VISCOSITY RESISTANCE CONTROL OF INTELLIGENT PROSTHETIC-LEGS

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Abstract

A viscosity resistance control method of the intelligent prosthetic legs is studied using an optimal control theory. The simulated results suggests that it is important to control the viscosity of the prosthetic knee joint in one period of walking to improve the usability. In this paper we describe modeling of the thigh prosthetic legs, optimal control and simulated results.

1. Introduction

People in general walk smoothly without waste motions. While, the physically handicapped person who lost a part of his legs is not easy to walk smoothly, even if an artificial leg is installed. Because passive mechanisms have been used for the artificial legs conventionally. It does not have actuators such as muscles. The walking gait with artificial leg is different from normal walking. Recently, a new artificial leg called Intelligent Prosthetic-Leg (IPL) was developed based on the mechatronics technology. The artificial leg can change the viscosity resistance of the knee joint with a pneumatic cylinder and a micro-computer as shown in Fig.1. IPL adjusts the viscosity automatically for various walking speed using an angular velocity sensor. IPL has better performance for the handicapped persons than the conventional artificial legs. However the walking gait is not the same as that of normal walking also. Although the joint viscosity is changing always in general walking, IPL uses a constant value of the joint viscosity in one period of walking.

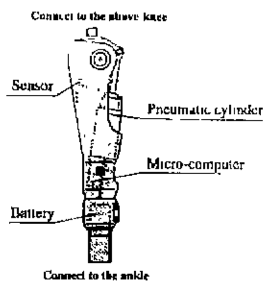

Fig.1 Intelligent Prosthetic-Legs

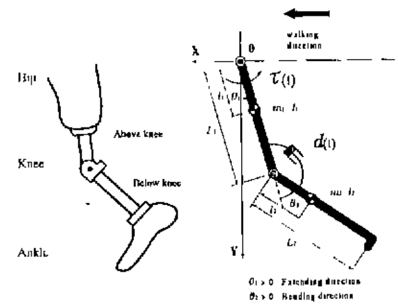

Fig.2 Swing-phase model of the Prosthetic-Legs

In order to improve the usability of IPL it is important to change the viscosity resistance of joints in one period of walking. There are two phases in walking. One of them is the stance phase whose function is to hold the standing posture. The other is the swing phase in which the speed and rhythm of walking are determined. As the first step of the research walking in the swing phase is examined in this paper. The aim of the present study is to find the control method of the viscosity resistance in one period of walking based on the optimal control theory.

2. Modeling

We adopt a two link model for the artificial leg as shown in Fig.2. The upper joint, joint 1, shows the thigh joint of the handicapped person, the lower joint, joint 2, indicates the knee joint of IPL. The joint 1 can generates a torque. The viscosity of the joint 2 can be controlled. The dynamic equation of the model is written by

$$\tau = M(\theta)\theta' + H(\theta, \theta') + G(\theta) + d\theta' \qquad (1)$$

where, τ is the joint torque vector, θ is the joint angle vector, d is the viscosity coefficient matrix, $M(\theta)$ is the inertia term, $H(\theta, \theta')$ is the Coriolis and Centrifugal force matrix, $G(\theta)$ is the gravity term. Let define the state variable vector as $x=[\theta, \theta']^T$. Then the state equation of the system is derived from equation (1) using the state variable vector.

$$x' = \begin{bmatrix} \theta' \\ [M^{-1}(\tau - d\theta' - H(\theta, \theta') - G(\theta)] \end{bmatrix} \qquad (2)$$

3. Optimal Control

The aim of the simulation is to find the time function of the viscosity coefficient d(t) in the swing phase with satisfying the boundary condition of the state variable. To this end, the following evaluation function is used.

$$J = g(t_f, x(t_f)) + \int_{t_0}^{t_f} f_0(t, x(t), u(t))dt \qquad (3)$$

$$g(t_f, x(t_f)) = w_1(\theta_1(t_f) - \theta_{1f})^2 \qquad (4)$$

$$\int_f(t, x(t_f)) = w_2(\theta_2(t) - \theta_{2d}(t))^2 + w_3 \tau^2(t) \qquad (5)$$

where, w_1, w_2, w_3 are weight coefficients, $u(t)$ is the manipulated variable. θ_{1f} is the final condition of the joint 1, $\theta_{2d}(t)$ is the desired trajectory of the joint 2. We used the initial and final angles of the thigh joint in the swing phase as the boundary conditions of joint 1. For the joint 2, the trajectory of the knee joint in normal walking [1] is used as the desired trajectory.

Fletcher-Reeves method [2] is utilized to minimize the function. This method is one of the conjugated gradient method. The minimization search is iterated 2000 times.

4. Simulation

The simulation has been done based on the model of the artificial leg described above. The various walking speeds are adopted such as 120, 80 and 60 [step/min]. Two kinds of the simulations are performed to examine the effect of viscosity control in prosthetic walking. In the first case, a constant value is used for the viscosity coefficient. In the second case the variable viscosity is utilized.

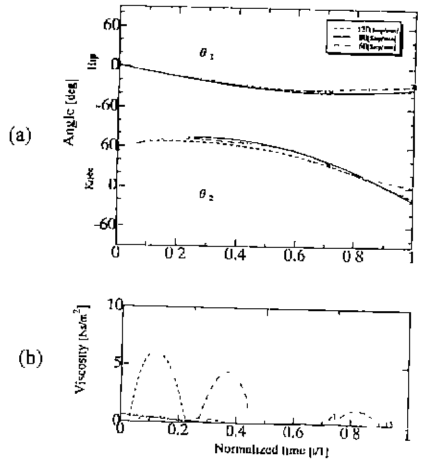

Fig.3 Simulated results in the swing phase

In the constant viscosity case, it was impossible to generate enough torque of the thigh joint. To follow the desired trajectory the thigh joint must generate huge torque. On the other hand, when we used the variable viscosity it was possible to follow the trajectory of the knee joint in normal walking as shown in Fig.3 (a). In this case, we need more viscosity in the first and last part of the swing phase (Fig.3 (b)). This simulated result shows the effectiveness of the variable viscosity control during the walking.

5. Summary

A viscosity resistance control method of the intelligent prosthetic legs is analyzed based on an optimal control theory. The study suggests that the prosthetic walking approaches the normal walking of human by changing the viscosity resistance of knee joint in one period of working. Since the viscosity of the intelligent prosthetic-legs is constant conventionally, it is important to control the viscosity in walking to improve the usability.

References

[1] Y. Ehara, S. Yamamoto, et. al: "Analysis of Walk based on Joint Moment," Ishiyaku Shuppan, (in Japanese), 1997.

[2]H. Kano: "Optimal theory and Optimization of Systems," Korona Inc. (in Japanese) ,1987.