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Hexapod Robot Leg Dynamic Simulation and Experimental Control using Matlab

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Abstract: In this paper the authors present a hexapod robot structure. For the leg has been developed a simple simulation interface to ease the analysis of the motion. The control part is an experimental one and uses Matlab and Arduino Duemilanove development board. The movement of the leg tip along a predefined trajectory was made using a walking algorithm. Moving the leg tip from one point to another is made in two steps: stance phase and swing phase. The communication protocol is also presented. In order to control the robotic leg the direct kinematical model and inverse kinematical model were used. Also the dynamic model using Lagrange method was developed and implemented using SimMechanics toolbox and ode45 function from Matlab. The paper includes some experimental results related to the leg control and some simulations regarding dynamic model.

Keywords: Hexapod robot, Direct dynamics, Simulation platform, Matlab, SimMechanics.

1. INTRODUCTION

Walking machines allow locomotion on terrains that is inaccessible or too expensive to modify for other types of vehicles, since they don't need a continuous support surface. But the complexity of leg coordination and control are far more complex than wheeled robots, Nitulescu (2002).

Even with the first walking systems developed, researchers from robotics field tried to create robots that mimic complex animal-like motion, Nelson et al. (1997).

Building a mechanical structure that mimics an animal leg is still in progress, Figliolini (2007). The most challenging part is how to control it to act like a real one and to harvest its maximum potential.

In time the researchers have increased the capabilities of the control systems, some biologists have attempted to implement neuronal networks, genetic algorithm and other types of controls. The most used types of control implemented at joint level are PD and PID schemes.

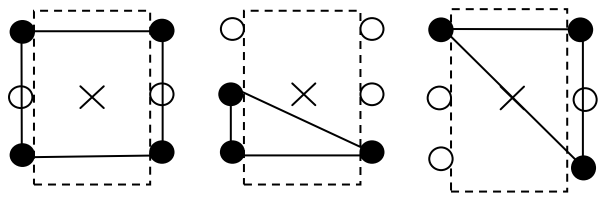
The number of mechanical walking robot designs has increased lately, hexapod robots being an important research group from all over the world, Xilun Ding et al. (2010). The ability to handle uneven terrain makes hexapods a very useful structure.

In legged animal locomotion the periodical excitation of the flexor and extensor muscles is needed in order to produce effective walking movements. For a walking structure to be able to traverse rough terrain, it needs at least 2 DOF on each leg to move forward or backward or lift over objects.

One of the most important features for a robot is to walk around its environment in a stable, efficient and naturalistic manner. If we examine the current state of art we can see that a robot can have either stability and versatility or efficiency and naturalism but never all four of them. Fundamental to the locomotion of animals is that they move by lifting their legs and placing them at new position.

One of the most studied problem for multi-legged robots consists in stability analyze during lifting off and placing the legs. The motion of legged robots can be divided into statically and dynamically stable. Static stability means that the robot is stable all the time during its gait cycle. Dynamic stability means that the robot is only stable when it is moving.

For legged robots, static stability demands that the robot must have at least three legs on the ground all the times and the robot's centre of mass is inside the support polygon, i.e. the convex polygon formed by the feet supporting the robot (Fig. 1).



Statically stable Statically unstable Critically stable

Fig. 1. Stability cases for a hexapod robot: stable, unstable critically.

2. HEXAPOD ROBOT STRUCTURE

The hexapod robot platform (Fig. 2) considered is similar to BH3 robotic platform from Lynxmotion but we have modified the length of all the segments and replaced some of the electronics. The legs were modified for better terrain adaptation and desired experimental applications. With the new legs a new problem also emerges, the original servomotors weren't up for the job and we had to replace them. The electronics now consists in a development board (Arduino Duemilanove, www.arduino.cc) and a servo controller (SSC32 – ServoController, www.lynxmotion.com). Each leg has 3 DOF controlled by 3 servomotors (Fig. 3). For the leg in question the direct kinematical model and the inverse kinematical model has been derived, Schilling (1990).

Fig. 2. Hexapod structure.

2.1 Hardware and Software Leg Control Interface

In order to control the leg, both hardware and software, a simple Matlab interface was made using GUIDE toolbox, Brian et al (2001). The interface is presented in figure 4 and allows both hardware and software control using the block diagram presented in figure 5. The "Connect" button initiates communication between the real leg and Matlab. The connection status is displayed below. The "Off-Line" button allows only simulation of the leg. The controls in the left allow modification of the leg tip coordinates. The system proposed by the authors (Fig. 4) is similar to the system xPC-Target component of Matlab. The software that make possible the communication between Arduino board and Matlab has been released with the last version of Matlab.

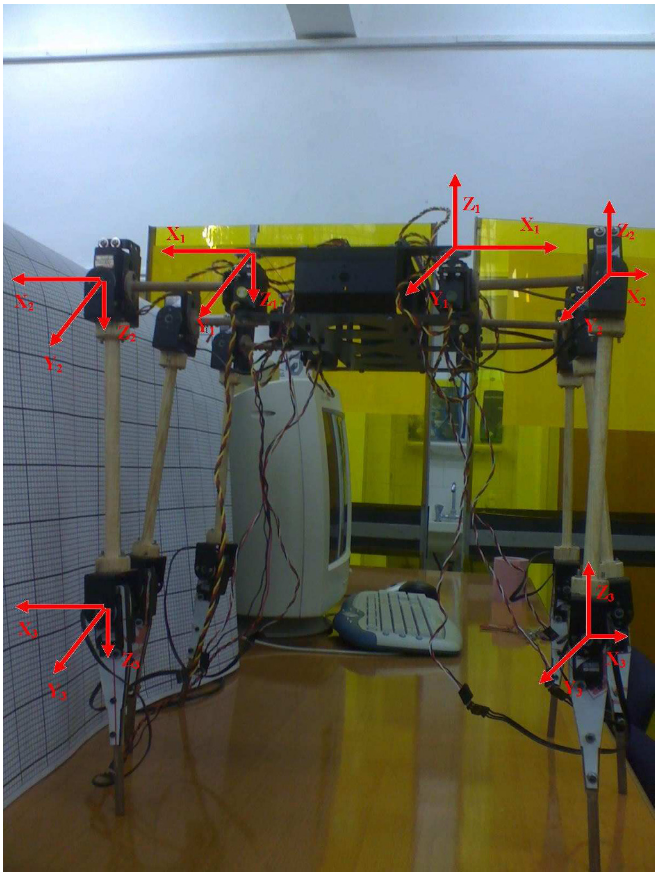


Fig. 3. Robotic leg with attached coordinates frame.

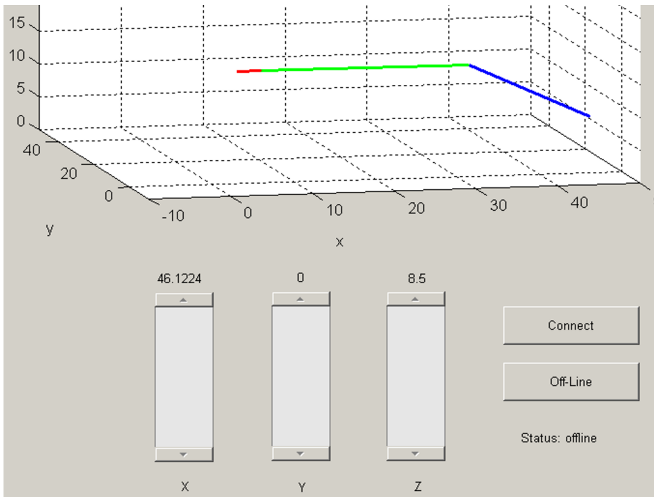
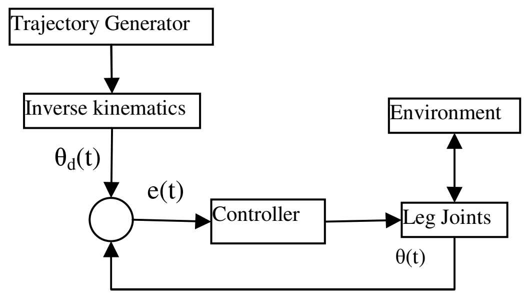


Fig. 4. Leg control interface

Mathworks (www.mathworks.com) has also developed support for Arduino in Simulink. A part of the communication software is uploaded on the Arduino board and plays the server role. There are two programs that can be uploaded on the board:

- adiosrv.pde with which all the input and output of the board can be manipulated.
- motorsrv.pde exclusively designed for motor control via motor shield



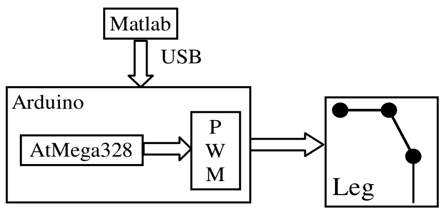


Fig. 5. Leg locomotion control.

The other part is a Matlab class and plays the role of the client. Once the class is instantiated it makes possible sending commands over USB port. Examples of some commands used for controlling the legs joints are:

```
% connect the board to port COM5
    a=arduino ('COM5');
% attach servo #1
    a.servoAttach(1);
% returns the status of all servos
    a.servoStatus;
% rotates servo #1 of 45 degrees
    a.servoWrite(1,45);
% reads angle from servo #1
    val=a.servoRead(1);
```

2.2 Dynamic Model

The purpose of robot dynamics is to determine the generalized forces required not only to overcome the self-inertial loads (due to the weight of the links of the robot) but also to produce the desired input motions.

In order to obtain a more precise model we divided the mass of each link in two (M_i- servomotor mass, m_i-link mass, $M_i > m_i$) (Fig. 6).

Lagrange equation is an analytical approach, in which an operator called the Euler – Lagrange operator is applied on the difference between the kinetic and potential energy. The first step of the Lagrange denoted by *L* algorithm is to calculate the kinetic and potential energies of the system E_C respectively E_P.

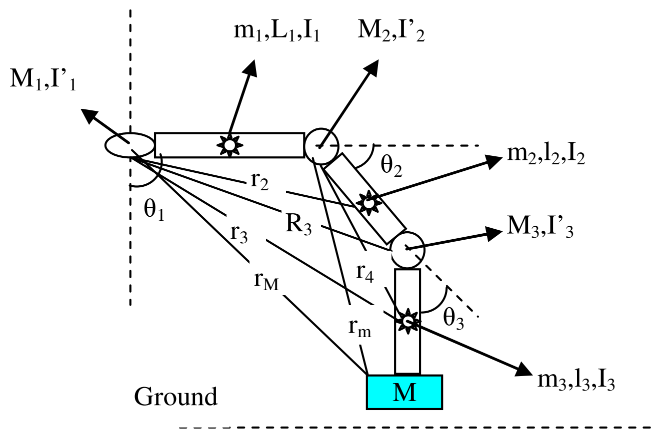


Fig. 6. Illustrations for developing dynamic model of the leg.

Mechanical systems, such as robots, have two important properties:

-the potential energy is a function of generalized coordinates only

-the kinetic energy is a quadratic function of the derivates of the generalized coordinates.

The kinetic and potential energy for each component is composed from two parts:

-one due to translations $E_{ct} = \frac{mv^2}{2}$,

-one due to rotation: $E_{cr} = \frac{I\omega^2}{2}$,

where:

v – is the translation velocity of the body
ω – is the angular velocity of the body
I – inertia matrix of the body

In this case the potential energy is the gravitational potential energy and has the form:

$$E_p = mgh \tag{1}$$

where:

h – height of the body.

Summing the above we obtain:

$$L(q,\dot{q}) = E_c(q,\dot{q}) - E_p(q) \tag{2}$$

Considering the generalized coordinates vector q = [q_1, q_2, q_3]^T the generalized vector forces can be computed using the below equation:

$$\tau_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} \tag{3}$$

Considering (3) and fig. 6 the generalized forces are:

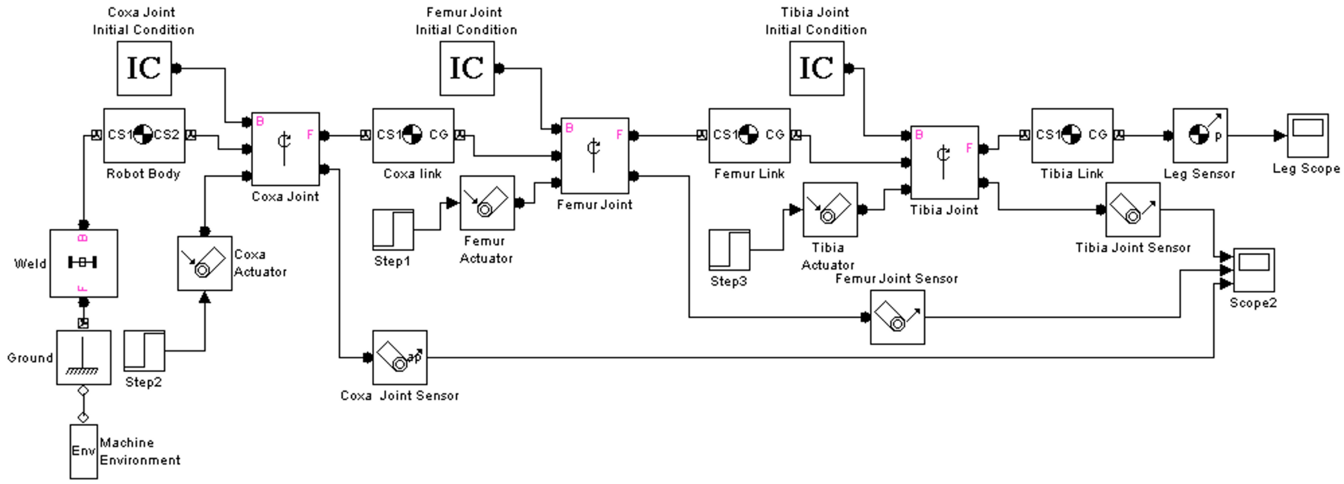


Fig. 7. Implementation of the dynamic of the leg.

$$\tau_1 = \ddot{\theta}_1\{A+B+2Fl_1l_2\cos\theta_2+2El_3[l_2\cos\theta_3+l_1\cos(\theta_2+\theta_3)]\}-$$
$$2\dot{\theta}_1[Fl_1l_2\sin\theta_2\dot{\theta}_2+El_2l_3\sin\theta_3\dot{\theta}_3+El_1l_3\sin(\theta_2+\theta_3)(\dot{\theta}_2+\dot{\theta}_3)] \quad (4)$$

$$\tau_2 = \ddot{\theta}_2(C+2El_2l_3\cos\theta_3)-2E\dot{\theta}_2\dot{\theta}_3l_2l_3\sin\theta_3-\{\dot{\theta}_2^2l_2l_32E\sin\theta_3-$$
$$\dot{\theta}_1^2[Fl_1l_2\sin\theta_2+2El_2l_3\sin\theta_3+2El_1l_3\sin(\theta_2+\theta_3)]+ \quad (5)$$
$$g\left[Fl_2\cos\theta_2+El_3\cos(\theta_2+\theta_3)\right]\}$$

$$\tau_3 = D\ddot{\theta}_3-\{\dot{\theta}_1^2\left[-El_2l_3\sin\theta_3-El_1l_3\sin(\theta_2+\theta_3)\right]-\dot{\theta}_2^2l_2l_3E\sin\theta_3+$$
$$gEl_3\cos(\theta_2+\theta_3)\} \quad (6)$$

where:

$$A = I_1^{'}+I_1^{''}+M_2l_1^2$$
$$B = m_2(l_1^2+\frac{l_2^2}{4})+M_3(l_1^2+l_2^2)+m_3(l_1^2+l_2^2+\frac{l_3^2}{4})+M(l_1^2+l_2^2+l_3^2)$$
$$C = I_2^{'}+I_2^{''}+M_3l_2^2+m_3(l_2^2+\frac{l_3^2}{4})+M(l_2^2+l_3^2) \quad (7)$$
$$D = I_3^{'}+I_3^{''}+Ml_3^2$$
$$E = \frac{m_3}{2}+M$$
$$F = \frac{m_2}{2}+M_3+m_3+M$$

$I_i^{'}$ – are the moments of inertia associated with the servo-motors;
$I_i^{''}$ – are the moments of inertia associated with the links;
M_i – mass of the servomotors
m_i – mass of the links
M – additional mass

For our experiments we considered that all three servomotors have the same mass M_1=M_2=M_3=M_1 and the last two links have the same mass m_2=m_3=m_2 but different lengths. The additional mass M was introduced in order to compensate the part of the weight of the robotic structure.

The dynamic model was validated using SimMechanics (Fig.7) (Matlab toolbox) and also using ode45 function.

3. EXPERIMENTAL RESULTS

3.1 Hardware Leg Control

The algorithm for controlling the leg joints, including direct kinematics and inverse kinematics, was implemented in Matlab in order to analyze leg performance. The results of the tests can be seen in the chart below.

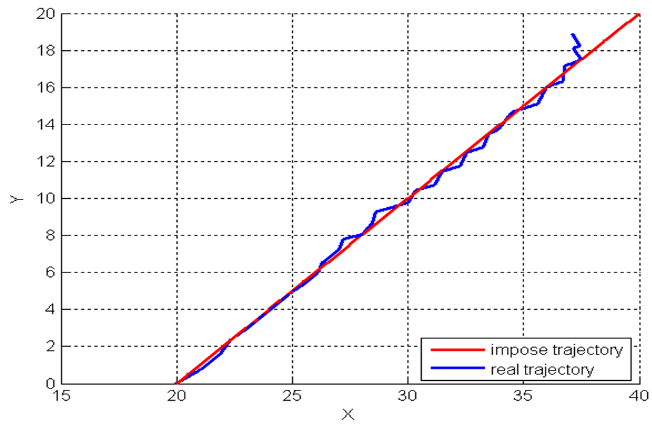


Fig. 8. Leg control results

The main errors occurred due to the fact that we can only send integer numbers for joint values.

Other errors occurred due to the fact that the joints are assembled using bolts and nuts. Normal usage of the robot leg causes the nuts and bolts to loosen causing clearance in the joints.

3.2. Dynamic Analysis

For dynamic analysis we tested the responses of each joint at a step signal. Also we were interested of the effects on the other joints.

Next there the responses of each joint at step signal and the effects on the other joints are presented. In the first and second charts the effects on coxa joints aren't figured because they are neglected.

As stated before the dynamic model was validated using SimMechanics and all the charts presented were obtained with its help.

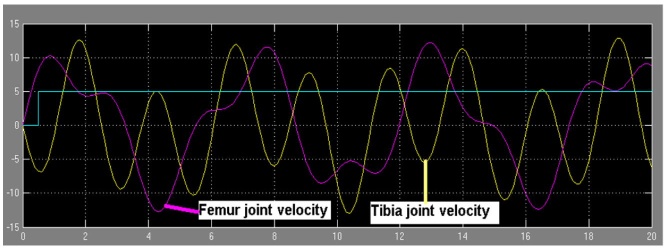


Fig. 9. Femur joint velocity response and the influence on tibia joint velocity

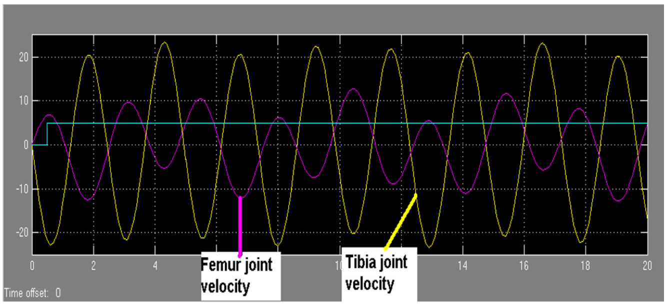


Fig. 10. Tibia joint velocity response and the influence on femur joint velocity

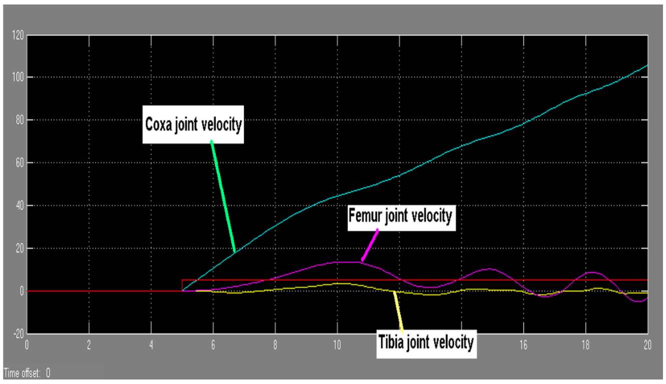


Fig. 11. Coxa joint velocity response and the influence on femur and tibia joint velocity.

4. CONCLUSION

The movement of the leg tip along a predefined trajectory was made using a walking algorithm. In order to control the robotic leg the direct kinematical model and inverse kinematical model were used.

The control part for the robotic leg is an experimental one and uses Matlab and Arduino Duemilanove development board and it will be improved in the future.

Regarding dynamic analysis, the simulations performed helped us choosing better servomotors for our experimental hexapod.

An advantage for developing the dynamic model and implementing it in SimMechanics is the possibility of viewing more types of signal such as: angles, angular acceleration, computed torque, reaction torque, reaction force.

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