Gait Pattern Analysis of an Asian Elephant

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Abstract— **Elephants have to maintain stability of a body weighing 2700 kg – 4500 kg in a wide range of unstructured terrain conditions. To achieve this, the dynamic walking control strategies of an elephant should be able to manage the large inertial forces working on the leg muscles. Therefore, understanding the gait patterns of an elephant can indicate the possible robust control strategies that an elephant may be adopting by exploiting its body dynamics and kinematics. This paper presents a simple method to analyze the gait patterns of an elephant using videos and snapshots. In the research, we have used three Asian elephants to capture videos and snapshots in order to obtain primary data. Finally, two outcomes were illustrated. Firstly, the ratios of body segments of the elephant were calculated using snapshots, and secondly, movements of the four limbs in the sagittal plane were measured and graphs were generated against time. Since the data used here were obtained from the images, errors can be occurred due to the scale of the image and measuring techniques. These errors were mitigated by carrying out appropriate error corrections.**

I. Introduction

Biomechanics of animals provide a good source of theoretical inspirations to develop kinematic structures and actuators for robotic systems. Bio inspired robots were built with this basic concept. Therefore bio robots can be further developed for task oriented environment to deliver tasks efficiently which use optimum energy [1],[2].

Generally the body structure of the animal greatly assists the actuations of the body. For example the gait of the animal is an overall effect of the body structure and weight trying to respond to the variability in the dynamics of walking [3]. Therefore, to initiate a detailed analysis, a structural analysis should be performed first. The knowledge of the body structure of the animal provides us evidences to elaborate kinematics and dynamics of the animal precisely. There were number of researches conducted for gait analysis for many quadruped animals such as dogs [4] and biped animals like frogs [5], and even human [6],[7]. These experimental data can contribute in robot modeling in terms of structural designing of robots to respond to the corresponding conditions [6],[7][8]. On the other hand kinematics and dynamic analysis contributes to understand the body mechanisms of animals [9] which can be later used for clinical purposes and build bio prosthetics in future.

The gait analysis is one of the tasks where a proper experimental methodology is practiced. There are various approaches including joint motion measurement, joint torque assessment, collisional implications assessment using force platforms [6],[10] electromyographic (EMG) motion tracking using recording [4],[11] and high speed cine films [5],[12],[13]. These experiments are usually performed inside laboratories with very advance devices or organized setups. Therefore the animal of our interest should be carried to such places and connect the sensors and apparatus [13],[14]. The test results are usually displayed on a screen.

One drawback of these methods is when dealing with large animals or untamed animals, it is impossible to take them into laboratories. Further it is difficult to attach testing apparatus such as position sensors or EMG apparatus on these animals. This paper presents a methodology to analyze the gait of a large animal without using advance apparatus.

The main objective of this paper is to analyze gait using snapshots and videos. Elephant has a unique locomotion pattern which differs from the other quadruped animals [9],[15],[16]. The stability of the large body while walking is another important fact. The step size and the frequency of the footfall and the height of the limb lift up when walking are important measurements in determining the gait pattern of the elephant.

II. Procedure

A. Calculate the dimensions of the body using images

Three elephants were chosen and snapshots were taken parallel to the elephant maintaining a constant distance (4.65m) from the center. The length and the height of these elephants were measured in order to calculate the scale of the images. Taking the coordinates of the feet while walking The images were imported to software and the important points were marked. The coordinates of these points were taken using a grid to calculate dimensions. The ratio of the body segments to the height of the head is also calculated (see TABLE I).

Three grown up elephants were selected. They were walking on a plain for 30.6m distance at an average speed of 0.8 m/s. The elephant was taken along a boundary wall and the camera moved on a path which was marked in the ground parallel to the boundary wall. The camera was moved parallel to the path of the elephant following a white mark on the elephant belly. The time taken to pass the boundary wall by the elephant and the camera was measured hence the speeds were calculated. Videos were taken using a 16.1 Mega Pixel camera. These videos were digitized into 30 frames per second. The images were analyzed with respect to time to track the path of the elephant in x-direction and the joint movements in y- direction. Figure 1 shows few digitized images of the movement of left front limb.

When taking a real object to an image the scale should be known for the dimensions are to be calculated. In order to compensate this problem the path coordinates obtained from the image were recalculated according to the following equation to obtain real coordinates.

$$\text{Real Coordinate} = \alpha(\text{Image Coordinates}) \qquad (1)$$

α is the ratio between the real length of the elephant to corresponding length of the image (10.77).

Note that the value obtained here can be different due to the zooming percentage of the software used.

Fig. 1: Set of digitized images used for the analysis

A set of digitized images were used to obtain the coordinates of the left forelimb movement. Some of the hind and fore limb movements were shown in Figure 1. One step of a limb can be shown on average of 15 digitized images. The elephant was filmed by maintaining about 4.5m distance from the center of the elephant. This video was captured at a location which has a flat area.

When taking the coordinates of right side limbs a scaling error will occur due to the fact that the distance from the camera to the right side limbs differs from that to left side limbs. Therefore, a proper scale given in equation (2) was calculated to compensate this effect.

$$\beta = \frac{\text{Length of the left limb}}{\text{Length of the right limb}} \qquad (2)$$

Here, β is the ratio of image dimensions between of the left and right limb lengths of the elephant (1.089).

III. Results and Discussion

A. Calculate the dimensions of the body using images

The following results were obtained when calculating the ratios of the body segment lengths according to the equation 3

$$\gamma = \frac{\text{Length of body segment}}{\text{Height of the head (GH)}} \qquad (3)$$

γ is the ratio between the lengths of the body segments.

As shown in the table 1 the actual length and the height of the elephant are respectively 4.21m and 2.29m. The scale of the real dimensions to the image dimensions are 10.79.

TABLE I
Ratio of the Body Segments and Original Lengths of the Elephant

segment	height (GH)	
GH	**1.0**	**0.99**
EF	0.8	0.82
FK	2.6	2.60
Trunk	1.9	1.87
IJ	1.5	1.50
AB	2.0	2.07
CD	2.1	2.12
EK	3.4	3.42

Body segment	Ratio to the corresponding leg height	Actual Length (m)
AB	**1.0**	**2.07**
AK	0.65	1.35
KB	0.35	0.73
CD	**1.0**	**2.12**
CM	0.75	1.60
MD	0.25	0.52

Original lengths of the segments were calculated by using the calculated ratios into actual dimensions. Figure 2 depicts the body segments of the elephant.

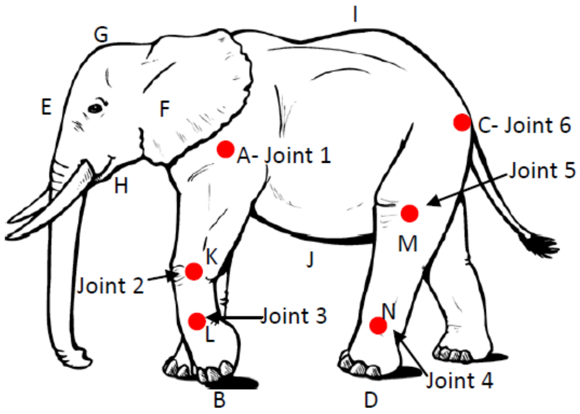

Fig. 3: The elephant body segments: Points A and C are the fore and hind limb joints of the elephant respectively. The neck is marked as point F .

The behavioral fact that elephants are very alert on every movement happening around them posed a challenge to data collection.

Since physical measurement of limb lengths is a difficult and sometimes dangerous task especially on an untamed elephant, a more plausible approach would be to define a set of body proportions that can be used to scale a given elephant image. Here we present an image based method to obtain such generalized proportions across a group of Asian elephants.

The images were taken standing parallel to the center of the elephant in a constant distance (d). Distance between the camera and one end of the elephant is different from d. But the error due to this effect is very small and considered negligible.

Therefore to obtain real values this image coordinates were multiplied by the scalar α given in equation (1). The real coordinates were analyzed with respect to the time and the following graphs were generated.

B. *Taking the coordinates of the feet while walking*

Joint coordinates were obtained by analyzing the digitized images as in Figure 1. These images were imported to a grid based worksheet and converted to x and y axis coordinates multiplying the image coordinates by the scalar α given in equation (1). Then the following graphs in figure 4-8 were generated.

As described in the procedure section the videos were captured along a parallel path to the movement of the elephant following a white mark on the elephant belly. The results presented here covers a one gait cycle approximately for 2 sec. Thus during this small time period it is assumed that the relative motion of the camera and the elephant is zero.

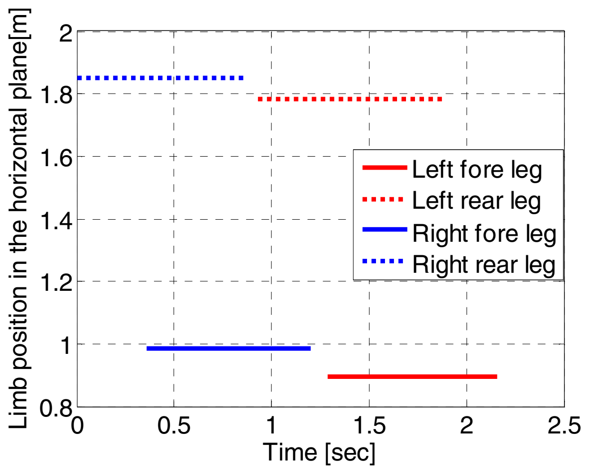

Fig. 4: Foot positions on the horizontal plane during one gait cycle.

The Figure 4 shows the four positions of the active elephant limbs with respect to the time. Time is measured with the beginning of the right rear foot. It shows the duration for the swing phase for each leg. According to the graph for a complete cycle approximately 0.8-1.0 seconds an elephant leg travels through the air.

According to the literature the phase difference between the strides of the elephant is 25% [11],[17]. In Fig. 4 this phase different can be clearly seen. The time duration of all four graphs were in 25% phase difference. Therefore the gait cycle can be deduced from this graph. According to the graph starting from the right rear foot stride, the gait cycle completes with right fore foot stride, left rear foot stride and left fore foot stride during the concerned time.

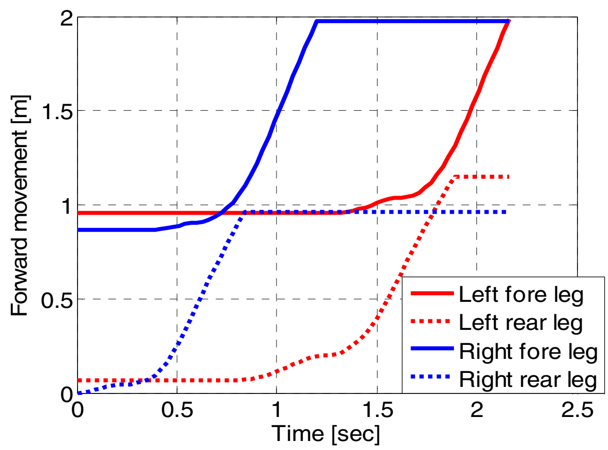

Fig. 5: Forward movement of each foot during a gait cycle

Fi

gure 5 shows the total displacement of the four feet along the horizontal plane with time. Each leg moves approximately 1.0 m per 1 step. When one leg is nearly touching the ground at its stride the consecutive leg initiates its step. There is a period of about 0.12 sec where only one leg moves with the other three legs firmly on the ground. Then the other leg on the same side starts to move so that two legs on the same side swing forward for about 0.7 sec. This short time span is no different to a bipedal stance phase. This is followed by a simultaneous movement of the leg that started to move later and the diagonaly opposite leg for another 0.12 sec leading to a single leg swing phase again. This suggests that the gait pattern tries to achieve several static and dynamic objectives. The single leg swing phase tries to distribute the total weight on three legs while accelerating the body forward. Then the one sided double support phase may try to swing the zero moment point back to the other side similar to a biped walker. The diaganal swing phase apparently exploits the inertia and the diverted trajectory of the zero moment point to let the body fall diagonally like an inverted pendulum with minimum extra effort. The final single swing phase lets three legs on the ground to make any corrections for stability while distributing the inertial forces across. Figure 6. Shows the footfall pattern of the fore foot of the elephant while walking.

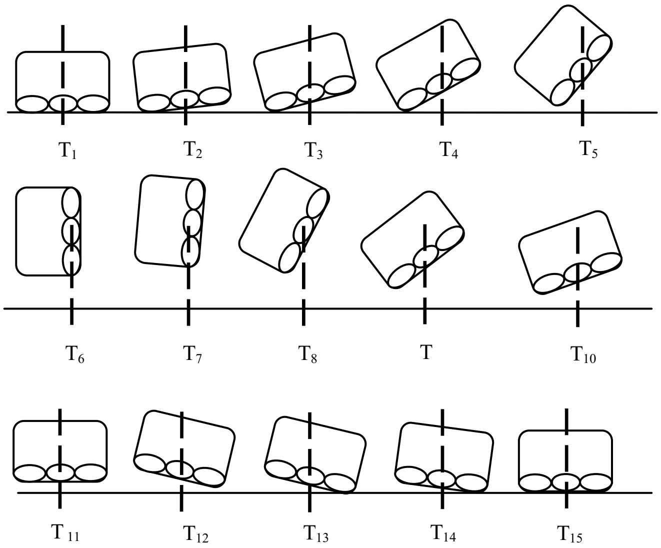

Fig. 6. Fore foot orientations of the elephant limb of one step.

Figure 6 and 7 were generated by analyzing a set of digitized images of an elephant video. T_1-T_{15} shows the movements of the fore foot and rear foot orientations in every 0.06 sec time durations. These figures represent feet orientations corresponding to a single step. As shown in figure 6 the horizontal displacement of the
foot gradually increases over foot posture T_4-T_8. The knee (Joint 3) bends about 90^0 at T_7 foot orientation.

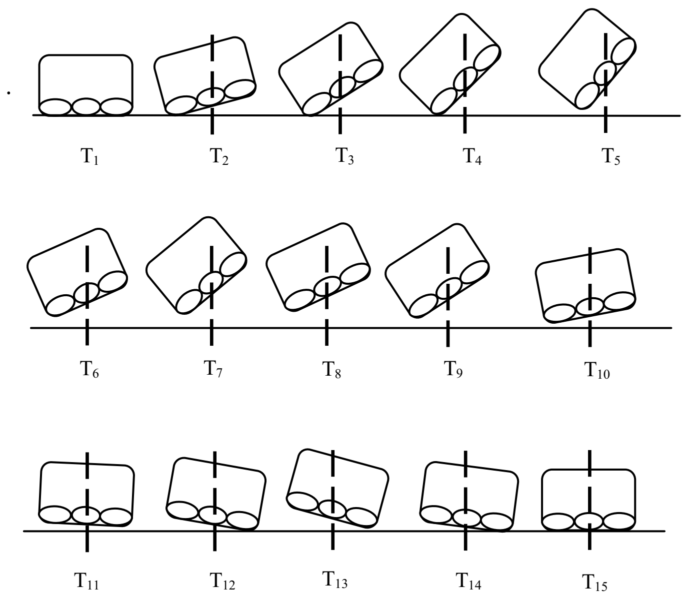

Fig. 7: Rare foot orientations of an elephant limb.

Figure 7 shows the rear foot fall pattern. The maximum angle of the bend of about 45^0 of the rear knee can be seen in posute T_5 The verticle displacement of rear foot of the elephant is larger than the fore limb displacement of the elephant.

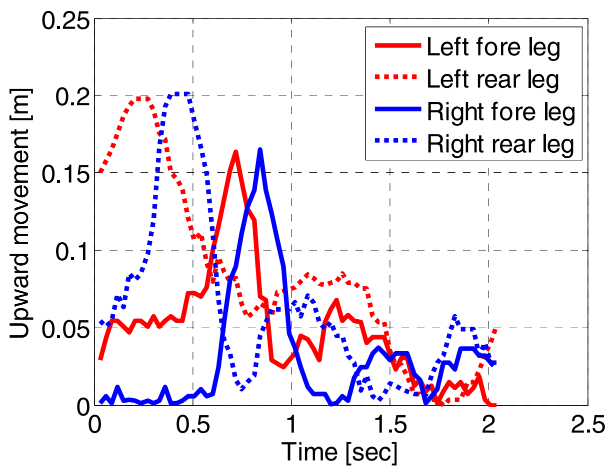

Fig. 8: Feet movement in *y* direction plotted against time. It shows the vertical displacement the four feet

Figure 8 shows the vertical displacement of the four feet while walking. The dimensions were measured with reference to the standing posture of the elephant. Therefore due to the foot fall pattern the variation of the graph which we can observe here was occurred. The maximum upwards movements of the rear feet were approximately 0.2 m. The maximum upwards movements of the fore feet were approximately 0.16 m. The graph presented in figure 8 was obtained by analyzing several gait cycles of an elephant. It shows the vertical displacement of rear legs is greater than those of fore legs.

IV. CONCLUSIONS

This paper presents the kinematic features of gait pattern and important kinematic ratios of an Asian elephant based on cine film motion capture technology.

Kinematic and dynamic analysis of animals was often performed by using advanced technology under laboratory conditions [5],[13],[14]. But some occasions may arise where analysis should be done for untamed or huge animals which cannot be carried out in laboratories. The procedure followed here would be advantages for such occasions. Accuracy of this method has been improved by applying error compensating methods.

Firstly the error due to scaling of the image was corrected by calculating a ratio (α) between the real dimension and the image dimension of the elephant. The value presented here can be different with the zoom percentage of the image. Finally the real coordinates of the elephant leg positions were obtained by multiplying the observed coordinates by α.

Videos were obtained from the left side of the elephant. Therefore, an error occurred when reading the coordinates of four limbs. The distance from the camera to the right side limbs differes from that to left side limbs. Due to that we can observe the right side legs are much shorter than the left side legs in the image. Hence the coordinates of the right side legs are not accurate. This error was calculated by obtaining a ratio between the bilateral leg lengths (β), assuming the bilatteral legs of the elephant are similar in height. Then the error was compensated by multiplying the coordinates of the right side leg by β.

Videos were captured perpendicular to the center of the body, parrelel to its' path.Therefore when reading the coordinates of the legs an error can be occurred due to different distances between the camera and the elephant body. The calculated error was very small and hence it was neglected.

Finally there are some limitations of this work as follows. The skin artefacts while moving the animal may have affected the accracy of the coordinates [18]. When doing an analysis to measure kinematic parameters such as joint angles and joint torques of body segments this effect should be compensated by doing a proper error correction method. The elephants possess unique walking patterns when it is closely observed. The duration between steps, orientation of the feet while walking and application of pressure to the legs are some of the points which make their unique walking pattern. Due to some defects of the body or due to changing environment condition or else in the presence of human, elephnats' walking patterns may deviate. Therefore, better results can be obtained by data captureandanalysis carried out in their natural habitats. The elephants used in this experiment were taken from an elephant riding club where they behave according to the elephant rider. Therefore, with an extremely busy environment gait cycle of the elephants presented here would have been deviated from the natural gait cycle.

Elephants generally move in fairly low speeds compared to other quadruped animals. It is also a mechanism where they use to stabilize their massive body while moving. A regular digital camera with a 16.1 mega pixel was used to obtain snapshots and videos. Due to the low moving speed of the elephant this camera performance was sufficient for the analysis. Otherwise a high speed cine film should be used to obtain videos to capture the movements [5],[11],[12].

Similar to the other quadruped animals elephant gait also initializes with rear legs followed by corresponding fore leg. When analyzing the body structure of the elephant the limb heights are almost same. But the muscular weight is greater in rear legs than of fore legs. Thus fore legs are used as supportive to stabilize the body weight while moving.

About 90 of digitized images were analyzed in order to do a proper gait analysis of the elephant. Using snapshots which were taken parallel to the elephant the ratios of the body segments were calculated. These values were compared with real values and presented here. The kinematic ratios obtained using real animals can be used to scale down kinematic and dynamic properties of real animals. The gait data would be useful for inverse dynamic analysis to model bio inspired robots [1],[18],[19].

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