DYNAMIC MECHANISMS TO SMOOTHEN MOTIONS OF REHABILITATION ROBOT

Chapter -8
DYNAMIC MECHANISMS TO SMOOTHEN MOTIONS OF REHABILITATION ROBOT

8.1. INTRODUCTION

In this chapter, three dynamic mechanisms have been presented to smoothen dynamic motions of the rehabilitation robot. Three dynamic mechanisms are as follows:

- A kneecap was used to prevent the leg from inverting, which makes control of height easy.
- A compliant ankle limit was also employed so that the center of pressure on the foot travels forward with the center of mass of the body.
- The natural swing dynamics of the leg was exploited to make swing control simpler. An algorithm was developed to stabilize lateral motion through foot placement and ankle torque.

8.2. THE DYNAMIC MECHANISMS

8.2.1 Kneecap

Walking with straight support legs is more efficient than with bent legs since energy requirements in muscles and motors are proportional to the torque at the joint, even if there is no velocity. As the leg is to support the weight of the body, a straight leg poses an interesting challenge. Figure 8.1 illustrates the advantages of kneecap. When the body is directly over the foot (A), no torque is required at the knee. But, this is an unstable latch configuration. If the knee moves slightly either way, the leg buckles (B or C). A kneecap (D) can greatly simplify the control and make the resultant motion smoother and more efficient. A very simple control technique to keep the leg straight is to apply a constant torque so that the knee pushes against the stop.

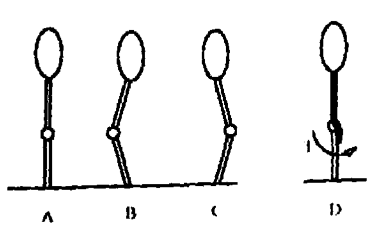

Figure 8.1. Diagram illustrating kneecap advantages.

8.2.2 Compliant Ankle

Feet and ankles provide many benefits to human walking. They reduce velocity fluctuations since the center of pressure on the foot can travel forward, staying below the center of mass of the body. They also help to control speed and to inject energy at the end of the stride through toe off. However, the torque requirements can be quite high, since the foot provides a significant lever arm when the center of pressure is near the toe.

A compliant ankle provides most of the benefits of a foot and ankle but without the torque requirements. An actuator can then be used in addition to the passive ankle for fine control and energy injection at toe off as shown in. Figure 8.2. In configuration A, the center of mass is behind the foot and there is zero ankle torque. In configurations B and C, the center of mass is traveling forward. The ankle torque increases, thereby moving the center of pressure of the foot forward from the heel to the toe. In configuration D, the robot goes into toe off, releasing the energy stored in configurations B and C and perhaps injecting some more, through active torques, to maintain walking. A quadratic spring configuration that could give the ankle the desired compliance was used.

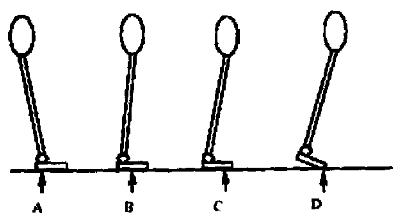

Figure 8.2. Diagram illustrating compliant ankle.

8.2.3 Passive Swing Leg

The human walkers use control techniques to control the swing leg along a trajectory to a desired landing position. However, with a suitable leg, the swing dynamics are such that once the swing starts, the leg will continue without any intervention, as illustrated in Figure 8.3. Gravity alone can be used to initiate swing, as in the case of the passive dynamic walkers. Hip torque can be added in order to make the leg swing faster. In this work, the passive swing properties of the leg were employed in the control. The hip was driven forward to a desired angle and the knee was allowed to swing freely. At the end of the swing, moderate damping was added to the knee to prevent from banging into the kneecap and finally it was locked once it hit the kneecap.

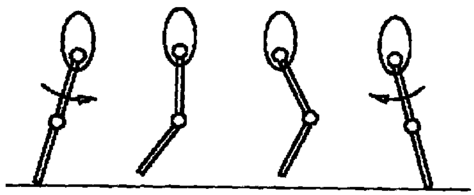

Figure 8.3. Diagram illustrating passive swing.

8.3. THE SIMULATION ALGORITHM

The dynamic mechanisms described above were employed in the control of a virtual rehabilitation robot. The simulation had an actuated hip, knee, and ankle on each leg. The simulation algorithm is summarized in Figure 8.4. Each leg acted separately and had a simple state machine. The leg could be in either Support, Toe Off, Swing, or Straighten states. In Support and Toe Off states, the hip was used to servo body pitch to maintain balance and the knee was locked to maintain height. In Support state, the ankle pitch was unactuated (only the passive ankle compliance was present). The ankle roll was used to dampen lateral velocity. During Toe Off state, the ankle was servoed to an angle using a Proportional-Derivative (PD) controller in addition to its passive compliance. The transition from Support to Toe Off was occurred when the heel was lifted off the ground due to the passive compliance of the ankle.

The rehabilitation robot was transited from Toe Off to Swing when the force on the foot was below a threshold. In both Swing and Straighten states the hip pitch was servoed to an angle using a PD controller and the foot was servoed to be level with the ground so that the rehabilitation robot did not stub its toe. In Straighten state, the hip roll was used for lateral foot placement, to control lateral velocity. In Swing state, the knee was damped while in Straighten state the knee was locked straight using a PD controller. The rehabilitation robot t was transited from Swing to Straighten state after a constant amount of time passed. Finally, the human robot was transited from Straighten to Support state when the heel of the swing leg hit the ground.

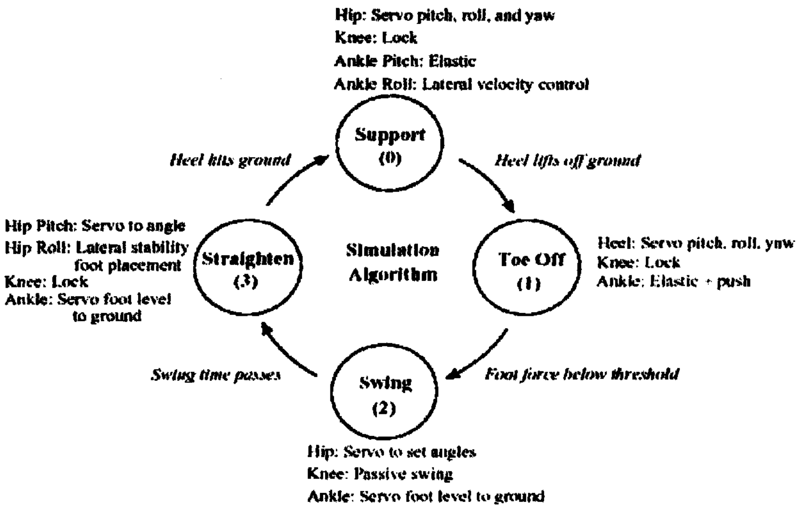

Figure 8.4. Simulation algorithm

8.4. EVALUATION OF DYNAMIC MOTIONS OF REHABILITATION ROBOT

The simulation parameters were first manually tuned, and then fine tuned. Efficiency was computed as distance traveled divided by total joint energy after ten seconds of walking. Total joint energy was computed by integrating the total joint power, which is the sum of the absolute values of the mechanical power at each joint:

$$E_{total} = \int P_{total}dt \;=\; \sum_{joints}\left|P_{joint}\right| \quad \text{where,} \quad P_{joint} = \tau_{joint}\dot{\theta}_{joint} \tag{8.1}$$

After a couple generations, the walking resulted. The results of dynamic motions are plotted graphically in Figure 8.5. It can be observed that the simulated rehabilitation robot walked at a moderate speed (approximately 0.8 m/s). It is believed that the speed is stabilized in a similar way to passive dynamic walking machines. That is, if the rehabilitation robot goes too fast, it takes a longer step due to the swing leg dynamics and hence slows down on the next step. Similarly, if the rehabilitation robot moves too slowly, it takes a shorter step and hence speeds up on the next step. It is interesting that the algorithm does not contain any explicit speed control mechanism, yet speed is stabilized. This is due to the dynamic mechanisms.

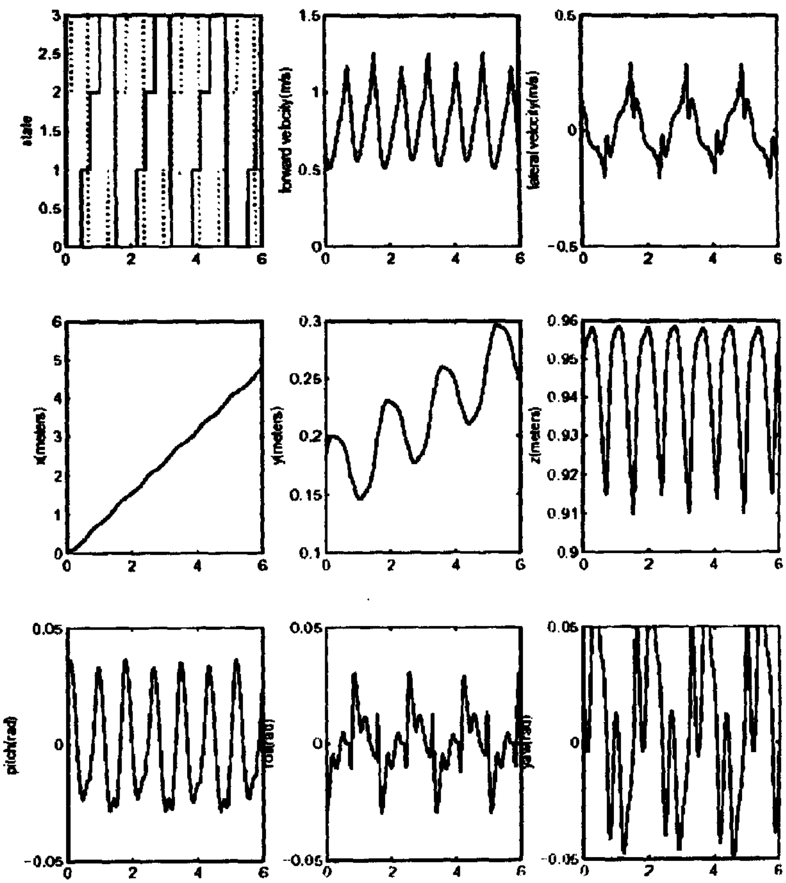

Figure 8.5 Simulation data. The first row contains, left to right, state of the legs, forward velocity, and lateral velocity. The second row contains forward distance, lateral motion, and body height. The last row contains body pitch, roll, and yaw.

CONCLUSIONS