DESIGNING A PD CONTROL WITH GRAVITY COMPENSATION FOR A SIX LEGGED ROBOT

Gorrostieta E., IEEE Member[1], Vargas E. IEEE Member[2]

[1]Instituto Tecnológico de Querétaro Av. Tecnológico esq. Escobedo C.P 76150 Santiago de Querétaro ,Qro. México. efren.hurtado@usa.net
[2]Centro de Ingeniería y Desarrollo Industrial, Pie de la Cuesta 702, Col. San Pablo, C.P. 76130 Querétaro, Qro. México.

Abstract. **In this work is shown the design of a PD control with gravity compensation for the generation of leg trajectories of a six-legged robot. The paper is divided in three parts. In the first part the dynamic model for the robot's leg is introduced. The second part shows the control law designed by considering the gravity effect and the dynamic parameters. Finally in the third part we discuss the results obtained by computer simulation.**

Keywords
Walking machine, control trajectory, hexapode robot.

I. INTRODUCTION

The design of the control system in a walking robot plays an important role for efficient walking manner. Several problems have to be solved in order to get an automatic locomotion gait. Some of these problems are the stability control during the walking process, the working space restriction to avoid crashing impacts between legs or body, the force distribution in the robot and the adaptable manner to walk on different terrains. At the time, several ways exist to make the walking locomotion easy with a kind of adaptability but more research is needed.

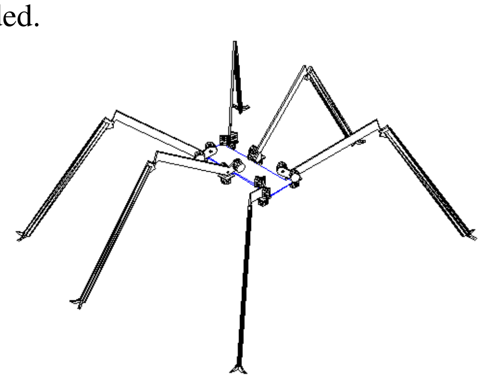

Fig. 1. Configuration of the walking robot.

We focus our attention in the control law considering the gravity effect of the legs as a way to increase the speed locomotion and reduce the energy consumption. Figure 1 shows the robot design; the morphology of the robot is similar to the ant. [1]

II. DYNAMICS MODEL OF THE LEG

The design of the control law is based in the dynamic model of the robot's leg. Each leg of the robot consists of a basic configuration of three degrees of freedom as shown in figure 2. The parameters using to make the mathematical model of the robot are the following: θ_1, θ_2, θ_3 are the relative angles between the links, these angles are independents, l_2 and l_3 are the effective longitude for the link 2 and link 3, respectively.

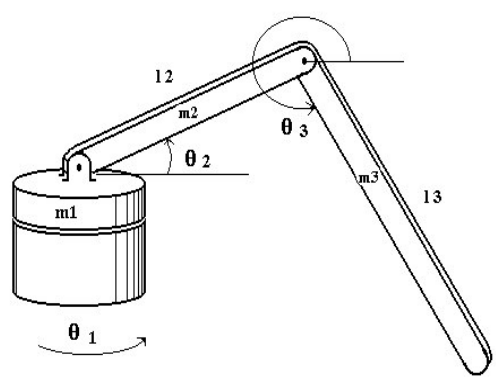

Fig. 2. Parameters used for the modeling leg.

We consider each link, as a rigid body. The parameters m_1, m_2 and m_3 are the mass for link 1, link2 ad link3, respectively. In the same sense, J1, J2 and J2 represent the inertia for link1, link2 and link3. From and energetic point of view, the Lagrange technique is used to obtain the dynamic model for the legs. Equation 1 is a fundamental relationship between internal and external energy. K represents the kinetic energy of the mechanical system and U represents the potential energy.

$$L = K - U \tag{1}$$

Equation 2 is the fundamental relationship to determine the external torque for each generalized coordinate.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_n}\right) - \frac{\partial L}{\partial \theta_n} = \tau \tag{2}$$

The mathematical dynamic model for the legs is expressed by equation 3, the system can be reasonably represented for a second order differential equation.

$$\begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix}\begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{\theta}_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ b_{21} & 0 & b_{23} \\ b_{31} & b_{32} & 0 \end{bmatrix}\begin{bmatrix} \dot{\theta}_1^2 \\ \dot{\theta}_2^2 \\ \dot{\theta}_3^2 \end{bmatrix} + ..$$

$$+ \begin{bmatrix} c_{11} & c_{12} & 0 \\ c_{21} & 0 & c_{23} \\ 0 & 0 & c_{33} \end{bmatrix}\begin{bmatrix} \dot{\theta}_1\dot{\theta}_2 \\ \dot{\theta}_1\dot{\theta}_3 \\ \dot{\theta}_2\dot{\theta}_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & f_{22} & f_{23} \\ 0 & 0 & f_{33} \end{bmatrix}\begin{bmatrix} m_1 g \\ m_2 g \\ m_3 g \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \end{bmatrix} \tag{3}$$

In equation 4 the coefficients of the inertia matrix are defined.

$$\begin{aligned} a_{11} &= J_1 + m_3 l_2^2 cos^2\theta_2 + \frac{1}{2} m_3 l_2 l_3 cos\theta_2 cos\theta_3 + \frac{1}{4} m_3 l_3^2 cos^2\theta_3 \\ a_{22} &= J_2 + \frac{1}{4} l_2 m_2 + l_3 m_3 \\ a_{23} &= \frac{1}{2} m_3 l_2 l_3 (sen\theta_2 sen\theta_3 + cos\theta_2 cos\theta_3) \\ a_{32} &= \frac{1}{2} m_3 l_2 l_3 (sen\theta_2 sen\theta_3 + cos\theta_2 cos\theta_3) \\ a_{32} &= \frac{1}{4} l_3 m_3 + J_3 \end{aligned} \tag{4}$$

$$\begin{aligned} c_{11} &= -(m_3 l_2^2 sen2\theta_2 + \frac{1}{2} m_3 l_2 l_3 sen\theta_2 cos\theta_3 + \frac{1}{4} m_2 l_2^2 sen2\theta_2) \\ c_{12} &= -(\frac{1}{2} m_3 l_3 l_2 cos\theta_2 sen\theta_3 + \frac{1}{2} m_3 l_3^2 sen2\theta_3) \\ c_{21} &= \frac{1}{2} m_3 l_2 l_3 (cos\theta_2 sen\theta_3 - sen\theta_3 cos3) \\ c_{23} &= \frac{1}{2} m_3 l_2 l_3 (cos\theta_2 sen\theta_3 - sen\theta_3 cos3) \\ c_{33} &= \frac{1}{2} m_3 l_2 l_3 (sen\theta_2 cos\theta_3 - cos\theta_2 sen\theta_3) \end{aligned} \tag{5}$$

The Coriolis and centrifugal terms are defined by the conjunction of square angular velocity effect and the multiple coordination of the angular velocity for each generalized coordinate.

$$\begin{aligned} b_{21} &= -\frac{1}{2} l_2^2 (m_2 sen2\theta_2 + m_3 sen2\theta_2) - \frac{1}{4} m_3 l_2 l_3 cos\theta_3 sen\theta_2 \\ b_{23} &= \frac{1}{2} m_3 l_2 l_3 (sen\theta_2 cos\theta_3 - cos\theta_2 sen\theta_3) \\ b_{31} &= \frac{1}{2} m_3 l_3 (l_2 cos\theta_2 sen\theta_3 - \frac{1}{2} sen2\theta_3 \\ b_{32} &= \frac{1}{2} m_3 l_2 l_3 (sen\theta_2 sen\theta_3 + cos\theta_2 cos\theta_3) \end{aligned} \tag{6}$$

Coefficient fij are the terms for the gravity effect of the masses.

$$\begin{aligned} f_{22} &= \frac{1}{2} l_2 cos\theta_2 \\ f_{23} &= l_2 cos\theta_2 \\ f_{33} &= \frac{1}{2} l_3 cos\theta_3 \end{aligned} \tag{7}$$

III. DYNAMICS CONTROL OF THE ROBOT´S LEG

Once constructed the dynamic model of the leg, we can propose a mathematical model that represents the behavior of the system. We focus our attention in the making of the model by considering the system torques of each joint which are the inputs and the join angles are the outputs. In order to describe the position of each leg in a cartesian coordinate frame, a mathematical model to transform the robots positions to cartesian positions (X,Y,Z) was done. On the other hand, we design the control law by transforming the angle joins errors to calculate the torques, and then evaluate the dynamic model to get new angles for the joins. Figure 3 shows the diagram block of the control law, this scheme is well known as control with gravity compensation. C(g) represents the effect of the gravity of the dynamic model for the leg of the robot. [2].

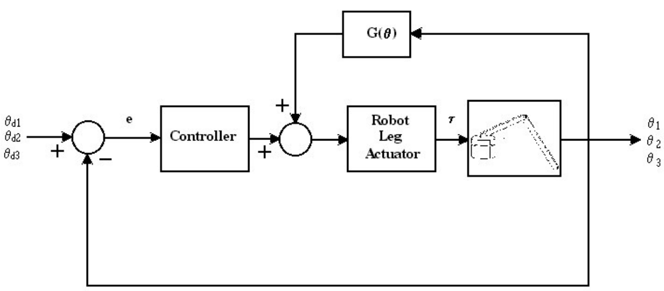

Fig. 3. Block diagram of the control law.

The control used to move a leg by simulation was a PD control system, this means that it is required to tune two constants by each degree of freedom, proportional gain K and the derivative gain Kd. In our interests to control the position and velocity of each angle, we must tune a total of 12 variables.

TABLE I
PD CONTROL CONSTANTS FOR POSITION CONTROL

Constants	K1	K2	K3	Kd1	Kd2	Kd3
Value	0.06	0.09	0.2	0.009	0.6	0.01

TABLE II
PD CONTROL CONSTANTS FOR VELOCITY CONTROL

Constants	K1	K2	K3	Kd1	Kd2	Kd3
Value	0.06	0.09	0.2	0.009	0.6	0.01

In table 1, the values obtained for the parameters of PD control system for leg's position are shown. The position that will be due is carried-out according to a trajectory generator. In table 2 values of the PD control system for velocity control are shown. By the same manner of position, we design a velocity trajectory generator. These values of the control guarantee us that the movements of the output variable move very smoothly until arriving at the value wished, without on passing this value and avoiding some kind of oscillation. As a result of this control system, we have that the trajectory pursuit is good but many deviations in the pursuit for the velocity appear in computer simulations.

IV. TRAJECTORY FOR THE LEG

The primary target that is tried for the control proposed in this paper is to follow a trajectory for a step leg. To evaluate the trajectory, we consider l_2= 0.130 m, and l_3=0.240 m. The trajectory is a parametric equation, and it can change according to the type of land or application of the robot. Figure 4 shows a parabolic type trajectory motion for the leg, and Figure 5 shows a triangle trajectory [3][4].

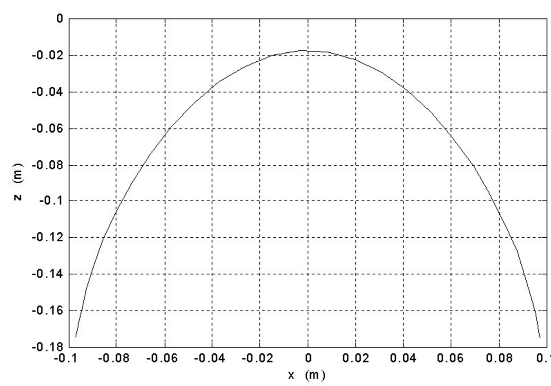

Fig. 4. Parabolic trajectory motion.

In figure 5 the trajectory is based on the movement appears in mammalian, in this case the equations of for the three degrees of freedom in the leg are described by equations 8 [5].

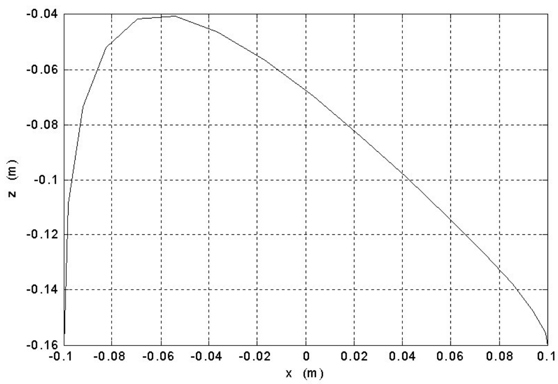

Fig. 5. Triangle trajectory motion.

$$\begin{aligned} \theta_1 &= d\gamma - A\gamma(\cos\xi - 1) \\ \theta_2 &= d\beta - A\beta(\cos\xi - 1) \\ \theta_3 &= d\chi - A\chi(\cos\xi - 1) \end{aligned} \quad (8)$$

In equation 9, we show the values considering the dimension that is required in the generation of passage for the walking robot.

$$\begin{aligned} d\gamma &= 70 \quad A\gamma = 20 \\ d\beta &= 4 \quad A\beta = 15 \\ d\chi &= 310 \quad A\chi = 10 \end{aligned} \quad (9)$$

Equations 10, shows the polynomial approach of triangle trajectory motion.

$$\begin{aligned} \theta_1 &= 90 - 18(sen2\xi - 1.5) \\ \theta_2 &= \text{-}18.4\xi^4 + 124\xi^3 \text{ - } 270.6\xi^2 + 190.7\xi \text{ - } 5.6035 \\ \theta_3 &= 0.0085\xi^4 + 2.3\xi^3 \text{ - } 9.4\xi^2 + 6.6198\,\xi + 326.4759 \end{aligned} \quad (10)$$

V. SIMULATION RESULTS

After determine the type of movement and the dynamic control law, we evaluate the leg step by analyzing the motion of each degree of freedom.

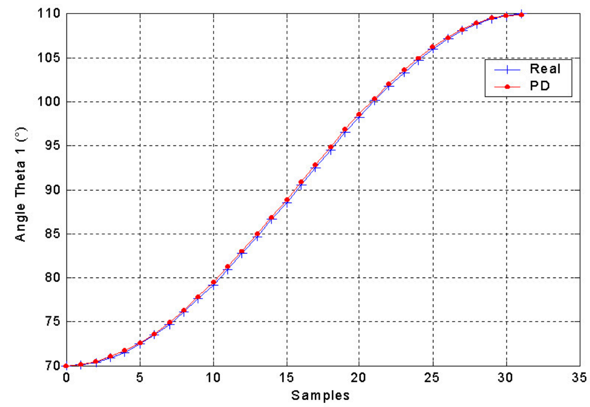

Fig. 6. Trajectory motion for the first degree.

One of the considerations we did in our experiments it was to generate smooth movements at the beginning and the end of the trajectory, as shown in Figure 6 for angle θ_1.

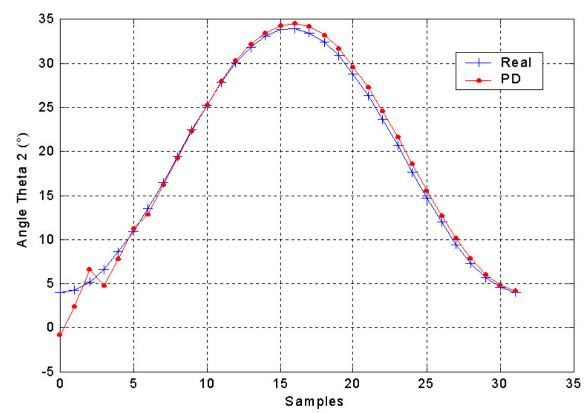

Fig. 7. Trajectory motion for the second degree.

In figure 7 a virtual real trajectories and the designed trajectory for θ_2 is shown. Points draw the virtual real trajectory and the designed trajectory is drawn with a continuous line. Figure 8 show a similar graphic result for the angle θ_3, which is also similar to the movement described for θ_2. The final tracking error at the end of the both trajectories is small for practical locomotion.

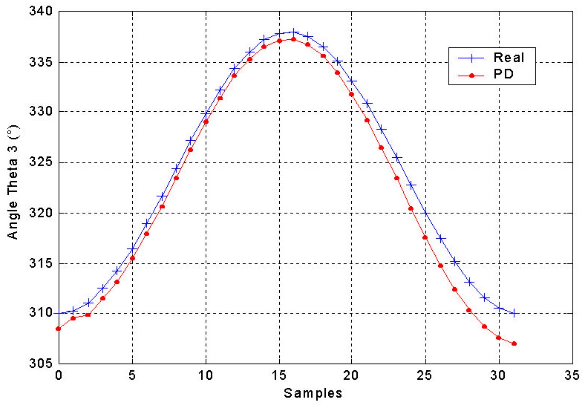

Fig. 8. Trajectory motion for the third degree.

The step for a leg is constructed by using the simultaneous movements of θ_1 , θ_2 and θ_3 . We can see in Figure 9 the step trajectory projected in a plane. For this step generation we simulate the altitude and step distance made for the leg, which is essential information to design algorithms oriented to adapt the step to the terrain, according with the legs positions.

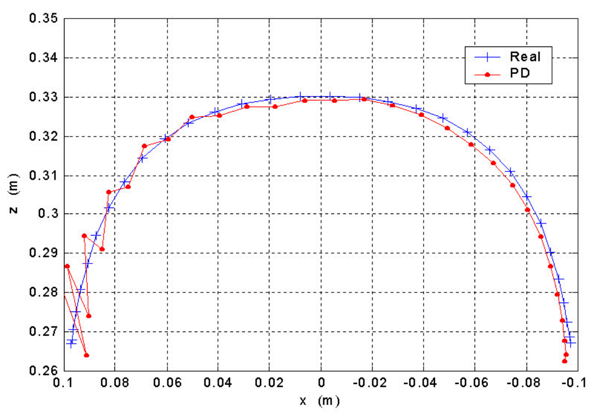

Fig. 9. Step trajectory generation.

VI. Conclusion and Future Work

The dynamic model described for a leg of a six-legged robot is a system highly nonlinear, this complicates the design of the control, in despite of that. PD control with gravity compensation was designed with satisfactory results. A series of preliminary trajectories were evaluated by simulation considering a parametric mathematical model to facilitate the walking adaptation for the leg. We could use the coefficients of the tables 1 and 2 to help us for the design of a walking generator algorithm. We will continue this research by considering intelligent algorithm as the case of a neuronal network. It is also necessary to make research about the flexibility of the working space area for the legs, cause the mobility of the robot can be increased substantially. The determination of the mobility for the robot and the stability evaluation is possible by using a 3D graphic simulator which is under construction.

Acknowledgment

The authors would like to thank to Dr. Guillermo Rodríguez for his support of this research in the Postgraduate Unit at the Industrial Development and Engineering Center, CIDESI.

References

[1] Solano. J, Vargas E, Gorrostieta E, Morales. C. 2000 “Designing a Walking Robot of Six Legs ” In Proceedings of International Symposium on Robotics and Automation ISRA’2000 (Monterrey N. L. , Mexico, Nov 10 – 12).

[2] Tomás Francisco Calyeca Sánchez, Sergio Javier Torres Méndez, Germán Ardul Muñoz Hernández . 2000 “PD control system whit gravity compensation ” In Proceedings of International Symposium on Robotics and Automation ISRA’2000 (Monterrey N. L. , Mexico, Nov 10 – 12).

[3] Peter Nehaus and H Kazerooni. 2001. “Industrial-Strength Human-Assisted Walking Robots”, Robotics and Automation Magazine of IEEE, Vol. 8, No.4 , December 2001.

[4] V. Feliu, A Garcia, J. A. Somolinos. 2001. “ Gauge-Base Tip Position Control of a New Three-Degree- of –Freedom Flexible Robot”, in The international Journal of Robotics Research, Vol. 20 No. 8 August 2001.

[5] W. Ilg, T. Mühlfriedel, K. Berns, and R. Dillmanm “Hybrid Learning Concepts for a Biollogically Inspired Control of Periodic Movements for Walking Machines” In Soft Computing in Mechatronics. Germany 1999.

[6] Shaoping Bai, H Low and Weimiao Guo “Kinematographic Experiments on The Leg Movements and Body Trayectories of Cockroach Walking on Different Terrain” In Proceedings of International Conferences on Robotics and Automation (San Francisco Cal, April 2001)