Kinematic Analysis and Simulation of Quadruped Robot in Simscape Multibody

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Abstract: This paper presents forward kinematics and inverse kinematics of one leg of quadruped robot since all leg are identical, which is connected to platform. Then, it is combined with help of mapping or transformation approach for remaining leg of robot. Forward kinematics is carried out by closed form solution approach due to less number of DOFs are involved. Simulation is carried out in Simscape Multibody environment. Model of quadruped robot with eight DOFs is created with help of different available blocks. By using repeating sequence stair input different value of angle is supplied to the all the joints of quadruped robot. By contact friction force library, the contact between leg end point and ground is carried out. At the end, Simple animal walking pattern is simulated in simscape Multibody.

***Keywords* - Quadruped robot, legged robot, kinematic analysis, simscape Multibody**

I. INTRODUCTION

Robotics is an interdisciplinary branch of engineering and science that includes mechanical engineering, electronic engineering, information engineering, computer science, and others. Increased research in robotics has been very remarkable. The costs and time invested in the development of prototype equipment are very high. Bio- inspired robotics is one of popular branch of robotics. There are many research is carried out in this field. Bio- inspired robotics is about analyzing the concepts from Mother Nature and applying them to the design of robotics systems. More specifically, this field is about making robots that are inspired by biological systems. The biological systems have been optimized for specific tasks according to their habitat. However, they are multifunctional and are not designed for only one specific functionality. It is about studying biological systems, and look for the mechanisms that may solve a problem in the engineering field. Bio- inspired robot is classified as legged robot, limbless robot, climbing robot, jumping robot (in case terrestrial locomotion) while swimming robot (aquatic locomotion). Legged robots have one, two, four, six or many legs depending on the application. One of the main advantages of using legs instead of wheels is moving on uneven environment more effectively. Biped, quadruped and hexapod locomotion are among the most favorite types of legged locomotion in the field of bio-inspired robotics.

Quadruped robots, kind of bio-inspired robots, have a bright perspective because of its superiority in locomotion stability, rapid moving velocity and adaptation to rough terrains in natural environment. Self-contained quadruped robots, such as Tekken, BigDog and AiDIN-III, have been developed. In case of a quadruped robot with two/three degrees of freedom per leg, it is required to synchronize, eight/twelve joints for the desired function. The quadruped animal mainly inspires such robots. One of the main reasons to develop a four-legged walking robot is to overcome the lack of mobility of wheeled vehicles on irregular terrains. The ability to traverse uneven or varying terrain at high speeds, turn sharply, and start or stop suddenly are all ordinary aspects of four-legged locomotion.

II. LITERATURE REVIEW

The review of literature is divided forward kinematics, inverse kinematics and simulation of quadruped robot.

W. shuhai et al. developed virtual prototype model is created based on the structure and size of the quadruped robot. The workplace of the foot-end is planned, which is the basic of the gait planning. Then the planned straight walk gait is simulated using of ADAMS simulation software to verify the feasibility. Robot's movement is sequencing of support phase and swing phase; gait planning is process of sequencing of support phase and stance phase and speed with which it can done [1].

Z. huang et al. propose a gait transition strategy for a quadruped robot using the Hopf Oscillator model and trajectory planning. The Hopf Oscillator model used to generate rhythmic moving pattern during trot gait, and trajectory planning based on the Stability Margin (SM) employed to implement walk gait as well as the transition between walk gait and trot gait [2].

J. kolter et al. consider the task of planning smooth trajectories for robot motion. They present a method for cubic spline optimization; this technique lets us simultaneously plan optimal task-space trajectories and fit cubic spines to the trajectories, while obeying many of the same constraints imposed by a typical motion-planning algorithm. The algorithm uses convex optimization methods to efficiently plan task-space trajectories, while obeying collision constraints, kinematic feasibility and avoiding contact [3].

W. zhanhao Quadruped, robot gait planning with stair environment constraints, where the environment constraints are mainly embodied in the form of robot gait planning constraints and robot stair traversing feasibility, etc., and the problem of quadruped robot gait planning can be solved theoretically with Stair-Aimed-SSG (Static Stable Gait). The feasibility of this scheme proved by MATLAB and RecurDyn simulation [4].'

P M Krishna et al. The flexible body quadruped robot (FBQR) has 14 DoF with three DoF per leg and two DoF for the body. Flexing of the body in pitch and roll is effected by body joints 1 and 2 respectively. Hopping height, average speed and foot clearance has increased with flexible body quadruped compared to fixed body quadruped robot. Hence, flexible body provides higher speed and enhanced mobility [5].

Y J lee et al. they consider the problem of planning a feasible path for a quadruped walking robot in an environment of obstacles. In conventional path-planning problems, the focus is merely collision avoidance with obstacles since a wheeled robot is involved. However, in the case of a legged robot, both collision avoidance and crossing over obstacles have to take into account in the process of path planning [6].

X. shao et al. represented parabola method plans the travelling paths over obstacles in Cartesian coordinate system. The constraints on velocities, accelerations, and jerks at waypoints are employed to generate the time-efficient smooth cubic spline joint trajectories by nonlinear optimization technique. Such a trajectory requires the minimum movement and minimizes the power requirement [7].

H. wang et al. compared with the serial mechanism, the parallel mechanism has many advantages. Using the parallel mechanism as the basic leg mechanism of a walking robot, not only the payload-weight ratio can be improved, but also the robot walking stability and security performance can be enhanced. By combining the kinematics features of 3-UPU parallel mechanism with the structural features of the quadruped walking robot [8].

M. gor et al. The legs contain telescopic tubes with axial compliance. The developed model is first simulated for trot gait, and the obtained simulation and animation results are compared with the experimental results for model validation. Its versatility is demonstrated by performance analysis, which shows that the compliant legged robot is more energy efficient than rigid legged robot, a dynamically stable trot gait is more energy efficient than a statically stable amble gait, and a foot trajectory consisting of maximum possible step length with minimum leg lift gives energy efficient performance [9].

III. KINEMATIC ANALYSIS

It is known that, the quadruped robot consists of four identical robot connected to platform. Therefore, kinematic analysis of one leg is sufficient. For other leg, kinematics analysis can be found by the transformation or by mapping method. Following is the model of quadruped robot created in simscape Multibody environment.

Figure 1: Model of quadruped robot made in simscape Multibody

A. FORWARD KINEMATICS:

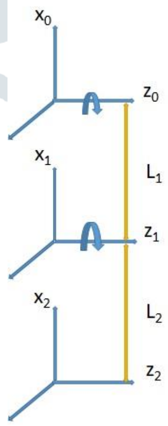

Figure 2: frame assignment of one leg

The homogeneous transformation matrix for each joint of the leg can be obtained using the DH-parameter as follows [10] :

Table 1 D H Parameter

link	Link Length(ai)	Link Twist(αi)	Joint Offset(di)	Joint Angle(θi)
1	L1	0	0	θ1
2	L2	0	0	θ2

$$^{0}T_{1} = \begin{bmatrix} C_1 & -S_1 & 0 & L_1C_1 \\ S_1 & C_1 & 0 & L_1S_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$^{1}T_{2} = \begin{bmatrix} C_2 & -S_2 & 0 & L_2C_2 \\ S_2 & C_2 & 0 & L_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$^{0}T_{2} = \begin{bmatrix} C_{12} & -S_{12} & 0 & L_1C_1 + L_2C_{12} \\ S_{12} & C_{12} & 0 & L_1S_1 + L_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Equation (3) shows the overall homogeneous transformation matrix from base frame to the end effector of the robot. Transformation matrix consists of rotational matrix as well as translation matrix. By using the transformation approach one can find position and orientation from C.G. of platform. By mirroring and translating one can find position and orientation of other leg also.

B. Inverse kinematics:

It is the process to determine all the joint variables with the help of DH parameter on the base of known/desired position and orientation of the end effector or tool point or it can defined as reverse mapping of joint variables form configuration to joint space.

$$\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix} = \begin{bmatrix} C_{12} & -S_{12} & 0 & L_1C_1 + L_2C_{12} \\ S_{12} & C_{12} & 0 & L_1S_1 + L_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

By using closed form solution method;

$$\theta_1 = \tan^{-1}\left[\frac{r_{24} - L_2 r_{21}}{r_{14} - L_2 r_{22}}\right] \quad (5)$$

$$\theta_2 = \tan^{-1}\left(\frac{r_{21}}{r_{11}}\right) - \theta_1 \quad (6)$$

IV. SIMULATION

MATLAB has inbuilt rich library of Simulink, Simscape Multibody, so decided to work with MATLAB for simulation of Quadruped robot. Here it is aim to create the model and simulate it such like that robot mimics the animal like walking pattern. In simscape Multibody, Simulink environment model of quadruped robot is created. World frame of robot is located at middle of platform. By using solid block different solid can be inserted in model like brick, cylinder etc. Connection between links are done by the rigid transformation block. As per requirement desired joint can be inserted between the links like revolute, prismatic, planer, 6- DOFs etc. Here in this configuration of robot revolute joints required only. One leg is created first by using cylinder, revolute joint and rigid transformation matrix. Other legs are created by only translating to a distance of half of width and length. Joints are excited such a way that leg are move likes an animal walking. By using transport delay block one can insert time delay between two-leg motions. Therefore, diagonal legs motions are synchronized and one pair of diagonal robot is at stance phase then other pair is at swing phase. Which mimics the animal like walking pattern. To maintain contact between ground and leg contact friction force library is used. As the inputs are given to the revolute joint by using repeating sequencing input. For animal walking pattern time delay of half of gait period for switching between stance and swing phase. Here are some simscape Multibody blocks used to create the robot.

A. Simscape Multibody and block

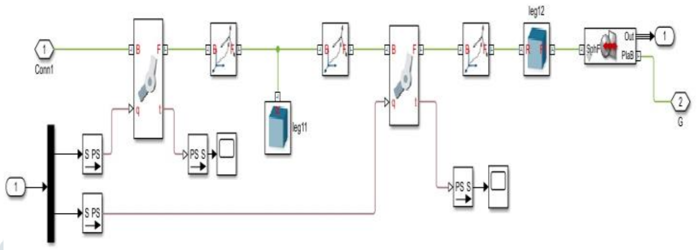

Figure 3: one leg of quadruped robot, which is connected to all corner of platform

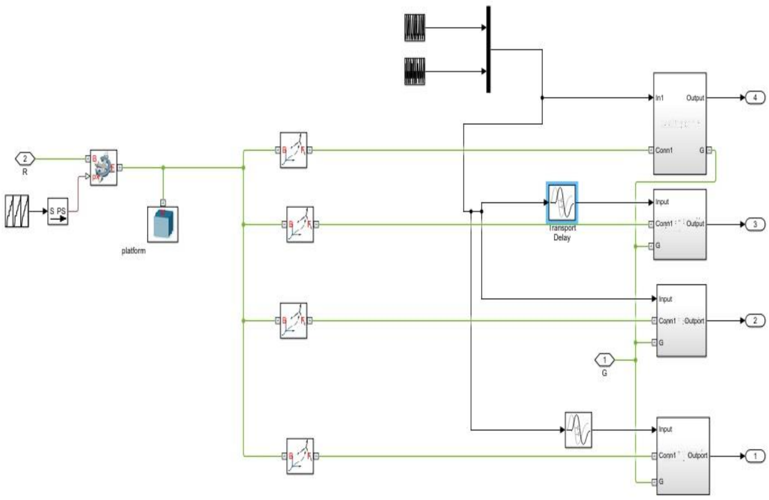

Figure 4: Complete quadruped model

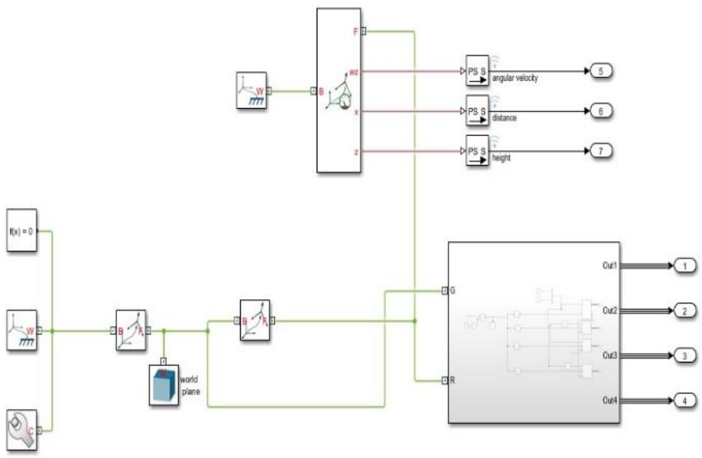

Figure 5: quadruped robot with ground

B. SIMULATION RESULT

Here are some of simulation result in simscape Multibody environment. Initially robot is steady, as per angle**,** values are given revolute joint whole robot moves on the horizontal plane. Here contact friction force library is used so leg are not slide over the ground. It will smoothly move over the horizontal plane. Position of legs at time increment of 1.5 seconds is shown in below figure 6. Diagonal legs are colored with blue and yellow for better clarification.at top side downward arrow shows the initial position of robot, from which one can judge the distance travelled by it.

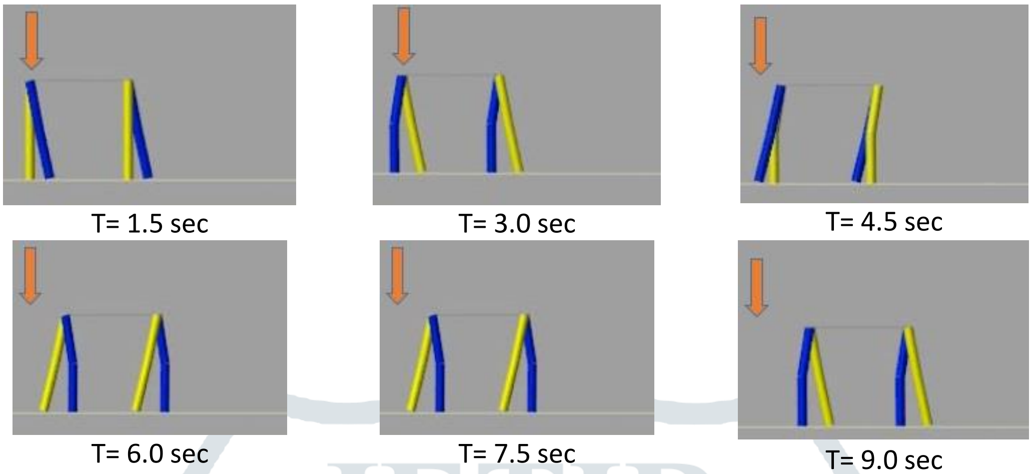

Figure 6. Position of leg at different interval of time duration

V. CONCLUSION AND FUTURE WORK

From this study, a two DOFs leg with the kinematic modeling that used in quadruped robot has validated through simulation in simscape Multibody. According to the overall results, the acquired initial position can be used as a basis for other legs. The robot leg point of contact with the ground is determined by the angle of servomotors. At beginning, two DOFs of the leg is sufficient for quadruped robot movement. However, an additional Dof at the hip is necessary to increase the Dof for the robot movement. Therefore for future work, a controller will be applied to coordinate the angular position of all joints consisting 8/12 DOFs for the quadruped robot.

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