IMPEDANCE CONTROL FOR LOWER EXTREMITY REHABILITATION EXOSKELETON

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ABSTRACT

This paper proposes an intelligent lower extremity rehabilitation training system controlled by impedance controllers. The structure of the robotic leg exoskeleton can be divided into three parts including hip joint, knee joint, and ankle joint, which is driven by linear actuator and pulley. Therefore, we can control the motion of the robotic leg exoskeleton by driving the linear actuators. Finally, the results of simulation are illustrated that the design of proposed controller presents good performances and effectiveness.

Keywords: impedance control, exoskeleton, Simmechanics simulation.

I. INTRODUCTION

Scientific and technological work on exoskeletons began in the early 1960s, but only has recently been applied to rehabilitation and functional substitution in patients suffering from motor disorder [1]. After brief and unsuccessful attempts in these years, advances in sensing, actuation and computing technologies have renewed the confidence in the viability of developing an autonomous exoskeleton system for human performance augmentation. Not only do these advances permit the realization of more compact, lightweight and robust robotic hardware design, but they also permit the development of increasingly sophisticated control laws in terms of both real-time processing capability and design and analysis computer aided tools [2-5]. The proposed robotic leg exoskeleton is configured with either a powered treadmills or a mobile platform to provide various rehabilitation purposes. The exoskeleton is comprised of two anthropomorphic legs and spine that provides a versatile loading interface. The device is to be designed and controlled in such a way that the human can conduct a wide spectrum of activities without feeling the device. The future possible applications of exoskeletons are endless and include construction workers, earthquake rescue personnel, space exploration, and physical rehabilitation. Currently, the demand of health care is the strongest need in the modern society.

II. STRUCTURE OF EXOSKELETON SYSTEM

The exoskeleton system includes two exoskeleton legs, one treadmill, and one suspension bar. Legs of the exoskeleton are designed with ability to adjust the length of thigh, shin to fit every patient. And the exoskeleton is shown in Fig. 1.

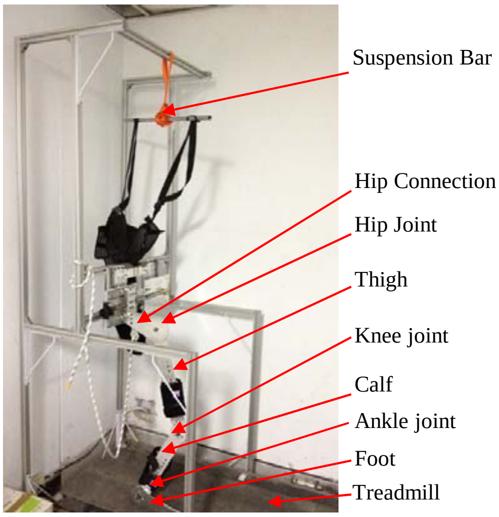

Fig. 1. Structure of the Exoskeleton

Hip joint angle, knee joints angle, and ankle joint angle will be driven by linear actuators (LAS3-1-1-50-24GE) and pulley as shown in Fig. 2. Two linear actuators can drive a joint angle as shown in Fig. 3. The schematic diagram of exoskeleton system is shown as Fig. 4. Five coordinate systems (CSs) are used including one Reference CS and four CSs for four joints (prismatic hip joint, revolute hip joint, knee joint, ankle joint).

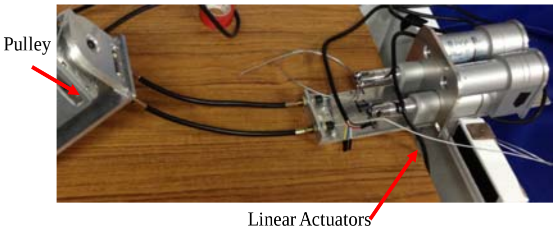

Fig. 2. Linear actuator and pulley

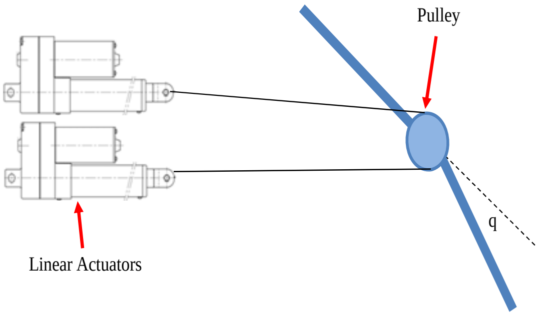

Fig. 3. One pulley driven by two linear actuators

Table 1. Parameters of LAS3 linear actuator

Model	**LAS3**
Thrust max.	1200N
Pulling max.	1200N
Holding force	800N
Speed max.	12 mm/s
Stroke	50 mm
Protection	IP 54
Duty cycle	10%
Potentiometer	21(ohm/mm)
Supply voltage	24 VDC

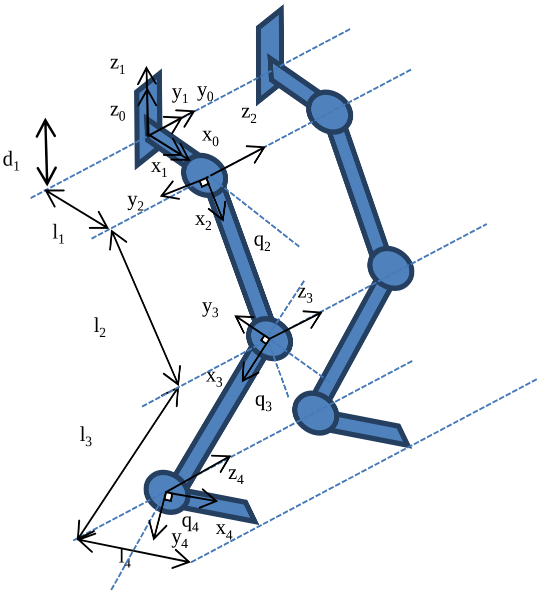

Fig. 4. Schematic diagram of exoskeleton system

The linear actuator's internal parameters are shown in Table 1. Embedded potentiometers are able to measure positions of actuators. Therefore, positions of joints can be measured.

After calculating the kinetic energy and potential energy in cooperation with Lagrangian function, the following equations are acquired:

$$\vec{T}_a + \vec{T}_h = A_{sw}(\vec{q})\ddot{\vec{q}} + \vec{b}_{sw}(\vec{q},\dot{\vec{q}}) + \vec{p}_{sw}(\vec{q}), \qquad (1)$$

Where: $T_a = [T_2\ T_3\ T_4]^T$ is the joint input torque vector (include friction). $T_h = [T_{h2}\ T_{h3}\ T_{h4}]^T$ is the human-machine joint torque vector. $q = [q_2\ q_3\ q_4]^T$ is the joint angle vector. A_{sw} is the kinetic energy matrix. $\vec{b}_{sw}$ is the vector comprising of the centrifugal and Coriolis acceleration terms. $\vec{p}_{sw}$ is the joint torque vector induced by gravity. And the dynamics model of exoskeleton can be expressed as,

$$\vec{T}_h = A_{sw}(\vec{q})\ddot{\vec{q}} + \vec{b}_{sw}(\vec{q},\dot{\vec{q}}) + \vec{p}_{sw}(\vec{q}) - \vec{T}_a \qquad (2)$$

Where: $\vec{T}_a$ denote all the external torque exerted in the exoskeleton.

III. CONTROL METHOD

This paper uses the impedance controller in the exoskeleton system. This research is to make the exoskeleton walk autonomously as a human. The impedance controller can be applied to control the hip joint angle, knee joint angle, and ankle joint angle. Matlab

Simmechanics is used to simulate impedance control method selects a generalized force vector such that the control law is constructed in the machine's joint space rather than a set of forces and torques applied at a point on the body. The block diagram of the virtual torque control law is shown in Fig.5. G_a represents the system transfer function, which is difficult to get the accuracy model. G'_a is an estimate of the machine forward dynamics. T_h denotes the torque exerted on the exoskeleton by human. T_a denotes the torque exerted by actuator. The human machine torque can be modeled as:

$$T_h = K_h(q_h - q) \qquad (3)$$

K_h is the impedance between the human and the machine, q_h is the human's position, and q is the machine's position [6].

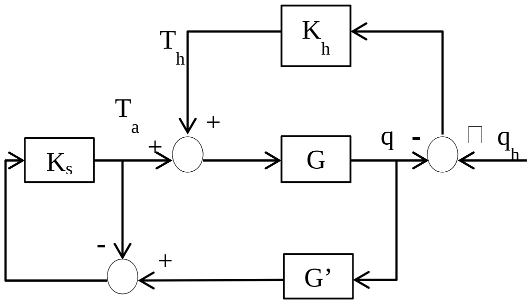

Fig. 5. Block diagram of the virtual torque controller

If the system transfer function G is perfect, we have GG'=1. K_s is chosen as a PD controller. [7]

$$K_s=K_p+K_ds \qquad (4)$$

IV. SIMULATION RESULTS

In simulation, we assume that the prismatic joint movement does not affect the revolute joint movement and the method to control pulleys by linear actuators will be other parts of this research. In this section, we use two examples to demonstrate that the impedance controller can be used in the exoskeleton system. In the first example, a virtual prototyping model for 1 DOF is shown in Fig. 6. Fig. 7 illustrates the curves of the exoskeleton position q and the human position q_h. In this figure the sinusoidal signal is used to be the input position q_h, hip joint position tracking is performed precisely. Fig. 8 illustrates the curves of the actuator T_{act} and the human T_{hm} and shows that the actuator provides much more torque than the human's which means that the system is effective. In the second example, a virtual prototyping model for 3 DOF is shown in Fig. 9. Fig. 10-12 illustrates the curves of the knee joint, knee joint, and ankle joint angle. When K_p term of K_s controller is increased, the better trajectory tracking is performed. Fig. 13-15 illustrates the curves of the torque exerted in the hip joint, knee joint, and ankle joint. Fig. 16 shows the affection of integral term in the controller Ks. This term should not use in the exoskeleton because overshoot will harm patients.

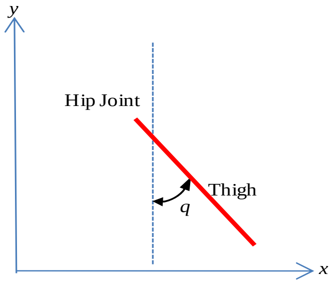

Fig. 6. Virtual prototyping model for 1-DOF

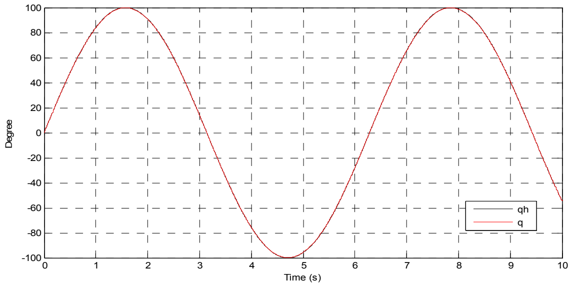

Fig. 7. Curve of the joint angle

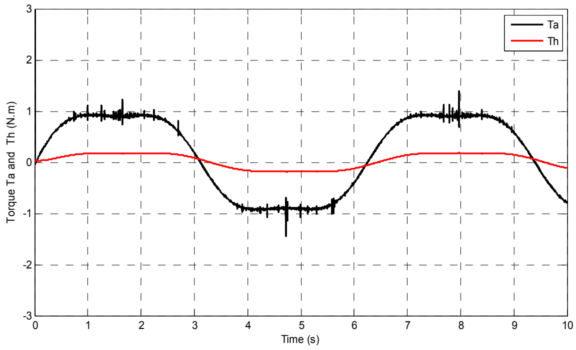

Fig. 8. Curve of the torque exerted by human and actuator

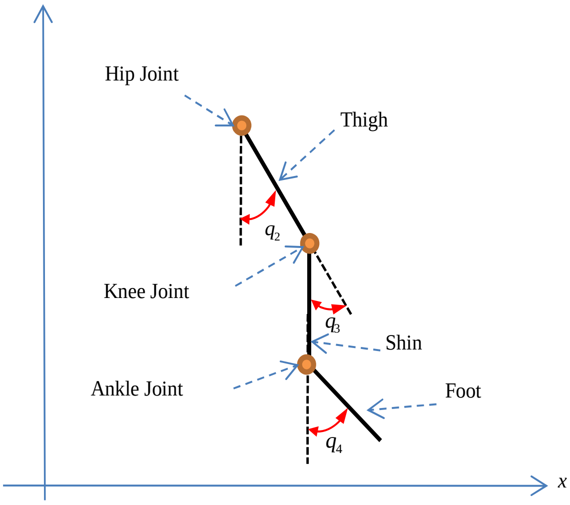

Fig. 9. Virtual prototyping model for 1-DOF

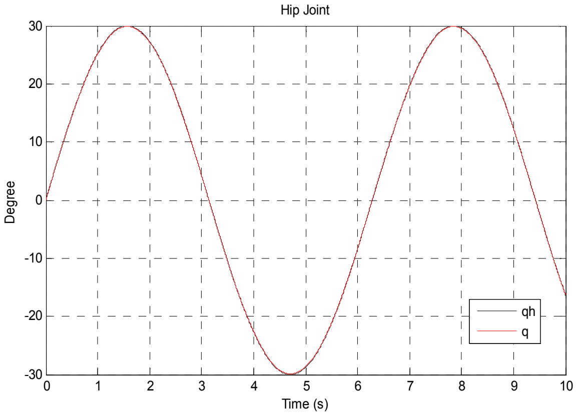

Fig. 10. Curve of the hip joint angle

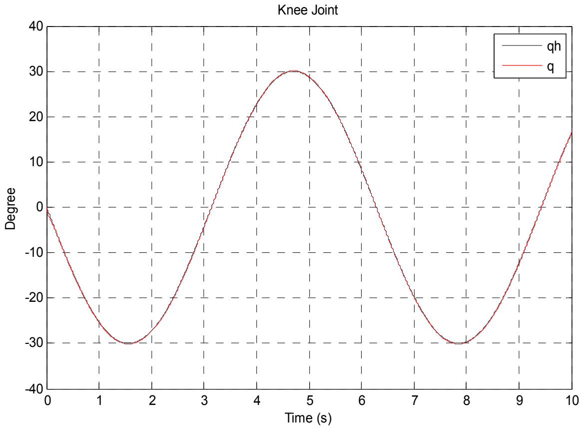

Fig. 11. Curve of the knee joint angle

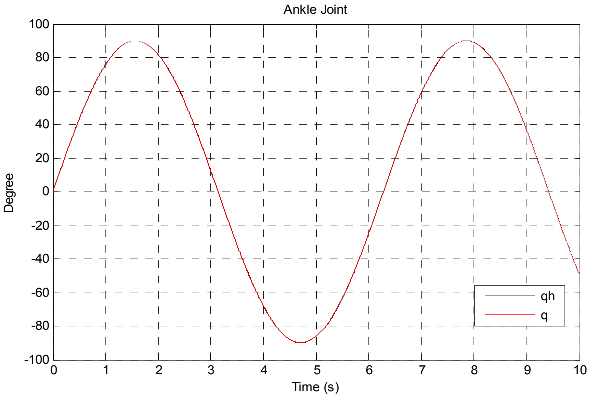

Fig. 12. Curve of the ankle joint angle

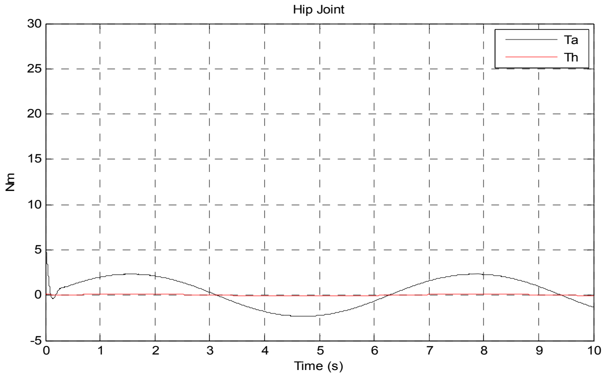

Fig. 13. Curve of the torque exerted in the hip joint

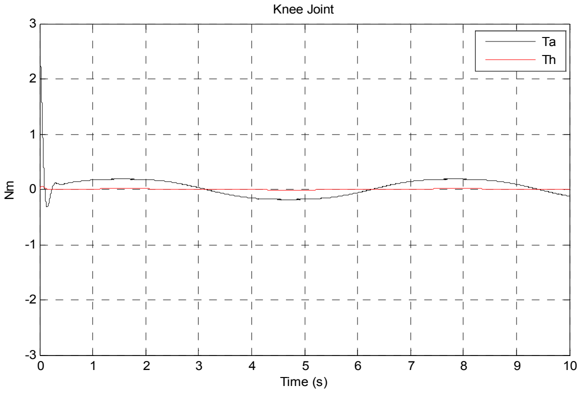

Fig. 14. Curve of the torque exerted in the knee joint

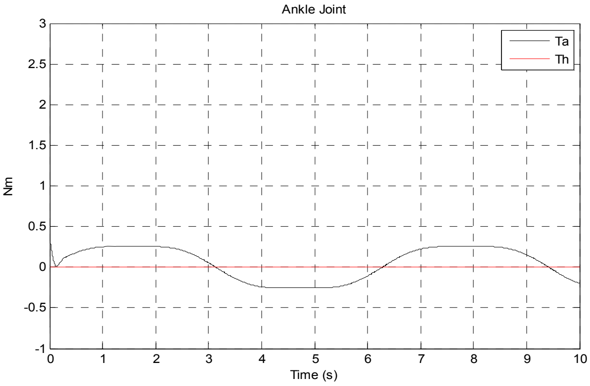

Fig. 15. Curve of the torque exerted in the ankle joint

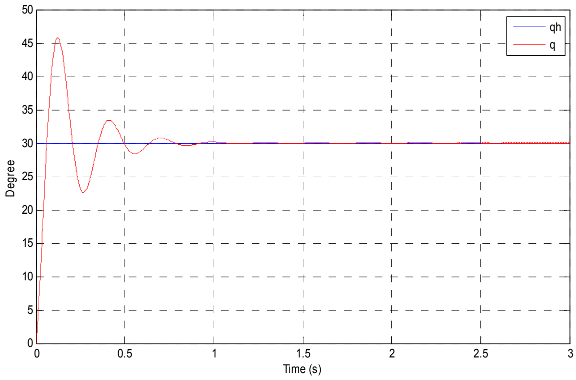

Fig. 16. Impedance controller in case Ks is PID controller

V. CONCLUSION

In this paper, a novel intelligent lower extremity rehabilitation training system is proposed for robotic leg exoskeleton. The impedance controller is used to drive each joint in robotic leg exoskeleton. Finally, it should be re-emphasized that the intelligent lower extremity rehabilitation training system proposed in this paper can achieve a good performances and effectiveness. In the future, this system will provide a series of rehabilitation programs for the elderly and muscle disease patient rehabilitation in technical combination with prismatic hip joint and linear actuators.

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