A Study on Locomotions of Quadruped Robot

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A Study On Locomotions of Quadruped Robot

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Abstract: In this study, we focus on planning the gait of quadruped robot on flat terrain. Modeling and simulation of quadruped robot with three joint legs are carried out with MSC ADAMS software. The two phase discontinuous gait represents the sequential motion of the legs and the body robot for the locomotion of going straight and turning. The simulation presents the values of the moment on joint of leg and the trajectory of the center body. The experiment analyzes the locus of center gravity of the body robot in the gait: go straight; go straight and turn right, go straight and turn left, go forward and backward, turn the corner. The results of simulation and experiment provides theoretical basis for building algorithm the quadruped robot motion control.

Keywords: Quadruped robot, kinematics simulation, dynamic modeling, MSC ADAMS simulation, trajectory planning, gait, stability.

1 Introduction

A multi-legged robot possesses a tremendous potential for maneuverability over rough terrain, particularly in comparison to conventional wheeled or tracked mobile robot. It has more flexibility and terrain adaptability at low speed. However, the requirements for coordinating between the leg motion, controlling and computing of four legs robot encountered more difficulties than other types. Kinematic and dynamic characteristics of the quadruped robot comprehensively impact the ability to meet the motion control of the robot. For robot can move according to our purpose, we must plan the gait, calculate kinematic problem and construct dynamical system with complex dynamics of the interaction between links-joints, including trunk body, and contacting the ground with feet. Therefore, the purpose of this research is to build a complete kinematic models, plan the gait, make sure the shape is moved, the stability for the robot, from which to build dynamic models, this is the basis for the construction of motion controllers, enhances the ability to move, perform the task, and the optimization of energy supply.

This paper has presented the gaits for four-legged robots and built dynamic models more accurate than current methods with the combined method of Lagrange-Euler with model simulation on ADAMS (Automatic Dynamic Analysis of Mechanical System). From there we will create the basis for the construction of the motion control for robot to interact with the model that was built on the ADAMS.

2 Problem Formulation

2.1 Quadruped model

A simple 3D model of four-legged Robot built on environment of ADAMS/View is shown on Fig. 1.
Robot has all 13 parts with 12 DC Servo motors. In this model, the robot has 4 legs, each leg has three degrees of freedom, and movement of the legs make it possible to free movement of the body (6 degrees of freedom). So robot has a total of all 18 degrees of freedom (3x4 +6 = 18DOF).

Table 1. Physical parameters of each leg

Link parameters		Body	Link 1	Link 2	Link 3
Mass (Kg)		6	0.2	0.3	0.4
Moment of Inertia (10^{-2}. kg.m^2)	I_x	5.4	0.294	0.498	2.320
	I_y	4.927	0.247	0.493	2.316
	I_z	1.687	0.247	0.108	0.189
Length (mm)		400x200x150	50	100	200

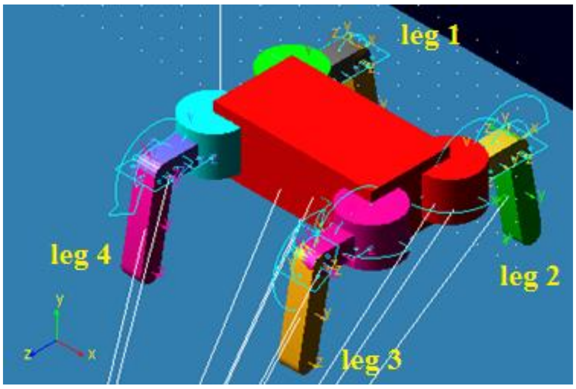

Fig. 1. Quadruped robot model in MSC.ADAMS

2.2 Planning the gait

The gait of robot is two-phase discontinuous [1]. With models such steps, at each point of the robot body is kept in balance by three legs on ground, making it very stable when moving robot. Robot motion with gait is two-phase discontinuous. The body is propelled forward/backward with all of the feet securely placed on the ground and a leg is transferred with all other three legs and body halted. For every phase of robot body will propel forward once. The gait is shown on Fig. 2.

1. Go straight gaits:

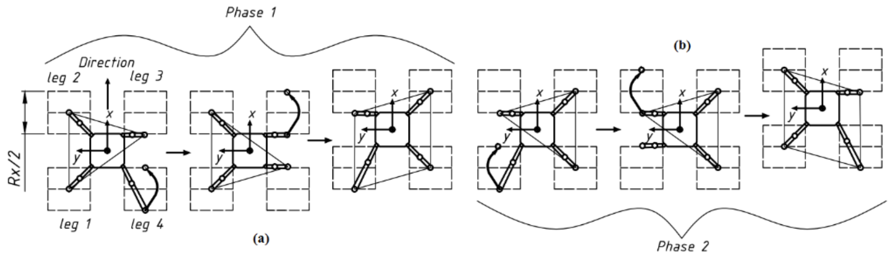

Fig. 2. Diagram of two phase discontinuous gait, (a) phase 1, (b) phase 2.

2. Turning gaits:

Fig. 3 shows the leg state at the beginning (dot line piece) and finishing (dark solid line) in the first phase. Body robot and leg space at the end of phase 1 rotate an angle α/2. In phase 1, the sequence of transferring leg is 1-4-3-2. Similarly, in phase 2 is 2-3-4-1. With this sequence, the turning process would ensure stability.

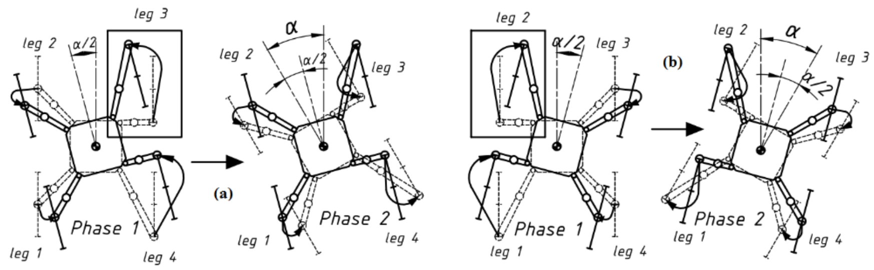

Fig. 3. Diagram of turning gait, (a) turn left, (b) turn right.

2.3 Kinematic problem

This section derives the forward kinematic model by using the Denavit - Hartenberg (D-H) convention [2]. The D-H notations have been used in kinematic modeling of each leg (refer to Fig. 4).

Table 2. D-H parameters for three joint legs.

Link	a_i	α_i	d_i	θ_i
1	a_1=33mm	$\pi/2$	0	θ_1
2	a_2=78mm	0	0	θ_2
3	a_3=130mm	0	0	θ_3

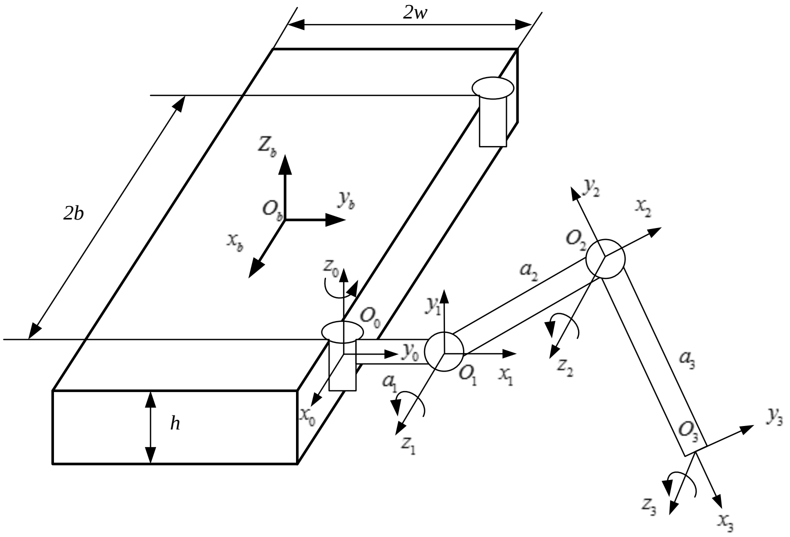

Fig. 4. Four-legged walking robot model.

3. Forward kinematic:

To describe the relationship of the orientation and position of the coordinate system attached to two adjacent stages (link *i* to link *i-1*), we used the matrix ${}^{i-1}T_i$, is represented by the transformation. The foot tip reference frame {3} can be expressed in the hip or leg reference frame {0} as given below.

$$ {}^{i-1}T_i = Trans(Z_{i-1};d_i).Rot(Z_{i-1};\theta_i).Trans(X_{i-1};a_i).Rot(X_{i-1};\alpha_i) \quad (1)$$

$$ {}^0_3T = {}^0_1T.{}^1_2T.{}^2_3T = \begin{bmatrix} C_1.C_{23} & -C_1.S_{23} & S_1 & C_1(a_3.C_{23}+a_2C_2+a_1) \\ S_1.C_{23} & -S_1.S_{23} & -C_1 & S_1(a_3.C_{23}+a_2.C_2+a_1) \\ S_{23} & C_{23} & 0 & a_3.S_{23}+a_2.S_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

where $C_1 = cos\theta_1$; $S_1=sin\theta_1$; $C_{12}=cos(\theta_1+\theta_2)$; $S_{12}= sin(\theta_1+\theta_2)$;.......

$$\Rightarrow \begin{cases} p_x = C_1(a_3.C_{23} + a_2C_2 + a_1) \\ p_y = S_1(a_3.C_{23} + a_2.C_2 + a_1) \\ \quad p_z = a_3.S_{23} + a_2.S_2 \end{cases} \tag{3}$$

4. Inverse kinematic

The inverse kinematics consists in determining the joint variables ($\theta_1, \theta_2, \theta_3$) in terms of the foot position and orientation.

By solving equations (3), the joint angles: $\theta_1, \theta_2, \theta_3$ have been determined as given below.

$$\begin{cases} \theta_1 = a\tan 2(p_y; p_x) \\ \theta_2 = -a\tan 2(B, A) + a\tan 2\left(D, \pm\sqrt{A^2 + B^2 - D^2}\right) \\ \theta_3 = a\tan 2(p_z - a_2.S_2; p_x.C_1 + p_y.S_1 - a_2.C_2 - a_1) - \theta_2 \end{cases} \tag{4}$$

$$\text{where} \begin{cases} A = -p_z;\ B = a_1 - (p_x.C_1 + p_y.S_1) \\ D = \dfrac{2.a_1.(p_x.C_1 + p_y.S_1) + a_3^2 - a_2^2 - a_1^2 - z^2 - (p_x.C_1 + p_y.S_1)^2}{2.a_2} \end{cases} \tag{5}$$

3. Simulation and Experiment

3.1 Result of simulation

The process simulation was carried out in MSC.ADAMS/View software [7], it provides a dynamic environment like real environment to get high accuracy: contact between foot to ground, coefficient friction, coefficient damping, gravity, external force…

The result of simulation shows parameters of joints and trajectory center gravity of body robot. Fig. 6 shows that in the period from 0 to 4s, the trajectory of the center of the robot body coordinates x by the time estimate the road, so that robot moves in a straight line, starting from the first 4 seconds, the robot stops and rotates in a position to turn.

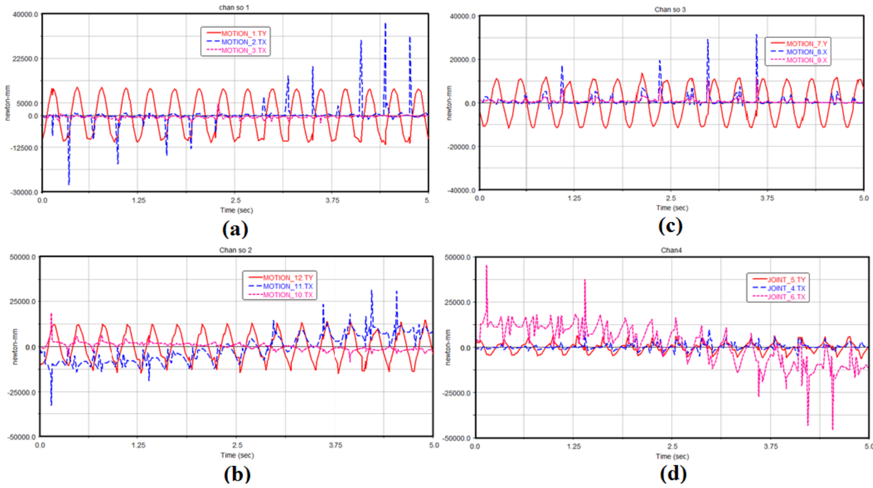

Fig. 5. (a) (b) (c) (d) joint torques of leg 1, leg 2, leg 3, leg 4.

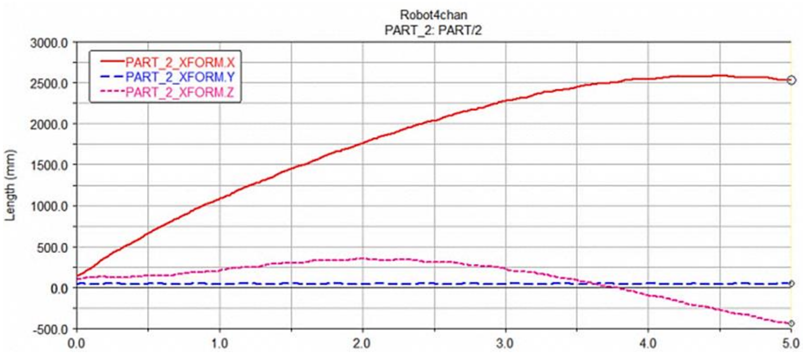

Fig. 6. Trajectory center of the body.

The simulation results are moving trajectories and torque properties at the joints in each legs robot. Due to the characteristics of the problem is simulated robot motion, it is the result of the evaluation data to the system, since the construction of the robot motion controller error of trajectories so huge and unregulated. The simulation results are moving trajectories and torque properties at the joints in each legs robot. Due to the problem of robot motion simulation, this result is data to evaluate the system, since the construction of the robot motion controller, so the error of trajectories is very large, and not controlled.

3.2 Results of experiment:

3.2.1. Experiment:

In going straight gaits have four basic 1-2-3-4 states (refer Fig. 2). The process will be done straight away by following cycle (refer in Fig. 7). Fig. 8 and 9 show the gait in real model.

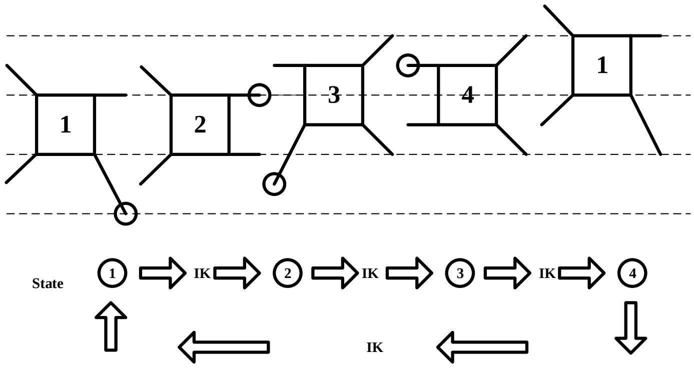

Fig. 7. The basic state of robot's legs (*IK: inverse kinematic*)

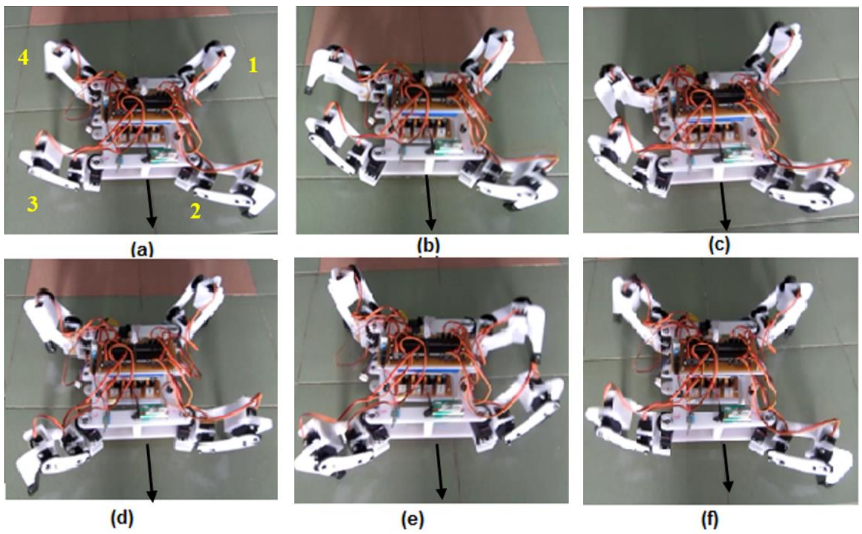

Fig. 8. Sequence of going straight forward, (a) initial position, (b) step 1 of phase 1. Leg 4 lifted up and moved forward, (c) completed step 1 of phase 1, (d) step 2 of phase 1. Leg 3 lifted up and moved forward. And then body robot propelled up a segment $R_x/2$. (e) Step 1 of phase 2. Leg 1 picked up and moved forward. (f) Step 2 of phase 2. Leg 2 lifted up and moved forward. And then body robot propelled a segment $R_x/2$.

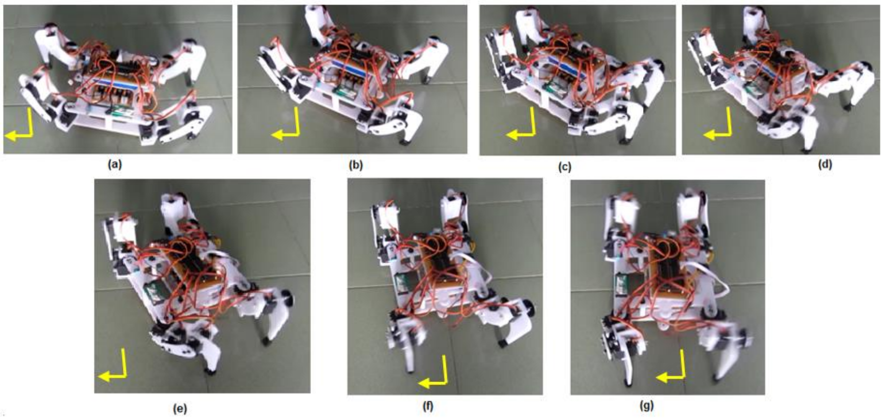

Fig 9. (a),(b), (c), (d), (e), (f) Sequence of turning right

3.2.2. Estimation result

Experimental process has simulated the robot according to the original plan already gait. Robot has carried out the trajectory to go straight and turn 90^0 left, right, go forward and backward, turn 60^0.

To evaluate accuracy of trajectory, the author uses image processing methods to identify the locus of center body robot. Camera was calib to get exact locus of the circle center on the body robot.

Distance 1 *pixel* on camera obtained 7.14 *mm* respectively with accuracy ±5 *mm*.

- **Trajectory of going straight and then turning right angle 90^0:**

The camera results are obtained in Fig. 10 (a), the robot go straight 128 pixels (914mm), then proceed to turn and go a segment 84 pixels (600 mm), the deviation from turning point (186;-125) to end point (102;-132) according vertical is 7 pixels (50 mm). So the error of angle of turn right is 4.7^0.

- **Trajectory of going straight and then turning left angle 90^0:**

In the Fig. 10 (b), the robot go straight 125 pixels (892mm), then proceed to turn left 90^0 and go straight 144 pixel (1028mm), we find that deviations from turning point (170;-125) to stopping point (129-; 316) according vertical axial is 4 pixels (28.56 mm). So the error of angle of turn left is 1.59^0.

- **Trajectory of going forward and backward:**

Robot go straight forward and backward on the length of 1 *m*. Fig. 10 (c) shows the robot trajectories at the end is deflected a segment horizontally 9 pixels (64mm). In the half of path going backward, trajectory overlap, starting at half the difference between the two trajectory goes on and on.

❖ **Trajectory of turning a angle 60^0:**

With each cycle phase is 15 degrees, robot has carried out three cycles to achieve an angle 60^0. From Fig. 10 (d), the robot performs the trajectory goes straight forward 77 pixels (550 mm), then the robot turns right and goes straight from point (180,-77) to point (316,-15). The corner turn that robot achieved is 69^0. So the error of angle of turn is 9^0 on a length of 145 pixels (1035mm).

❖ **Estimation result:**

At the beginning of the turn (Fig. 10 a and b) robot has sliding phenomenon, this is explained by the robot rotating in place, the force acting on the ground of foot is not controlled due without sensor underfoot. However, the results are accepted with the trajectory programming, no feedback signal, just based on the position kinematic.

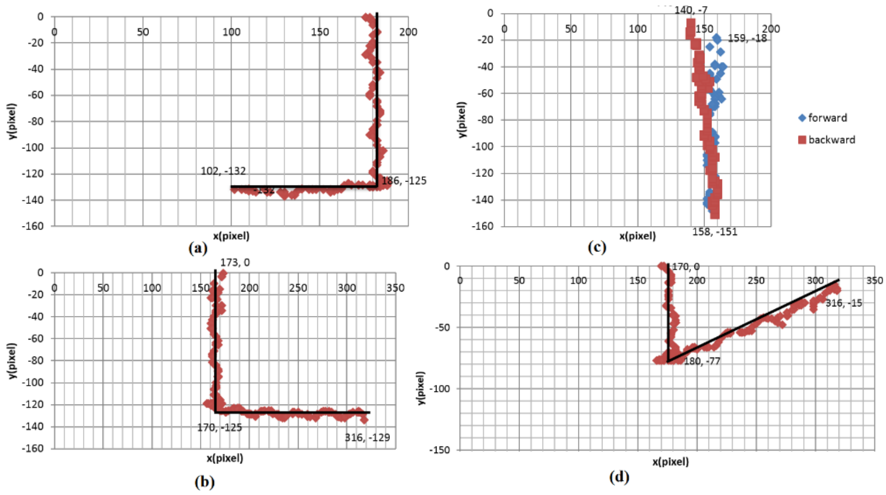

Fig. 10. The trajectory of robot (a) go straight and then turn right 90^0, (b) go straight and then turn left 90^0, (c) go forward and backward, (d) turn an angle 60^0. The black dark solid line shown the desired trajectories.

The results in Figure 10 shows that, with the uncontrolled interaction force between the foot to the ground, can not be determined coplanar between the body to the ground, this creates a different impact of the foot on the ground, so the trajectory error exists. The largest error of straight trajectory is 3 pixels (21.42 mm), turning an angle 90^0 is 4.7^0, and turning an angle 60^0 is 9^0, this is explained by repeated cycles of turning angle increases, this proves in every phase of the rotation exist an error, cause error accumulation. Trajectory of going forward and backward has error, the cause is the open-loop controller, we do not control the foot position changes, so we can not make to overlap position between going forward and backward.

To increase the accuracy of the robot move, we need to control the impact force from the legs to the ground and the reaction from ground to the legs. Therefore, robot should have force sensor. Simultaneously, to move correctly, there must be additional compass to determine the direction, camera system for image processing, accelerometer sensor to determine the inclination of the robot body. In addition, the mechanical structure must be accurate and reliable.

4. Conclusion

The simulation results will be the basis for the motion control of the robot. Simulation conditions are still limited, excluding the case from sliding foot robot, the robot moves only on a flat surface, not simulated stability on inclined surfaces. However, experiments have achieved certain results, to facilitate further research. Future research on the topic is to develop a motion controller of the robot, the robot moves on different terrain, reduce slip, increase the accuracy of the trajectory, and optimize energy consumption with a quadruped robot model more complete.

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