ABSTRACT

Human walking is a smooth, highly coordinated, rhythmical movement by which the body moves step by step in the desired direction. Impairment in walking ability after paralysis is quite common. The clinical stepping motion training is currently limited because the training is labor intensive. Multiple therapists are often required to control the pelvis and legs. Recently, a new approach to locomotion rehabilitation called body weight supported (BWS) training has shown promise in improving locomotion after paralysis. The technique involves suspending the patient in a har, ess above a treadmill in order to partially relieve the weight of the body, and manually assisting the legs and pelvis while moving in a walking pattern. Patients who receive this therapy can significantly increase their independent walking ability. It is hypothesized that the technique works by stimulating force, position, and touch sensors in the legs during stepping in a repetitive manner, and that the circuits in the nervous system learn from this sensor input to generate motor output appropriate for stepping.

Implementing BWS training with robotics is also attractive because it could improve experimental control over the training, thus providing a means to better understand and optimize its effects. A difficulty in automating BWS training is that the required patterns of forces at the pelvis and legs are unknown.

This research work was aimed at to explore an alternate approach toward generating strategies for developing dynamic motion planning for walking and training the paralyzed legs with a walking robot attached to the pelvis. The dynamic properties considered in this work were mass, center of gravity, moments of inertia of each link and the friction at each joint. The dynamic properties were estimated based on the lie group formulation.

The B-spline curves were used for the trajectory planning of dynamic motion. The semi-infinite constraints were transformed into a set of linear inequalities by exploiting the convex hull property.

The least square method was used to identify the dynamic properties after exciting the walking robot and collecting the data of joint positions, velocities, accelerations and applied forces. Three dynamic mechanisms (viz., Kneecap, Compliant ankle, and Passive swing leg) were also used to smoothen dynamic motions of walking robot. The governing optimal control problem was converted into a direct parameter optimization in which the gradient was determined analytically.

Using the dynamic motion optimization (in terms of joint motions and joint torques) technique, four different rehabilitation robot configurations have been studied:

- **Configuration-1:** Paralyzed swing leg with motion captured stance hip orientation (no optimization). This case was studied to determine if simply applying a normative pelvis trajectory would effectively control the swing leg.

- **Configuration-2:** Unimpaired swing leg with effort minimization of all joints. This case was studied to determine if the optimization technique produced a realistic gait trajectory if the leg was fully actuated.

- **Configuration-3:** Paralyzed swing leg with effort minimization of the stance hip torques. This case was studied to determine to what extent swing of a paralyzed leg could be controlled with pelvis motion.

- **Configuration-4:** Paralyzed swing leg with effort minimization of the stance hip torques and bounded stance hip orientation.

The motions of key body segments for an unimpaired subject during treadmill walking were captured using a video-based system. External markers were attached to the subject at the antero-superior iliac spines (ASISs), knees, ankles, tops of the toes, and backs of the heels. A least squares method was used to convert the positions of markers to the link lengths and joint angles based on forward kinematics of the dynamic model. Motion capture data recorded from an unimpaired human subject was compared to the simulation results obtained from the dynamic motion optimization.

The results corresponding to the different walking speeds for each configuration were discussed. The applied effort, root-mean-square (RMS) of the position error (compared to the actual human gait), and norm of the final position error corresponding to different gait durations for different configurations were evaluated. The fully actuated model in configuration-2 yielded the best performance compared to the others. The results suggest that it is feasible to create a gait for a paralyzed person that is close to that of an unimpaired subject by controlling the pelvis with a rehabilitation robot.

Three dynamic mechanisms were exploited for smoothening of walking: the swing leg could swing freely once started; a kneecap could be used to prevent the leg from inverting; and a compliant ankle could be used to naturally transfer the center of pressure along the foot and help in toe off. Each of these mechanisms helped to achieve uniform and smooth walking with a rehabilitation robot.

LIST OF PAPERS PUBLISHED FROM THE PRESENT RESEARCH WORK

A. Referred Journals :(Appendix –D)

1. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Dynamic trajectory planning of robot arms, Journal of Manufacturing Technology Today, Vol.3, June 2004, pp.15-18.

2. A. Chennakesava Reddy, B. Kotiveerachari and P. Ram Reddy, Finite element analysis of flexibility in mobile robot manipulators, Journal of Institution of Engineers, Production Engineering, Vol.85, No.2, 2004, pp.27 – 31.

3. A. Chennakesava Reddy, B. Kotiveerachari and P. Ram Reddy, Different methods of robotic motion planning for assisting and training paralyzed person, International Journal of Advanced Production Technology, Vol. No.22, No.2, 2007, pp.25-29.

B. Reviewed Conferences:

1. A. Chennakesava Reddy, B. Kotiveerachari and P. Ram Reddy, Kinematic model of a flexible link using local curvatures as the deformation coordinates, Proceedings of National Conference on Advances in manufacturing Technology, 15-16th February 2003, Palghat, India, pp.101-105.

2. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Two methods for computing reduced-form dynamics of closed – chain mechanism, national Conference on Trends in Mechanical Engineering, 30th August 2003, Warangal, India, pp.133-136.

3. A.Chennakesava Reddy and P. Ram Reddy, Hazard detection for multi - agent reactive robotic system using on - line software analysis of safety constraints, National Conference on computer integrated design and manufacturing, November 28-29th 2003, Ettimadai, Coimbatore, India, pp.294 – 301.

4. A. Chennakesava Reddy and P. Rami Reddy, Elastic rigid-body dynamic modeling of planar parallel robot actuated by servomotors, National Conference on advanced materials and manufacturing techniques, Hyderabad, India, 08-09 March, 2004, pp.273 – 279.

5. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Optimization of path dependent trajectory for an arm – like serial chain robot using genetic algorithm, National Conference on Recent Trends in CAD/CAM, Bidar, 29 – 30th July, 2004, pp. 25 – 33.

6. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Optimization of robot arm path planning without collision in its workspace using genetic algorithm, International Conference on Emerging Technologies in Intelligent System and Control, 5 – 7th January 2005, Coimbatore, pp. C06: 1-9.

7. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Optimum trajectory path planning for 3-dof planar robot with minimum disturbances, National Conference on Advances in Manufacturing Technology in the Era of Globalization, 21 – 22nd, January 2005, Pune, pp. 8 – 14.

8. A. Chennakesava Reddy, P. Ram Reddy and B. Kotiveerachari, Studies on the effect of vibration of robot links on the end point trajectory path using CAD, International Conference on Recent Advances in Material Processing Technology, 23 – 25th February 2005, Kovilpatti, pp. 195 – 202.