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Design and Development of A Four Legged Robotic Horse

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***Abstract*—** In this world, where human beings and the other animals have access to every nook and corner, the existing wheeled vehicles are far behind. In this paper we present the design and development of a four legged walking robotic horse. The main vision of our work is to represent the four legged robotic horse prototype that can serve in much larger range of environment and most difficult terrain, where the wheeled vehicle fails. The design of the robotic horse is bio inspired and is analogous to the biological horse. Prior to the development of the quadruped robot, the gait pattern of a horse with walk, trot and gallop styles are analyzed. A robotic prototype with gait patterns walk, trot and gallop similar to its biological counterpart, has been developed which is actuated by servomotors and controlled by microcontrollers. This paper presents the various analysis of the gait patters and development of the robotic prototype.

***Keywords*—** Quadruped robot, walk, trot, gallop, legged robot, robotic horse

I. Introduction

Locomotion has been an area of research since the advent of modern engineering. Although wheel based system dominates majority of locomotion system, researchers in the field of robot locomotion, led to the conclusion that the principles involved in natural legged locomotion system result in superior mobility characteristics due to its easy access to irregular terrain [1]. Creating effective motion in a four legged robot is not an easy task. Legged robots can be classified as dynamic and static. Gregorio and et al. described the one legged robot, the ARL Monopod and claims to be one of the fastest electrically actuated robot of the time with a speed of 4.3km/h [2].

Research in the field of quadruped locomotion started as early as in the fourth century, when a four legged wooden structure was developed to carry goods. A four legged walking robot called BISAM which offers the flexibility of both reptile and mammal like walking with one mechanical concept, was designed by Berns et al. [3]. Phoney pony described in [4] is regarded as one of the earliest quadruped's realized. The contribution of Boston Dynamics in the field of development of robot is worth mentioning. They have developed a series of laboratory robots including monopods, bipeds, quadrupeds that moved dynamically with good balance in the 1980s and 1990s.Boston Dynamics Big Dog is a benchmark in the history of development of rough terrain quadruped robot. Designed with sophisticated computing, terrain sensors and highly energy efficient power system, the Big Dog has the capability to capture the mobility, autonomy and speed of living creatures. The history of the development of the Big Dog, its physical structure along with various functions performed by it is presented in [5]. A simple quadruped design featuring one degree of freedom per leg that can walk, climb and run despite its mechanical simplicity is described in [6]. Each hip is actuated by servo motors, and mechanical switches are used to detect the ground contact. They aimed at developing a simple, low cost, mechanically robust system with rich set of behaviors as walking, climbing staircase, running etc.

Inspired from the works of the great researchers, a step has been taken to design a quadruped robot that can perform all gait pattern as its biological counterpart. A prototype of the same is designed that replicates the gait pattern of a real horse and results presented.

II. Methodology

Gait is the rhythmic characteristic movement of horses' feet and legs in motion. There are three natural gaits namely walk, trot and gallop [7-8]. The walk is a slow, natural, flat footed, four beat gait. The sequence of the hoof beats after the horse is in motion can be described as: right fore, left fore, right rear and left rear. The trot is a rapid two beat diagonal gait. The fore foot on one side and the opposite hind foot take off and strike the ground at the same time. The four beat gallop is the fastest of all the paces. Unlike walk and trot, gallop is an asymmetric gait pattern.

Eight set of angles are observed for eight joints of the real horse, for walk, trot and gallop gait patterns. Figure 1 shows the legs position of the horse at a particular instant during a walk cycle. The different angles of displacement formed by the hip and knee joints of all limbs are shown in the figure.

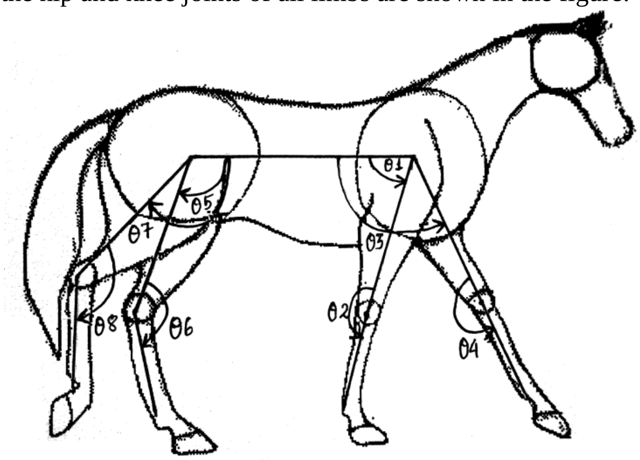

Figure 1. Figure showing the different joint angles of horse's leg [7]

ϴ1 = Right Front Leg Base to Knee (Hip) angle, taken in anti-clockwise direction.
ϴ2 =Right Front Leg Knee to Toe (knee) angle, taken in anti-clockwise direction
ϴ3= Left Front Leg Base to Knee(Hip) angle taken in anti-clockwise direction.
ϴ4=Left Front Leg Knee to Toe(knee) angle, taken in anti-clockwise direction
ϴ5 = Right Back Leg Base to Knee(Hip) angle taken in clockwise direction.
ϴ6= Right Back Leg Knee to Toe(knee) angle, taken in clockwise direction.
ϴ7 = Left Back Leg Base to Knee (Hip) angle taken in clockwise direction.
ϴ8= Left Back Leg Knee to Toe (knee) angle taken in clockwise direction.

After the clear understanding of the horses' limb angles, the data of various angles are measured from animated horse video at different time instants [7-8]. For one cycle of walking pattern a total of 32 data points have been measured and the different equally spaced time instants is denoted by

Table 1: Angles for front right leg (hip and knee joint) for walk gait pattern

Time	$ϴ_1$ in degrees	$ϴ_2$ in degrees
T_0	71	180
T_1	68	180
T_2	66	180
T_3	64	180
T_4	61	180
T_5	65	180
T_6	66	180
T_7	67	170
T_8	70	163
T_9	76	152
T_{10}	82	148
T_{11}	83	142
T_{12}	96	143
T_{13}	100	145
T_{14}	103	150
T_{15}	108	160
T_{16}	110	170
T_{17}	111	180
T_{18}	110	180
T_{19}	105	180
T_{20}	100	180
T_{21}	96	180
T_{22}	94	180
T_{23}	82	180
T_{24}	89	180
T_{25}	87	180
T_{26}	86	180
T_{27}	84	180
T_{28}	83	180
T_{29}	80	180
T_{30}	75	180
T_{31}	74	180
T_{32}	74	180

$T_1, T_2 \ldots T_{32}$. The observed angles ϴ1, ϴ2 for walking gait pattern is shown in Table 1. Similarly the other angles (ϴ3, ϴ4, ϴ5, ϴ6, ϴ7, ϴ8) are observed for walk, trot and gallop gait patterns. The angles are measured in degrees and time in seconds.

The angles observed at various time instant for a complete gait cycle have been plotted with respect to time using the tool MATLAB. The plots of hip and knee angle against the various time instants for walk pattern are shown in Figure 2 and Figure 3 respectively.

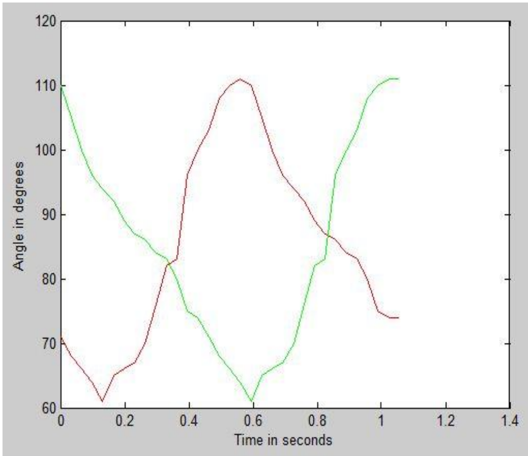

Figure 2. Front right and left leg hip angle ($\Theta_1$and Θ_3) vs time

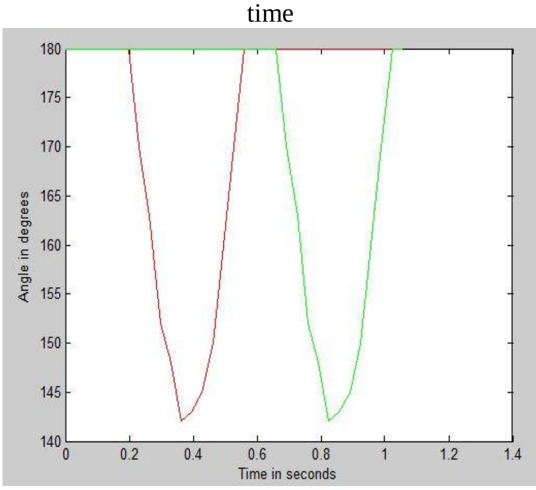

Figure 3. Front right and left leg knee angle (Θ_2 and Θ_4) vs time

Similarly for other angles the graphs are plotted using MATLAB. The graph in red color represents the right leg whereas the one in green color represents the left leg of a real horse.

An appropriate equation for each of the graph is obtained using the Curve Fitting Tool of MATLAB. The obtained equations are used for replicating the locomotion of the real horse. The equation gives the angle of the arms at different time instant, *x*. The equations for the right front leg hip and knee joints for walk gait pattern are given by equation (1) and (2) respectively.

$$\Theta_1= 7256 \times x^6 + 23040 \times x^5 \; 26690 \times x^4 +13220 \times x^3 -2387\times x^2+ 75.54\times x+72.11 \qquad (1)$$

$$\Theta_2=301.4\times \sin(1.929 \times x + .8576)+145\times \sin(3.391 \times x + 3.448) +11.63 \times \sin(13.15 \times x + 0.3349) + 4.049 \times \sin(20.3 \times x + 3.198) \qquad (2)$$

Similarly the equations for the remaining angles for various gait patterns are obtained.

III. MECHANICAL DESIGN

The robot prototype is made on a wooden base. To make a legged robot mobile, each leg must have minimum of two joints. The robot developed has four legs, each leg having two joints- the hip joint and the knee joint. The schematic design of a leg of the robot consisting of two arms and two joints is shown in Figure 4. Each arm is actuated by a servo motor which is mounted at the joint. Therefore, a total of eight servo motors are required to implement the four legs of the robotic horse. The schematic design of four legs of the prototype is shown in Figure 5.

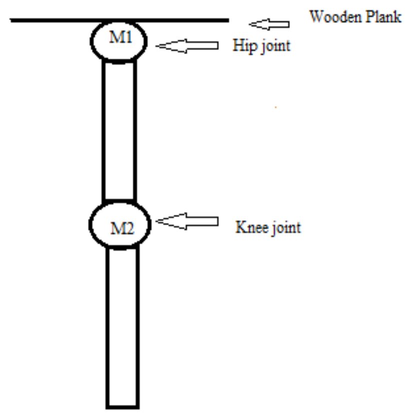

Figure 4. Structure of a leg of the prototype

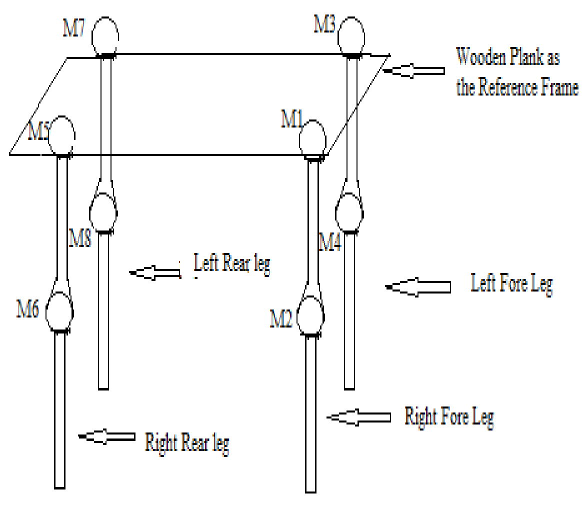

Figure 5. Schematic design of the four legged robotic horse

After the completion of the mechanical design, the motors are programmed in a manner that the gait pattern made by them resembles that of its biological counterpart. The servo motor is operated with the help of Atmega 328 microcontroller. The equations designed for various joints are fed to the servo motor. Once the motors receive the desired equation, in presence of desired power (5 volts), the locomotion of the robot prototype are observed. Figure 6 shows a photograph of the developed prototype robotic horse model.

IV. RESULTS AND DISCUSSIONS

Extracting the various angles, designing the equations and then feeding the same to the servo motors resulted in locomotion in the robotic prototype which is similar to its biological counterpart. A few instance of walk gait pattern of the real horse and the prototype is compared and is shown in Figure 8. The gait of walking at a certain instant of the animated horse and the developed prototype at the same instant is shown in Figure a) and b) and Figure c) and d) respectively. It can be seen that the gait and the angles of different arms is similar in animated horse and the prototype. The developed prototype can produce all the different gait patterns of a horse using the obtained equations.

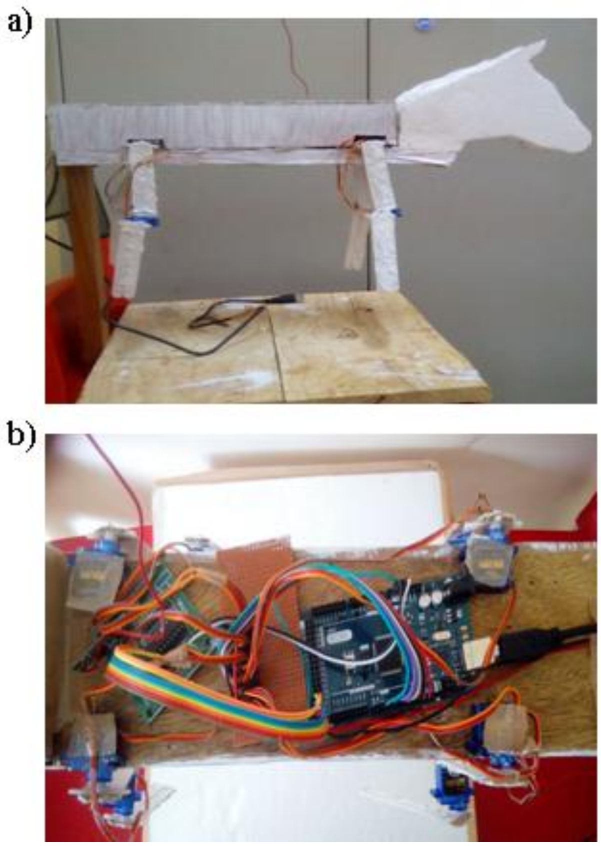

Figure 6. Photograph of the developed prototype robotic model a) side view and b) Controlling electronics mounted on top

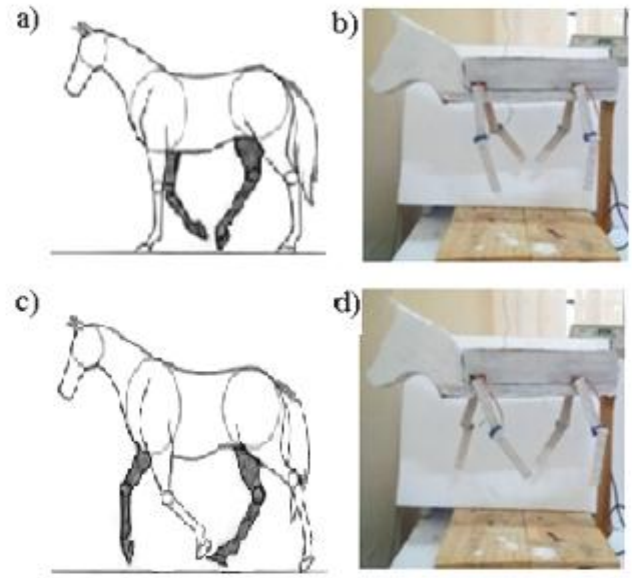

Figure 7. Instance of walk gait pattern of an animated horse and the robotic prototype.

V. CONCLUSION AND FUTURE SCOPE

The locomotory maneuvers of a real horse are thoroughly analyzed, and have been represented as complex mathematical function which has been later fed into the robotic prototype. The gait pattern of the developed model is found to be similar to that of its biological counterpart. The obtained results are found to be satisfactory and the developed model has successfully been made to imitate the locomotion of a biological horse.

The future holds a lot of prospects for this project. There is ample scope of future research in it. The robotic prototype may be upgraded with suitable pothole and obstacle detection sensor for automatically avoiding the pothole and obstacle. Further automatic self balancing algorithm may be implemented for automatically balancing the walking legged robot when external force (such as a push or pull) tries to misbalance the system. Implementation of legged robot will enable it to walk on a plain surface as well as on a rough terrain.

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