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Generating believable Gait Patterns for Quadruped Locomotion using Fourier Analysis

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Abstract: In animation attaining a realistic gait pattern for a virtual quadruped character is very time-consuming for the animator. This research provides a prototype system for creating an initial layer of natural-looking animation to serve as a starting point for an animator. Starting with a reference video of an actual Tiger's walking, joints are animated to create a rotoscoped animation. This animation represents the animal's natural motion achieved manually through the keyframe technique, which contains numerous errors in the form of inaccurate motion curves. Joint angle values for the legs are sampled per frame of the animation and conditioned for Fourier analysis. FFT Fast Fourier Transform provides frequency information that is used to create mathematical descriptions of each joint's movement. Using this Fourier Analysis, the animation curves are optimized to generate a more believable and natural looking animation curves.

Keywords: Fourier Analysis, Quadruped Locomotion, Fourier Series, Gait Patterns;

I. Introduction

The use of Animation is gaining immense popularity in the field of technology and with the rapid development in animation industry, different techniques are used to generate animation automatically through different techniques to rapidly produce character animaton to be used in animated movies [1]. The animation is a process in which images are manipulated to look as moving objects . Animation means to be able to bring a 3D virtual object to life, using computers. Animation is a process, in which we simulate the dynamic attributes of a virtual object with a real object [2][3]. Quadruped animation is becoming a popular feature within animated live-action films such as The Chronicles of Narnia [2], the Shrek and Madagascar series, and in video games such as Red Dead Redemption, Cabela's African Safari, and Assassin's Creed [4]. Creating a realistic walking animation pattern using a keyframe is a time-consuming process, For creating reliable gait patterns, real character motion needs to be studied. This research defines an innovative system for the walking gait pattern of a tiger using video reference and optimizing the animation curves using Fourier Analysis.

In animation, if we have to create a one-second video it will contain 24 frames. Similarly, if we are going to create a 10 second video it will consist of 240 frames, it means we have to create 240 frames for 10seconds video this is very times consuming process. The animator traditionally uses the keyframe animation technique, in which the animator only uses key poses or mainframes where the change in position of the object occurs. In these techniques, the animator took 5 to 8 frames instead of 24 but there is a gap between frames. In Maya, these gaps mean inbetween frames, which are automatically generated but they are not smooth. This is the main problem and research gap that the animation curves generate manually are not accurate and contain lots of noise. Due to which the graph between each frame in Maya is not perfectly smooth and accurate, resulting in sloppy and non-believable animation. Thus, in this research work, the optimization of these generated curve values of animation is optimized and corrected using the Fast Fourier Transform (FFT). This problem is highlighted in Figure 1.

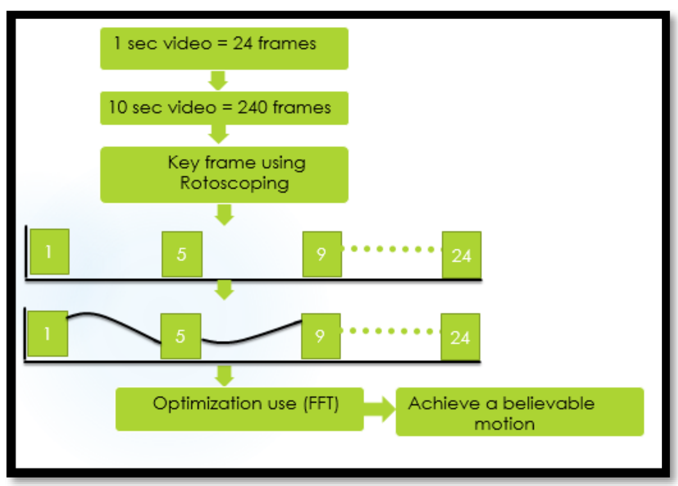

Figure I: Animation process using keyframes.

Each rotation value of the tiger's joint was considered as a periodic signal. The angle between the rotation of each joint are varying over time. The motion of each joint was observed using FFT (Fast Fourier Transform). FFT is an advance version of DFT which allows us to view and analyze the signal in the frequency domain. Signal can easily represent significant frequencies.

II. Literature Review

Quadruped Animation is addressed by multiple other techniqes from Physics Based approach [5] [6]–[10] to Data Drieven approach using Mocap or Template based precalculated data [11] [12][13][14], Kinematics based procedurally driven animation [15][16][17][18][19][20].

However, Fourier analysis refers to the process of decomposition of signal this term is also known as Fourier transform. It also represents the sinusoidal function in complex signals [Wikipedia].

The work done by S. Cureton used the Fourier Analysis on quadruped horses to generate the believable patterns of walk gait [21]. They apply the FFT over the motion curves generated from Sampling the curves extracted from the rotoscoped animation. Another technique called Fourier analysis is used to create an illustrative model for gait motion. Hoffmann and Düffer's research [22] states that Fourier analysis can drive the controller command and generate space model for frequency for a four-legged character.

Unuma et al. described a similar approach of unique human figure locomotions were modeled through Fourier expansions for actual human behaviors. The method shows the running and walking realistically and smoothly, and they have also defined the procedures for creating an ironic difference in human walk [23]. Mr. Duffert and Jan Hoffmann [5] Developed a model for Improving the walk for four leg robots using a genetic algorithm. Mr. Muneteshi et al [24]. Applied Actual human behavior on animation using Fourier principal. They controlled the step-length speed and hip Position and got the desired animation. Mr. Torko et al. [25] used a trajectory optimization algorithm to the synthesis of quadruped motion optimization problem can be solved efficiently and strongly Results include walking, jumping and running of quadrupeds.

III. METHODOLOGY

The purposed system methodology is segregated into 3 main phases as shown in Figure 2. In phase-I, the rotoscoping based sampling of Locomotion data is done. In Phase-II, the FFT based sampling of the motion curve is done to achieve optimized curves for believable animation. In the last 3rd phase, the optimization values are applied through synthesizing the gait patterns on the 3D characters.

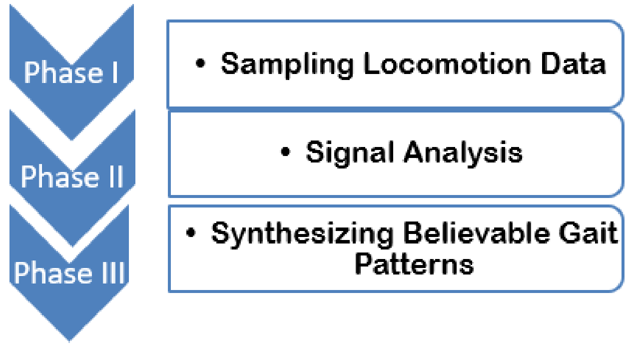

Figure 2: Three phases of Research

A. Sampling Locomotion Data:

Sampling means to pull out raw data. In this phase, we extracted animation of quadruped character, using a rotoscoped technique that shown the tiger's real motion. Using real video reference, the locomotion data has been sampled for walking tiger. Video has provided a side view of the tiger. The side view showed the perfect information about each leg's joint motion [26]. The rotation and translation of each leg's joints have been done using a sagittal view of the tiger. Tiger has a symmetrical nature for walking gait. One side view has provided enough information for all four legs. The video has been converted into frames and imported into Maya and joints have Traced over video frames. Each joint's value has been sampled per frame for the front and rear legs. Each joint's wanted signal value is calculated and stored into an excel file. The output sampled values are preparing the conditioned for Fourier analysis.

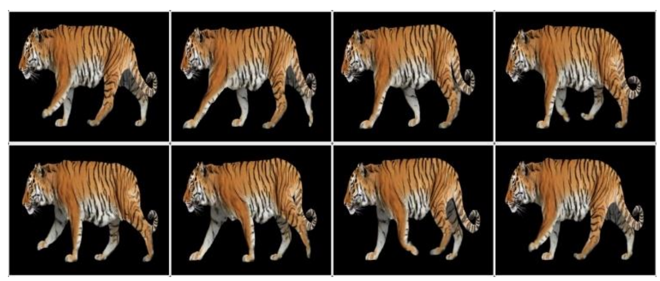

Figure III: Extracting video in an image sequence

The footage of a real tiger's motion was extracted into still images sequence then imported it into Maya 2018 as shown in Figure 3. Which show the image plane of an orthogonal camera [27].

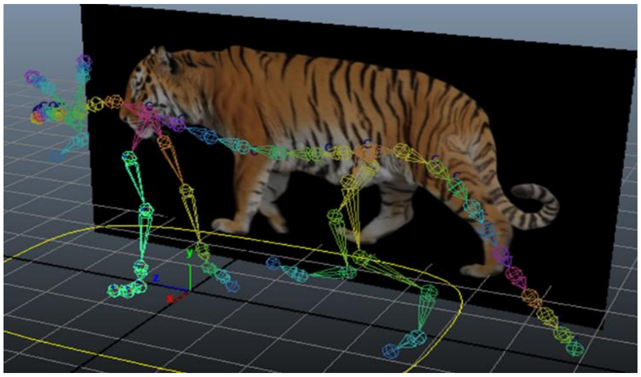

Figure 4: Rotoscoping did use Maya 2018.

The forward kinematic joint chains of front and rear legs were created using Maya's joint tool [28] as shown in figure 4. Skeletal Hierarchy made by the joints called the skeleton of a virtual character [23]. According to Maya online documentation skeleton is a hierarchical articulated structure of joints. It provides a contort model that is similar to the skeleton of the human body.

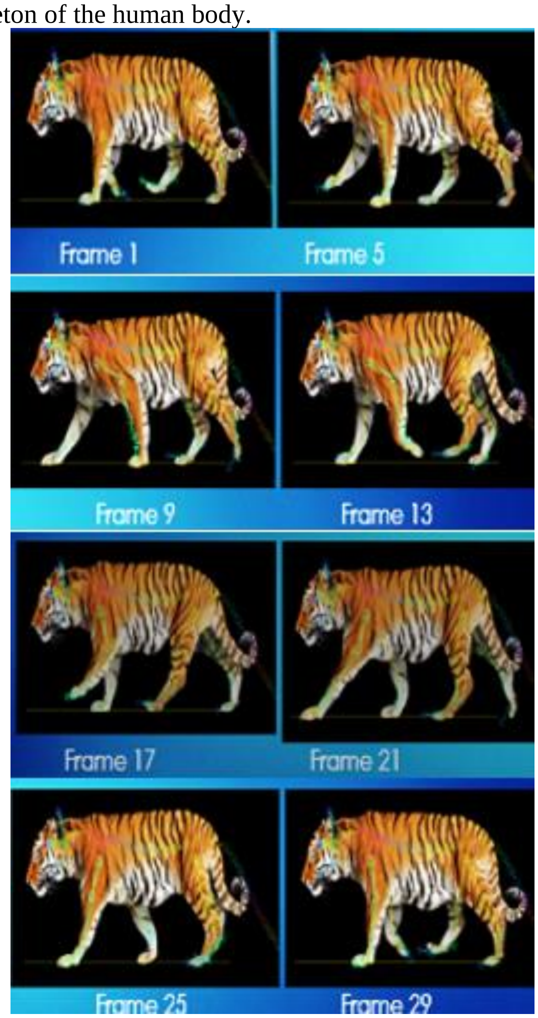

Figure 5: Front and rear leg joints separately animated over the real tiger's frame.

In this part of the research, joints could be assumed as tracing objects for producing as rotoscoped animation. Each joint was animated manually. Figure 5 shows the method of matching the joints with real image joints.

B. Signal Analysis:

The process of extracting raw data from rotoscoped animation is known as sampling, which represents the natural motion of the tiger. The desired motion value of each joint is calculated from rotoscoped animation stored in an excel file. The motion of each joint based on rotation which determines the orientatin of each joints angle. To develop a model for a believable gait pattern it is necessary to sample the appropriate value of each joint angle, which is obtained in Vector form as shown in Figure 6.

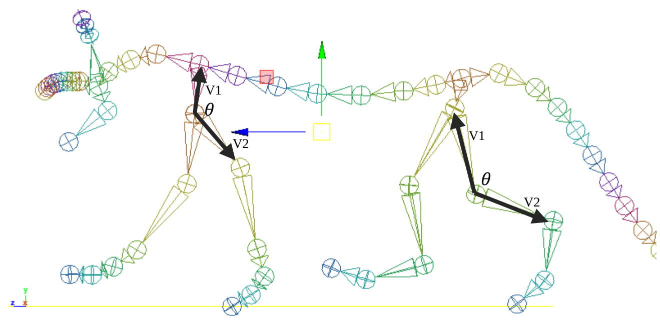

Figure 6: Quadruped Joint Vector calculation

$$\theta = cos^{-1}\left(\frac{V_1.V_2}{|V_1|\,|V_2|}\right) \quad (1)$$

$$V_3 = V_1 \times V_2 = (V_1, V_2, V_3) \quad (2)$$

If $V_{3z} < 0$,
$\theta = \theta$

If $V_{3z} \geq 0$,
$\theta = 2\pi - \theta$

In the above equations (1) calculation of each joint angle is shown. To determine the position (angle) of two vector dot product is used, and to confirm the side of joint calculation we use the cross product. Less than 180-degree angle is returned in dot product, but this was a problem for calculating the joints value, then the cross product was the solution. Using the cross product of two vectors angle was calculated with the dot product. It was also ensured that the proper angle was calculated by using a cross products. The values of the resulting vector were inserted in a text file.

This process is concerned with the signal generation. In this phase the signal for each joint motion is analyzed for creating a mathematical model. Initially, each joint's value has ben unsampled. Then Fast Fourier Transform has been applied to unsampled value for getting the information about the signal in the frequency domain. The output result helped to understand better that which frequency is more valuable within a given signal. The result has been used in truncated form Fourier series to approximate the mathematical expression for the signal. This process has been applied on the front and rear parts of the tiger's joints. The output of this phase used as input in the next phase.

Front Leg Joints Value

Frame Number	Shoulder	Elbow	Knee	Ankle
1	0.7616506	3.54861	3.080954	4.046707
2	1.0410433	3.66536	3.08209	4.009523
3	1.2749915	3.75994	3.085288	3.915292
4	1.4709016	3.83237	3.090229	3.790032
5	1.6666128	3.88269	3.096589	3.659798
6	1.8170754	3.9168	3.104057	3.517801
7	1.8772405	3.94194	3.112327	3.351031
8	1.8772405	3.96016	3.121038	3.203212
9	1.8772405	3.97355	3.129599	2.966261
10	1.8772405	3.98416	3.135486	2.804591
11	1.8772405	3.99407	3.151525	2.669314
12	1.8248409	4.00535	3.159016	2.577366
13	1.6957637	4.02006	3.16629	2.543513
14	1.5321914	4.04033	3.172686	2.727906
15	1.3763071	4.06266	3.177811	3.08244
16	1.2264485	4.08071	3.181205	3.553678
17	1.0644223	4.08814	3.182431	3.738063
18	0.9076141	4.03499	3.182431	3.630853

Rear Leg Joints Value

Frame Number	Hip	Stifle	Hock	Ankle
1	1.332163	2.146083	4.524122	3.858226
2	1.172032	2.182177	4.395917	3.932411
3	1.089667	2.269388	4.249427	4.00099
4	1.049971	2.376105	4.129221	4.051371
5	1.017845	2.470713	4.079221	4.070961
6	0.986981	2.552671	4.078939	4.042935
7	0.971132	2.63621	4.078794	3.969071
8	0.965292	2.711869	4.07874	3.864725
9	0.964458	2.770186	4.078733	3.745301
10	1.042762	2.805149	4.175672	3.626249
11	1.228709	2.822966	4.389988	3.522989
12	1.448837	2.832506	4.605211	3.450611
13	1.629686	2.842639	4.703233	3.423404
14	1.77357	2.854193	4.602941	3.440609
15	1.912356	2.86295	4.382747	3.481394
16	2.016948	2.87021	4.163524	3.529251
17	2.058271	2.877273	4.064392	3.567239
18	2.02843	2.8844	4.092517	3.584446

Figure 7: Joints angle values that are inserted into a spreadsheet

In Figure 7: Front and rear leg's joint angle (Theta) values are shown in a Spreadsheet because it can show the data in the form of graphs quickly and easily.

C. Data Conditioning

Conditioning means creating a set of samples that describe the sampled signal and condition for the FFT. It is necessary to offer accurate data about the signal as input it must be periodic, balanced and characterized. The basic purpose of conditioning is to find out the repeated values from sampled joints motion frames. After Conditioning the FFT analyzes signal further

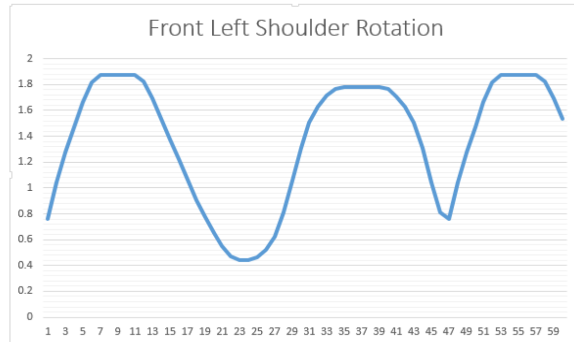

Figure 8: Shoulder rotation signal for sampling.

The motion values of each joint were sampled and inserted into a spreadsheet in Excel. And values were plotted into graphs for the primary stage of analyses shown in Figure 8. Tiger's stride length was observed from the period of each signal. Period length relied on the signal of the motion of each joint.

Figure 9: Stride length for shoulder rotation selected values for repeating

Every adjusted signal needed to keep a reliable period that was equal to the stride length, a signal was selected manually. Figure shows the selected values that have created a specific signal from the original signal. Actually, the aim was to choose those values which resembled with the natural part of the tiger's walk motion. It was found that values were repeated and it guaranteed that the period was accurate and repeated values produced a good prediction for original motion signal value. Few values were changed due to the errors in the sampling process. If data is collected using a highly reliable system just like Mocap we will get more reliable data.

D. Fourier Analysis Phase

Using Fast Fourier transform (FFT), the motion of each joint were sampled. The mathematical functions were created from the result of FFT for each joint of motion. The model for a believable gait pattern also was created by combining mathematical functions. As a result, this chapter will provide the mechanics for generating the synthetic gait pattern. The figure 10 is going to provide an overview of analysis for methodology.

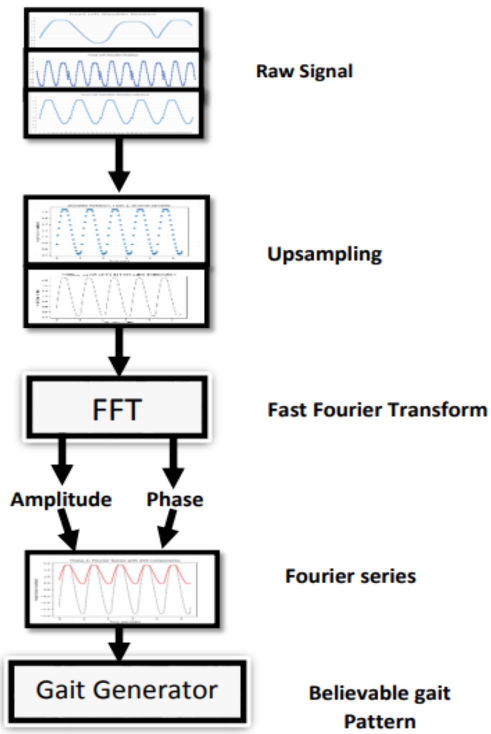

Figure 10: Overview of the analysis process.

To generate reliable results for Fast Fourier Transform motion signals must be in the form of discrete samples attained at a high sampling rate. In this situation, the earlier sampling rate was limited in rotoscope animation, at 24 frames per second.

The number of inputs during calculating the FFT must be a power of two for efficiency. It is known as a radix-2 FFT [29] and its common method for calculating the FFT. By dividing and conquer technique, the radix-2 FFT problem calculated the discrete FFT. Each joint was finally upsampled up to 32768 values for the satisfaction of radix-2. It was equal to the exponent of 15.

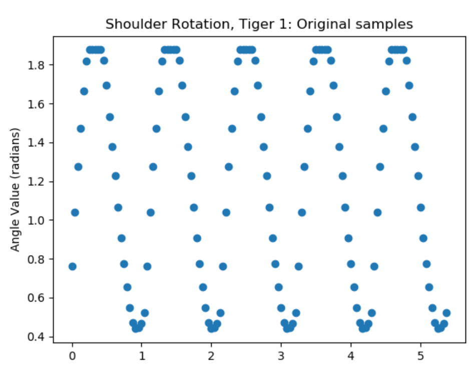

Figure 11: Original samples that are upsampled with 24 frames

In Figure 11, original sampled are shown that are upsampled at 24 frames and it was limited.

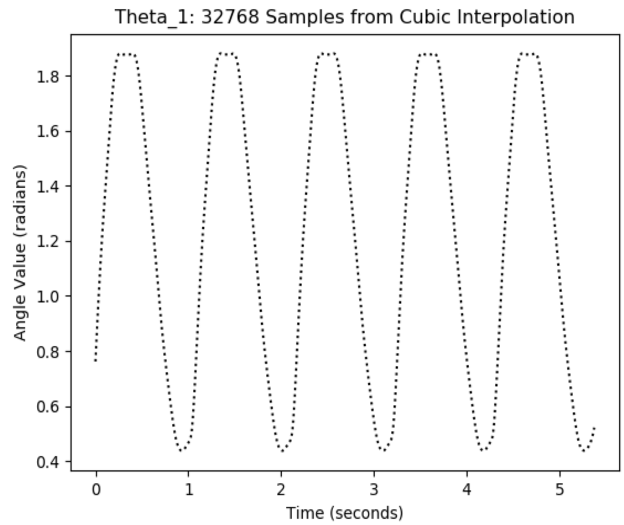

Figure 12: Cubic interpolation upsampled with 32768 samples component.

In Figure, cubic interpolations is shown that is upsampled at a very high rate up to 32768 components. It is a method that predicts a continuous signal between the original sampled points. It is a common method for calculating the FFT [21]. FFT has been calculated, and signal frequency components were obtained using FFT.

E. Analysis with the FFT

The analyzed signal was in the time domain but mathematical model, it is difficult in time domain if partial in the time domain, therefore FFT offered more reliable signal analysis by converting from a time domain to its frequency domain. Mostly Fourier transform receives expression from a time domain into the frequency domain. This provides easy and convenient analysis into the preparation of the signal.

$$\sum_{n=1}^{251} Amplitude \times \cos\left(\omega_{\Delta} \times (n) \times t + Phase\right) \tag{3}$$

The Equation (3) is a Truncated form of the Fourier series, used with 250 frequency components calculated through the FFT results [21]. Frequency information is provided through applying the FFT using the sampled value from the periodic signals. As a result description of the signal was clearly shown for the frequency domain.

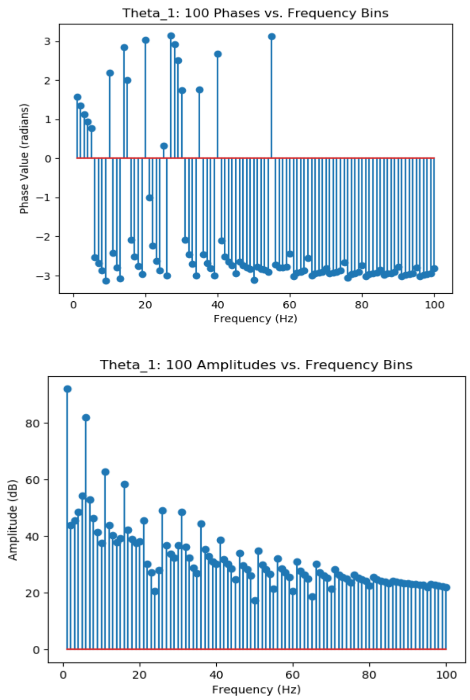

Figure 13: Amplitude (in dB) vs. frequency and phase value (in radians) vs. frequency are shown

Phase and amplitude value was calculated from the FFT result for the frequency of each joint signal. Phase value is calculated in radians and amplitude value is in decibel (dB) that can be seen easily in Figure . Although phase values are linear. Both amplitude and frequency values are said to be frequency components.

In Figure ; shows the original signal that is generated from values that are obtained using dot product between two joints imported into excel. Then each curve shows the various stages of processing each signal until the last curve wich is obtained asfter final optimization through Fourier.

F. Synthesizing Believable Gait Patterns:

Basically, an animation rig is known as a system of hierarchical kinematic joints of character's motion[30]. The data that comes from the above phase was used to producing synthetic joints for gait. Rigging is the procedure that enables to make cartoon or simulation more natural using joints tool. In this research, quadruped ring has been scripted for effective management. The script can be defined as it is a program that facilitates the programmer or animator to perform their tasks or functions automatically instead of done manually.

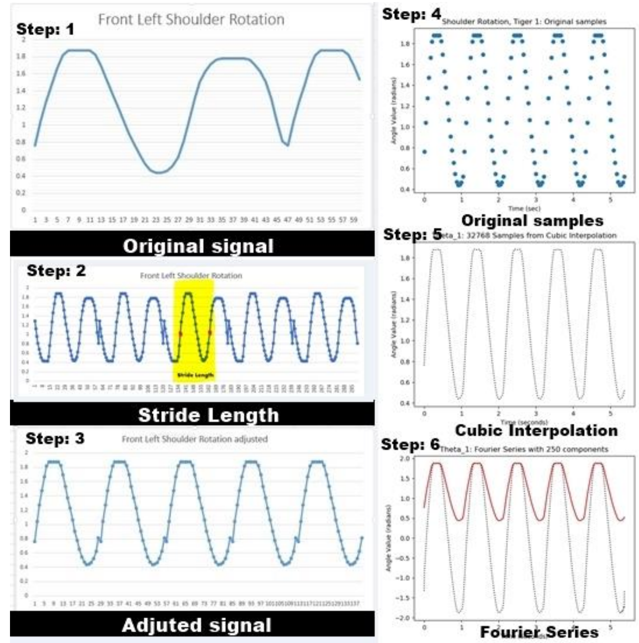

Figure 14: Front leg Shoulder rotation curves.

The rig was consisted of four limbs with joints and control object hierarchy. By duplicating the front and rear joint the hierarchy was created for the rotoscoping process. Synthetic animation was created by using the expression that has derived from the analyses phase. One side of the leg joint is different from the other side of the joint means the left and right side of the rig is different by a time shift equal to half the time of the tiger's walk length. The rotation has been performed on each joint of keyframe. The height of the joints has been created a cyclic motion simulating the real walk manner from the video that was referenced. Finally, the method has formed for four unnaturally animated legs, derived through the mathematical functions attained through FFT. The purpose of this research is to offer a prototype system for quadruped character in animation by providing the foundational believable gait pattern.

IV. CONCLUSION

This research provides a prototype system for creating an initial layer of natural-looking animation. A mathematical model is created using a rotoscoped technique that represents the tiger's natural motion. Using real video reference, the locomotion data has been sampled for walking tiger. Each joint's desired motion value is calculated and written to a text file. The output sampled values are preparing the conditioned for Fourier analysis. Each joint's value has unsampled. Then Fast Fourier Transform has been applied to unsampled value for getting the information about the signal in the frequency domain. The output result helped to understand better that which frequency is more valuable within a given signal.

The synthetic animation was created by using the expression that has derived from analyses. Finally, the method has produced four unnaturally animated legs, derived by the mathematical functions attained through Fourier analysis of natural motion extracted from video reference.

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