20 DOF Haptic Device for the Interaction with Virtual Environments

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Abstract

In this paper, we propose a new type of haptic device Sensor Glove Version 2.1 (SG-2.1) for interacting with virtual environments. SG-2.1 supports 20 degrees-of-freedom (DOF) which corresponds to the total DOF of a human hand. It can measure force and angle of each joint and can exert repulsive force in each joint. It works properly even when there are interactions with virtual objects. SG-2.1 implemes touch sense to be used in conjunction with vision for the interaction with the virtual world. So, a more precise data set about human manipulation is expected from the use of this device.
We show the design, characteristics and structure of the SG-2.1 system and display the experimental results to verify the stability and proposed device performance.

Key words: Haptic Device, Force Feedback, Virtual Reality, Teleoperation, Skill Acquisition

1 Introduction

Computer technology revolution in recent years has a dramatic inpact on VR systems as it has in many other fields. It is expected that VR will be an important tool for the implementation of teleoperation, entertainment systems and etc. However the VR systems do not allow interaction between the virtual world and the real world yet and are still far from being "realistic" and efficient in teleoperation environments. Human being uses five senses (vision, audition, touch, taste and smell) as input for his decisions. A perfect VR system should provide inputs and outputs for these five senses. But, it is considered that providing input and output corresponding to the three main senses (vision, audition and touch) is enough for most purposes (Figure 1)[7],[9]. However, most of the present VR systems consider only vision and audition for realizing interaction. Although there are few devices that provides interaction using the sense of touch they do not have the necessary specifications. The sense of touch is interactive and so, the construction of a "touch simulator" for Virtual Reality (VR) systems has found many problems.

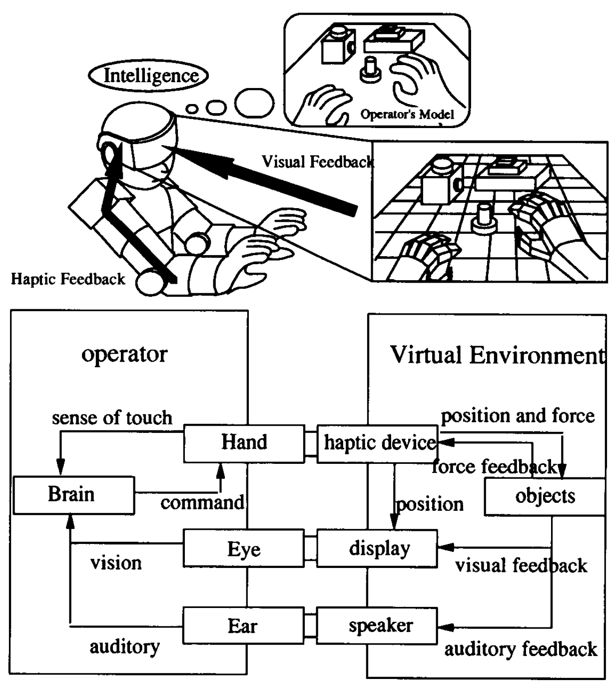

Figure 1: The ideal VR system

"Data Glove (DG)" [3] is the most popular device that provides interaction with the virtual world that uses the sense of touch. DG senses users' movements using optical fibers and allow us to see these movements in a display. This device does not provide force feedback from the virtual world and, so it can not be used to perform complex tasks such as moving objects in the virtual world. Systems using DG are able to provide the operator only visual feedback from the virtual world. The operator can not perform satisfactory dexterous tasks using these systems.

"PHANToM" [4] is another popular device for the interaction with the virtual world. It is connected to the operator's fingertip and provides force feedback. But the operator do not have a clear idea of the relationship among his fingers and virtual objects. The operator composes a non-linear model in his mind with the sense of touch and visual feedback of his finger. The operator is out of an important component for the "reality" sensation when using "PHANToM". Furthermore, "PHANToM" has the limit of 3 DOF finger motion at maximum.

There are other few devices that provide haptic feedback. However, most of them have limitations such as, few DOF, absence of force feedback (only collision detection), long delay time and shortage of frequency response. Operator will miss part of "reality" sensation using these devices.

It is said that the human being uses a non-linear model stored in his mind for performing dexterous tasks. This model is used to predict the movements when he is performing such tasks [1],[2]. The use of vision and touch for the interaction may allow the operator to use this model more naturally.

On the other hand, many robotics research have been done to study the human movement to perform similar tasks with autonomous robots. However, there are still few force data of the human hand joints for supporting this kind of research. So, the construction of a device to acquire a more precise human data is desirable for human skill research. The requirements of such a device are as follows:

- enough number of DOF
- wide movable range
- force feedback in each joint
- high frequency response
- little time delay
- force and angle data acquirable in each joint

Thus a better haptic device for improving the interaction between the virtual and the real world is felt necessary. This paper describes the design and implementation of a general haptic device SG-2.1 and evaluation of its usability in a VR system. The design was realized trying to satisfy the above requirements [8].

2 Design of SG-2.1

The glove was designed to adapt to the five fingers of a hand(Figure 2).Each finger has four DOF from three pitching movements and one yawing movement. It results in a total of 20 DOF in a hand. SG-2.1 was designed with 20 DOF to acquire all human finger's data.

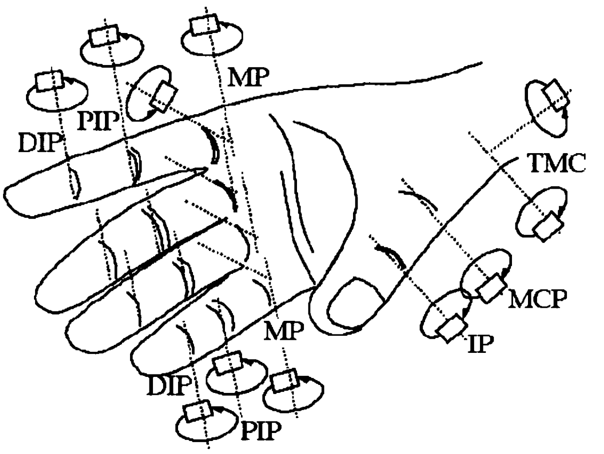

Figure 2: Movements of the human fingers

TMC	:	the trapeziometacarpal joint
MCP	:	the metacarpophalangeal joint
IP	:	the interphalaneal joint
MP	:	the metacarpophalangeal joint
PIP	:	the proxiaml interphalangeal joint
DIP	:	the distal interphalangeal joint

The device is attached to human hand by a band. A fixed base for all movements of the glove is constructed on metallic plate fixed on the back of human palm. Five yawing drive units are fixed in the plate. Three pitching drive components are placed on the yawing drive units. Figure 3 shows the structure of the three pitching drive components.

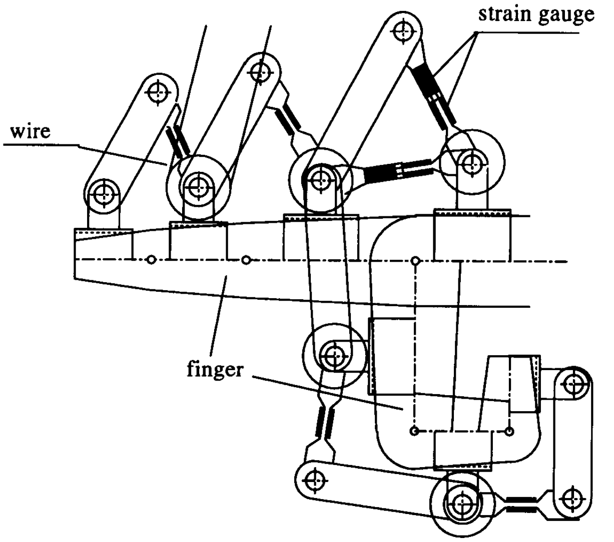

Figure 3: The structure of the Sensor Glove ver.2.1

The pulleys are connected with motors through inner wire in outer tube and transmit motor movement and force. All joints are controlled independently. Force and angle measurements are made in each joint to perform force feedback control. The force measurements are made by strain gauges. The angle measurements are done by rotary encoders. The encoder is linked with a motor through inner wires in outer tubes. The feedback force applied a motor is transmitted through inner wires in outer tubes. (Figure 4)

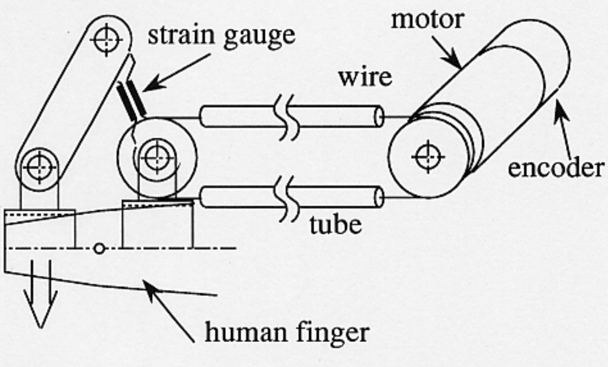

Figure 4: Machanism of Sensor Glove ver.2.1

The human fingers movement range and SG-2.1 movement range are shown in the below table.

	Motion range of a human finger	Motion Range of SG-2.1
MP(yaw)	-30 ~ 30	-
MP(pitch)	-20 ~ 90	-45 ~ 90
DIP(pitch)	0 ~ 90	0 ~ 100
PIP(pitch)	0 ~ 90	0 ~ 80

Table 1: The motion ranges of the Sensor Glove (ver.2.1)

It can be seen from the above table that the SG-2.1 motion range is wide enough to follow the human hand movements.

The SG-2.1 response frequency is higher than 40Hz. This frequency is almost the response frequency of the motors connected through inner wires in outer tubes. The DC servo motors exert repulsive force to the operator.

The spec of these motors are shown below.

- Maximum continuous torque $4.0kg \cdot f/cm$
- Maximum instantaneous torque $6.0kg \cdot f/cm$
- Maximum speed $55rpm$

These torques are enough to exert the necessary repulsive force to operator hands during the execution of dexterous tasks.

Figure 5 shows the photo of the SG-2.1.

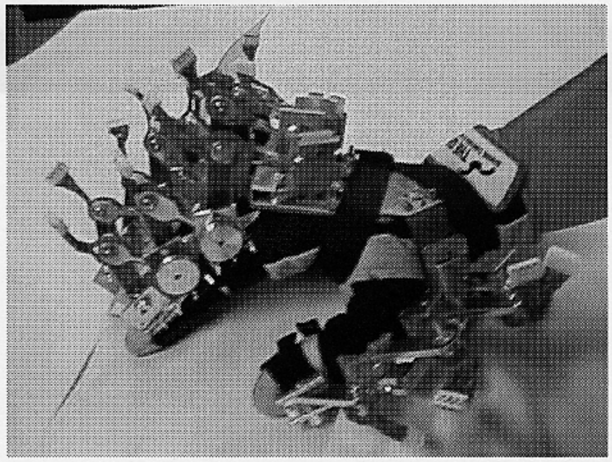

Figure 5: Sensor Glove 2.1 device

3 System Setup of the SG-2.1

3.1 Hardware Setup of SG-2.1

The overall structure of the SG-2.1 control hardware is shown in Figure 6. Each PC can control 8 joints. It means that 3 PC's are used for controlling a total of 20 joints. The PC's are connected to AD, DA, counter and memory link boards using an ISA bus.

DA boards control the 20 motors using amplifiers. Torques of fingers are measured by strain gauges, amplified, and read by AD boards. The fingers angles are measured by encoders connected to the counter boards.

The PC's are based on Pentium 133MHz processor. SG-2.1 can be controlled using sample periods greater than 2ms.

3.2 Software System of SG-2.1

The overall structure of the SG-2.1 control software is shown in Figure 7. The Virtual Environment (VE) is constructed inside a Graphics Computer. The interaction between the VE and SG is composed by four processes.

SG-2.1 is controlled by the first of these processes using AD, DA and a counter board. The data referring to 8-DOF controlled by one of the computer is written to memory link which is connected to "Communication PC".

All 20 DOF data of human hand is then transmitted to "Communication PC". A second process then transfers these data to Silicon Graphics workstation Indigo2 IMPACT 10000 using TCP/IP.

A third process receives the human hand data in the workstation using TCP/IP and writes it to shared memory. The fourth process constructs a VE inside the workstation using these data. The fourth process composes VE inside the workstation. The third and

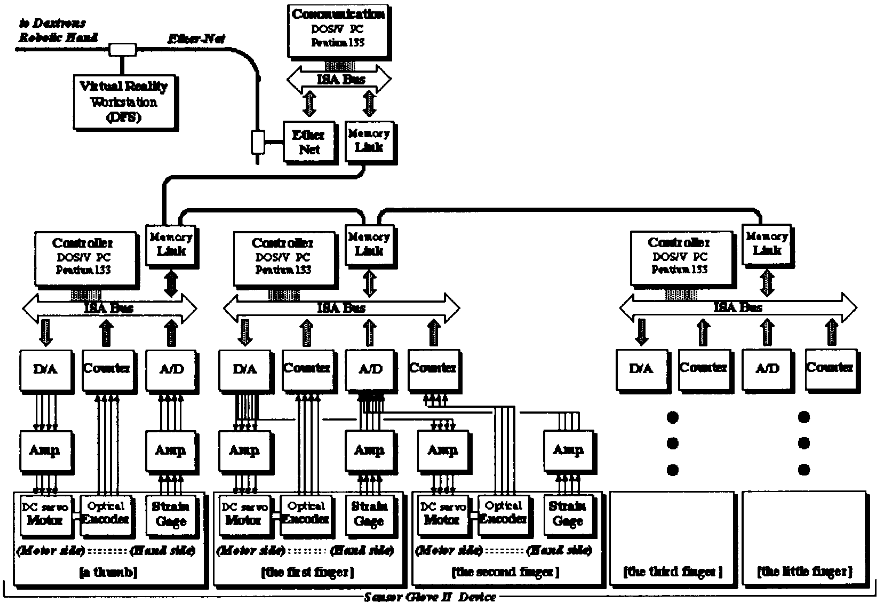

Figure 6: Sensor Glove 2.1 hardware system

fourth processes communicate each other.

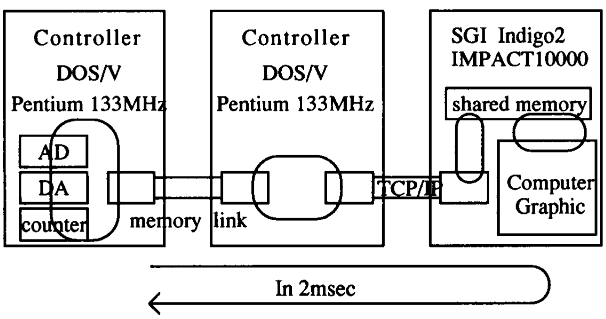

Figure 7: Sensor Glove 2.1 software system

All the interaction processes between the SG and VE is performed in less than 2 ms. Thus the communication delays caused by this interaction is small enough to allow a operation without any disturbance feeling for the operator.

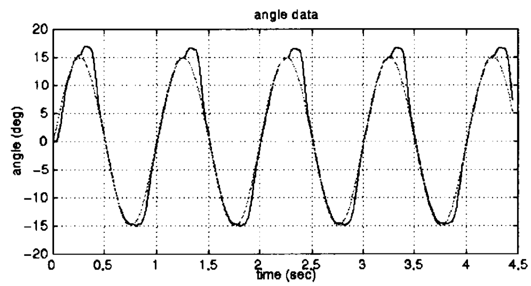

Figure 8: Angle data of one finger

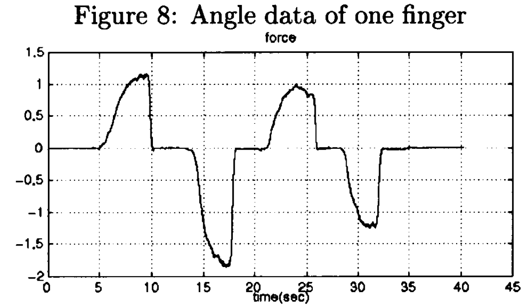

Figure 9: Force data of one finger

4 Experimental Results

4.1 The performance of SG-2.1

The angle data of SG-2.1 are shown in Figure 8. The target value is measured with artificial finger which is equipped with sensor. The target value moves with frequency of 1Hz and the amplitude of 15 degree.

The exprimental result shows the angle of one joint in free space. In the expriments, the stress of strain gauge was controlled to achive the zero value. Note the very close tracking of reference angle. Better results are expected with the future improvements in the control scheme. The error may be noticed mainly when the wire is with low tension.

The force data of SG-2.1 is shown in Figure 9. The strain gauge is pushed and pulled twice in this experiment. It was not possible to generate a appropriate target signal for tracking. It was possible to get good qualitative results with the sensor system. The next step is the validation of the force measurement system.

4.2 Human motion data in free space

This experiment shows the angle and force data when the forefinger is swinged lengthwise three times in the free space(Figure 10). In this experiment the stress of strain gauge is controlled to achive the zero value of the angle of the human forefinger. The fundamental control of SG-2.1 is performed using force control.

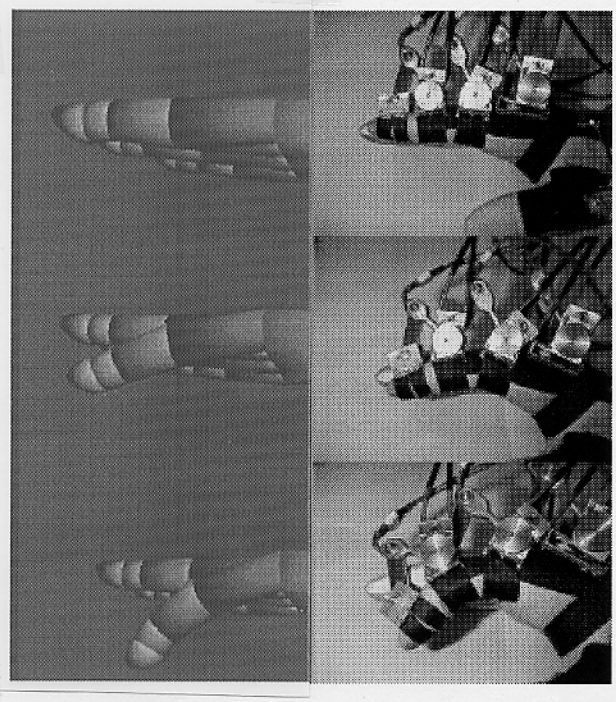

Figure 10: Computer Graphics connected to Sensor Glove Version 2.1

The forefinger feels small inertia of the device however the movement may be controlled very smoothly by a user. The CG shows the angle of the operator's forefinger by The force of the operator's forefinger is shown in CG using color changes.

The four data in Figure 11 from the top show force and angle data of each joints. In these graphs, the black lines show the angles and the gray ones show the forces. The experiments showed that the fingers angle has high frequency components. It conforms the fact that the human finger is vibrating all the time. On the other hand, the finger force measurements showed steps when the finger was moving. The angles are controlled using the forces output and these forces are related directly to the angular accelerations of SG-2.1. The force measurement is obtained using the reaction to the hand movements. It means that a good design should measure only low force values. The inertia of the SG may already be reduced using high gain loops. In this experiments the force data showed a maximum value of 150 gram.

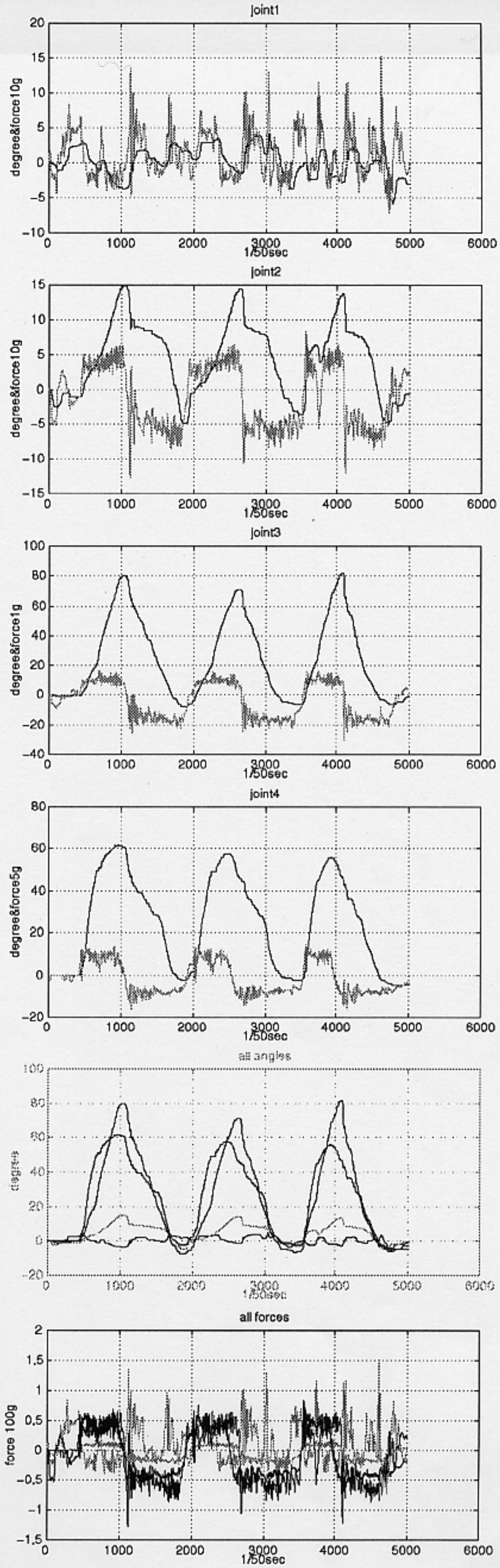

Figure 11: Human motion data in free space

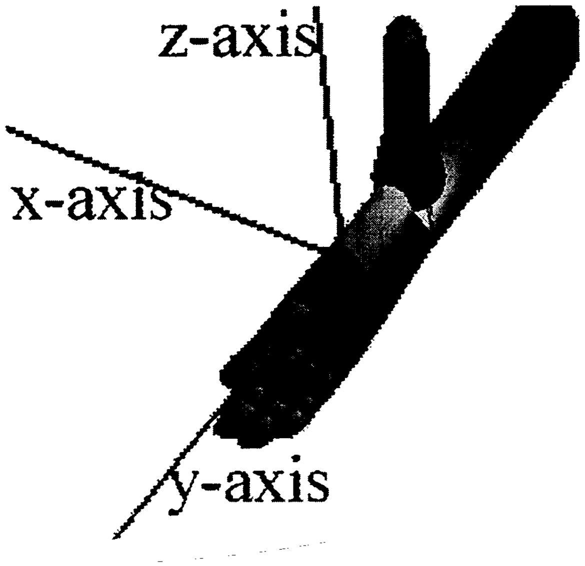

Figure 12: The axis of SG-2.1

It resulted in smooth joint movements. The operator already felt small inertia during the experiments with those values.

The relationship of each joint angle and force is shown in the fifth and the sixth graphs of Figure 11. All pitch joints are moving synchronously.

The view of the movement of fingertip from left-side is shown in the first graph of Figure 13. The second graph shows the movement of fingertip in three dimentional space. These graph's axis position in relation to the hand is shown in Figure 12.

If the operator feels any problem, the brain of human being will recalibrate his movement with visual and haptic feedback. So, the achivement of dexterous tasks will be accomplished naturally.

4.3 Human motion data with force feedback

This exprimental result shows the angle and force data when the finger swing lengthwise four times and touches the virtual wall with force feedback.

The virtual wall is set on 20mm under the operator's palm. The first four graphs in Figure 14 show force and angle data of each joint with force feedback. In these graphs, the black lines show angle and the gray ones show force. The forces are not directly related to the angular accelarations of SG-2.1. These forces also contain the wall reaction components. In the experiment not used high reaction forces will test the capability of simulating high reaction forces.

The relationship of each joint angle and force is shown in the fifth and the sixth graphs of Figure 15. All pitch joints angles are moving synchronously.

The view of the movement of fingertip from left-side is shown in the first graph of Figure 16. The second graph shows the movement of fingertip in three dimention space. These graphs show that the movement of fingertip is stopped at the same point (20mm under the palm) by a virtual wall.

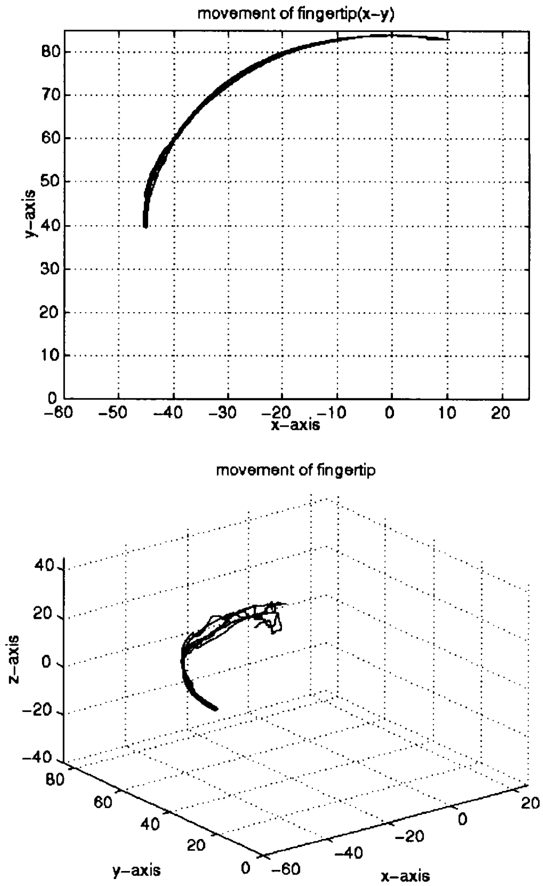

Figure 13: Human motion data in free space

5 Conclusion

We proposed the necessary conditions for VR system which shuold be satisfied by the operator to achieve the dexterous tasks. We showed the design of SG-2.1 haptic interface device to satisfy these conditions and explained about software and hardware to communicate with VE with small time delay. On the other hand, this device showed enough performance as a master system of teleoperation in respects of bandwidth, time delay and feedback torques [5],[6]. Finally, we showed the experimental results with VR system and human skill is acquisition.

6 Future works

Future developments aim to complete and improve the proposed system. The overall SG-2.1 system and

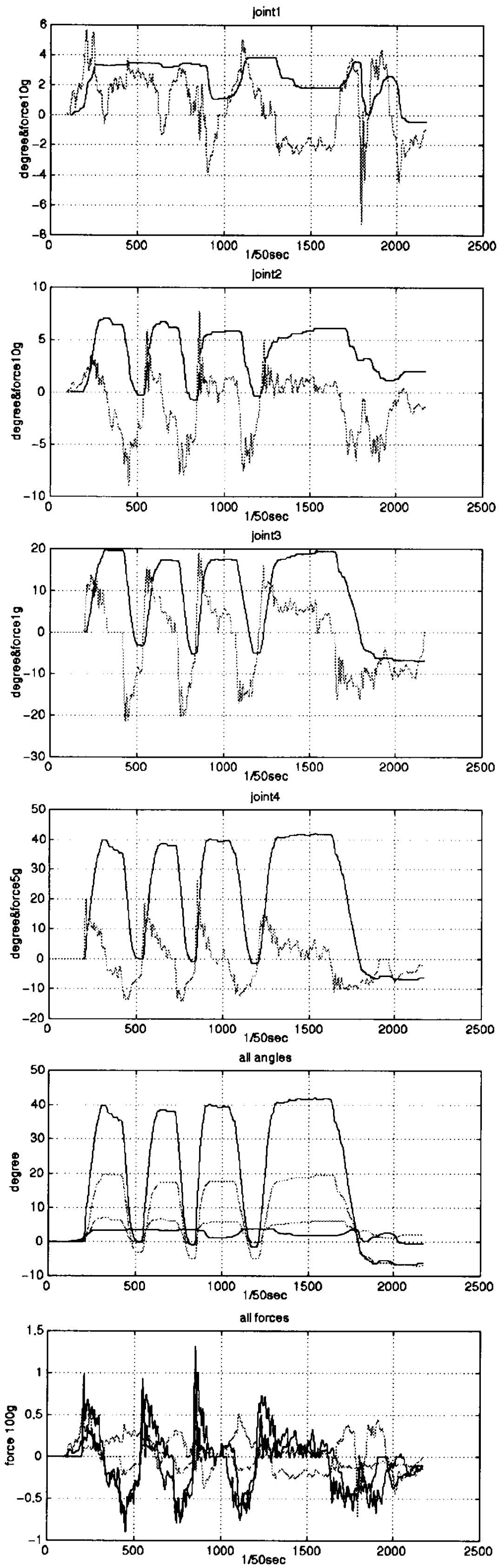

Figure 14: Human motion data with force feedback

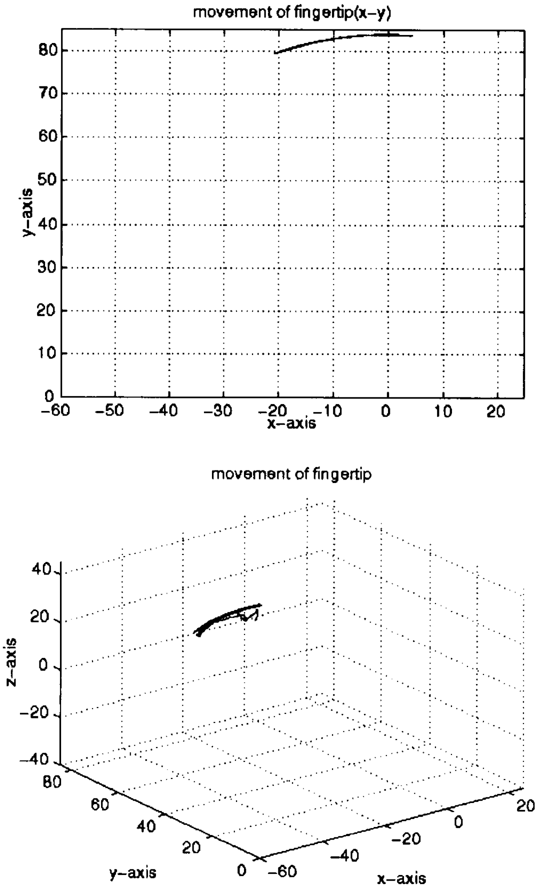

Figure 15: Human motion data in force feedback

VR Environment (Figure 9) elements must be completed and linked. The usefulness of acquired data from fingers movements in Virtual Environment in the control of a robot hand must be investigated. More efficient control algorithms must be tested to try the improvement of the reality sensation when using SG-2.1.

7 DOF Sensor Arm system is being developed concurrently with SG-2.1. The sensor arm has a set of independent systems for measuring angles/forces of each joint and for exerting force. Combining SG-2.1 with Sensor Arm is expected to result a 27 DOF device for a unprecedent interaction with virtual world.

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