MOTION ANALYSIS OF ELEPHANT TO ROBOTICS HARDWARE

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ABSTRACT

A methodology for constructing biologically inspired robot elephant for carrying huge external loads in unstructured environment is presented. Being the largest terrestrial animal it possesses a characteristic locomotion that maintains the body balance almost all the time. The construction of the model considering mostly with the identification of proper motion trajectory of the animal using cine films and apply forward kinematics to develop the animals' kinematic model that delivers accurate movements. New elephant dynamic matrices to be developed to justify the real time performance of the elephant. These matrices include minimizing of redundancy and effort during a task. However building an elephant inspired robot is a new effort for the field of robotics.

Key words- elephant locomotion, biomimetics, motion analysis, gait, quadruped

Introduction

Biologically inspired manipulators exhibit much greater robustness in performance in unstructured environments. By analyzing the natural dynamics of animals, useful mechanical and material properties are identified which would later be converted into robotic hardware or part of machinery.

Nowadays biologically inspired robotics becomes the newer trend of manufacturing task-oriented robots [1]. Animals such as octopi, elephants, worms, and snakes exhibit successful locomotion and behaviors that can be used in robotics and manipulators. In particular, the abilities of tongues, trunks, and tentacles intriguing examples for manipulators like robot arms and biologically inspired mobile robots [4,7]. But the machines in present become problematic when deals with unstructured, messy environments.

Elephants are the largest terrestrial animals and archetype of 'graviportal' animals [2] now living. They are unusual not only in their enormous size, but also in their special locomotion pattern. They can move smoothly to fairly fast speeds holding their massive body and sometimes huge external loads [2]. They possess pillar-like robust legs for supporting this massive load [2,5].

In this research the aim is to study natural dynamics of an elephant walk and convert it to a robot platform where it can carry huge loads and move on an unstructured environment effectively.
Despite conventional locomotion types such as wheeled, tracked or humanoid type, the four legged type of robots are more compliant and stable [1]. Being the largest animal exist on earth, stabilizing the massive body weight when climbing a mountain is considerable. Moreover while walking the body of the elephant move smoothly. This characteristic behavior of the elephant would be advantages to build a four limb robot to transport loads in uneven terrain. So that the presented model can be used in disastrous areas, earth quake areas, and unstable working areas like waters to transport heavy external loads autonomously.

The synthesis of animal motion is a complex procedure. It consists of accurate recognition and reconstruction of animal movements, modeling of musculoskeletal kinematics and dynamics then construction of more precise performance [1]. For a given desired elephant like robot, the motion behaviors should be specified to be controlled during the execution of the motion. Limb location, balance, effort minimization, and obstacle avoidance and joint limit avoidance are few aspects of the specified behavior.

Many researches were conducted to analyze locomotion patterns of animals as well as human [2,3,5,8]. Most of them have used cine film method to clarify the gait cycle. Accordingly it has been identified that the quadruped locomotion predominates the inverted pendulum mechanism [2,3,5]. But unlike other quadruped animals elephant maintain negligible vertical displacement of its Center of Mass (COM) while walking. They posses a lateral footfall pattern with the sequence of the left front foot hit the ground 20–25% of a stride after the left hind, and was followed 25–30% of a stride later by the right hind, which the right front foot followed by 20–25% of a stride [2].

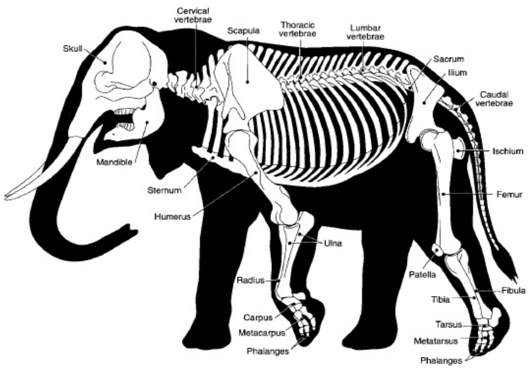

Fig.01- Elephant Skeletal system [9]

Motion analysis

Motion analysis was done using the cine film method. A lateral video of elephant locomotion is captured and it is digitized into number of frames [5]. Then by analyzing these frames the motion trajectory of the elephant can be captured. Using the method of direct data tracking of a real- time motion trajectory, the locomotion of the elephant can be reconstructed.

Kinematic Model

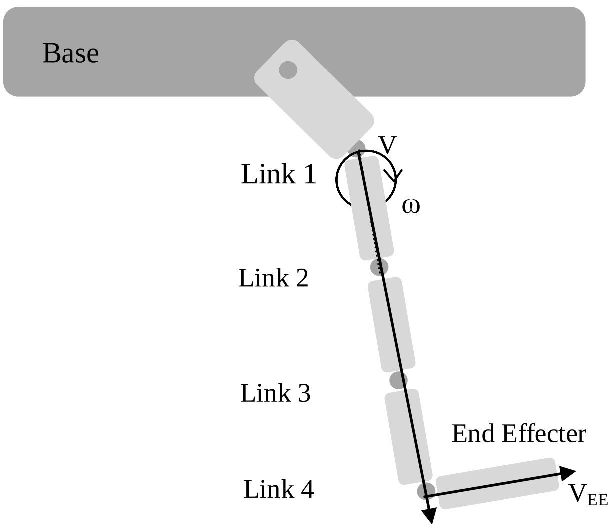

Fig.02- An example of a Kinematic Chain of a robot limb

The systematic way of modeling the robot is to develop the kinematic model first. There we need the Link description of the robot. For that we can use the elephants' skeletal system. This describes the position and orientation of rigid bodies in each link. Then we need to find the transformation between those rigid bodies during a task.

The kinematic model of a robot can be represented by the homogeneous transformation matrix [HTM]. A robot of ***n*** degrees of freedom (DOF) is formed by ***n*** links assembled by ***n*** articulations [1,7]. Thus, for 4 numbers of links the final links position and orientation is represented as,

$$^{0}L_{4} = {}^{0}L_{1}{}^{1}L_{2}{}^{2}L_{3}{}^{3}L_{4} \qquad \text{Eqn. 01}$$

The Denavit Hartenberg method describes robot's minimal set of parameters to represent the relationship of two successive links on a chain. From these parameters the forward kinematics are derived which will describe the joint angles and the position of the end effecter. From Eqn 01

$$^{n}L_{n+1} = \mathit{rot}(z,\Theta_{n+1})\,\mathit{trn}(0,0,d_{n+1})\,\mathit{trn}(\alpha_{n+1},0,0)\,\mathit{rot}(x,\alpha_{n+1})$$

Eqn. 02

Where Θ_{n+1}, d_{n+1}, a_{n+1}, α_{n+1} are the D-H parameters for the i link. The illustrated matrix will as follows

$$^{n}L_{n+1} = \begin{matrix} C\theta n+1 & -S\theta(n+1)C\alpha(n+1) & S\theta(n+1)S\alpha(n+1) & \alpha(n+1)C\theta(n+1) \\ S\theta(n+1) & C\theta(n+1)C\alpha(n+1) & -C\theta(n+1)S\alpha(n+1) & \alpha(n+1)S\theta(n+1) \\ 0 & S\alpha(n+1) & C\alpha(n+1) & d(n+1) \\ 0 & 0 & 0 & 1 \end{matrix}$$

Eqn. 03

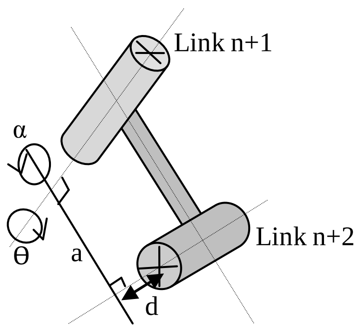

Fig.03- Link Description

The robot reconstruction come up with the forward kinematics consists with final (goal) position and orientation of end effecter regarding to a reference coordinates system. Forward kinematics is the relationship between joint angles and position of the end effecter.

Since the four legs of the robot are identical their kinematic models, the matrices for link position and orientation are the same. But the control mechanism may differ because when walking the joint angles and end effecter orientations are not the same.

Once the geometry of the chain objects is known the velocities and forces (or torques) are calculated. Using Jacobian the end effecter linear and angular velocities are calculated. Then these values can be used to find forces applied to the environment by the end effecter and the torque of the joints (or motors in the model).

Using the above fig. 02 the jacobian ($\dot{q}$) can be expessed as [7],

$$\begin{bmatrix} V \\ \omega \end{bmatrix} = J_0\,(q)\,\dot{q} \qquad \text{Eqn. 04}$$

Dynamic Model

The inertia relationship between links defines dynamics of the whole body system. In the kinematic model when substituting all joints with reaction forces and moments between joints a single body system is obtained. The segment wise values of jacobian velocities and forces on the kinematic chain can be add together to obtain the total behavior of the whole body segment. Then by considering the energy associated with the motion of rigid bodies the kinetic energy of moving mass (Eqn. 05) can be calculated. Thus by adding them altogether the total kinetic energy of the body can be calculated. Taking the velocities and jacobian relationship between velocities to connect them to joint velocities we can extract mass properties of the robot. Finally the Mass Matrix of the whole body system (Eqn. 06) is derived.

$$K_i = \tfrac{1}{2} \sum_{i=1}^{n} (m_i v_i^2 + I_i\, \omega_i^2) \qquad \text{Eqn. 05}$$

$$M = (m_i J_{v_i} + I_i\, J_{\omega_i}) \qquad \text{Eqn. 06}$$

Motion control

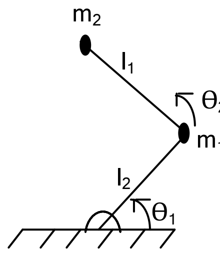

Fig.04- Manipulator Control- Joint space equation of motion

$$\Gamma = M(\theta)\ddot{\theta} + V(\theta, \dot{\theta}) + G(\theta) \qquad \text{Eqn. 07}$$

Γ – Torque of the motors

$M(\Theta)$ is the $n \times n$ inertia matrix, $V(\Theta,\dot{\Theta})$ is the $n \times 1$ vector of centrifugal and Coriolis terms, $G(\Theta)$ is the $n \times 1$ vector of gravity terms, and Γ is the $n \times 1$ vector of generalized control torques. In here torque 1 and torque 2 are applied to two motors at the points on m1 and m2 to create the behavior that is going to allow compensating those effects [7].

Inverted Pendulum Approach

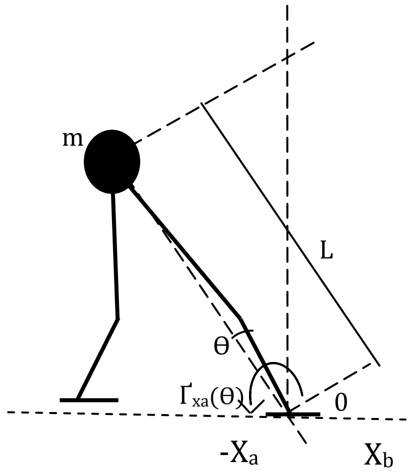

Fig.05- Robots Inverted Pendulum model applied to two limbs

This model is used to determine ankle torque. L is the leg longitude, Γ_{xa} (Θ) and Γ_{xb} (Θ) are the maximum and minimum possible torques for the ankle. Thus, this relationship can be described as:

$$\Gamma_{xa}(\Theta) = \frac{mg\, x_a\, (1 - \sin^2(\Theta))}{1 - \frac{\sin(\Theta)}{L}\, x_a} \qquad \text{Eqn. 08}$$

$$\Gamma_{xb}(\Theta) = \frac{mg\, x_b\, (1 - \sin^2(\Theta))}{2 - \frac{\sin(\Theta)}{L}\, x_b} \qquad \text{Eqn. 09}$$

Conclusion

According to the literature the gait cycle of the elephant can be modeled as below.

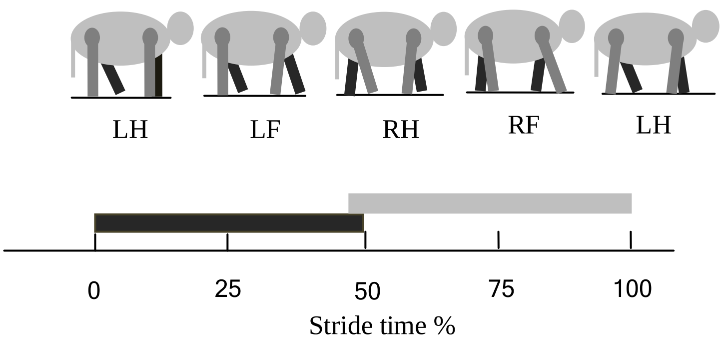

Fig.06- Hypothetical diagram of elephant walking - left front foot hit the ground 20–25% of a stride after the left hind, and followed 25–30% of a stride later by the right hind, then the right front foot followed by 20–25% of a stride [2]. (Walking started with the left hind leg)

The elephant locomotion is atypical of more familiar quadrupedal gaits. They possess this special gait type in order to withstand their enormous body. Like other quadrupeds they inherent a lateral footfall pattern with a 25% phase offset between limbs [2]. Left side foot stride lags the right side foot stride 50% of total stride time. Thus the body balance is maintained.

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