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Mathematical Modeling of Kandyan Dancing

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Abstract— Kandyan dancing is the traditional dance of Sri Lanka which performs an important role in the culture of Sri Lanka. The main building blocks of Kandyan dancing are Pa Saramba and Goda Saramba, which assist the dancers to improve their body movement techniques used in Kandyan dancing.

Goda Saramba consists of 12 sequences of hand and leg movements. Each of these movements can be analysed by considering them as a discrete sequence of joint angle variations at thw spine shoulder, shoulders, elbows, wrists, spine base, hips, knees and ankles. This article describes the modeling of the first Goda Saramba under the rhythm Wilamba using Discrete Fourier Transform. Therefore, the data on a cycle of first Goda Saramba was gathered from Pahim Path qualified Kandyan dancers for 10 trials using Kinect V2 device.

Then, the obtained data sequence at an angle was transformed into a frequency domain using Discrete Fourier Transform and the amplitude spectrum was constructed. It reveals remarkable results on variation of the angle. The average fundamental amplitude of the amplitude spectrum for an angle is approximately equal to the magnitude of that angle at the basic posture of Kandyan dancing. Furthermore, the amplitudes of the second to eight harmonics of lower body angles reveal information on basic postures of the first Goda Saramba.

Additionally, the effect of Body Mass Index on the constructed amplitude spectrum was investigated, and the only effect of Body Mass Index was on the amplitude spectrum of the spine base.

Keywords—Kandyan dancing; Discrete Fourier Transform; Goda Saramba; Posture errors; Mathematical Modeling; Body Mass Index

I. Introduction

Dancing has become a major part in special events of life today. Though it is difficult to access the history of dancing due to the unavailability of clearly identifiable physical artifacts, it is believed that it has been developed from the beginning of each worldwide culture as a method of healing and as a mode of transferring emotions, ideas and feelings [1].

"Kandyan dancing" (also called "Udarata dancing"), which originated 2500 years ago, is considered as the traditional dance of Sri Lanka [2]. The roots of Kandyan dancing have gone deeper such that it is performed in almost every cultural event in Sri Lanka, and many are practicing to become professionals in Kandyan dancing.

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At the early stages of the learning process of Kandyan dancing, it teaches how to evolve and develop the expressions of the limbs. The basic posture of Kandyan dancing is known as Mandiya, and it is depicted in Fig. 1. Expression of the limbs in Kandyan dancing is developed through Pa Saramba and Goda Saramba. Pa Saramba is used to develop the lower body movements (footwork) of an amateur dancer, and there are 12 Pa Saramba in Kandyan dancing. Goda Saramba is used to develop the hand movements of an amateur dancer by combining 12 Pa Saramba with 12 hand movements [3].

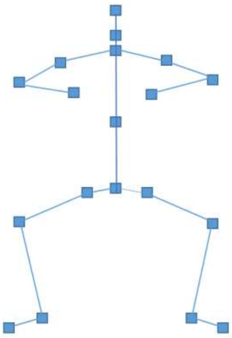


Fig. 1. Basic posture of Kandyan dancing

A student engaged in Kandyan dancing should learn and practice all these Pa Saramba and Goda Saramba according to three rhythmic skills, namely *Wilamba, Madya* and *Drutha*. The speed of the dance is increasing according to the three rhythmic skills, respectively. One who mastered 12 Pa Saramba and 12 Goda Saramba was able to practice *Vattam,* the traditional circular dance compositions, and *Vannam* the main 18 dances which depict the elegant movements of birds and other majestic animals [4].

A student who trained in Kandyan dancing for a period of 10 – 15 years will be considered as a fully-fledged Kandyan dancer after his or her graduation ceremony. This graduation ceremony for male dancers is known as *Ves Bandima* and for females, it is *Pahim Path Thabima*. Then the Ves dancers and Pahim Path qualified dancers are considered as the professional Kandyan dancers and they are allowed to teach Kandyan dancing to the next generation [2].

Technically, dancing can be considered as a combination of signals arising due to the variations occurring in joint angles. Therefore, this article reveals a method of analyzing the first one of the Goda Saramba (1st Goda Saramba) of Kandyan dancing as a combination of joint angle signals.

II. Theoretical Background

Discrete Fourier Transform (DFT) is the technique which is used to convert a discrete signal in the time domain to the frequency domain. This technique can be used to decompose a complex signal into simpler parts to facilitate the analysis [5]. For periodic discrete signal x(n) where n is the sample number from N samples, which represent complete one cycle can be Discrete Fourier Transform by using the equation (1).

$$X(n) = \sum_{k=0}^{N-1} x(k)\, e^{\left(-\frac{2\pi ikn}{N}\right)} \tag{1}$$

And, obtained frequency domain function can be converted into discrete time domain signal using the inverse Fourier Transform.

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)\, e^{\left(\frac{2\pi ikn}{N}\right)} \tag{2}$$

Here, X(i) represents the frequency domain function [6].

The obtained simpler parts may contain amazing information about the properties of time domain signals in real world problems. The DFT coefficients in the frequency domain consist of complex value numbers for real valued discrete time domain signals. For convenient analysis, the harmonic analysis which uses the amplitudes of the DFT coefficients as a spectrum can be used. The amplitudes of the DFT coefficients can be calculated by using the below equation (3).

$$|X(n)| = \sqrt{Re^2[X(n)] + Im^2[X(n)]} \quad (3)$$

Here, *Re[X(n)]* and *Im[X(n)]* are the real and imaginary parts of the X(n). In practice, the efficient algorithm Fast Fourier Transform (FFT) has been used for DFT.

III. METHODOLOGY

3.1 Data Collection

Five Pahim Path qualified female dancers between 24-26 years, with no broken limbs or genetic bone issues in lifetime were selected for data collection. Their weight and height range are selected to be 45-75 (kg) and 150 – 160 (cm) respectively. The small sample size is due to the inaccessibility of the dancers during the pandemic situation. The dancers performed the first Goda Saramba against the gold standard performance for 10 trials. On each trial the 3D space coordinates for joints; hand tip, hand, elbow, shoulder, spine shoulder, spine base, hip, knee and ankle were gathered using sensor Kinect version 2 and the supporting software Kinectron. Then, the angles were computed using these 3D space coordinates and the variations of each angle obtained as a discrete finite sequence of data.

3.2 Modelling First Goda Saramba

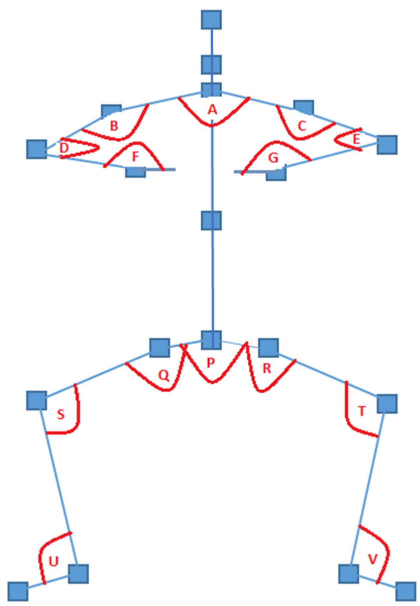


Fig. 2. Joint angles at basic posture

A cycle of first Goda Saramba, provided variations of the angles at joints (14): spine shoulder (A), right shoulder (B), left shoulder (C), right elbow (D), left elbow (E), right wrist (F), left wrist (G), spine base (P), right hip (Q), left hip (R), right knee (S), left knee (T), right ankle (U) and left ankle (V), and these angles at the basic posture of Kandyan dancing are depict in Fig. 2. These joints are used to model the upper and lower body movements and variations of angles. The first 7 of 14 joints are used for the upper body, the remaining for lower body.

For each angle, a 1D DFT amplitude spectrum was constructed using a program written with the help of the mathematical software MATLAB. This construction was based under the assumption that the occurrence of movements in left and right body joints are independent. The domain signal was first interpolated up to 512 data points by using Spline interpolation, and then converted to frequency domain using FFT. The obtained DFT coefficients were used to obtain the amplitude spectrum for the variation of a given angle. Furthermore, the basic features of the first Goda Saramba (Fig. 3.) were identified through the means of the DFT amplitude spectrum. They were extracted angle wise. i.e., for a given angle, the data points of the basic features dho(1), mi, ki(1), tha(1), ki(2), tha(2), dho(2) and the starting position were identified using step by step increasing Kinect V2 recordings. For example, the identified basic features for the left knee were shown in Fig. 4.

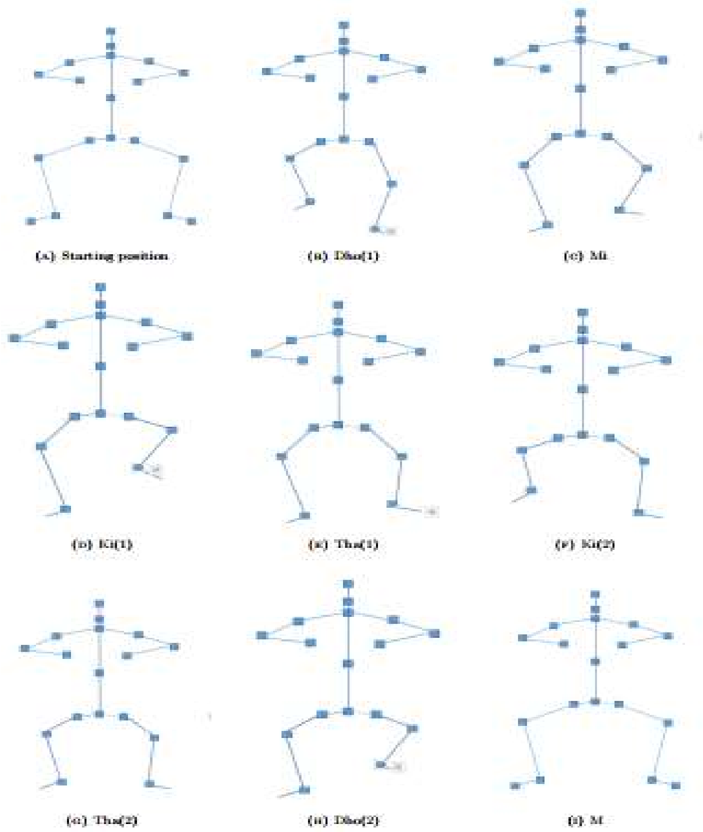


Fig. 3. Basic features of first Goda Saramba

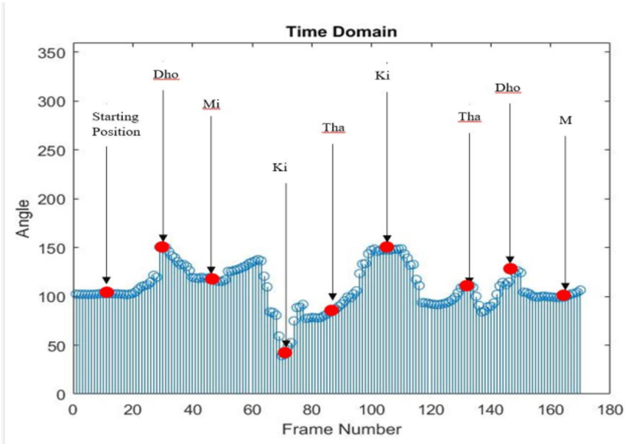


Fig. 4. Basic features for the left knee

Then, the obtained data sequence was decomposed into sub-data sequences of around 10 data points forward and 10 data points backward from the identified features. This constructed sub discrete time-domain signal was interpolated up to 512 data points using Spline interpolation and then converted to frequency domain using FFT. Then the amplitude spectrum for each feature for a given angle was constructed and compared with the amplitude spectrum obtained for the respective angle by considering the whole cycle of the first Goda Saramba. This comparison was used to recognize the features of the first Goda Saramba using the FFT amplitude spectrum for each angle.

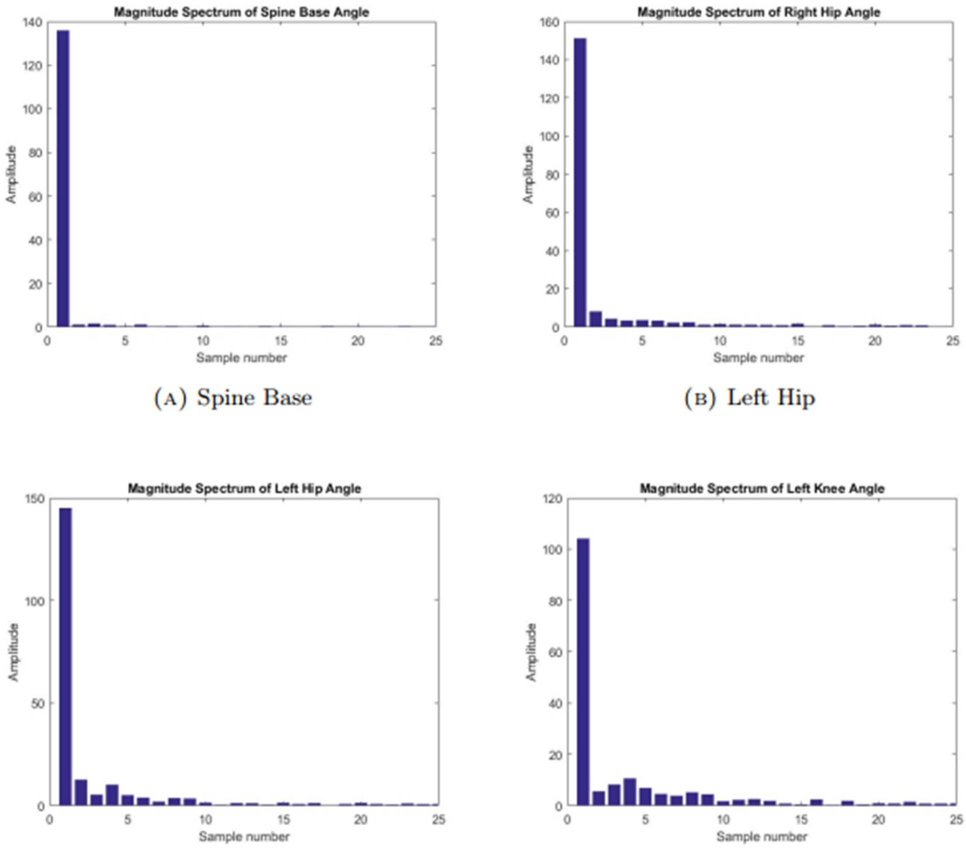
3.3 Impact of BMI on the Constructed Gold Stand Performance

The DFT amplitude spectrum between dancers with varied BMIs were analyzed and compared. For this analysis, the observations obtained via. the variation of angles and cross-correlation between the time domain signals of some dancers with varied BMIs were considered.

IV. RESULTS AND DISCUSSION

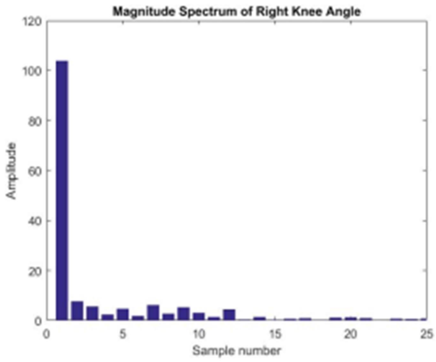
4.1 Modeling the Gold Stand Performance of First Goda Saramba

The gold stand performance model involves FFT amplitude spectrums obtained for 7 upper body angles (Fig. 5.) and 7 lower body angles (Fig. 6.). The considered upper body angles are spine shoulder; right and left shoulders, elbows and wrists while lower body angles are spine base; right and left hips, knees, and ankles.

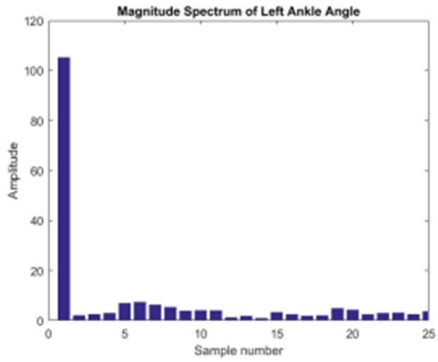


(A) Spine Base (B) Left Hip

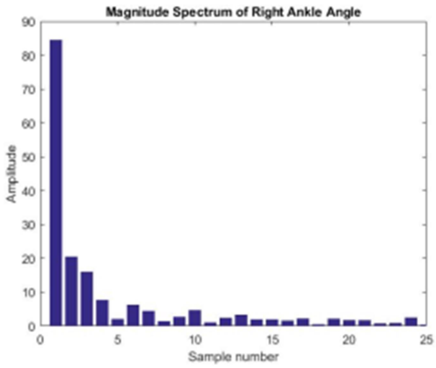
(C) Right Hip (D) Left Knee



(E) Right Knee

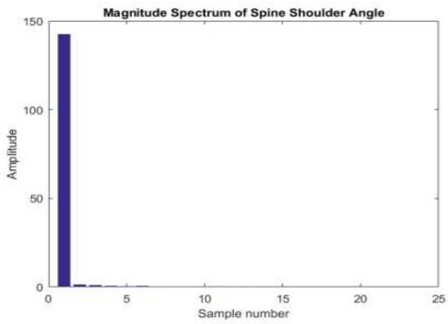


(F) Left Ankle

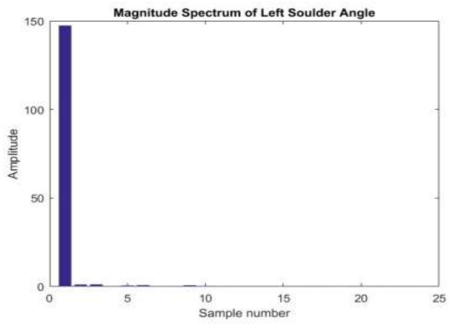


(G) Right Ankle

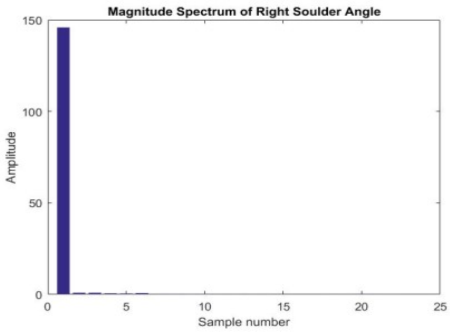
Fig. 5. First 25 amplitudes obtained for each lower body angles



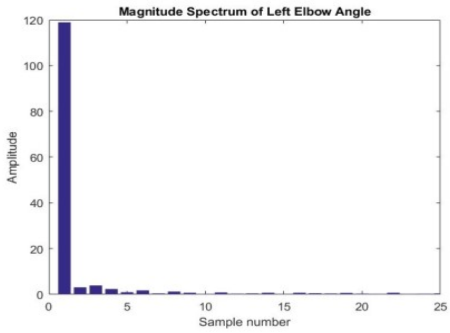
(A) Spine Shoulder



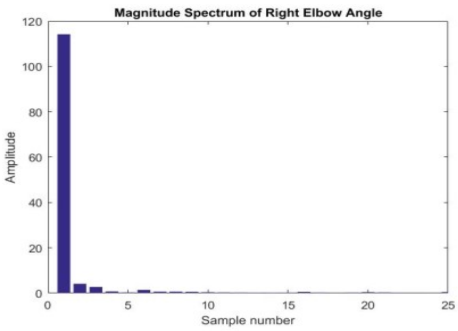
(B) Left Shoulder



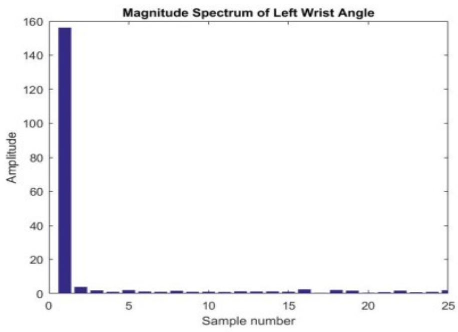
(C) Right Shoulder



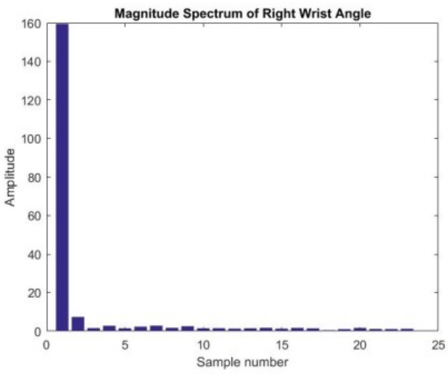
(D) Left Elbow



(E) Right Elbow



(F) Left Wrist



(G) Right Wrist

Fig. 6. First 25 amplitudes obtained for each upper body angles

In Kandyan dancing, the magnitude of each angle varies around the basic posture. It was identified that the average amplitude of the fundamental frequency of each angle is approximately equal to the magnitude of the angles in the basic posture. This relationship is numerically represented in TABLE I.

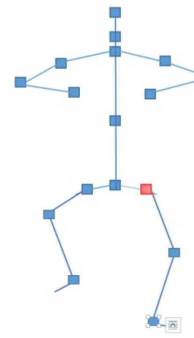
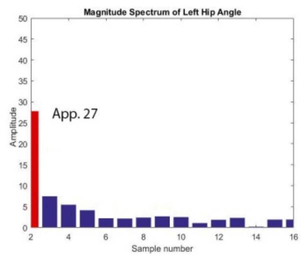
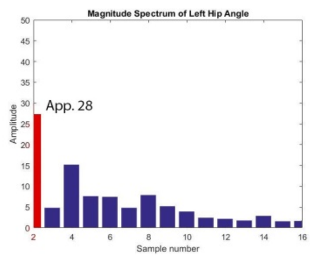
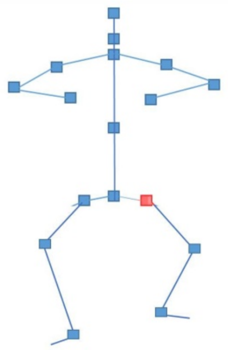
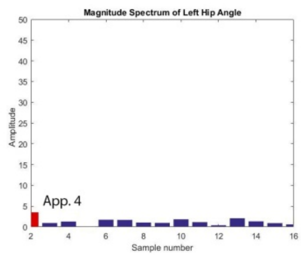
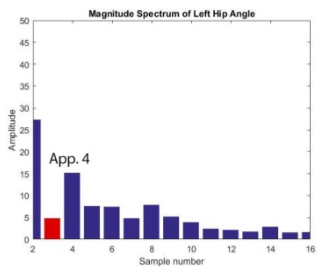
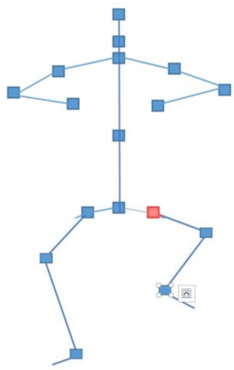
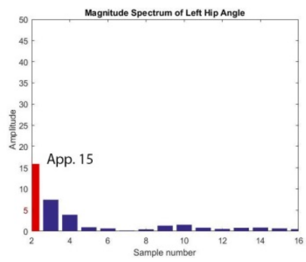
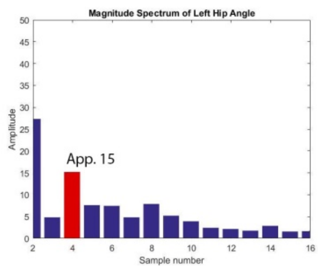
Table I. Comparison Of Magnitude Of Angles In Basic Posture Vs. Amplitude Of Fundamental Frequency

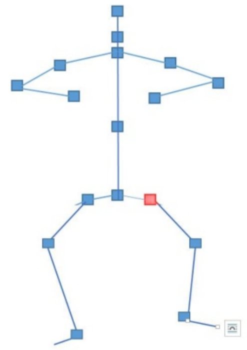
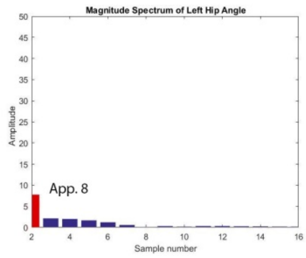
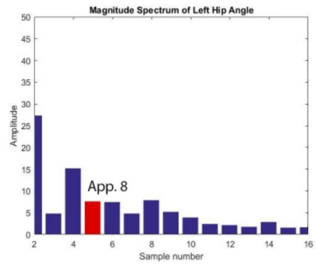
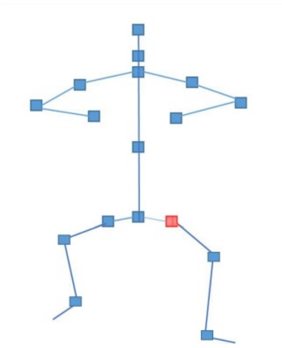
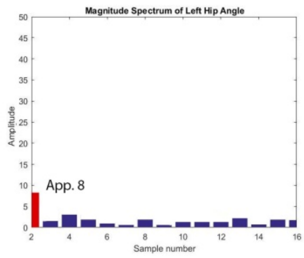
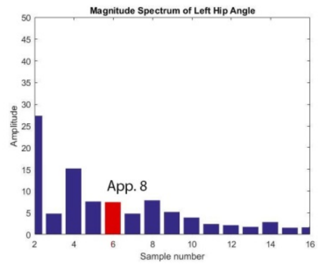
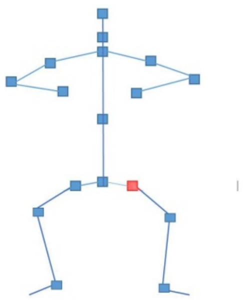
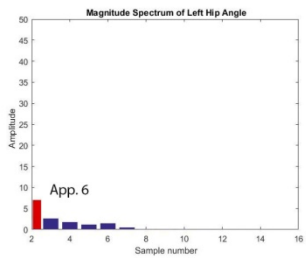
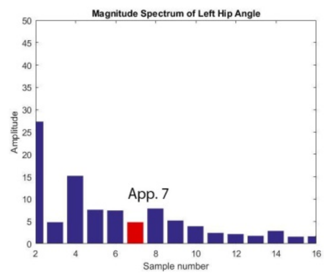
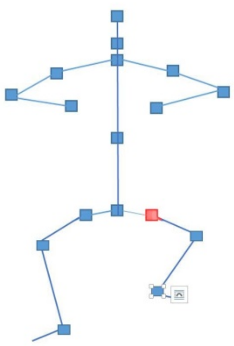
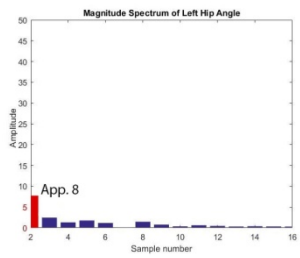
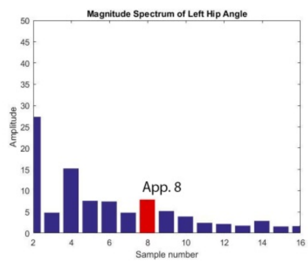
Angle	**Approximate magnitude of the**	**Amplitude of the fundamental frequency obtained for**
Spine Base	140^0	138.4756
Left Hip	145^0	139.1715
Right Hip	145^0	149.4118
Left Knee	105^0	108.1202
Right Knee	105^0	103.9304
Left Ankle	85^0	88.3015
Right Ankle	85^0	100.5934
Spine	145^0	145.6390
Left Shoulder	150^0	149.2547
Right	150^0	148.8326
Left Elbow	120^0	119.7663
Right Elbow	120^0	115.4720
Left Wrist	160^0	159.0853
Right Wrist	160^0	157.4183

Since, in first Goda Saramba it involves only rotations in hand movements throughout the first Goda Saramba the considered angles at spine shoulder, left shoulder, right shoulder, left elbow, right elbow, left wrist and right wrist were kept as a constant. Therefore, the amplitude spectrum for each of these angles consists of the only significant amplitude of the fundamental. The same result is obtained for the lower body angle at the spine base as it doesn't provide significant variations during the first Goda Saramba.

For lower body angles such as right and left hips, knees, and ankles, the lower frequency components of the amplitude spectrums reveal appreciable information on basic postures of first Goda Saramba. Commencing from amplitude of the 2^{nd} harmonic up to the 8^{th} harmonic, it provides clues on angles at the features dho (1), mi (1), ki (1), tha (1), ki (2), tha (2) and dho(2) respectively. Table II represents the relevant results for the left hip.

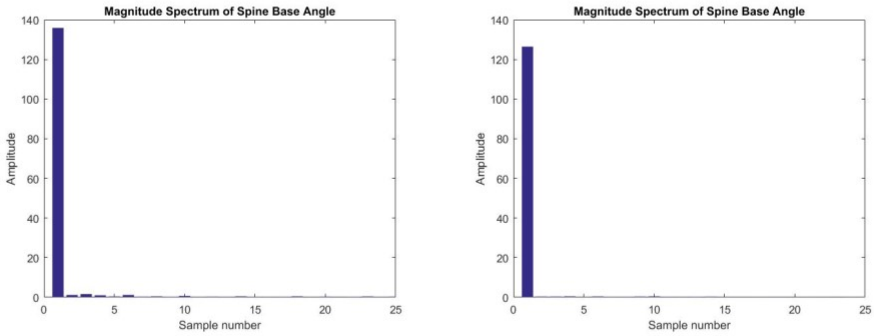
Table II. Identification Of Basic Features In Left Hip Angle

Angle	Posture	FFT amplitude spectrum from 2nd harmonic for sub signals around the posture	FFT amplitude spectrum from 2nd harmonic for first Goda Saramba
Dho (1) (90^0)			
Mi (1) (140^0)			
Ki (1) (110^0)			

Tha (1) (130^0)			
Ki (2) (135^0)			
Tha (2) (140^0)			
Dho (2) (135^0)			

4.2 Impact of BMI on FFT Amplitude Spectrums

Except for the amplitude spectrum of spine base angle, any other amplitude spectrums obtained for professional dancers at the considered joints didn't show a significant difference. The significant difference obtained in amplitude spectrum at the joint spine base is also raised in between the fundamental amplitudes obtained for the dancers with normal BMI and the dancer with overweight BMI. The angle at the spine base (P) (in Fig. 2.) of the dancers with normal BMI is approximately 140° while it was 120° with the overweight BMI dancer (Fig. 7.). A Cross-correlation comparison between the time domain signals with respect to BMI is shown in TABLE III.



(A) Spine Base (normal BMI) (B) Spine Base (over weighted BMI)

Fig. 7. Effect of BMI on FFT amplitude spectrum

Table III. Cross-Correlation Comparison Between The Time Domain Signals With Respect To BMI

Angle	**Cross-correlation between the dancers with normal BMI**	**Cross-correlation between the dancers with normal BMI and overweight BMI**
Spine Base	0.9186	0.8261
Left Hip	0.9007	0.7994
Right Hip	0.8661	0.8254
Left Knee	0.8473	0.8105
Right Knee	0.7916	0.7235
Left Ankle	0.8274	0.7839
Right Ankle	0.7381	0.7482

V. CONCLUSION

The amplitude spectrums for the upper body angles consist with significant amplitude only for the first harmonic. The value of this harmonic approximately represents the magnitude of each angle kept throughout the dance. The FFT amplitude spectrums for the lower body angles elaborate on the variations of leg movements of the first Goda Saramba. The first harmonic represents approximately the value of each angle in the basic posture of Kandyan dancing. The significant amplitudes obtained from the second harmonic to the eighth harmonic of the amplitude spectrums for each lower body angle except for the spine base, provides the information related to the basic features of the first Goda Saramba. The amplitude spectrum for spine base angle consists of significant amplitude only for the first harmonic. The value of this harmonic approximately represents the magnitude of that angle kept throughout the dance. The only difference identified was between the fundamental amplitude of the FFT amplitude spectrum of the spine base for the dancer with normal BMI and the dancer with overweight BMI.

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