Human-machine Intelligent Robot System Control Based on Study Algorithm

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***Abstract*-Based on the human-machine intelligent robot system of lower extremity carrying exoskeleton, the new control method is provided, where the virtual torque control is improved. The exoskeleton model is built using SimMechanics in Matlab. The dynamics mathematics model is gotten by study the human walking to construct the controller. The controller in virtual torque control uses nonlinear direct force control while not PID control. The control law presented in this paper simplifies the controller design and not making use of any information about the operator or of any of the mechanical characteristics of the human-machine interface. The most important of this method is the mass properties need not be identified, which overcomes the maximum defect of the virtual torque control. Simulation results show the valid of the given method.**

I. INTRODUCTION

Lower extremity exoskeleton carrying system is a typical human-machine intelligent robot system, which combines the human intelligence and the machine mechanical energy. It has numerous potential applications; it can provide soldiers, disaster relief workers, wildfire fighters, and other emergency personnel the ability to carry heavy loads such as food, rescue equipment, first-aid supplies, communications gear, and weaponry, without the strain typically associated with demanding labor.

The device is attached to the human at various points along the human's and upper body and assists the human to carry the load mounted on its torso. Operator is able to perform a wide range of physical activities while wearing the device. The exoskeleton shadows the motions of the human and never interferes with these motions. For the speciality of this system, the success of a control architecture for the exoskeleton will depend on its ability to fulfill certain requirements:

First, the exoskeleton should be anthropomorphic such that the geometry of the human and the machine approximately match one another. It should be able to match the human throughout the range of motion. The device should respond to the motion of the operator and the two should move in synchrony.

Second, The exoskeleton should be autonomous. The controller should be self-contained and should not rely on external computing power or sensor measurements.

The third, The design of the exoskeleton should be robust and reliable. The device is used for extended periods of time for potentially rigorous activities uncompromising environments.

For the exoskeleton system unique human-machine control, it has become a new control problem that provokes widely interests of international learners.

Many different exoskeleton robots have been developed from the early 1960s [1], [2]. They can be categorized in several ways: by power source, by actuators, by structure, by function, and by application. For purpose of discussion, exoskeletons are divided into two categories here. The first type of exoskeleton is one used to help gait disorder persons or aged people to walk. The second type of exoskeleton is used to help people walking who have to travel long distances by feet with heavy loads.

Most of the developed exoskeleton systems fall into the former type. Several exoskeletons were developed at the University of Belgrade in the 60s and 70s to aid paraplegics [3]. Although these early devices were limited to predefined motions and had limited success, balancing algorithms developed for them are still used in many bipedal robots. At present the mostly successful exoskeleton used for walking aid of handicapped and aged people is HAL (Hybrid Assistive Leg) which was developed in the University of Tsukuba by professor Saikai and his students [4]-[6]. HAL use the s-EMG (surface ElectroMyogram/Myoelectricity to sense the neuromuscular signal which generated when motion. But there many disadvantages when using s-EMG: 1) surface electrode is prone to fall off, transpose when there have a drastic movement; 2) the accuracy of the electrode will be influenced when people perspiring after a long time locomotion; 3) for the same electrode there exist difference between different people; 4) the electrode must be installed on the operator every time he (her) want to wear the exoskeleton. Some similarly exoskeleton is being studied in the University of Twente, Netherlands [7] and in the University of Abertay Dundee, United Kingdom [8].

In the latter type, the exoskeleton augments and enhances the strength and endurance for individual have to carry heavy load. The concept of exoskeleton first emerged in USA is in the 1960s. A report from the air force and Cornell Aeronautical Laboratory has described a preliminary investigation of a wearable, full-scale exoskeleton [9]. The first prototype of exoskeleton named hardiman build by General Electric appears in 1968 [1]. Hardiman is set on master-slave control. In the case of a robotic arm the motion of the operator's arm must be captured continuously through the use of an instrumented

This work was supported by National Natural Science Foundation of China under Grant No60705030 and postdoctoral science Foundation of China under Grant No 20060400293.

978-1-4244-1706-3/08/$25.00 ©2008 IEEE.

master exoskeleton worn by the user. It just realized the control of one arm and because of the limited of technique the project was abandoned finally. For the many and uncertain interface points between the human and the exoskeleton, the control method is unreliable to LEE. In robotic force control systems the force between the manipulator and its environment is maintained at a predetermined level through force sensor feedback. Eppinger[10], Whitney[11], and Craig[12]have described the traditional applications of force feedback in robot manipulator control. In force feedback control all interaction forces are measured and there is no other contact point between the human and the machine than through the force sensor. Although it is theoretically possible to build such a control law it would be quite difficult to implement the hardware associated with it. The latest research results in this area come out of the BLEEX (Berkeley Lower Extremity Exoskeleton) [2], [14], [15]. Racine proposed a method named virtual joint torque control [16], and apply it into the BLEEX. The virtual joint torque control needs no direct measurements from the pilot or the human-machine interface (e.g. no force sensors between the two); instead, the controller estimates, based on measurements from the exoskeleton suits only, how to move so the pilot feels very little force. This control scheme is an effective method of generating locomotion when the contact location between the pilot and the exoskeleton is unknown and unpredictable. The main disadvantage of this control law over master-slave and feedback force control is that of the exoskeleton accurate mass properties must be known, otherwise, the error will be large.

In this paper, the virtual torque control is improved. The exoskeleton model is built using SimMechanics in Matlab. The dynamics mathematics model is gotten by study the human walking to construct the controller. The controller in virtual torque control uses nonlinear direct force control while not PID control. The control law presented in this paper simplifies the controller design and not making use of any information about the operator or of any of the mechanical characteristics of the human-machine interface. The most important of this method is the mass properties need not be identified, which overcomes the maximum defect of the virtual torque control. Simulation results show the valid of the given method.

II. IMPROVED VIRSUAL TORQUE CONTROL

A. Description of Virtual Joint Torque Control

Virtual joint torque control 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 upper body. Such a control architecture based on the net external joint torque imposed on the machine can be applied to the 1-d.o.f. system shown in Fig.1.

Firstly we assume the system is a simple pendulum. Then the dynamic model of the system can be got by Lagerange equation.

$$T = J\ddot{q} + K_m \sin q \tag{1}$$

Where, J is the inertia coefficient and K_m is the gravity torque coefficient. Let G signify the dynamics of the plant, the human-machine system without actuation can be presented as in figure 2.

Fig.2 means the pilot exerts the total torque to move the exoskeleton. Where q_h denote the desired output angle of the system from the human. $1/(\tau_h s+1)$ denote a low-pass filter which is used to attenuate the un-modeled high frequency dynamics. $q, \dot{q}, \ddot{q}$, denote the output angle, angle velocity and angle acceleration respectively. T_{hm} denote the torque exerted on the plant by human. T_a denote the torque exerted by actuator. T denote all the external torque exerted on the exoskeleton suit except gravity torque and can be expressed in the form:

$$T = T_a - T_f + T_{hm} = T_a + T_{hm} - f\dot{q} \tag{2}$$

Where f is the damping and kinetic friction coefficient.

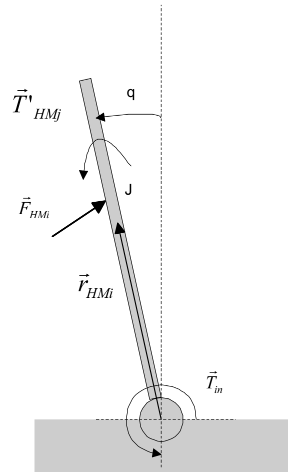

Fig.1 1-dof rotary system

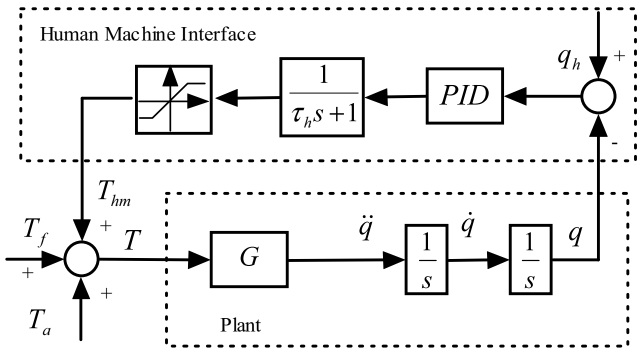

Fig. 2 Block diagram of human-machine system without actuation ($T_a = 0$)

When the actuator doesn't work ($T_a = 0$), the pilot needs to exert all the torque, from (1) and (2) we can get:

$$T_{hm} = J\ddot{q} + K_m \sin q + T_f \tag{3}$$

The control objective is to increase exoskeleton sensitivity to pilot forces and torques through feedback but without measuring T_{hm} . In other words, we are interested in creating a system that allows the pilot to swing the exoskeleton leg easily.

Design the controller as:

$$T_a = (1-\alpha^{-1})(J\ddot{q}+T_f)+K_m \sin q \tag{4}$$

Where α is the amplification number greater than unity. Then the torque exerted by human changed to be:

$$T_{hm} = \alpha^{-1}(J\ddot{q}+T_f) \tag{5}$$

If we choose α =10, the torque exerted by human will changed to very small. The block diagram of human-machine system with virtual torque control is shown in Fig.3.

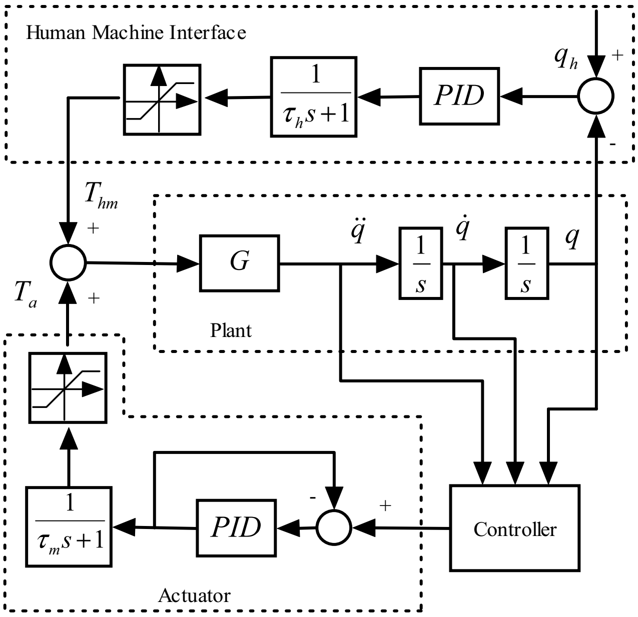

Fig. 3 Block diagram of human-machine system with virtual torque control

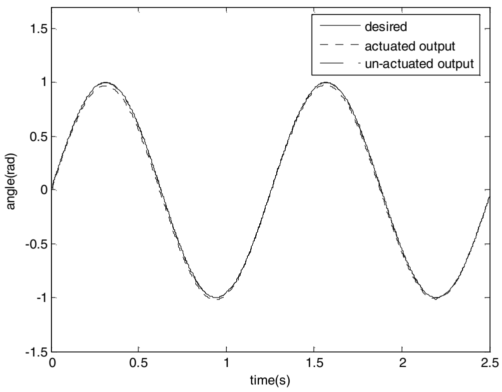

Fig. 4 Tracking performance under the two situation (with actuation and without)

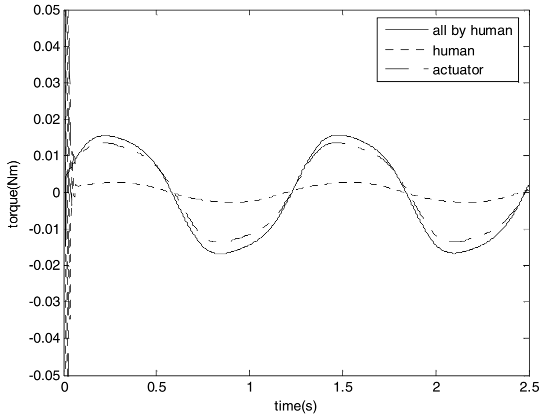

Fig. 5 Torque exerted by human and actuator under the two situations (with actuation and without)

The simulation result can be seen from Fig. 4 and Fig. 5. Fig. 4 shows that the pendulum has a good tracking performance under the two situations (with actuation and without). Fig. 5 show that all the torque need to be exerted by human under the situation without actuation and the pilot need to exert a little torque well the actuator exert most of the torque.

B. Control the swing phase using virtual joint torque controller

The swing phase is the situation in which the foot is not in contact with the ground. In this model, the inertia frame is chosen as the upper body and the exoskeleton leg in swing is assumed to be an independent 3-segment manipulator (thigh, shank and foot) pinned to the upper body at the hip (Fig. 6). The length of the thigh link is L_t, and the length of the shank link is L_s. The position of the centre of the gravity of the thigh by L_{Gt} and h_{Gt}, that of the shank by L_{Gs} and h_{Gs}, and that of the foot by L_{Gf} and h_{Gf} as shown.

The dynamic model can be written in a general form:

$$\vec{T} = \vec{J}(\vec{q})\ddot{\vec{q}} + \vec{B}(\vec{q},\dot{\vec{q}})\dot{\vec{q}} + \vec{G}(\vec{q}) \tag{6}$$

Where

$$\vec{T} = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \end{bmatrix}, \quad \vec{J} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix},$$

$$\vec{B} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}, \quad \vec{G} = \begin{bmatrix} G_1 \\ G_2 \\ G_3 \end{bmatrix}, \quad \vec{q} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix},$$

$\vec{J}$ is the inertia matrix and is a function of $\vec{q}$, $\vec{B}$ is the centripetal and Coriolis matrix and is a function of $\vec{q}$ and $\dot{\vec{q}}$, $\vec{G}$ is a vector of gravitational torques, is a function of $\vec{q}$ only.

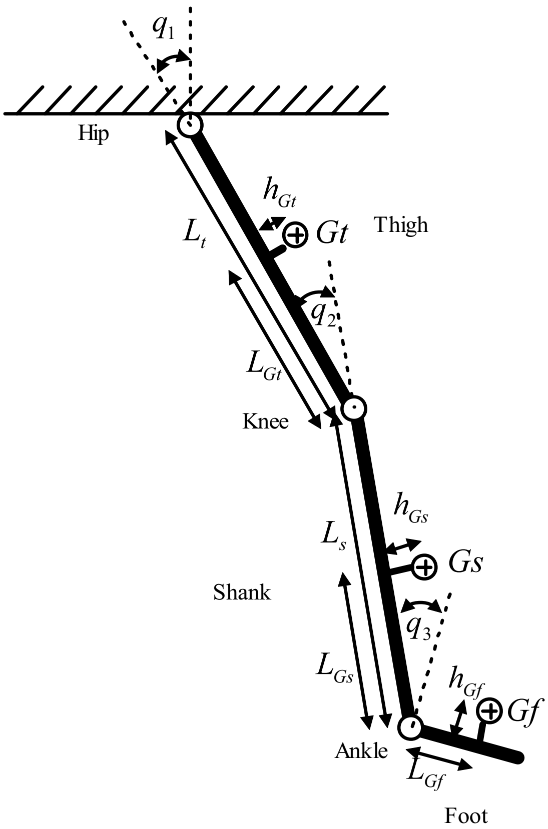

Fig. 6 Three segment model of the exoskeleton leg

Suppose the total torque exerted on the joint is:

$$\vec{T} = \vec{T}_{hm} + \vec{T}_a \tag{7}$$

The damping and kinetic friction torque, stiffness torque and static friction torque are not considered.

Design the controller using the improved virtual joint torque control as:

$$\vec{T}_a = (1-\alpha^{-1})[\vec{J}(\vec{q})\ddot{\vec{q}} + \vec{B}(\vec{q},\dot{\vec{q}})\dot{\vec{q}}] + \vec{G}(\vec{q}) \tag{8}$$

Then the torque exerted by human changed to be:

$$\vec{T}_{hm} = \alpha^{-1}[\vec{J}(\vec{q})\ddot{\vec{q}} + \vec{B}(\vec{q},\dot{\vec{q}})\dot{\vec{q}}] \tag{9}$$

If we choose α =10, compared to (6), the torque exerted by human will changed to very small, which show the valid of this control law.

III. EXOSKELETON MODEL BUILDING IN SIMMECHANICS OF MATLAB

Build the swing leg model using SimMechanics toolbox in Matlab, which is shown in figure 7. The inputs are three joint torque signals, the outputs are three joint angular signal, three joint angular velocity signals and three joint angular acceleration signals.

Making the SmiMechanics model of swing leg as a subsystem, the virtual joint torque controller is gotten as shown in figure 8. The SmiMechanics toolbox has a set of visual tools, which can be used to display the simulation result dynamically, as presented in figure 9.

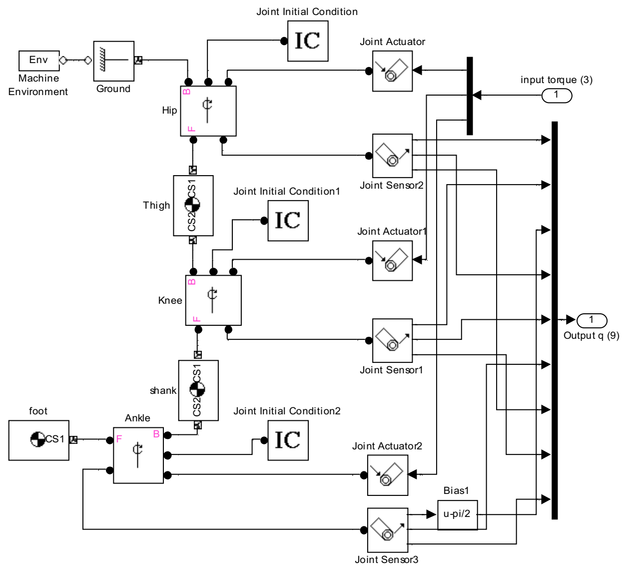

Fig. 7 SimMechanics model of swing leg

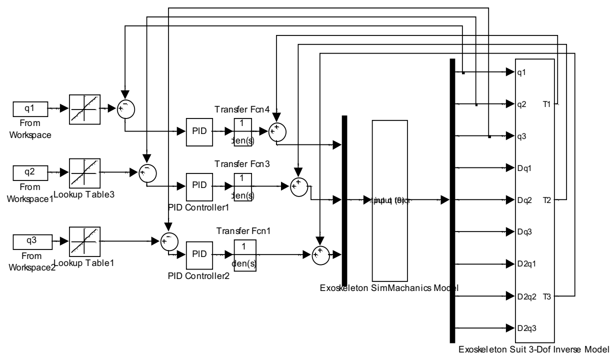

Fig. 8 Virtual torque controller model of swing leg

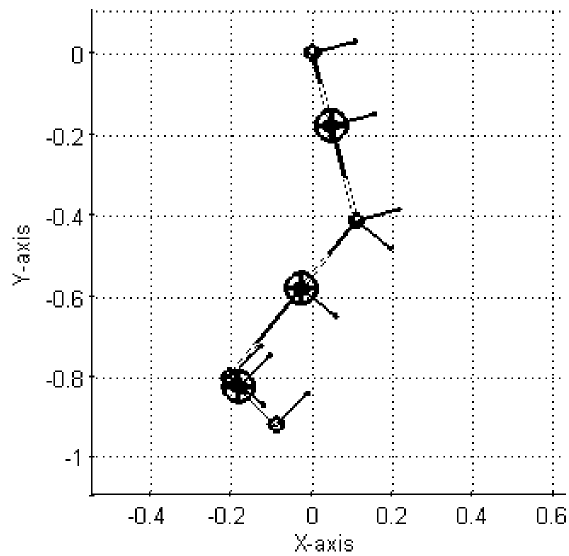

Fig. 9 Demo model of swing leg

IV. EXOSKELETON DYNAMICS MATHEMATICS MODEL BUILDING USING NEURAL NETWORK STUDY

For the dynamics mathematics model used in virtual torque controller can't be gotten accurately, such as $\vec{J}$, $\vec{B}$, $\vec{G}$,the BP neural network(NN) is used to study the dynamics mathematics model. The diagram of NN virtual torque controller is shown in Fig.10, Where the joint angular $\vec{q}$ is taken as NN input, while the joint torque $\vec{T}$ is taken as output.

In figure 11 and 12, the training and test results is given, which indicates the effectiveness of the NN.

V. SIMULATION RESULTS

Using the anthropometric data computed from Winter D. A. as the parameters of the exoskeleton leg [17]and choosing the swing phase data from the Clinical Gait Analysis (CGA) data as the desired motion of the human, assuming the pilot tied together with the exoskeleton at the hip joint and foot [18], the simulation results of swing phase is shown in fig.13, which illustrate the exoskeleton tracking the motion of the human very well and Fig.14 show the torque exerted by the human is very small and the actuator exert the most which means the pilot (human) can swing the exoskeleton easily and only need to exert a scaled down torque of the actuator.

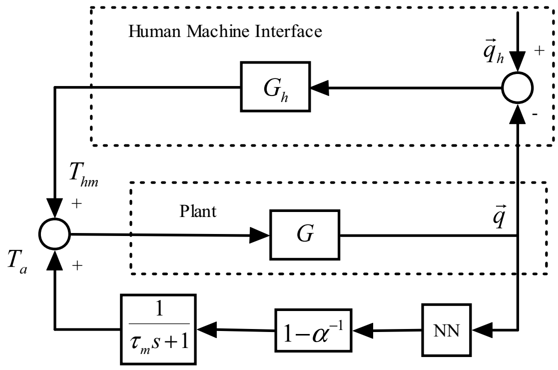

Fig. 10 Exoskeleton controller diagram with NN dynamics model study

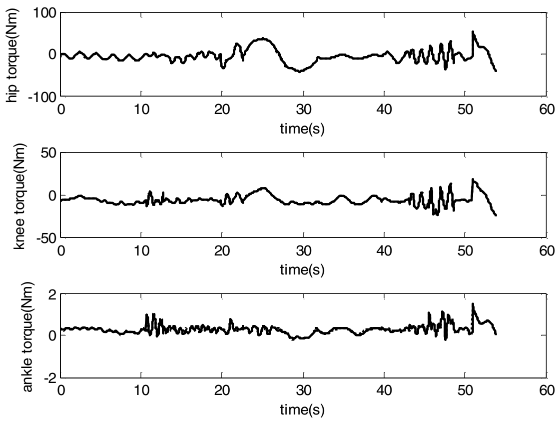

Fig. 11 Training data and NN output of swing leg
(solid line denote training data, dot line denote NN output)

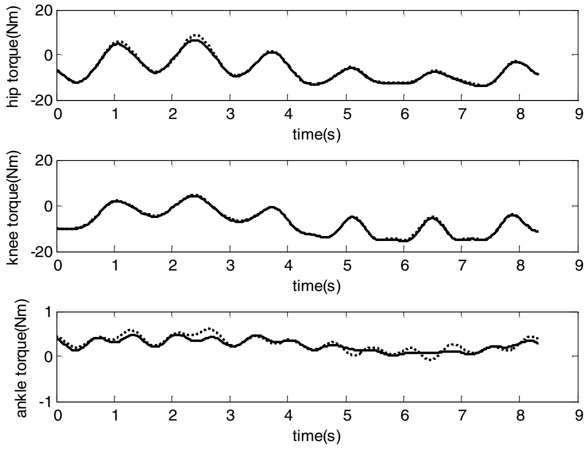

Fig. 12 Test data and NN output of swing leg
(solid line denote test data, dot line denote NN output)

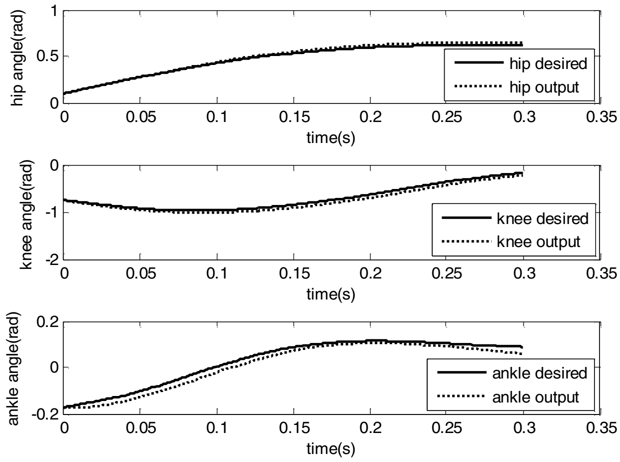

Fig.13 Tracking performance of the exoskeleton

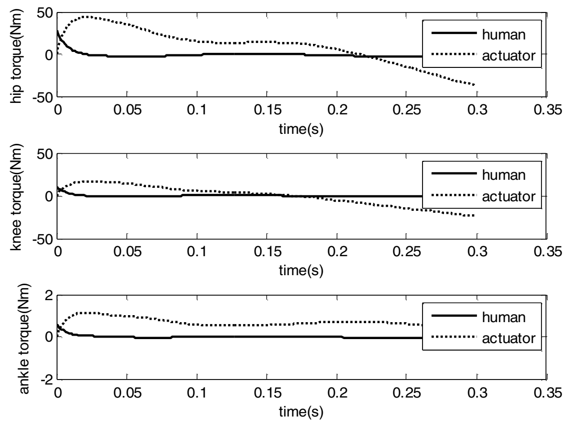

Fig.14 Torque exerted by human and actuator

VI. CONCLUSION

The virtual torque control method has the advantage that it need no sensor (e.g. force or EMG) in the interface between the pilot and the exoskeleton suit and one can push and pull against the exoskeleton in any direction and at any location without measuring any variables on the interface. The main goal of the controller is minimize the torque exerting by the human when the human-machine walking. The dynamics mathematics model is gotten by study the human walking to construct the controller, which overcomes the maximum defect of the virtual torque control. The exoskeleton mechanics model building in SimMechanics toolbox of Matlab simplify and accelerate the engineering design of exoskeleton. Further study will focus on the stability analyse and the refine of the exoskeleton model.

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