Chapter 6

Experimental results

6.1 Introduction

To achieve robustness in the control algorithms for the robot's balance control and walking sequence implemented at the "Dany walker" biped robot, some experiments in real time for the robot's balance were implemented. These experiments demonstrated an adequate real-time response performance. Also, some off-line adjustments (means a Matlab program) for the robot's walking sequence parameters to achieve stable trajectories where necessaries to guaranty initial and final velocities near to zero or even of zero.

6.2 Balance control algorithm performance

In order to test the performance of the balance control algorithm proposed in this thesis. Some experiments were designed. In such experiments, the output of the balance controller was the biped robot lateral motor's positions and the balance controller performance indicators were the evolution of the ZMP, the ZMP *error* and *rate*. The gain values for the balance controller (incremental fuzzy PD controller) were obtained empirically and then used in all the experiments. Thus, error gain value (Ge) was 2, rate gain value (Gr) was 2, and Gu *=1.*

Is important to mention that before to start with the experiments was necessary to filter the force sensors signals, who are use to calculate the ZMP. These signals were filter using a low-pass filter (implemented on the microcontroller)

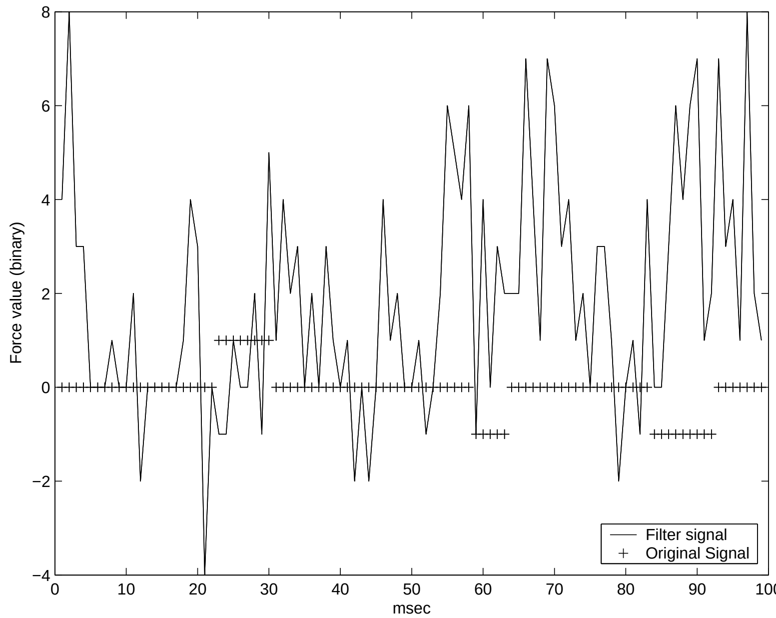

Figure 6.1: Filter signal (+), and original signal (-).

the Figure 6.1 shows the original and the obtained filter signal for one force sensor.

The first experiment, consist in to apply a x-direction impulse in the biped robot. In figure 6.2, the robot's ZMP evolution during 10 seconds as a result of the balance controller compensation is shown. The Figure 6.3 shows the ZMP error and ZMP rate evolution during the same impulse application.

Then, a second experiment was implemented, this experiment consisted in to apply and maintaining an inclination angle (perturbation) to the robot with regard to the horizontal plane and register the performance of the *balance control algorithm* trying to compensate this perturbation achieving a new vertical robot's position. In figure 6.4 the *balance control algorithm* is trying to achieve a zero ZMP value. Figure 6.5 shows the ZMP *error* and ZMP *rate* evolution for the same experiment.

Figure 6.6 shows, one waist motor's position (0-255) output calculated by the balance controller for the second experiment.

Finally a third experiment was implemented, it consist on making the robot walked six steps with the balance control algorithm active and registering the performance of it during the walking. Figure 6.7 shows the ZMP evolution

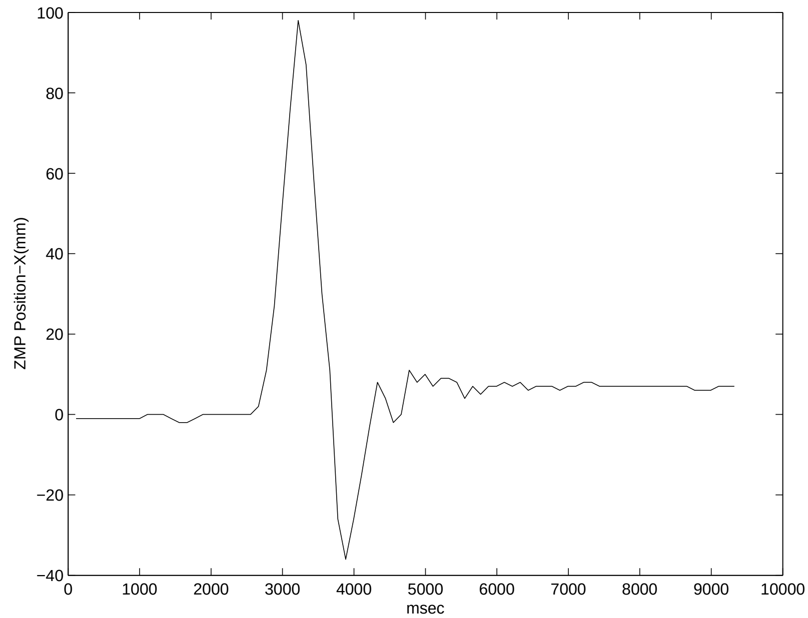

Figure 6.2: Robot's ZMP evolution during 10 seconds after apply a x-direction impulse.

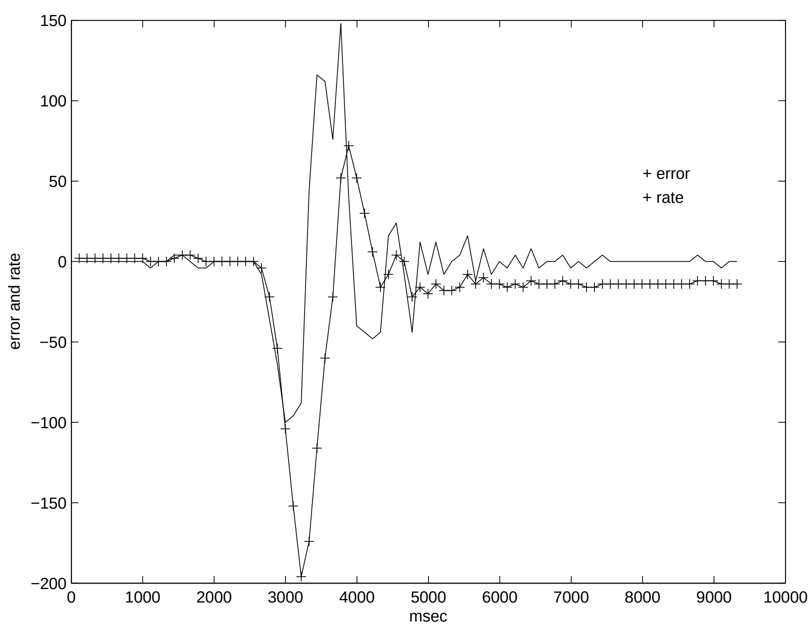

Figure 6.3: ZMP error and ZMP rate evolution during the impulse application.

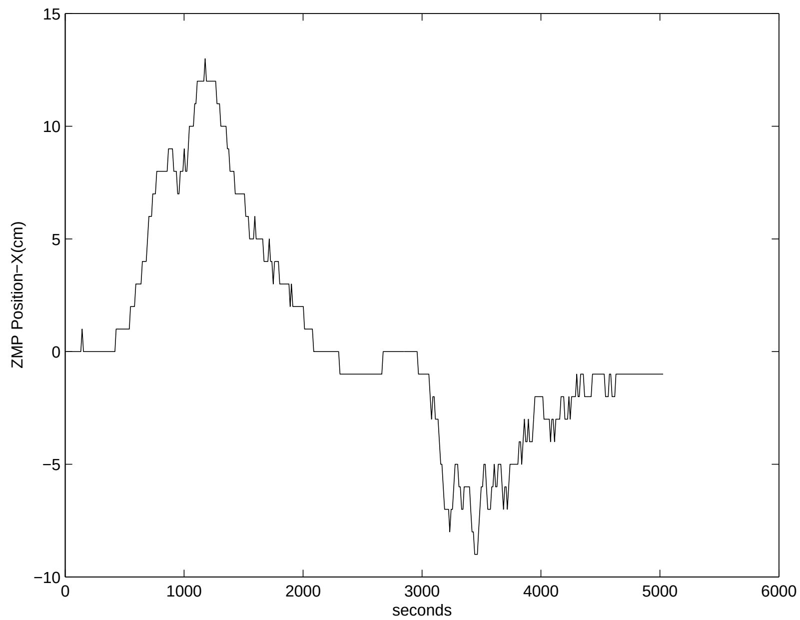

Figure 6.4: Performance of the biped's *balance control algorithm*, to achieve the vertical position.

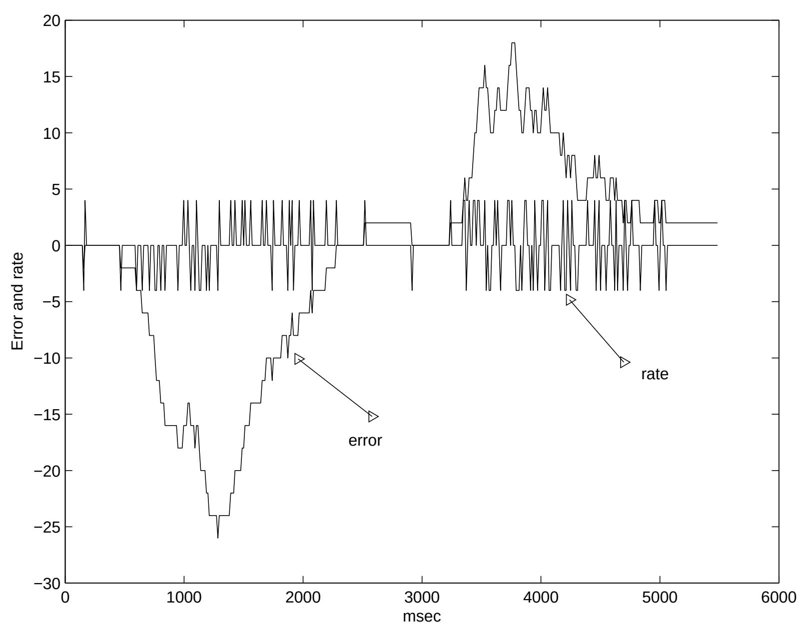

Figure 6.5: ZMP *error* and *rate* value to achieve a new robot's vertical position.

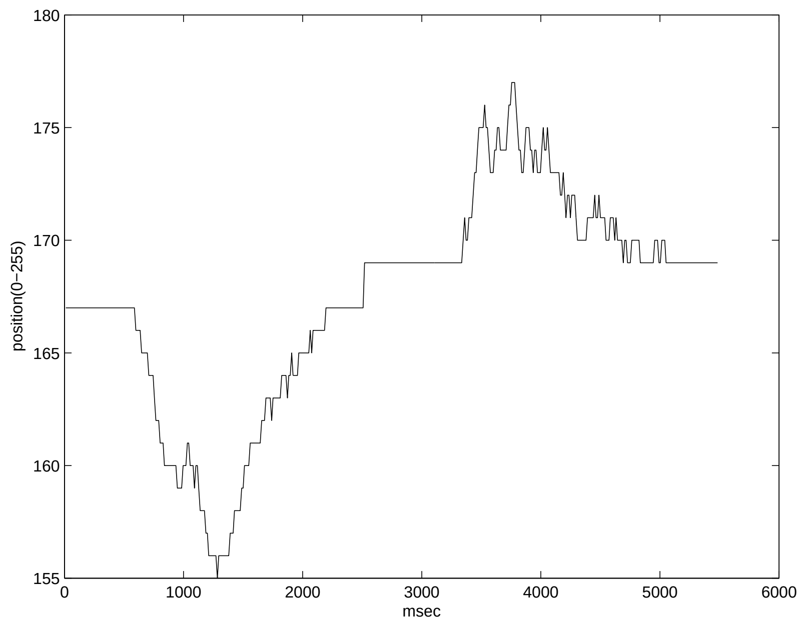

Figure 6.6: Waist motor's position value.

during six steps. Figure 6.8 shows the ZMP error and ZMP rate evolution for the same experiment. Finally, figure 6.9 shows the motor's output position (0-255) calculated by the balance controller algorithm during the six steps.

6.3 Walking sequence algorithm performance

As mentioned, the *walking sequence control* for the "Dany walker" biped robot was determined and achieved by controlling the hip and foot trajectories (see figure 5.18). Those trajectories were generated sending the calculated position to each motor to produce the desired angles and complete a walking cycle. These motor's positions were determined always following the criteria that, the change between simple supports phase and double supports phase should be smooth in order to achieve a stable dynamic walking. This criteria could be interpreted as the links velocities should be near to zero at the ending of the walking phases. As was explained, in this thesis *cubic polynomials* were used to control the sagittal motion and guaranties a smooth change between the walking phases [38].

As mentioned in section 5.6.2, the determination of the parameters T_p, V_{xhs}, T_1, T_m and zfm is not trivial because the modification of one of them supposes

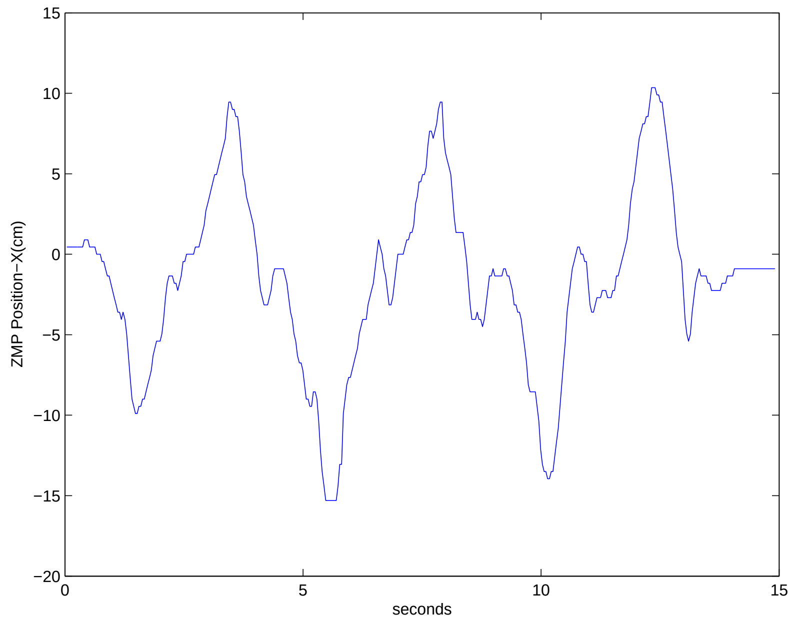

Figure 6.7: Evolution of the ZMP at walking (during six steps).

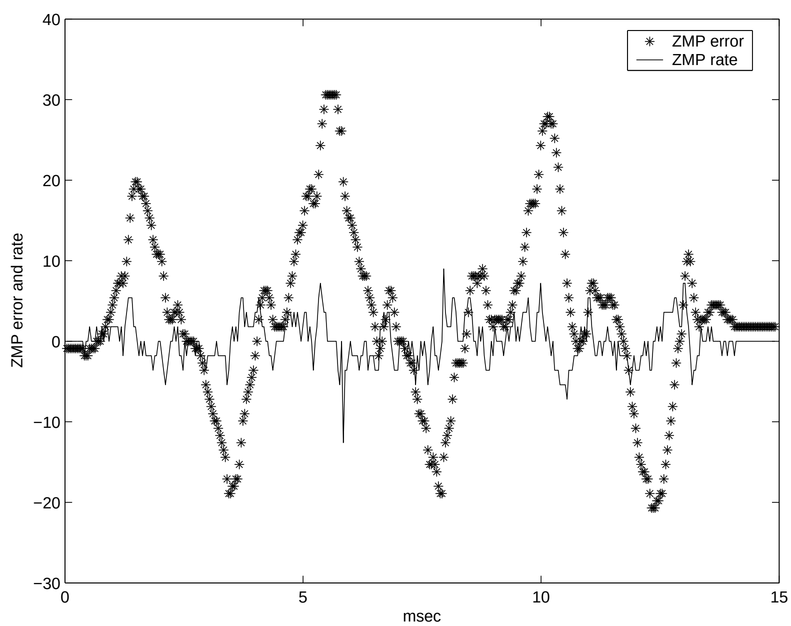

Figure 6.8: Evolution of the *ZMP error* and *ZMP rate* at walking (during six steps).

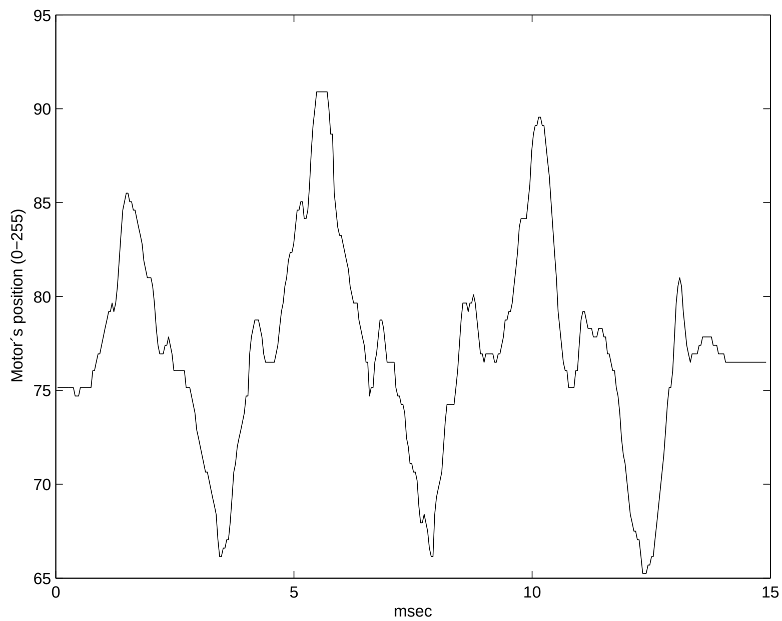

Figure 6.9: Motor's position output calculated by the *balance controller* at walking (six steps).

a change in the trajectory and conditions of smoothness in the velocity and accelerations. But, the goal is always that the velocity at the end of single support phase be zero or near to zero. Thus, a smooth contact with the floor surface is guaranteed. The values founded by the Matlab program (see figure 5.20) are showed in table 6.1. This table shows the values obtained after configure the parameters for the walking algorithm.

The trajectories for the hip and the foot at single support phase are calculated using equations [4.55], [4.57], [4.60] and [4.61]

$Parameter$	$value$
x_{hs}	-5
x_{he}	0
z_{hs}	20
z_{hs}	20
x_{h1}	-2.5
v_{xhs}	0.1
v_{xhe}	0.18
v_{zhs}	0.01
v_{zhe}	-0.03
T_s	2
T_1	1.14
T_p	4
a_0	-0.02
v_{xh1}	4.56
z_{fm}	3
T_m	1

Table 6.1 Parameter values for the walking algorithm.

For the case when the foot is in contact with the floor, the triangle in figure 6.10 represents the joint without angular movement, in this case the robot's foot and shows the necessaries link's trajectories for the ankle and knee produced by its respective joints (or motors). Figure 6.11 shows the angle's values for the ankle and knee joints and figure 6.12 shows the velocities for the ankle and knee links.

For the case when the foot is rising from backward to forward, triangle in figure 6.13 represents the joint without movement, in this case the robot's hip. For the ankle and knee, the figure 6.13 shows the links trajectories necessaries in this case, Figure 6.14 shows the angles for the ankle and knee and figure 6.15 shows the velocities for the ankle and knee necessaries for this case.

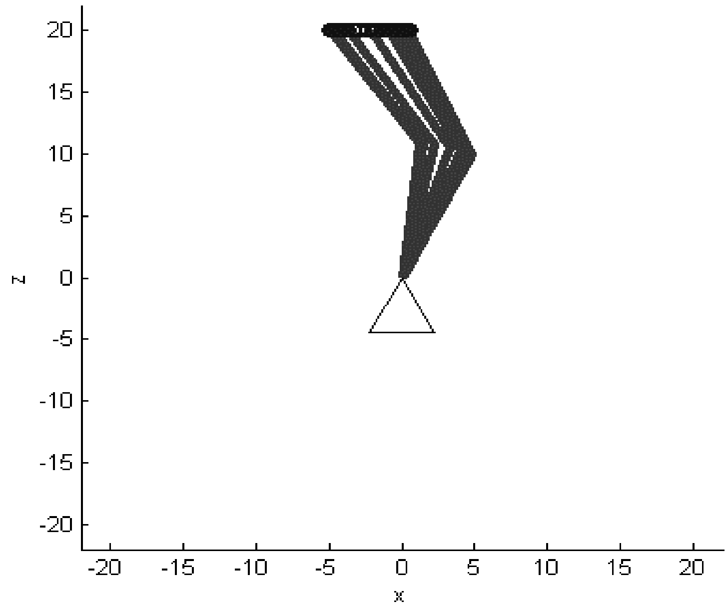

Figure 6.10: Joint's *trajectories* for the ankle and knee, when the foot is in contact with the floor.

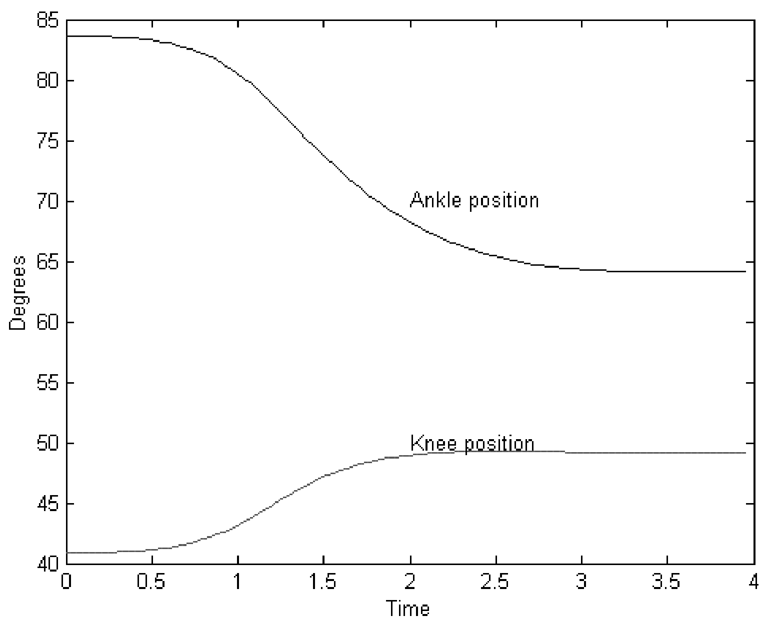

Figure 6.11: Joint's *positions* (angle) for the ankle and knee when the foot is contact with the floor.

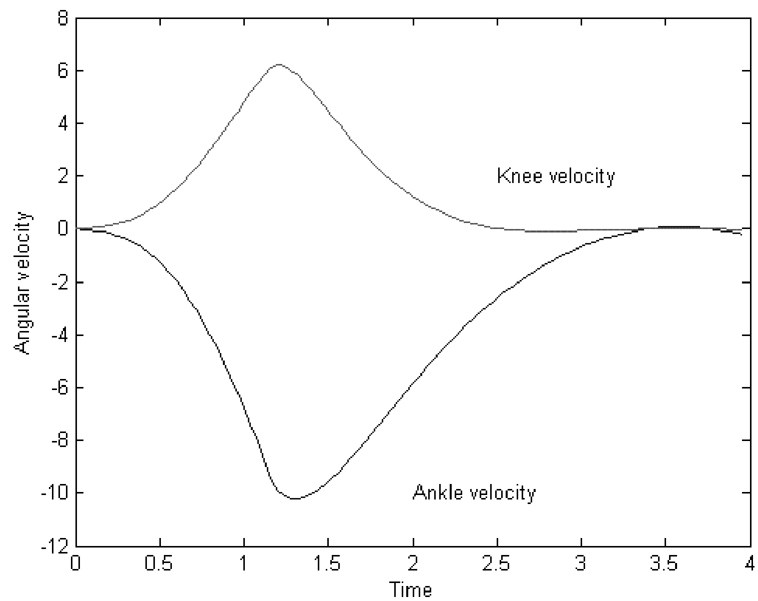

Figure 6.12: Velocities for the ankle and knee joints when the foot is contact with the floor.

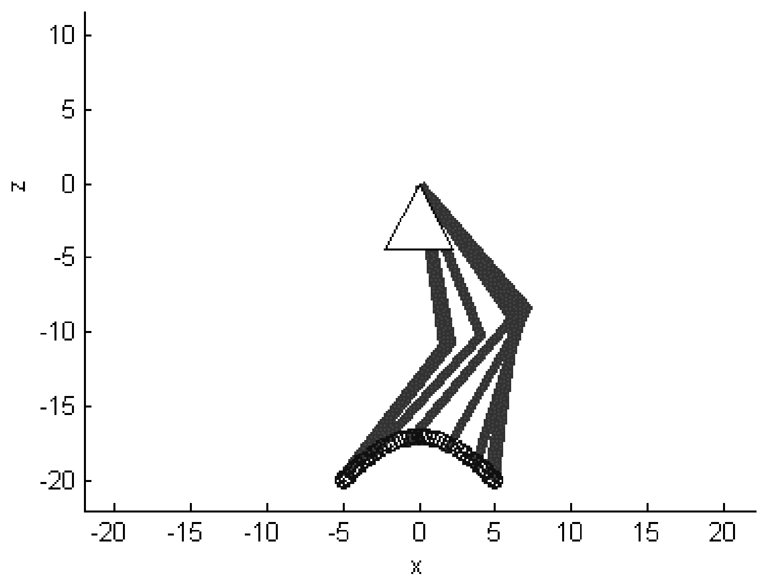

Figure 6.13: Joint's *trajectories* for the hip and knee when the foot is rising from backward to forward.

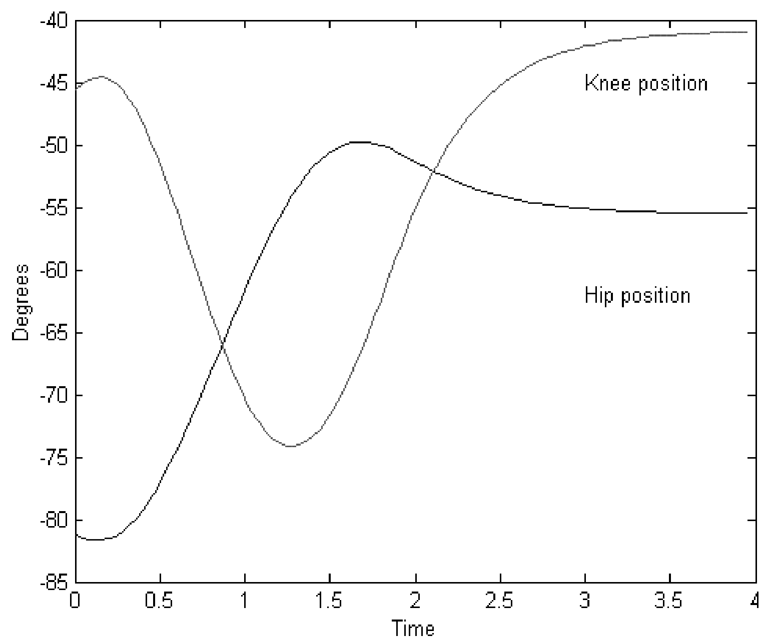

Figure 6.14: Joint's *positions* (angle) for the hip and knee when the foot is rising from backward to forward.

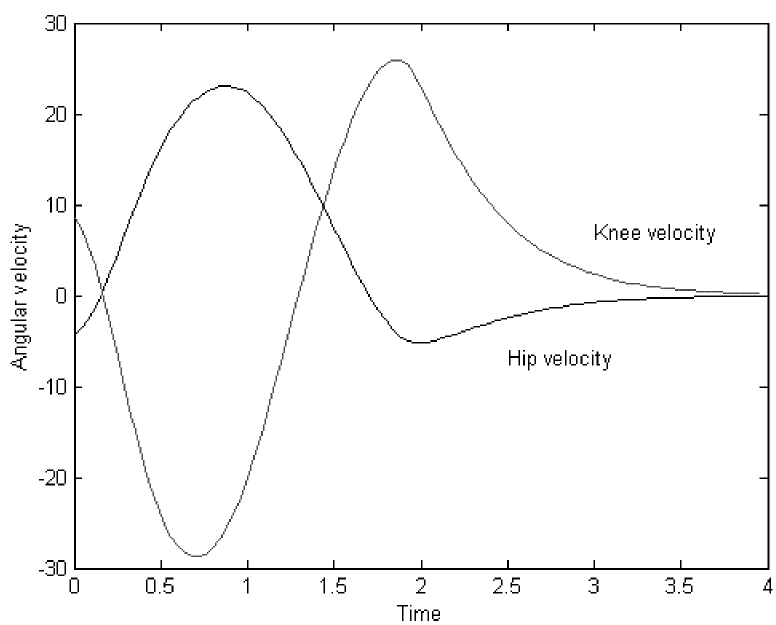

Figure 6.15: Velocities for the hip and knee joints when the foot is rising from backward to forward.