The research of light-weighted finger haptic device using voice coil

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Abstract

In recent years, with the research of interaction between human and computer, we can feel that creating the virtual reality world becomes so close to us. We can realize the interaction in the virtual world by haptic devices. But only force feedback cannot realize the feeling of touching soft bodies. So we propose a system with force-feedback to hands and stimulation-feedback to fingers at the same time to increase the width of touchable virtual objects from hard to soft.In order to reach this purpose, we proposed to develop a light-weight finger haptic device using voice coil to realize the tactile sense. We did some experiments to verify the validity of touching soft bodies and we created some soft objects similiar to real soft bodies by calculate the spring coefficient K and let users touch and feel them.

1 Introduction

There are many researches about that the skin tactile sense is widely being used in application of engineering. And it will be a brand-new area in human interface fields. Skin tactile sense is not only the path for the research of VR environment to follow, but also the clues for understanding the human intelligence and the possibilities of new tactile sense researches.

Fig. 1. Haptic interface device – Spidar-G developed by Sato Lab, Tokyo Tech [1]

Skin tactile sense interface is being used in different fields such as to assist visual and hearing, to support long-distance manipulation and virtual objects manipulation, to support some basic researches for VR and so on.

In our research, our lab has developed a kind of haptic interface device which is called SPIDAR(Fig.1), the force feedback interface device just like Novint Falcon [2] which is developed by Novint Technologies, Inc.(Fig.2) We can realize the interaction between users and virtual objects by touching objects in computer to occur force feedback to user‘s hand. But in the SPIDAR system [3] , user feels the force by holding grip or finger gaps. Natural receptor sense is feedback from musculature movement and it can only transfer part of haptic sense which is well behaved on hard objects. We purpose a system which is combined with force-feedback to hands and stimulation-feedback to fingers at the same time so as to enlarge the range of touchable objects from hard to soft. Therefore we also purpose to develop a light-weight finger stimulation device by voice coil.

2 Related Researches

Skin stimulation methods are generally regarded as mechanical movement such as transmission of vibration or position control of active button. In order to avoid complex mechanical structure, the electrostatic type actuator [4], the air pressure type actuator [5], and soft material type actuator [6] which is different from hard mechanical parts are widely developed and used in virtual reality research. In

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Fig. 2. Novint Falcon [2] ©Novint Technologies, Inc. All rights reserved.

recent years, it is reported that scientists make tactile sense with electrical stimulation [7], ultrasonic wave [8] and so on. Even the researches about the stimulation to the neuron which is called neuron interface [9] are started these years.

On the other hand, the prompting methods of skin tacitle sense are divided into two types in general. One is the type of desktop which can be touched by hands or fingers freely. This type of interface can transmit information by controlling the friction between objects and user's fingers [10] [11]. For example, users can experience different textures and concave convex feelings by touching desktop interface.Another one is sheet tensility control system [12]. This system can control the compliance of gum sheet by touching different contact positions to let user know inequable hardness feelings.

One is the type of device being installed in hands or fingers. Being different from desktop interface, portable type interface of skin sense is well designed by its weight and structure. It cannot realize complex behavior of virtual objects, but each portable device is designed to realize particular purpose. For example, there is a device which prompts softness of objects by controlling contact area [13]. There is also a device which can prompt the weight of virtual object by transmitting rotate force of motors. [14]. Furthermore, some wonderful ideas have been carried out. They put a sensor between tactile device and fingers, it is not to calculate the pressure but to detect the color of fingernail to analyze the contact pressure between device and fingers [15].

So we can see from that different research purpose caused different method of device development and experiment. In our research, we need to let user be aware of soft bodies in the virtual environment by touching them. So we need to realize to recognize two feelings between being touched or not being touched. We think the skin stimulation is the simplest way to realize this purpose.

3 Proposal of development of finger tactile device by voice coil

In our research, we want to make the stimulation as simple as possible and the device as small as possible in order to make the user's manipulation to be freely. In variety of stimulation methods, the vibration stimulation is the most effective and general. So we decided to develop a haptic device with voice coil and small magnet. The design principle is the law of John A. Fleming. We show the movement principle in Fig.3 and the construction of device in Fig.4. There are two small magnets in both sides of the coil. They can occur magnetic field from north magnet pole to south magnet pole like which the Fig.8 shows. The center of device is the small voice coil which can move up and down when the current is flowed. So we can control the current intensity so as to control the intensity of skin stimulation.

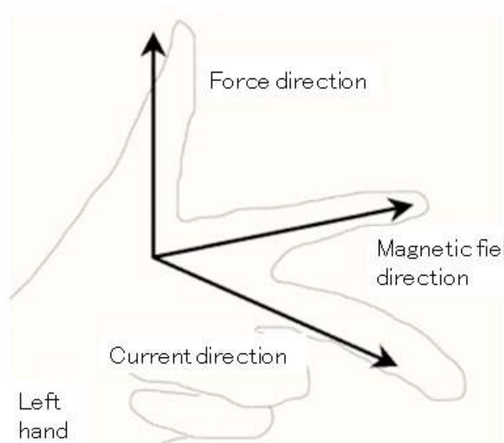

Fig. 3. Law of John A. Fleming

3.1 Size of tactile display with voice coil

As a skin tactile device for our system, there are some requirements to be satisfied with. The first is in order to be suitable for high degree of position accuracy to virtual point, device should be made as small as possible. This time we developed a device only 5g and the first knuckle size like Fig. 5 to satisfy with the accuracy requirement.

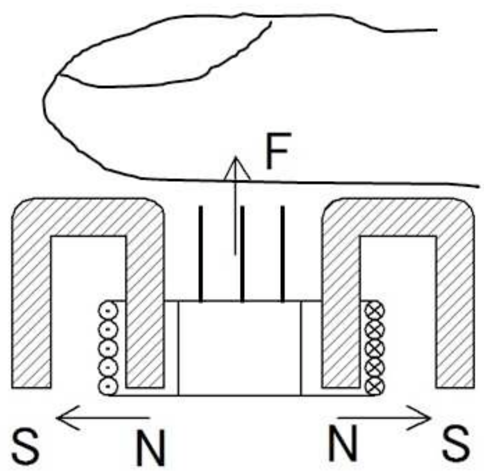

Fig. 4. The construction of tactile display(a)

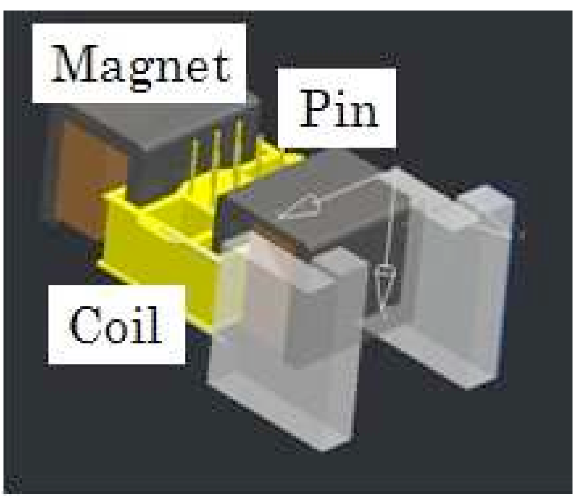

Fig. 5. The construction of tactile display(b)

3.2 High power efficiency

The second is high power efficiency. The axis of current and magnet field will have an influence on the output of vibration force. We keep two axis as vertical as possible and detect the output of finger force. Fig. 6 shows the relationship between detected output force and current control PWM module Duty ratio of this device. On the other hand we also have done the stimulation threshold value discrimination experiment which is the very important value in VR device performance function by limit method. The result of the experiment is up threshold value to be 20.5mN and down threshold value to be 21.6mN. It shows that this voice coil device have the same level discriminate performance function to the other tactile devices.

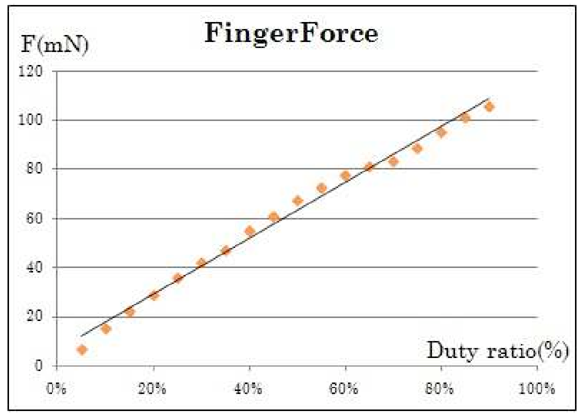

Fig. 6. Relationship of output force and PWM control module Duty Ratio

3.3 Responsiveness of the tactile display

The third requirement is in order to realize the comfortable VR environment following the huge development of computer science, responsiveness of the device is also very important to prevent the happening of incompatibility. So we did the responsiveness test for this device (Fig. 7). This time we output voltage pulse signal with 50% duty ratio by PWM module to test the start time which is from 10% to 90% of the whole output. The result is 4.1ms which is to indicate by medium value among 30 times tests. This data shows voice coil device is 8 times faster than motor drive device-Gravity Grabber.

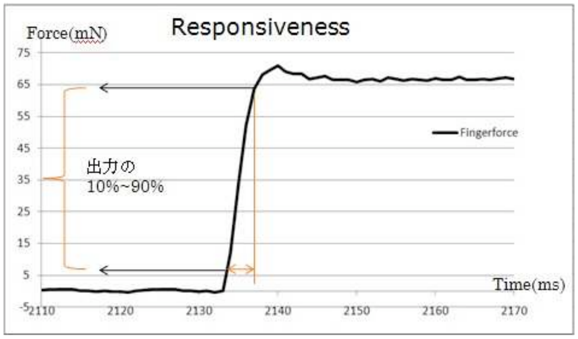

Fig. 7. Responsiveness of tactile display

4 Implementation of finger tactile device system

In our research, we purpose to realize the feeling of touching soft virtual bodies by force-feedback to hands or arms and stimulation-feedback to fingers on the same time. So we should have to consider to combine two systems into one to realize soft material touching.

4.1 Construction of system

Until now we can touch hard virtual objects by force-feedback interface system-SPIDAR. SPIDAR system consists of strings and motors. We can get 3D position by calculating the length of strings and turn it into the position of virtual point in frame of axes. On the other hand, we use general physical simulator ODE to calculate the virtual objects' stiffness and viscosity. Through Virtual Coupling, we can get the value of force-feedback and turn it to the torque of the motor. User can feel the force pulled by strings when touching virtual objects just like pushing real objects. That is which we called haptic interface.

In our research, we added the finger stimulation control into the system when haptic interface occurred. We use PIC24 module to control the finger tactile device. There are 9 channels of PWM module outputs in PIC24, so we can control 9 finger tactile devices at the same time. As control method, PWM module can change duty ratio to change output voltage to the tactile device so as to output different voltages to control the power of the device. And PIC24 can also control interrupt of signals so as to realize different patterns of device movement.

In this system, we create an environment of touching virtual soft bodies. You can see the construction in Fig. 8. First, we get the position of virtual point and make it as the finger position. Second, we calculate the force by Virtual Coupling when finger touches the surface of bodies. At the moment finger enters into the surface of soft bodies, finger tactile device occurs the stimulation to the finger and user can get information for depth of soft body more correctly. The power of device is controlled by PWM duty ratio.

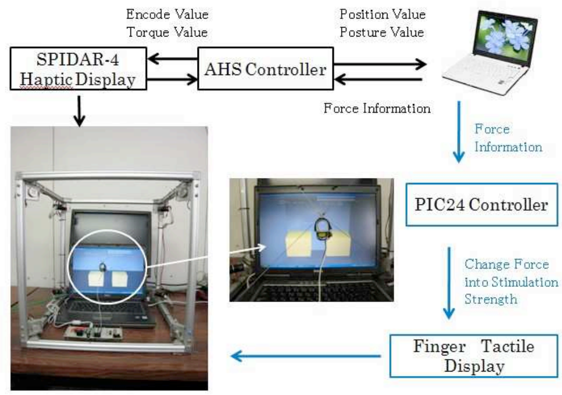

Fig. 8. The construction of new hatpic interface system

4.2 Method of controlling finger tactile device

In our research, it is important to show the relationship between the force user suffered and the strength of finger stimulation user received. As we all know, we can get the force strength from the weight of real object or Hook's law or modulus of rigidity and so on. Then turn it into the torque of motors so as to indicate the force when you hold objects or you touch some surface like real. But stimulation strength is different from force strength. It cannot be calculated from body's weight directly. So we find out a method- Fechner's law in physics psychology to realize the output of stimulation strength.

Fechner's law shows that when force strength increases by linearity the stimulation strength increases by logarithm at the same level. So according to Fechner's law, we use F–the feedback force calculated by Virtual Coupling, as force strength and V–the voltage outputted from PIC24 as stimulation strength this time. We can get formula 1 to indicate this relationship.

$$F = k_n \cdot \log V \tag{1}$$

F:feedback force calculated by Virtual Coupling

V:voltage outputted from PIC24

k_n:transform coefficient

In order to control the stimulation strength, we get the value of force from ODE physical engine in an 1KHz calculate loop and use formula 2 to turn it into value of PWM duty ratio. k_n is setted with 1.2N in this program to insure PWM Duty value is from 1% to 100%.

$$V = e^{(F/k_n)} \tag{2}$$

4.3 Application

This time we purpose to touch soft bodies through not only force feedback to hands but also stimulation feedback to fingers. You can see Fig.12 shows the situation of the whole system and Fig. 9 is the sample of application program. In this program, we designed 2 pieces of soft boxes to do the compare experiments. User can put one finger on each surfaces to feel the force and only up surface can offer finger stimulation. We will show you the detail in next chapter.

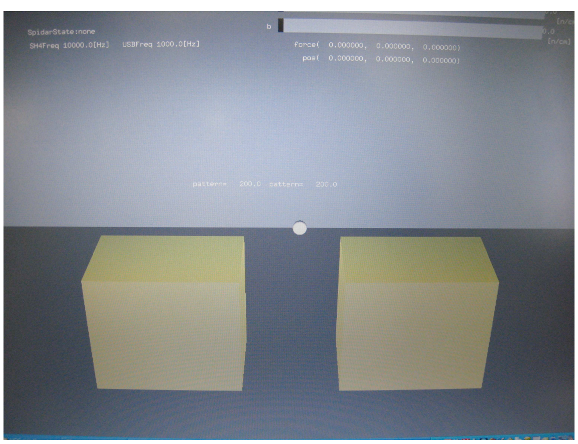

Fig. 9. Demo Application

5 Evaluate Experiment

In our evaluate experiment, we want to verify how wonderful the finger stimulation works by touching soft bodies. As we all know, when we touch a very hard object, we can feel the strong force feedback to muscle and obvious skin deformation at the moment we are in touch with the surface. Because the force and the deformation information tell us in that moment our skin has a collision with some object. This is why we feel it hard. On the other hand, how can we feel something is soft? When we touch soft body with fingers, we also can feel the force and skin deformation at the time we are in touch with the surface. But soft body has tiny resisting force and huge deformation not enough to stop finger going deeper. In this process, it seems very important how we get the texture information although our muscle cannot be stopped. Therefore, stimulation to cell receptor can offer information about texture or temperature is known by physiology. We want to realize this function also in VR environment. So we have developed the finger tactile device to offer tactile information to human's skin.

5.1 Discrimination of Virtual Surface

As the purpose we put forward, present system processes VR objects' collision using Spring-Damper System. Therefore there will be an overlap between to VR objects and it will take uncomfortable feeling to visual. So we want to verify whether users can get hold of the correct surface information or not by skin stimulation at the moment they are in touch with virtual surface.

We did the experiment like this. Users can touch virtual surfaces by one of their fingers but without visual. They are orderd to move their finger along axis Y and if they feel stimulation or force they must stop their finger at that position for a few seconds. The experiment is divided into only force feedback and both force and tactile feedback. We did the experiment with three different materials.

You can understand form three images below.

We made 4 experimenters to do this test and gain similar results from their position data (Fig. 10 - Fig. 12) . The black line shows the position of virtual surface. The blue line shows the position of finger when they received force and tactile feedback. The red line shows the position of finger when only force feedback. The result shows that with lessening of Spring Coefficient K, the sense of distance to correct surface for users becomes larger and larger. It shows that without the tactile feeling, user cannot be aware of in which moment they touch the virtual surface precisely. But with the tactile stimulation to the fingers, user can realize the virtual surface more precisely. The difference value can be showed by the distance between the mean value of red line and blue line in three images.

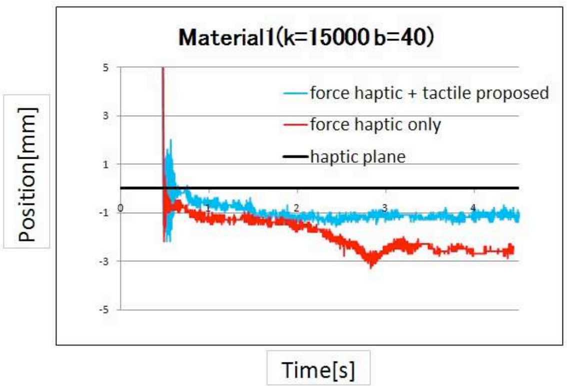

Fig. 10. Relationship of finger position and virtual plane position(K=15000N/m)

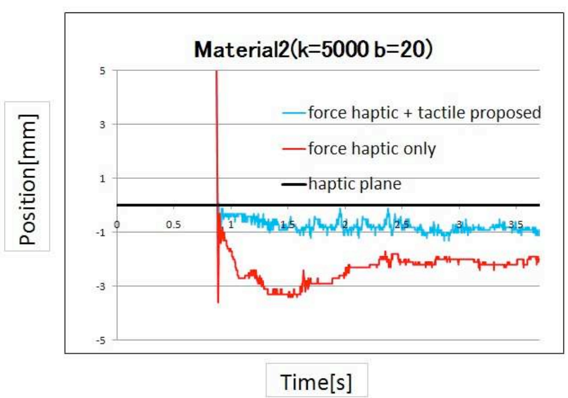

Fig. 11. Relationship of finger position and virtual plane position(K=5000N/m)

5.2 Discrimination of Different Soft Bodies

In order to proof the validity of the tactile stimulation to touching soft virtual bodies, we prepared this experiment: discrimination function of different soft bodies. Because of the construction of Spring-

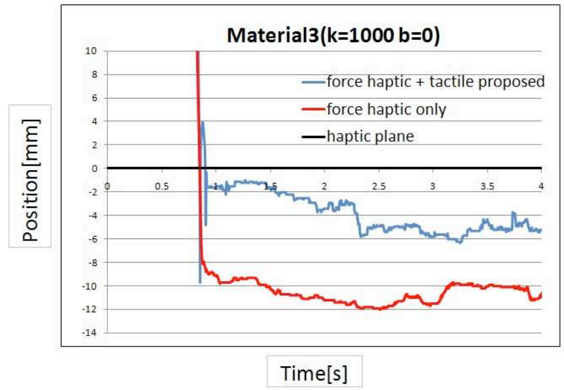

Fig. 12. Relationship of finger position and virtual plane position(K=1000N/m)

Damper System, we can realize soft bodies by lessening the Spring Coefficient K. But at the same time, without tactile stimulation to fingers user cannot master the correct distance they have immerged into the soft body. Therefore we want to compare the correct recognition rata of discrimination of the embedding distance to the soft bodies.

We have prepared two situations: force feedback with tactile stimulation and without tactile stimulation. In our test, we also prepare two soft bodies with different Spring Coefficient K. It shows the embedding distance is different. By touching two soft bodies, user should answer which coefficient K is smaller between K1 and K2. Considering user cannot answer this question directly, we prepared 15 groups of K1 and K2 and let user answer the embedding distance they felt. Which is longer and which is shorter. Then we calculated the correct recognition rate for users and compare them. You can understand from the Table. 1 below.

We think it is not very easy to understand the data in Table.1. So we also make Fig. 13 for it to show correct recognition rate for each group. The figure shows that participant can recognize K1 and K2 perfectly when the difference value of K1 and K2 is very big. If the difference value goes down to 30N/m, the correct recognition rate becomes lower sharply.

Furthermore, we use couple comparison method to calculate the correct recognition rate for each participant in Table 2 and show them in Fig. 14. In this test it shows that the correct recognition rate of with tactile stimulation is higher than without

Table 1. Correct recognition rate for each group of Coefficient K

Spring Coefficient K	Correct recognition rate
K1=200, K2=190	33.3%
K1=200, K2=150	100%
K1=200, K2=100	100%
K1=200, K2=50	100%
K1=150, K2=140	33.3%
K1=150, K2=100	91.7%
K1=150, K2=50	100%
K1=100, K2=90	25%
K1=100, K2=50	100%
K1=100, K2=30	100%
K1=50, K2=30	83.3%
K1=50, K2=20	100%
K1=30, K2=20	16.7%

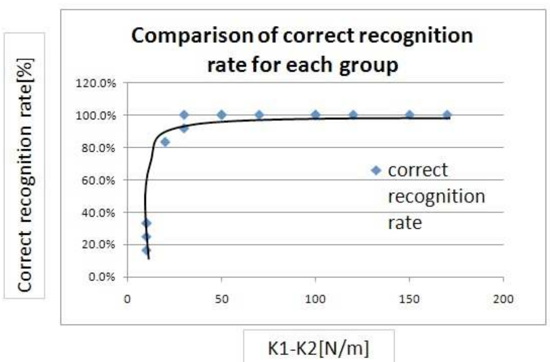

Fig. 13. Comparison of correct recognition rate for each group

tactile stimulation. This conculsion shows that with the tactile information to users, they can distinguish the virtual objects more and more precisely. But the stimulation effect is different to different participants. For example, the result of participant D is very good. Because the speed of moving fingers is too fast so as to let him feel the finger stimulation being delayed when touching the surface of the soft body. This action caused his correct recognition rate of without tactile stimulation is higher. But on the whole there is a good effect on discrimination of close softness objects by tactile stimulation.

Table 2. Correct recognition rate for each participant

With Tactile Stimulation	
Participant	Correct recognition rate
Participant A	93.3%
Participant B	73.3%
Participant C	80%
Participant D	73.3%
Participant E	86.7%
Participant F	93.3%
Average Value	83.4%
Without Tactile Stimulation	
Participant	Correct recognition rate
Participant A	80%
Participant B	66.7%
Participant C	73.2%
Participant D	80%
Participant E	73.3%
Participant F	73.3%
Average Value	74.4%

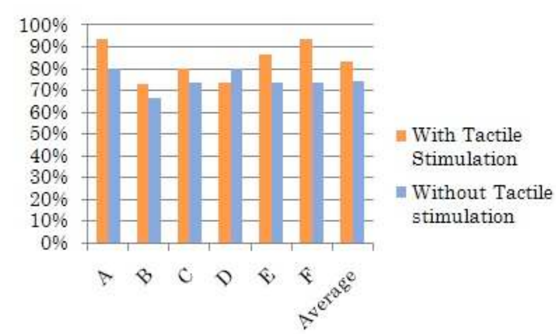

Fig. 14. Figure of correct recognition rate for each participant

6 Conclusion and Future work

Skin tactile sense interface is going to become topics in advanced science and technology fields. One example is that we think it is only right and proper that there are keyboard and mouse as computer interfaces in our daily life. But with the appearance of touch panel function, it has changed the conception of computer and mobile phone interface totally. In the near future, with the variation of connecting between computer and network, skin tactile sense interface will play a leading role in the development of interact information system. On the other hand, sensing unit and communication functions can be integrated into a silicon chip with is smaller than 1mm. Skin tactile sensor will be more and more universal in the future science research. Skin tactile device will also be subdivided by its control performance and its accuracy class.

In this research, we developed a tactile display to fingers and combined it with haptic display into a brand-new system. In our experiments, it also shows that with the tactile stimulation, the information about virtual objects and precision of feelings will be raised than just force feedback interface. But the science knowledge of skin tactile interface is still insufficient right now. In spite of this situation, we still want to suggest some research topics in skin tactile field in the near future. For example, tricolor can be checkout by visual receptor and how to use the sensible property with colors to give users stimulation is reported very clearly in previous researches. But in tactile field, how the tactile receptor works with skin deformation and how to match up deformation and tactile stimulation is still mysterious to scientists. In recent years, we can see nerve potential detect technology is rapidly developed. If we can use these data to definite tactile receptor sensible properties, I think we can do more works at developing devices and it must be a huge progress in research of skin tactile interface.

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