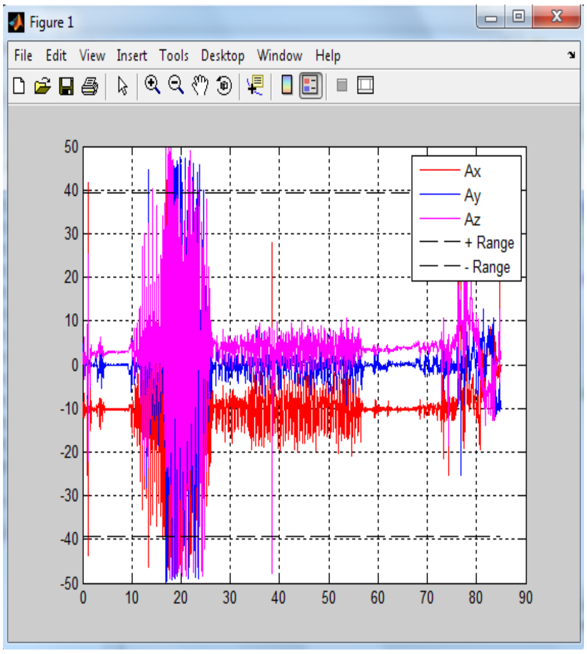


Fig 4: Input Acceleration Data

Hilbert Huang Transform (HHT) is applied to all three axes of the input data; HHT decomposes the input signal into number of Intrinsic Mode Function (IMF) in decreasing order of frequency. Here HHT is used as a filter to filter out high frequency signals as signals below 18 Hz is required. HHT is better filter as the physical characteristic of the signal is not lost as compared to other filtering techniques. In other filtering technique the amplitude of the signal is truncated which leads to loss of essential data. Once the signal is decomposed into several IMFs, first two-three IMFs is removed as they constitute to high frequency signals and the signal is reconstructed using the rest of the IMFs which is the desired signal. The decomposition of the input signal is shown in figure 5. HHT filtering of the input signal shown in figure 5 is for one axis, similarly this is done for all three axes to obtain filtered signal.

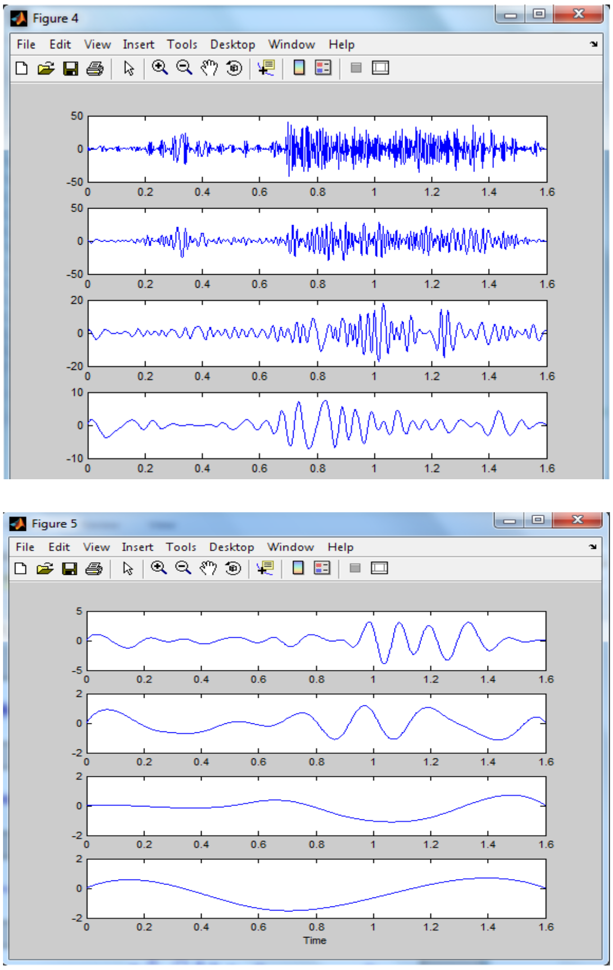


Fig 5: Decomposition of input signal

Once the input signals are filtered Energy Spectral Density (ESD) of each axis is obtained. Consider a case as shown in figure 6 in which the magnitude of the energy is maximum along x-axis when compared to z-axis. This indicates that there is flight or jumping in vertical axis due to which his/her energy is being wasted unnecessarily and needs to improve his technique. Usually all these parameters are not clearly visible to naked eyes. When such parameters other than speed and time are explored it gives the athlete clear picture of his performance.

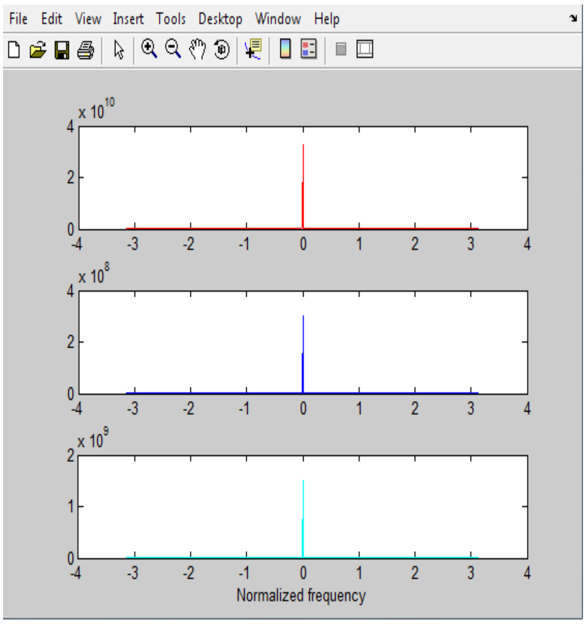


Fig 6: Energy Spectral Density Along X, Y and Z Axes

The total energy expended/kinetic energy was obtained as discussed above. The energy obtained is in terms of watts/kg, this converted to power by multiplying total energy/kinetic energy by mass of the subject. Table 1 below shows the results of all the subjects.

The results of all the athletes with their weight, height, maximum speed, time and energy expenditure/kinetic energy are tabulated in table 1. Consider subjects S2 and S5 from the table 1 it is seen that subject S5 is using more energy when compared to S2, where both the athlete are of almost the same height and weight. As it is seen S2 is attaining maximum speed of 26km/hr and is covering the distance in lesser time also. This shows that S2 is utilizing his energy properly when compared with S5. It can be indicated to S5 that he is unnecessarily using energy, if this is utilized in efficient way he can attain better speed and time. The best performer is athlete S2 as he attains maximum speed in minimum time and energy.

Table 1

Subject	**Sex**	**Time (sec)**	**EE/KE (watts)**	**Height**	**Weight (kg)**	**Max speed**
S1	M	3.68	717	6' 1"	70	20
S2	M	3.87	273	5' 7"	65	26
S3	M	4.08	611	5' 6"	63	20
S4	F	4.2	214	5' 5"	50	18
S5	M	4.63	680	6' 1"	60	16.9
S6	F	4.8	178	5' 3"	55	19

** Values tabulated in the above table are arranged in increasing order of time

V. CONCLUSION

The study identifies that HHT method is an effective filtering method to analyze energy expenditure and power of an athlete as the physical characteristics of the data received from the accelerometer are not lost.
The result from the present study provides a methodology to determine energy / power expenditure and Energy Spectral Density (ESD) of an athlete using accelerometer. ***This type of performance assessment is first of its kind conducted in Indian subcontinent.***
Energy spectral Density (ESD) indicates energy in the 3-axes; this gives better understanding if there is unnecessary energy spent in horizontal or vertical axes. Excess energy in horizontal axis (x-axis) indicates

sway and excess energy in vertical axis (y-axis) indicates flight.

Total Energy Expenditure parameter indicates how much energy is spent which helps the athlete in better energy management.

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