Research and development of 18-DOF master-Slave robotic systems

Nghiên cứu và phát triển một hệ thống robot chủ tớ 18 bậc tự do

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Keywords:

Robot hand, haptic hand, master-slave of haptic device, robot hand arm, haptic hand arrm.

Abstract

This paper introduces the new design and control of a master-slave system consisting of 18-DOF robot hand-arm and an 18-DOF haptic hand-arm. Both the robot hand and the haptic hand are designed to have 12-DOF and four fingers. Dimensions of the robot hand are closer to those of a human hand so the fingertip positions of human can be transferred to the fingertips of the robot hand. The haptic hand is combined with a 6 DOF haptic device to make a 18-DOF master system while the robot hand is assembled with a 6 DOF serial robot to make 18-DOF slave system. A control system is developed to control the positions of the slave robot as well as to control the forces of the haptic master.

Từ khóa:

Bàn tay robot, ngón tay robot, thiết bị haptic, bàn tay haptic, thiết bị robot chủ tớ

Tóm tắt

Bài báo này giới thiệu về một hệ chủ tớ gồm có một cánh tay-bàn tay robot với 18-DOF (bậc tự do) và một cánh tay-bàn tay haptic cũng với 18-DOF. Trong đó bàn tay robot cũng như bàn tay haptic đều được thiết kế với 4 ngón tay và 12-DOF. Kích thước của bàn tay robot được thiết kế gần bằng với bàn thay thực của con người nên dễ dàng hơn cho các thao tác cầm nắm và điều khiển. Bàn tay robot sẽ kết hợp với một robot chuỗi 6-DOF, còn bàn tay haptic sẽ kết hợp với một thiết bị haptic cũng có 6-DOF. Như vậy thiết bị chủ và tớ đều có 18-DOF có thể làm việc linh hoạt trong không gian. Đây là một thiết kế hoàn toàn mới và đã được chế tạo, vận hành thử nghiệm thành công. Bài báo cũng đã đề xuất một cấu trúc điều khiển chủ tớ mới.

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1. INTRODUCTION

A hand is one of main component in the human structure. The hand can grasp an object in one place and release it in the other place. Structures based on the human hand architecture have many applications in industry and living as well. Therefore many types of robot hands have been developed. They are designed with at least three fingers [1]-[3], four fingers [4]-[7] and five fingers [8] and [15]. Each finger can be constructed by only one degree of freedom (DOF) for the simple structure [1] or 2-DOF [2], [4], [7] for complex structures. However, the real human fingers consist of 4-DOF so the 3-DOF finger mechanism may represent the operation of fingers well [3], [5], [6], [8], [15]. The higher DOF robot hand may lead to very complex mechanisms and not necessary, because the finger tip can be assumed that it has a kinematic constraint with another link. Because of limited space, small DC motors with high gear ratios are normally selected to control active joints of fingers. The AC actuators can also be used to increase the torques and reduce the dimension [4]. The motors can be placed on the base frames to reduce weight influences [2], [4], [7], [8] or directly installed on the fingers to avoid using cables and increase compactness [3], [5], [6]. Similar to the robot hands, haptic hands are also designed with 3, 4 or 5 fingers. Each finger may consist of 1-DOF [9] or 2-DOF [10]. However the higher DOF mechanisms are often selected to extend the operation of fingers [11]-[14]. Users can use their fingertips to move the finger holders of haptic hands in the opposite direction [9]-[12] or they can wear the haptic hands to operate in the same direction [13], [14]. The opposite mechanisms can extend the workspaces and avoid interferences while the wearing mechanisms can generate the convenient motions to grasp objects.

The robot and haptic hands are combined to make teleoperation systems in which the haptic hand is the master device and robot hand is the slave device. The robot hands can be installed at the end effector of serial arm [6] and the haptic hands also can be installed on the serial structures [10]-[12], [15] to operate in the large workspace. A typical master-slave control system for the robot and haptic hand is presented in [15] where the haptic hands provide positions for the robot hands and receive reaction forces. A teleoperation control system is also presented in [13] and control hardware architecture is shown in [12].

Design and analysis for both a robot hand and a haptic hand are presented in this paper. They are designed with 12-DOF four fingers. Workspaces, convenient motions and avoidance of coupling problems are considered in design as shown in [5]. A teleoperation control system of the slave robot devices using the master haptic devices is proposed.

2. HAND DESIGN

2.1. Robot Hand

The robot hand presented in this paper is designed with 12-DOF four fingers as shown in Fig. 1. Each finger is controlled by three geared DC motors to increase joint torques. Bevel gears are used to convert directions of rotations so the motors can be placed along the links of the finger. A 3-DOF force sensor is installed on each fingertip to measure contacting forces when it touches an object.

The mechanism of index finger (the same as middle and ring fingers) is shown in Fig. 2. The motor 1 is connected with the bevel gear 1 to drive the bevel gear 2 which drives bevel gear 3 assembled on the first link of finger. Therefore the motor 1 can control the first link rotated about the shaft of bevel gear 3. The bevel gear 1 and 3 are assembled with a suitable leaning angle so they are not touched each other. The motor 2 is connected with the bevel gear 4 to drive the bevel gear 5 assembled with the shaft of first link. Therefore the motor 2 can control the whole finger rotated about bevel gear 5. The motor 3 is used to control the second link while the fingertip is control through a passive mechanism so the torque of motor 3 is shared for the second link and fingertip. This mechanism has three active joints and one passive joint that can provide 3-DOF at the fingertip. Thes fingers are designed to avoid coupling problems as presented in [5].

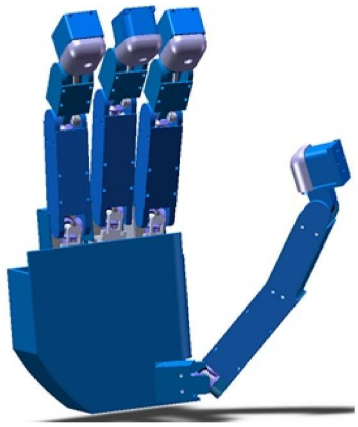

Fig. 1. Design of Robot Hand

The mechanism of the thumb is shown in Fig. 3. This design also provides 3-DOF at the fingertip without a passive joint. The bevel gear 1 is connected with the motor 1 to control the bevel gear 2 assembled with a shaft of the second link (contain motor 2). The motor 2 is connected with the bevel gear 3 to drive the bevel gear 4 directly assembled with the second link. Therefore the second link can be controlled by two motors to provide 2-DOF rotations. The motor 3 along the third link is used to control the fingertip while the second and third links are fixed by a given angle.

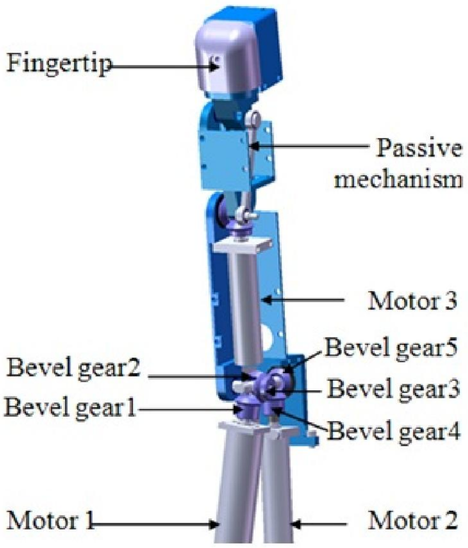

Fig. 2. Mechanism of Robot Index Finger

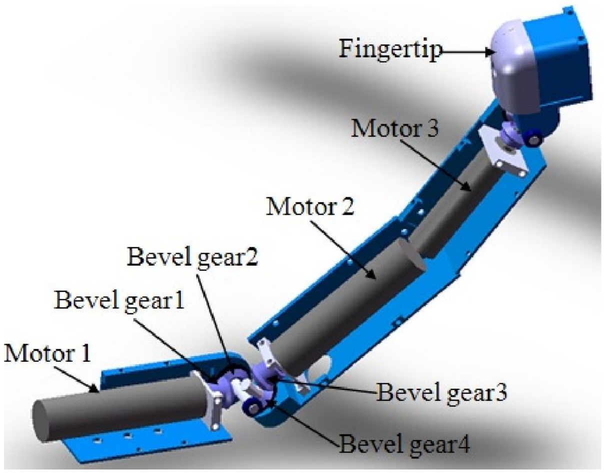

Fig. 3. Mechanism of Robot Thumb Finger

2.2. Haptic Hand

The haptic hand shown in Fig. 4 is also designed with 12-DOF four fingers so as to control the robot hand. Each finger has 5-DOF to provide the position and orientation for the fingertip. Three DC gear motors are used to supply torques for three active joints while the remaining joints have free rotations. Each haptic finger is combined with the user’s finger model to make a closed loop chain. The user's fingertips are also fixed on the haptic finger holders. Therefore the fingertip positions can be determined if the user's finger model is given. The links of fingers are light, thin but strong enough to reduce gravity effects. The mechanism of haptic index finger is shown in Fig. 5. The link 1 is controlled by the motor 1 and 2 to provide 2-DOF active rotations about the shafts of bevel gear 3 and 5. The bevel gears of the haptic hand are also assembled as the same method of robot hand.

The motor 2 is fixed on the base frame while the motors 1 and 3 are moving when the fingers are operated. The motor 1 should be selected with higher torque than the other because it produces the main torque when the finger holder grasps the object. The motor 3 drives the third link connected with the finger holder through a passive joint. Ball bearings are used for all passive joints and shafts to reduce frictions.

Fig. 4. Design of Haptic Hand

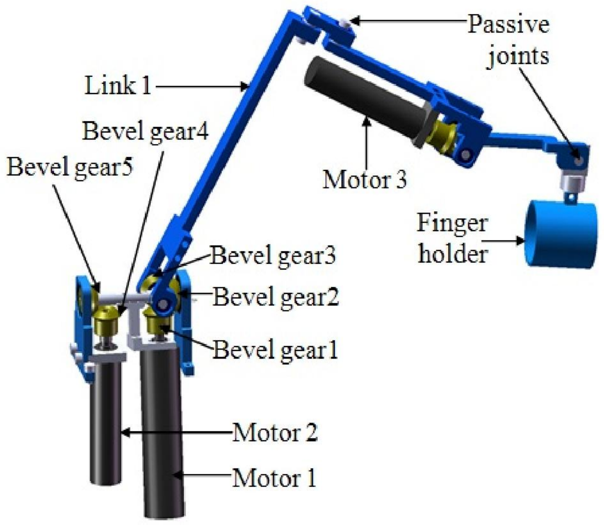

Fig. 5. Mechanism of Haptic Index Finger

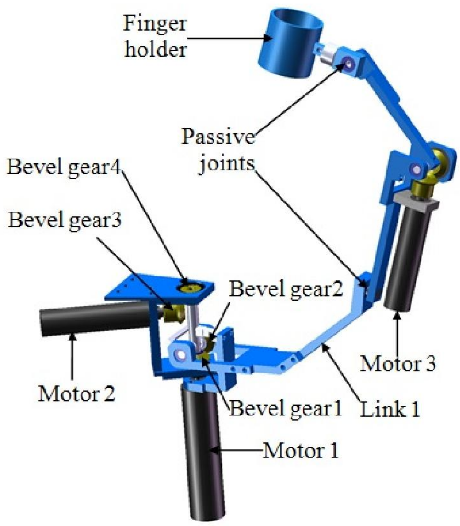

Fig. 6. Mechanism of Haptic Thumb Finger

The mechanism of haptic thumb is shown in Fig. 6. The motor 1 and 2 are also used to control the link 1 rotated about two axes. However the mechanism differs from the index finger. The motor 1 is connected with the bevel gear 1 to drive the link 1 about the bevel gear 2. This motor endures the main forces from the fingertip so it is selected with the higher torque. In addition the motor 1 is coincidently assembled with the shaft of bevel gear 4 which connects to the bevel gear 3 and controlled by the motor 2. Therefore the motor 1 is rotated by itself when the motor 2 drive the bevel gear 4. The motor 2 also drives the thumb finger about the shaft of bevel gear 4. This finger is assembled with the haptic palm by two leaning angles to represent better the configuration of human's thumb finger as well as to extend its workspace. This mechanism also provides 3-DOF position at the fingertip.

3. 18-DOF MASTER-SLAVE SYSTEMS

In this research a 6-DOF haptic device [17] is assembled with the 12-DOF haptic hand to make a new master haptic system as shown in Fig. 7. The end effector of 6-DOF serial robot is also assembled with the 12-DOF robot hand to make a new slave robot system as shown in Fig. 8. This teleoperation system consists of the 18-DOF master devices and the 18-DOF slave devices.

The 6-DOF haptic device provides a position vector in the Cartesian space for the 6-DOF serial robot and its end effector tracks this trajectory. When the user wears the haptic hand-arm device and generates movements, The fingertip positions of the haptic hand are transferred to the controller and used as the desired fingertip positions of the robot hand-arm system. The positions and orientations of arm wrist are determined as the position vector of haptic device's handle so it can use as the position command for the end effector of serial robot. Therefore the master haptic system provides 18-DOF fingertip and arm wrist positions for the 18-DOF slave robot system.

Each fingertips of robot hand may be assembled with a 3-DOF force sensor to measure contacting forces when it touches the object or contacts with the environment. The force vectors from the slave system are used as the force commands for the master system.

The real 18-DOF haptic hand device and 18-DOF robot hand device is constructed as shown in Fig. 9.

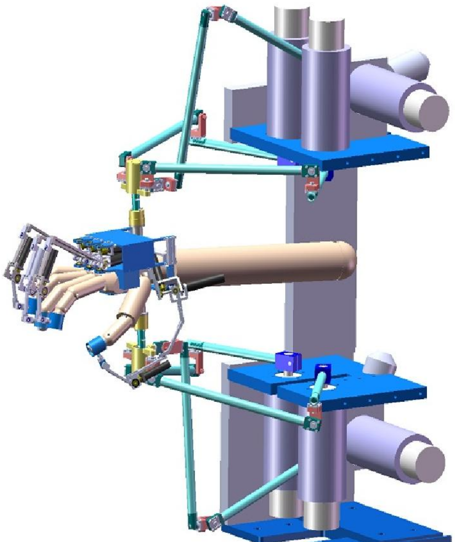

Fig. 7. Master system including a haptic hand

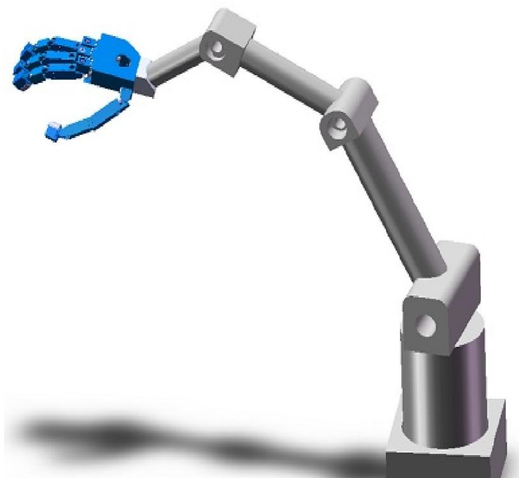

Fig. 8. Slave system including a robot hand

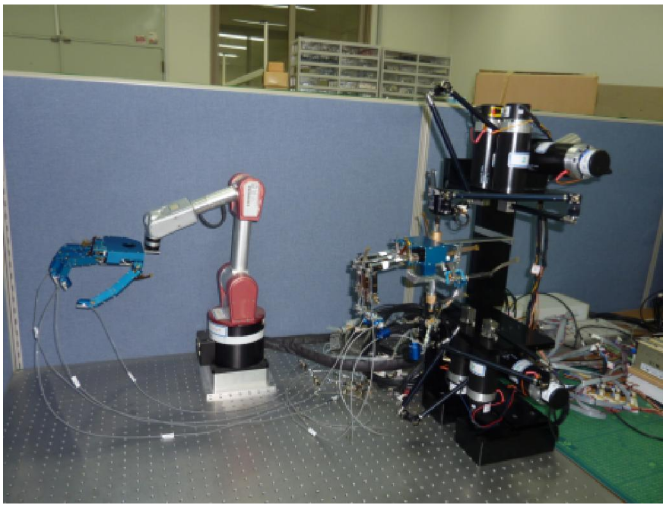

Fig. 9. A test rig of the 18-DOF master-slave robotic systems

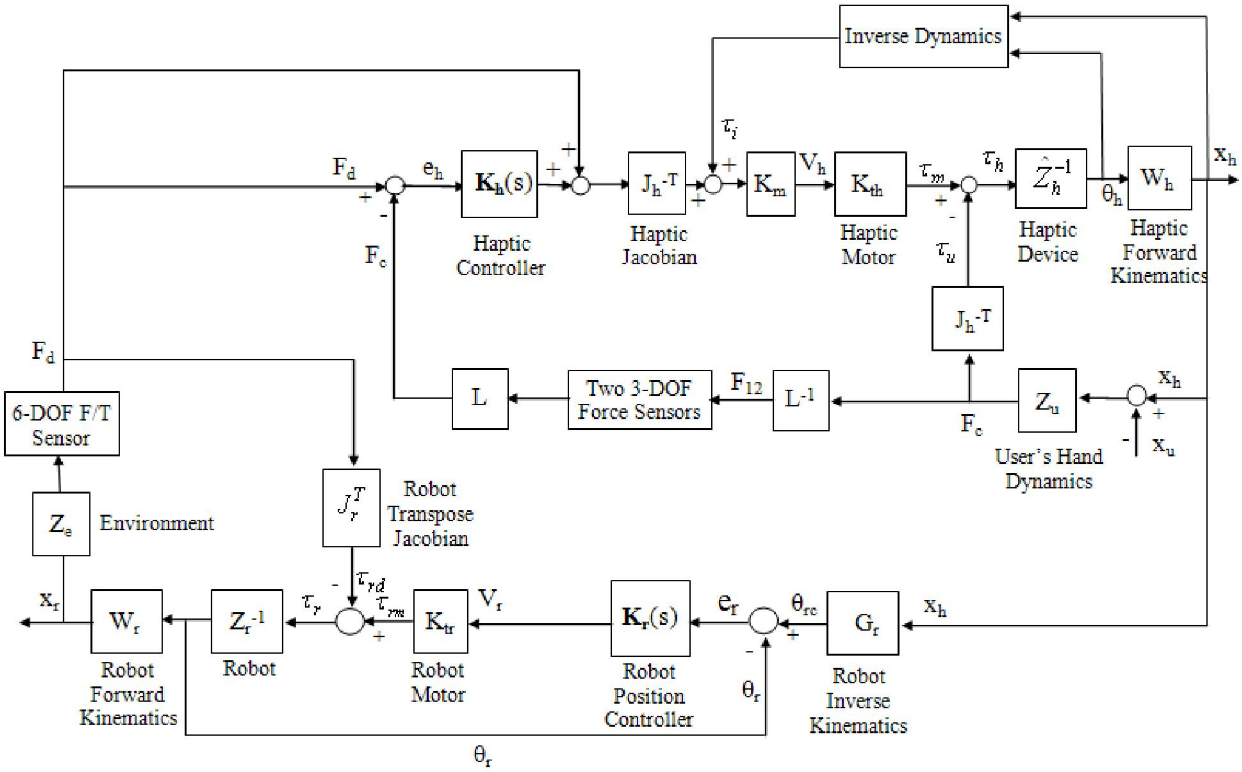

Fig. 10. Teleoperation control diagram of a 6-DOF haptic device and a 6-DOF serial robot

4. EXPERIMENTS

The control system can be divided into two main parts: the teleoperation control of the 6-DOF serial robots using the 6-DOF haptic device and the teleoperation control of a 12-DOF robot hand using a 12-DOF haptic hand. In this section a position and force control system of 6-DOF haptic device and 6-DOF serial robot is presented and shown in Figure 10. However only the experiments of position control is demonstrated.

Figure 10 consists of position control of 6-DOF slave serial robot and force control of 6-DOF master haptic device. Users can generate motions of hand x_u so the haptic device can follow with motion x_h. The motions of the haptic device are measured by encoders. These joint angles are used to calculate forward kinematics of haptic device so that its trajectory is determined. This trajectory is composed of three positions and three rotations of the center of the handle. The slave serial robot uses this trajectory to find joint angle commands, θ_{rc} through inverse kinematics G_r. The error between the command, θ_{rc} and feedback, θ_r joint angles is the input of position controller, $K_r(s)$. Its output is converted into voltage commands, V_r for the robot's motors. The rotations of robot joints determine the trajectory of end effector, x_r. There exist some tracking errors because of robot dynamics.

The hardware of teleoperation system consists of two digital controllers as dSPACE1103 and dSPACE1104. These controllers include almost useful interfaces such as ADC, DAC, Encoder, I/O and RS232, RS485 so they are very convenient to connect with a real system. In addition these controllers are supported to work directly with SIMULINK/MATLAB in real time so the heavy control algorithms also can be implemented to do experiments. These controllers can communicate with computers by ControlDesk software to monitor and record data. The contact environment is constructed as a spring and damper system to supply contacting forces for the end effector of serial robot. This contacting force is measured by a 6-DOF force sensor whose signals are transmitted to dSPACE1103 controller to process.

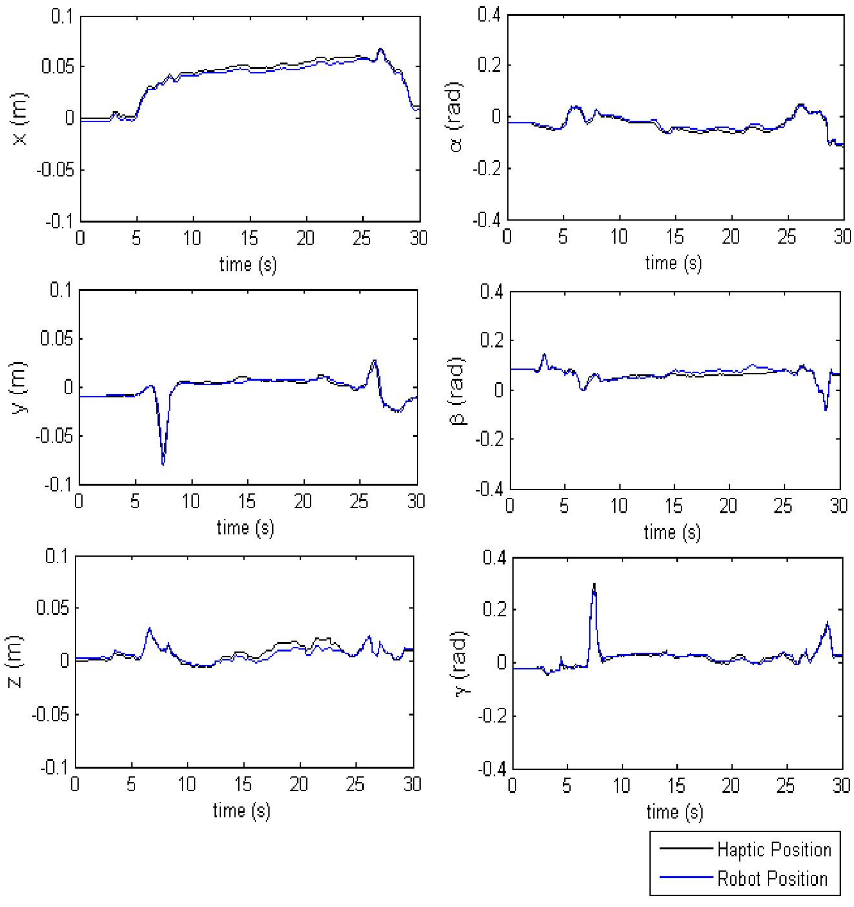

Fig. 11. Trajectory comparisons of the 6-DOF teleoperation system

Experiment results of the closed loop teleoperation system with PID control are recorded when the user keeps the handle of 6-DOF haptic device to move the 6-DOF serial robot. These comparisons are shown in Fig. 11. indicate that the the slave robot has tracked well those of haptic device. However, there exists small position errors because of gravity and external forces from environment.

5. CONCLUSIONS

The robot hand and the haptic hand have been designed with 12-DOF four fingers. The robot hand represents well the configuration of human hand so it can grasp complex objects. In addition dimensions of robot hand are designed closed to the real human hand so the fingertip positions of the haptic fingers can be used as the desired fingertip positions of the robot fingers. The haptic hand and robot hand are combined with the 6-DOF haptic device and 6-DOF serial robot to make the 18-DOF teleoperation systems. This system can be operated when the user wears the haptic hand and generates movements. The positions of the haptic device can be recognized as the positions of the arm wrist while the fingertip positions of human hand can be determined as the fingertip positions of the haptic hand.

The 18-DOF master-slave systems are the new design and has been constructed. Experiments have been done for the position tracking performances of the 6-DOF haptic devices and 6-DOF serial robot. Future works are devoted to the detailed controller design and control experiments for the full 18-DOF systems.

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