Wireless Performance Evaluation of Sun Salutation Using Body Mount Accelerometers.

Shravan.T.R[1] & Dr S.N. Omkar[2]
1. Jonier Research Fellow, 2. Chief Research Scientist
Dept. of Aerospace Engineering, Indian Institute of Science, Banglore 560012
Email: shravantr@gmail.com

Abstract
Sun salutation is well known for the diverse health benefits it provides by following few simple body postures with synchronized breathing. Each set consists of 10 different body postures and every posture has its own significance and unique impact on the body. Understanding the transition phase during motion is a challenging task and thus, new methods need to be employed. The paper discusses a methodology that can be used in everyday environment to analyze and evaluate the performance. Body orientations and accelerations at selected points on the body are acquired from the accelerometers developed by Shimmer®. Pitch angle in the sagittal plane is analyzed using Empirical Mode Decomposition (EMD). Relevant IMF's are chosen using coefficient of correlation. Fast Fourier transform is then applied to the IMF to convert time domain data into frequency domain. The frequency response is an indicator of gracefulness for inter and intra subject exercise performance. From statistical analysis, the evaluated results are represented in a form that is comprehendible by both the instructor and the performer himself. The technique can be utilized to develop a wireless system that is used to evaluate exercises which involve repeatable performance with grace.

Keywords*:* Empirical mode decomposition, Fast Fourier transform, Self-evaluation, Skewness and Kurtosis.

Introduction
In today's scenario, the need for physical and mental fitness has been more than ever before. One of the solutions to this is believed to be coming from the practice of an ancient Indian technique known as Yoga. Yoga is a discipline designed to bring balance and health to physical, mental, emotional, and spiritual dimensions of the individual [1].

Today many forms of these techniques are being followed based on different scripts written. Yoga has many ambiguous things and its transmission is mainly based on Master-Prentice Pattern, with the result that the spreading effect of Yoga is not satisfactory [2]. This problem demands for a methodology to monitor the exercises and evaluate the performance. Many of the exercises in yoga need to be repeated for several cycles, and it is very important to take care that the postures are repeated in the same way during each cycle. Sun salutation is one such exercise that needs to be repeated for several cycles.

Sun salutation is considered to be one of the most beneficial exercises in yoga. It comprises of 10 different body postures, each having its own significance. The sequence of postures is such that every posture is complimentary to the next. Due to the complimentary postures, muscles of the entire body experience stretch and pressure alternately and therefore it is said to give more benefits with less expenditure of time [3]. It has been called "Sarvang Sunder Vyayam" or the best all round exercise[4]. The above discussed benefits lead researchers to analyze more on Sun salutation.

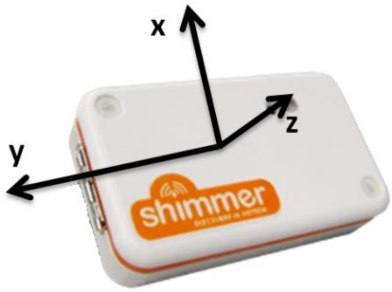

Figure 1: Tri axial accelerometer Shimmer® module is shown above with the directions of three axes.

Figure 2: 10 postures of sun salutation are pictorially represented above.

To capture the experimental data, Inertial Measurement Units (IMU) were chosen over Motion capture systems. IMU's prove to be very suitable to realize outdoor applications because of their immense portability, compactness and useful, accurate movement information they supply [5][6]. The data from these instruments are transferred in real time to a nearby computer for data analysis. Further only by using a tri-axial accelerometer it is possible to compute both linear acceleration and angular movements [7]. These advantages of tri-axial accelerometers have led us to eliminate the use of gyroscopes and magnetometers for this study. In this experiment, tri-axial accelerometers from Shimmer® are utilized. Shimmer® is a lightweight, low power, wirelessly enabled sensor platform which can be utilized for body worn application either by using Bluetooth or 802.15.4 radio communications [4]. In this experiment two accelerometers are used.

The signals from the accelerometers are non-stationary and non-linear. To analyze these signals conventional signal analysis tools like Fourier transforms fail, as they only represent the frequency of the signals with respect to their amplitudes and no information about when these frequencies occurred can be inferred. Short-time Fourier transforms has been developed to analyze non-stationary signals but their resolution is limited to their window size. Further tools like Wavelet analysis[8] and Wigner-Ville distribution [17] were developed for non-linear but not for non-stationary data [9]. A comparative study on performance of Sun Salutation [10] using Fast Fourier transforms, Wavelet transforms and Hilbert Huang Transforms (HHT) has been done. From the study it was concluded that HHT gave the best results for the performance analysis of Sun Salutation.

The methodology in this paper makes use of the strengths of both Empirical Mode Decomposition (EMD) and fast Fourier Transform together to analyze and represent the performance of the exercise using statistically parameters. EMD is a part of Hilbert Huang Transform, EMD is an empirical method and has no mathematical proof but it has been tested extensively based on empirical methods. EMD is based on decomposing a signal into its constituent fundamental frequencies which when combined along with the residue results in the original complex frequency signal. The frequencies are decomposed in descending order of constituent frequencies i.e. the frequency components are decomposed from higher frequency to lower frequency. Every constituent decomposed signal is called as an Intrinsic Mode Function (IMF), so the first IMF represents the highest frequency component of the original signal and the successive IMF's represent the lower order frequencies of the signal [11]. The relevant IMF is selected based on the correlation coefficients[12]; the methodology is discussed in the mathematical section. The relevant IMF is analyzed using Fast Fourier Transform to get the frequency response of the signal. Skewness and Kurtosis of the frequency response are computed for further inferences.

Methodology

Participants: For the experiment 9 healthy subjects who had prior experience in Yoga are considered for the performance analysis. The subjects selected fell into the following range of parameters, Mean±SD Age: 30±20 years, Height: 170±25cm & weight: 64±20kg. The experiment was conducted in a Yoga centre so that a safe and performable condition was provided to the test subjects. All the protocols to be followed while doing the exercise were briefed to the test subjects well before the start of the experiment.

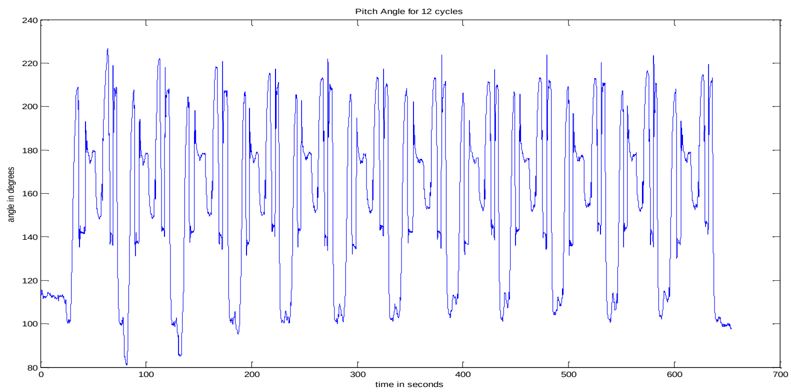

*Figure*3:Raw data from the accelerometer

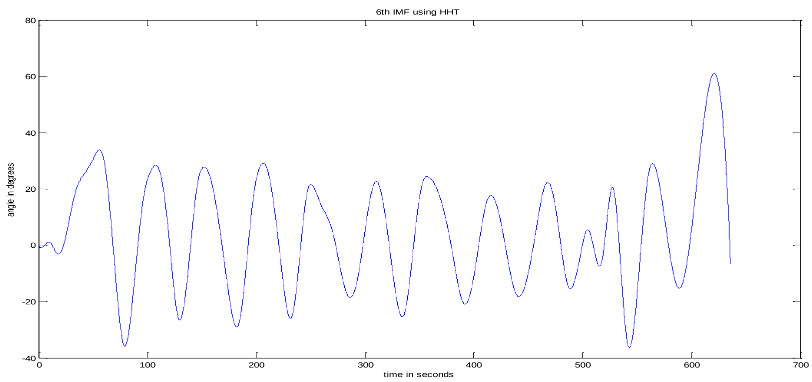

Figure 4: 6th Intrinsic Mode Function after applying EMD to the raw data.

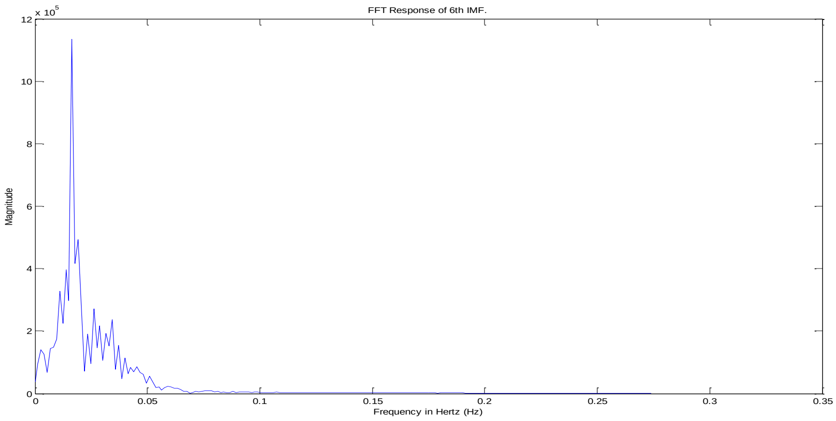

Figure 5: Frequency response obtained by applying FFT to 6^{th} IMF.

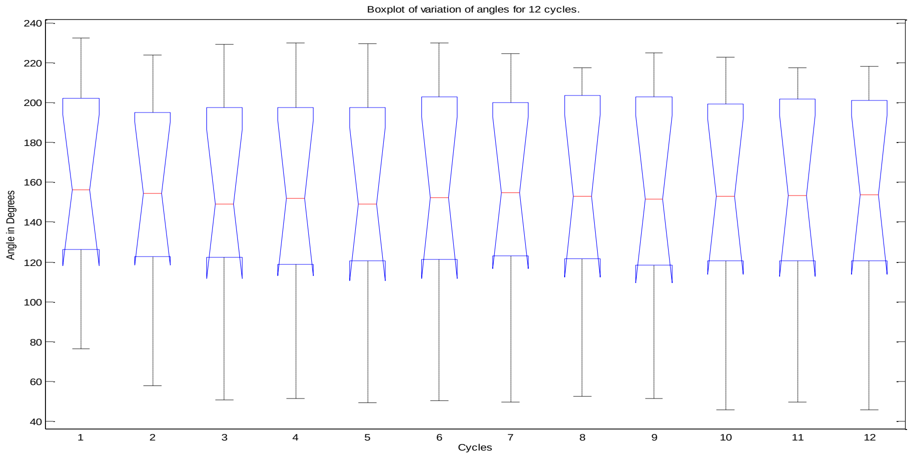

Figure 6: Variation of angular position for each of the 12 cycles.

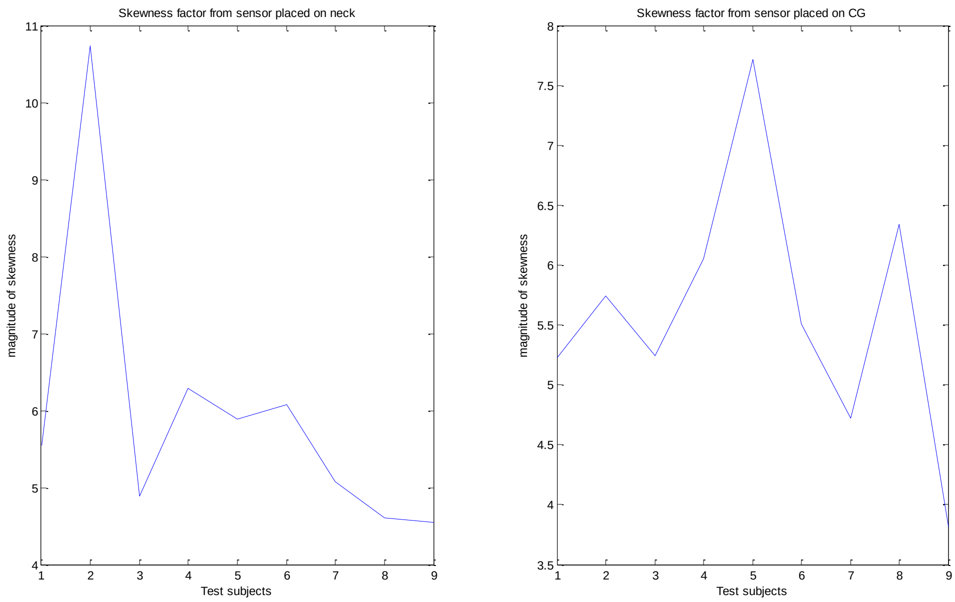

Figure 7: Skewness factor on neck and CG.

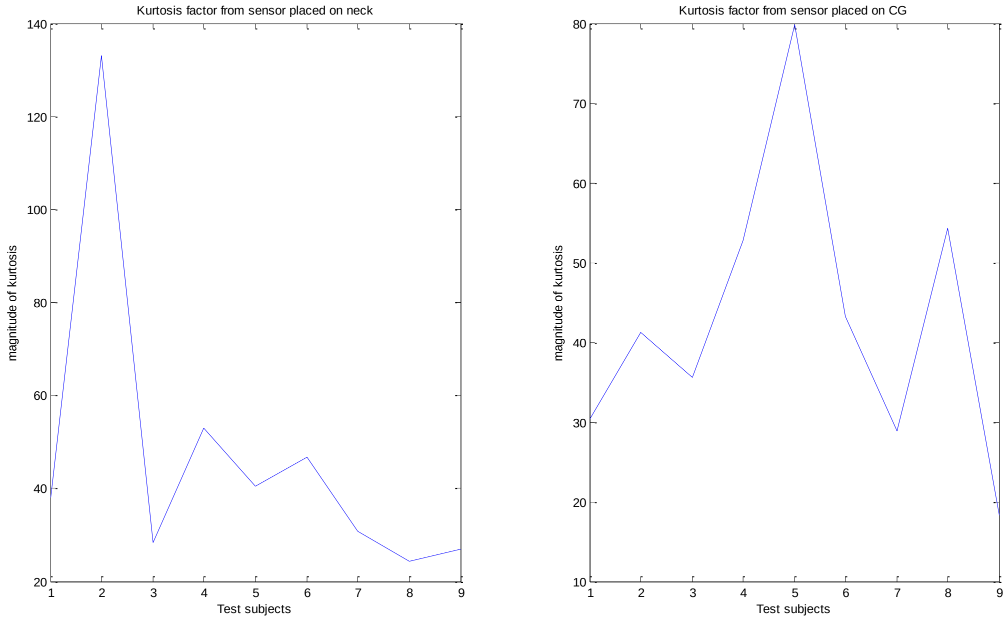

Figure 8: Kurtosis factor on neck and CG

Measuring units and mounting

For the data measurement two, tri-axial accelerometers from Shimmer® are used. The accelerometers are calibrated for a range of ±12g acceleration values. The Shimmer® module consists of an inbuilt microcontroller which converts the raw voltages into calibrated range of acceleration values and the output is in m/sec^2 unit. Both the sensors are set at sampling frequency of 128Hz. The accelerometers are strapped on to the subject using a special velcro strap provided with an accelerometer holder, this ensures a firm placement of the sensor onto the body. One placed at the Centre of Gravity (COG) located at sacral promontory, anterior to S2 at 55% of body height, and the other at the apex of the spine (just below the neck).

Data Acquisition

For data acquisition LAB View® program provided by Shimmer® was utilized. The program was very flexible to vary the various parameters like sampling frequency, G-values, sensor board selection and also convenient to start and stop the data streaming whenever necessary. The data is transmitted to a nearby computer in real time via a Bluetooth link established between the computer and the sensor. The real time data from all the three axes with the respective time stamp is saved to an excel sheet for the data analysis. Accurate time synchronization between the two sensors is taken care by the software.

Procedure

The subjects are asked to go through their routine before doing the actual exercise. Once the subjects are ready the sensors are mounted on to the body and they are asked to take the initial stance.

As said before the Sun salutation consists of 10 sets of postures for every cycle. This is pictorially represented in *Figure* 2. During the exercise, subjects are instructed to concentrate on their breathing technique. Every 5 seconds a signal is given to the subject to change to the next posture in the sequence. This timing gives an advantage during data analysis. The procedure is repeated for 12 continuous cycles.

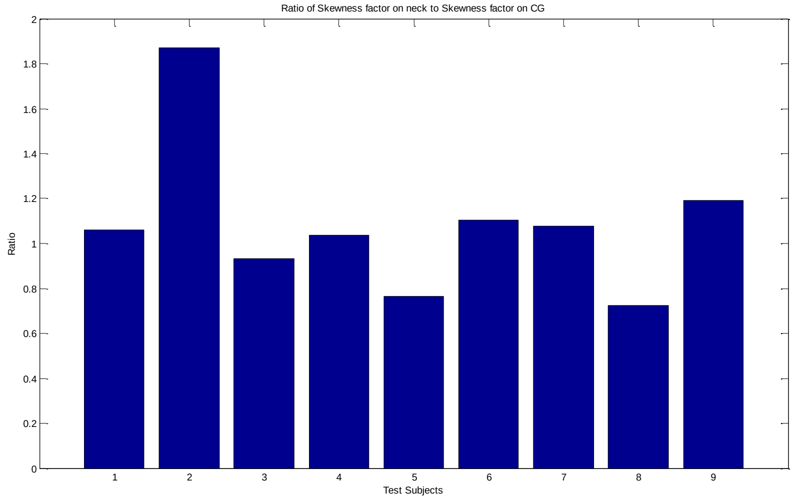

Figure 9: Ratio of Skewness factor of neck to CG.

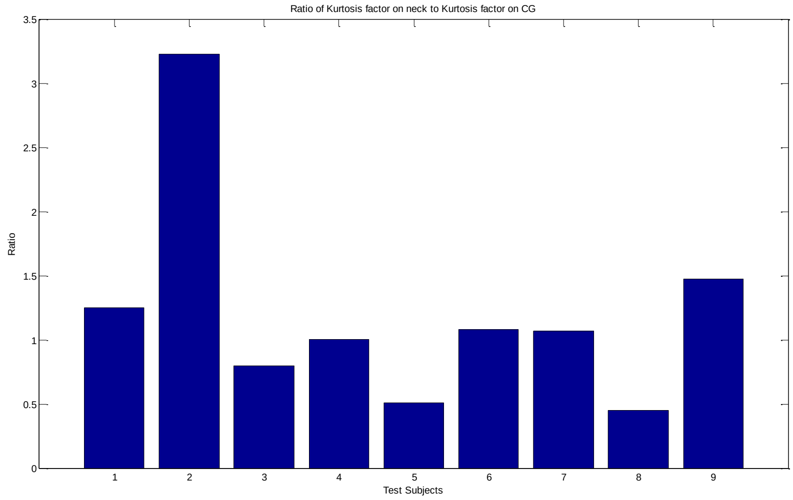

Figure 10: Ratio of Kurtosis factor of neck to CG.

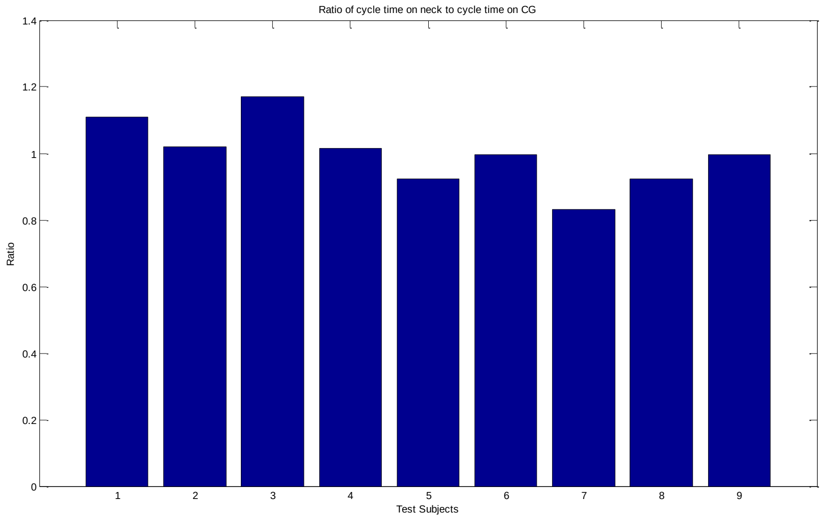

Figure 11: Ratio of Cycle time of neck to CG.

Results and Discussions

The raw data is filtered for noise and then using gravity vector resolution method the angles at each posture are obtained for all 12 cycles. The boxplot representation for the variation of angle for one of the subject's performance is shown in *figure 5*. From the plot it is seen that the person has a consistent repetition of cycles. But this does not give any insights into the transitions between the postures.

The sensor data from the accelerometers mounted on the neck and lower back are decomposed using EMD. The raw data from the sensor and the decomposed 6th IMF is shown in *figure 3*. The decomposed signal represents the complete performance, including the transitions between postures. To analyze the transition, the frequency response of the decomposed signal is obtained. *Figure 4* represents the frequency response of the IMF using fast Fourier transform.

Figure 6 & 7 represents the skewness and kurtosis value of frequency response obtained from sensors placed on neck and the CoM of the body respectively. A larger skewness value indicates the lack of symmetry in the response curve and kurtosis indicates the sharpness or peakedness. Here the kurtosis factor here plays a major role in determining the gracefulness of the movements. If the frequency response has a sharper peak then the kurtosis factor would show a larger value indicating that all the cycles were done smoothly without any changes in between.

For a better understanding of the performance the ratios of the statistical parameters for neck and CoM are obtained and plotted in *Figure* 8 & 9. Ideally both the neck and the CoM must have very close statistical values, which means that ratio must be close to one for a good performance. Values more than one indicate that the person is moving his/her neck more than the CoM and if it is less than one then it means that the person has performed the experiment with more bending of CoM than the neck. *Figure 10* shows the ratio of cycle time between neck and CG. While the experiment was performed, it was visually observed that few subjects moved their neck and hip and different speeds. This is clearly seen in few of the subjects in the plot. The majority have very good synchronization of speed between their head and trunk.

Conclusion

From *Figure*8 & 9 we can see that for a good graceful performance of sun salutation the ratio of statistical parameters must be closer to one. Many of the subjects have the Kurtosis ratio lesser than one indicating that their bending of hip/ CG position is not enough and it needs to improved. This paper has shown a very simple yet effective way to quantize sun salutation. It also shows that exercises like sun salutation and other repetitive exercises can be quantized using two low cost tri-axial accelerometers instead of high cost motion capture system. The use empirical mode decomposition in analysis of sensor data is very clearly explained in the paper. This method can serve as a handy tool for instructors and students to self-evaluate their performance. The experiment provides a platform for wireless monitoring of the exercises. In future the results from the wireless sensors can be sent to a mobile phone through Bluetooth® connection, and then the same can be transmitted to an expert for his opinion on the performance. Also the data can be logged for periodic assessment of the performance and this provides a chance for better performance, enjoying more health benefits and avoiding any injuries due to imperfect practice.

References

1. S. Patil, A. Pawar, A. Peshave, A. N. Ansari, and A. Navada, “Yoga tutor visualization and analysis using SURF algorithm,” in Control and System Graduate Research Colloquium (ICSGRC), 2011 IEEE, 2011, pp. 43–46.
2. W. Wu, W. Yin, and F. Guo, “Learning and Self-Instruction Expert System for Yoga,” in Intelligent Systems and Applications (ISA), 2010 2nd International Workshop on, 2010, pp. 1–4.
3. Motion analysis of sun salutation using magnetometer and accelerometer Omkar S N, Mour M, Das D - Int J Yoga.” [Online]. Available: http://www.ijoy.org.in/article.asp?issn=0973-6131;year=2009;volume=2;issue=2;spage=62;epage=68;aulast=Omkar. [Accessed: 17-Jan-2014].
4. K. J. O’Donovan, B. R. Greene, D. McGrath, R. O’Neill, A. Burns, and B. Caulfield, “SHIMMER: A new tool for temporal gait analysis,” in Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE, 2009, pp. 3826–3829.
5. R. E. Mayagoitia, A. V. Nene, and P. H. Veltink, “Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems,” J. Biomech., vol. 35, no. 4, pp. 537–542, 2002.
6. R. Zhu and Z. Zhou, “A Real-Time Articulated Human Motion Tracking Using Tri-Axis Inertial/Magnetic Sensors Package,” IEEE Trans. Neural Syst. Rehabil. Eng., vol. 12, no. 2, pp. 295–302, Jun. 2004.
7. W. Dong, K. Y. Lim, Y. K. Goh, K. D. Nguyen, I.-M. Chen, S. H. Yeo, and B.-L. Duh, “A low-cost motion tracker and its error analysis,” in Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on, 2008, pp. 311–316.
8. J. Morlet, G. Arens, E. Fourgeau, and D. Glard, “Wave propagation and sampling theory-Part I: Complex signal and scattering in multilayered media,” Geophysics, vol. 47, no. 2, pp. 203–221, 1982.
9. S. N. Omkar, K. Vyas, and H. N. Vikranth, “Time-frequency analysis of human motion during rhythmic exercises,” in Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE, 2011, pp. 1279–1282.
10. S. U. F. F. Transform, “A Comparitive Study on Performance Analysis of Sun-Salutation Using Fast Fourier Transform, Wavelet Transform and Hilbert-Huang Transform.”
11. N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H. H. Shih, Q. Zheng, N.-C. Yen, C. C. Tung, and H. H. Liu, “The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis,” Proc. R. Soc. Math. Phys. Eng. Sci., vol. 454, no. 1971, pp. 903–995, Mar. 1998.
12. A. AYENU-PRAH and N. ATTOH-OKINE, “A CRITERION FOR SELECTING RELEVANT INTRINSIC MODE FUNCTIONS IN EMPIRICAL MODE DECOMPOSITION,” Adv. Adapt. Data Anal., vol. 02, no. 01, pp. 1–24, Jan. 2010.
13. Z. K. Peng, P. W. Tse, and F. L. Chu, \A comparison study of improved Hilbert{Huang transform and wavelet transform: Application to fault diagnosis for rolling bearing," Mech. Syst.Signal Process., vol. 19, no. 5, pp. 974{988, Sep. 2005.
14. D. Kim and H.-S. Oh, “EMD: A package for empirical mode decomposition and hilbert spectrum,” R J., vol. 1, no. 1, pp. 40–46, 2009.
15. M. P. Bhutkar, V. M. Bhutkar, B. G. Taware, V. Doijad, and B. R. Doddamani, “Effect of suryanamaskar practice on cardio-respiratory fitness parameters: A Pilot Study,” Al Ameen J Med Sci, vol. 1, no. 2, pp. 126–129, 2008.
16. J. M. de Sá, Applied Statistics: Using SPSS, Statistica and Matlab. Springer, 2003.
17. T. A. C. M. Claasen and W. F. G. Mecklenbr□auker,\The Wigner distribution|A tool for time-frequency signal analysis,"Philips J. Res., Vol. 35, pt. I, pp. 217{250; pt. II, pp. 276{300;pt.III, pp. 372{389, 1980