The SmartTool:
A system for augmented reality of haptics

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Abstract

Previous research on augmented reality has been mainly focused on augmentation of visual or acoustic information. However, humans can receive information not only through vision and acoustics, but also through haptics. Haptic sensation is very intuitive, and some researchers are focusing on making use of haptics in augmented reality systems. While most previous research on haptics is based on static data, such as that generated from CAD, CT, and so on, these systems have difficulty responding to a changing real environment in real time. In this paper, we propose a new concept for the augmented reality of haptics, the SmartTool. The SmartTool responds to the real environment by using real time sensor(s) and a haptic display. The sensor(s) on the SmartTool measure the real environment then send us that information through haptic sensation. Furthermore, we will describe the prototype system we have developed.

1. Introduction

Many augmented reality systems use vision to send information to the human[1]. For example, M. Bajura et al. proposed an augmented reality system for medical application, which uses an ultrasound scanner to scan and visualize the inside of the patient's body, and the operator can see that image through an HMD[2]. M. Kanbara et al. proposed an augmented reality system that superimposes a virtual image to the real environment by using a stereoscopic video see-through HMD[3]. They also proposed a new registration method between the virtual environment and the real environment, which is another important problem for augmented reality systems.

Through vision and acoustics, complex information can be sent to humans, especially when using literal or verbal messages. However, the human needs to interpret that kind of information before he or she can move. This interpretation can be a stressful job in some specific situations like surgical operation or some kind of dangerous situations. In these situations, it is often hard to read, hear, and understand the message. The human can only pay attention to one thing at a time, and paying attention to the visual or acoustic message means less attention to the task itself. Thus, to relieve the necessity of stressful interpretation, a flashing message or an alarm is often used to send redundant information to the human. However, these messages do not have any effect on the task itself, and there is still the delay of human signal processing because the human can only move after interpretation and judgment of the message. To solve that problem, some research has focused on using haptic sensation in augmented reality. Touch is a very intuitive human sensation that does not need interpretation. Besides, when using force sensation, the force could support the human task in a practical way.

For example, in surgical operations, there are many vital tissues that should not be damaged in human body. When a surgical tool is in the proximity of such tissue, the blinking message or alarm itself does not have any practical effect on avoiding accidental damage - only the human can do that. In such cases, using haptic sensation could be a solution. Hong et al. proposed an interactive navigation system, which navigates an endoscopic camera in the human colon[4]. They make a potential field inside the colon to navigate an endoscopic camera. The force from that potential field prevents the camera from damaging the tissue, and leads to the target polyp. They made the potential field based on static CT data of the patient's colon. However, such static data is not always appropriate because the real environment changes dynamically. Simulations can be used to respond to a changing environment, but they are often hard to update in real time. Frank et al. proposed a real time haptic simulation using a finite element method[5], and described the trade-off between the number of nodes and the speed of their algorithm. Mendoza et al. proposed a system to touch deformable virtual objects using physical simulation[6]. For real time display of haptic sensation, they separate their system to a haptic display component and a physical simulation component, but the servo loop of the haptic display component has a frequency of 1kHz, and the physical simulation component has only 10Hz. In addition, registration between static data and the real environment would require great effort. Generally, such

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registration is always a big problem for augmented reality systems, and a real time sensor would be an efficient way to solve that problem. If the sensor measures the real environment, then the system can respond to that directly. Owaki et al [7] have developed a real time system for virtually touching objects in the real world using a real time image sensor and a haptic display. Their system enables the user to touch what the image sensor sees. In other words, their system “haptizes” visual information.

Here, we propose a new augmented reality system of haptics, the SmartTool, which consists of real time sensor(s), a conventional tool, and a haptic display. The sensor(s) measure the dynamic real environment, and the haptic display sends that information to the human through haptic sensation. For example, generating a repulsive force from the haptic display would indicate that the tool is in proximity of some kind of restricted area. In addition, the user can work with the conventional tool that is integrated into the system. Although we use a haptic device, we do not have to use force or pressure sensors. All we need to know is what the conventional tool touches in real time, therefore we can use any kind of sensors to measure the real environment. In other words, that is an enhancement of the human sensation. The sensor can receive information in the real environment that could never be felt by the original sensation of the human.

In this paper, we will describe the SmartTool, a system for augmented reality of haptics. In section 2, we will describe the concept of the SmartTool. In section 3, we describe details of our prototype system. Then we will describe two experiments using the prototype system in section 4. Section 5 is a discussion and section 6 is a conclusion.

2. The SmartTool

We have developed a system called the SmartTool for haptization of sensory information. The SmartTool consists of sensor(s) to measure the real environment, a conventional tool to work with, and a haptic display for displaying sensory information. In this section, we will describe details about each part of the system.

2.1. Sensor(s)

As we mentioned in section 1, we should use some kind of sensor(s) to measure the real environment. Otherwise, it is hard to detect changes of the real environment in real time. For the sensor(s), we must consider:

- Latency and sampling rate
- Sensing area and position of the sensor
- Size of the sensor(s)
- Material of the sensor

For the stable display of haptic sensation, the closed loop servo of the system should be 1kHz. Therefore, it is desirable for the sensor(s) to have the same or higher sampling rate, with low latency.

The next point is position of the sensor and the sensing area. Basically, the choice of the sensor depends on the tool and the tasks at hand. However, all that we want to know is what the tool touches, so a wide sensing area is not always necessary. In addition, sensor(s) for surrounding area such as a camera are not always necessary either. The area where the tool contacts the real environment would be a single point, or relatively very narrow area, which is often hidden by the tool itself. Besides, sensors for a remote area or wide area are often slow and have high latency. For example, cameras can measure a remote and wide area, but their sampling rate is generally on the order of 30 Hz, with a latency of about 1/30[sec]. Therefore, instead of using such sensor(s), we can use contact sensor(s), or non-contact sensor(s) for the proximity area. Then to relieve the necessity of registration with the environment, we install the sensor(s) on the tool tip. By doing so,

- The sensing area and the working area of the tool is the same
- What the sensor detects is what the tool touches

In many augmented reality systems, the registration of sensor(s) is one of the most important but troublesome tasks. By installing sensor(s) to the tip of the tool frees us from such tasks. The system of Owaki et al [7] has an image sensor, but the sensor is not on the tool itself so the registration problem remains.

However, when installing sensor(s) on the tool tip, other problems could arise. The user works with a conventional tool, with sensor(s) on the SmartTool. Therefore, the size of the sensor and the sensor material would be a problem. Obviously, sensor(s) should be as small as possible to not disturb the task with the tool. Further, because the tool tip and sensor(s) often contact other objects, there are possibilities of breaking the sensor, or of sensor inaccuracy due to residue that could accumulate around the sensor(s).

2.2. A tool and a haptic display

In general, it is often said that haptic displays should be changed if the task changes. However, there is no need to change the whole system – changing the tool is enough. It is because the human always feels reacting force through the tool, which is the interface between the system and the human. Therefore, we use conventional tool. Besides, using a conventional tool means less necessity of training for the new system. In other words, by using a conventional tool for the SmartTool, we could use existing human skill.

In this system, we can use existing technology related to haptic displays in displaying sensory information. If the sensor on the tool tip detects nothing, apart from the weight of the system itself, the actuators generate no additional force. Besides, the space around the working area of the tool must be free. If there is no free space, we could not install sensor(s) on the tool tip and could not work with the tool. For example, when using the popular haptic display system, the PHANToM (SensAble, Co., Ltd.,[8]), the user holds a stylus device on the system. However, the tool tip is linked to the base system hence the user could not cut or write anything with the tool in the real environment.

2.3. Characteristic of the SmartTool

As we mentioned in section 2.1 and 2.2, the SmartTool consists of:

- Real time sensors
- A conventional tool
- A haptic display

The real time sensors on the conventional tool tip measure the real environment, and the haptic display displays that information through human haptic sensation. The characteristics of the SmartTool are:

- Free from registration between the virtual haptic sensation and the real environment
- Modality transformation from another kind of sensation to haptic sensation
- Haptization of the information
- Relieving the stressful interpretation of messages from the sensors

The sensors are on the tool tip and it is the same point as the working point of the tool. Therefore, "What the Sensors Detects is What the Tool Touches". Furthermore, we could use any kind of sensors that satisfies the conditions described in section 2.1. We can also use sensors that are not related to haptic sensation, such as optical sensors, ultrasonic sensors, electricity sensors, bio-chemical sensors, etc. Then the system displays information from these sensors through human haptic sensation. The system could transform the modality of any kind of sensation to haptic sensation. Therefore, we can "feel" many kinds of information (optical, ultrasonic, electrical, etc.) through our haptic sensation. Actually, the system "haptizes" sensory information to enhance human haptic sensation.

When using a blinking message or alarm to display sensory information, the user has to pay attention to that all the time (upper figure of Figure 1). In such case, a loop between the user, the tool, the environment, and the sensors has been established. The performance of the whole system including the human depends on the speed of this loop. However, the human can not maintain attention for too long.

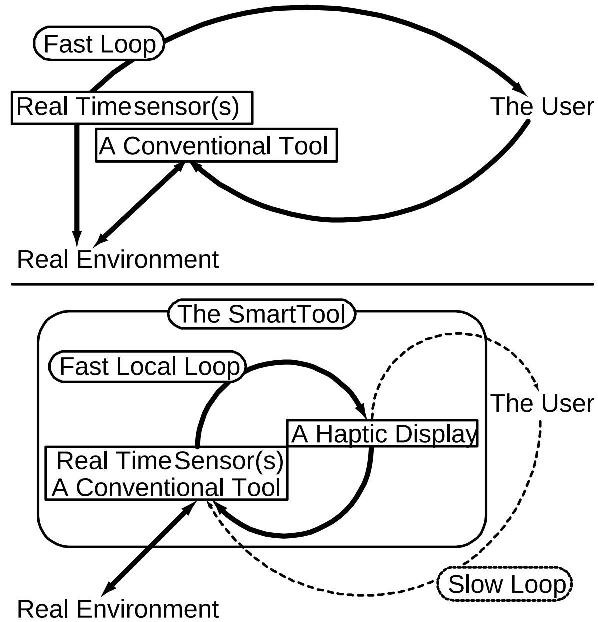

Figure 1 The information flow (The upper figure: with normal tool and sensors The lower figure: with the SmartTool)

When using the SmartTool, the loop has established between the haptic display, the tool with sensors, and the environment (lower figure of Figure 1). This loop is implemented into the system so it is fast. In the prototype system we describe below, this loop runs 1kHz. Then a relatively slow loop has established between the user and the SmartTool. The user interacts with the environment through the SmartTool. That interaction does not have to be so fast because the SmartTool always sees the environment. For example, in the case of making a restricted area, the SmartTool always monitors what the tool touches. If the tool is going to penetrate that area by accident, the haptic display on the system generates repulsive force in order to not penetrate the area. The tool would not penetrate the area because of the fast loop inside the system.

From one point of view, the SmartTool is a supporting system. The SmartTool generates force based on sensory information, but that does not mean the system forces some task upon the user. The user could act against that force if he wants to do so. In our SmartTool, the force is strong enough to attract the user's attention and avoid a hazardous situation, but weak enough for the user to act against the force if needed. The human is always the master and the system is always the follower. Only the master could determine whether to follow the suggestion from the system or not.

3. Specification of the prototype system

In this section, we describe the prototype system of the SmartTool (see Figure 2). This system has 6DOF, but only 3 of them are active (no torque). We use 10[W] DC motor (Maxon Japan corporation, RE25-118746) with 1/20 reduction gears for each axis.

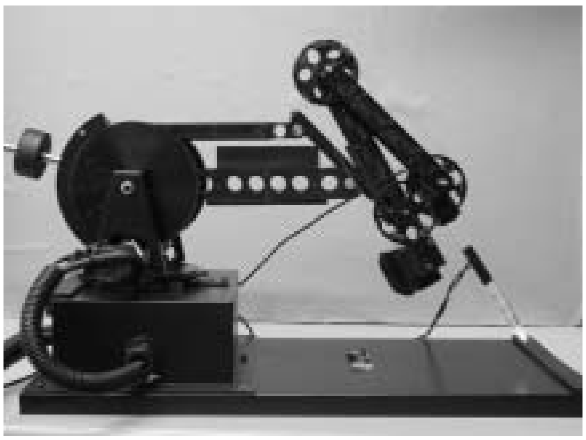

Figure 2 The picture of the system

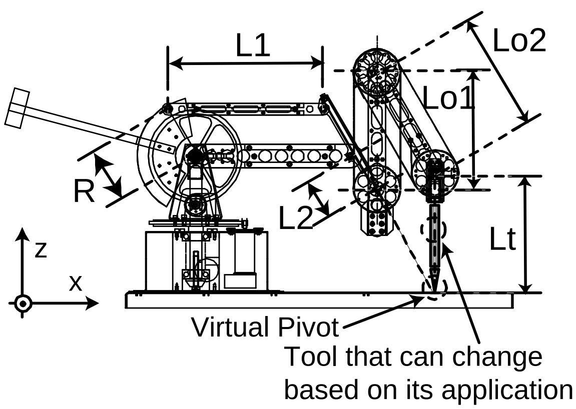

Figure 3 Design of the SmartTool

This prototype system consists of the base component and the tool component. The base component is parallel linked 3DOF haptic display. For the tool component (see Figure 4), we use a wire based parallel link mechanism to make a virtual pivot at the working point of the tool in use. That parallel link mechanism makes a necessary free space around the tool. In addition, the tool component has a socket on the end, which enables the user to use many kinds of conventional tools. The weight of the tool component is about 500[g] and a counter-weight is mounted on the base component.

To measure the position of the tool tip, encoders (Maxon Japan corporation, HDES-5540 110511) are installed on each motor. The resolution of each encoder is 500[ppc] and we use them multiplied by 4. Figure 3 shows the design of the prototype system and Table 1shows the system specifications.

Table 1 Specification of the prototype system

L1	200(mm)
L2	50(mm)
R	70(mm)
Lo1	150(mm)
Lo2	150(mm)
Lt	150(mm)
Range of Motion (X axis)	280(mm)
Range of Motion (Y axis)	400(mm)
Range of Motion (Z axis)	400(mm)

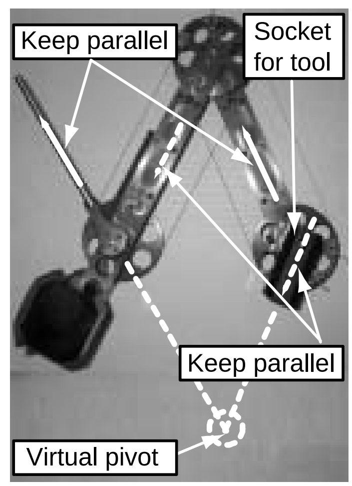

Figure 4 The tool part of the SmartTool

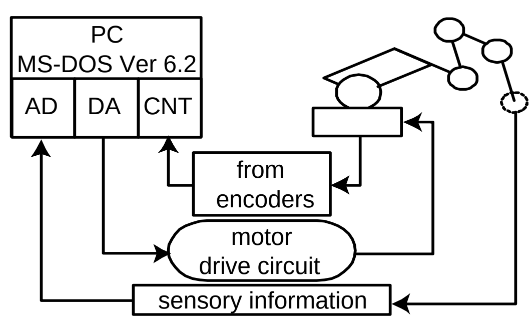

Figure 5 The system configuration

For a controlling system, we use a PC/AT machine with MS-DOS (Ver. 6.2, see Figure 5). We use a PCI AD/DA Board (Interface Corporation, PCI-3523A, AD: 12bit, DA: 12bit) and a PCI Counter Board (Interface Corporation, PCI-6201, 24bit). For a drive circuit, we use Titech Robot Driver PC-0121-2 (Okazaki Sangyo Co., Ltd.) for each motor. The sensor on the tool tip measures the real environment, then the PC receives the information through the AD Board. The PC calculates an appropriate force, and outputs force signals through the DA Board. We use a current control method for the DC servomotor.

4. Experiments

4.1. Cutting only an egg white

In our first experiment, we cut a hard-boiled egg. We regarded the egg as a human body. The yolk of the egg indicates vital tissue, while the egg white indicates tissue that can be safely incised. We use a scalpel for the conventional tool on the SmartTool. Under these conditions, we make a restricted area around the yolk, and if the scalpel is in the proximity of this area, a repulsive force will be generated from the SmartTool in order to not damage the yolk. The user holds the scalpel and can move it freely when the sensor on the scalpel detects nothing. If the sensor detects the yolk, the user would feel the existence of a solid virtual wall. However, as we mentioned in section 2, the user could penetrate the wall if necessary.

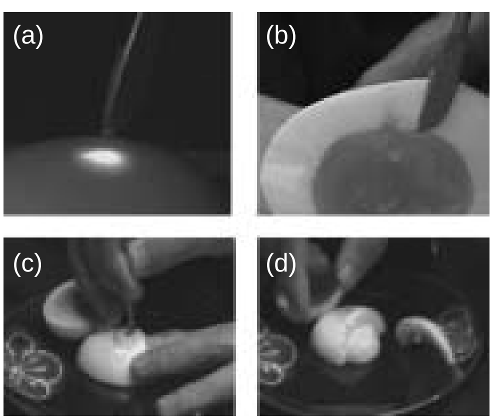

Figure 6 (a) using an optical sensor, (b) the scalpel stops at the yolk, (c)(d) cutting the egg with the SmartTool

For the sensor, we use an optical sensor to detect the egg yolk (see Figure 6, (a)). The sensor consists of two optical fibers, one for the reference light and the other for the reflected light. We use blue light (wavelength: 470 [nm]) as the light source and a phototransistor for the light receiver. These two fibers lead from the light source to the tip of the scalpel. This sensor is composed of two optical fibers so it can install on the tool tip. We measure the difference of reflectance to detect the change of the material. The image (a) of Figure 6 shows the light from the sensor on the tip, and the image (b), (c), and (d) of Figure 6 show the scalpel stopping at the yolk. The Figure 7 shows the structure of the optical sensor that we use.

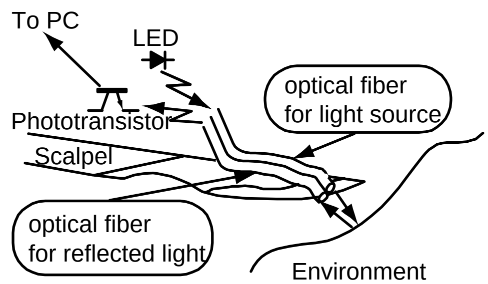

Figure 7 The structure of the sensor for cutting egg

4.2. Touching the interface between oil and water

The next experiment is touching the interface between oil and water[9]. We use oil and water in a small tank, and the system haptizes the chemical difference between them in real time. This experiment shows that the system could work in the changing environment. If a wave occurs in the tank, the sensor on the tool tip detects the movement of the interface in real time, and the system sends the information to the user through haptic sensation. As a result, the user could not only touch the interface, but they could also feel the movement of the wave in the tank. It is hard to simulate such a wave in a real time.

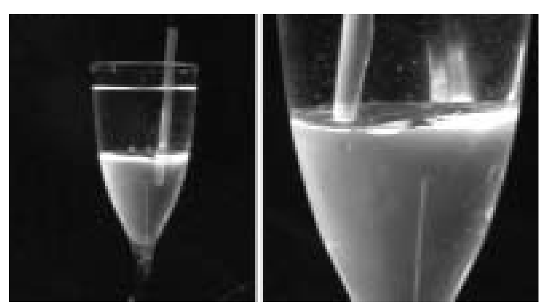

Figure 8 Touching the interface between oil and water (Left: normal tool penetrate the interface Right: the tool of the SmartTool stops at the interface)

For the tool of the SmartTool, we use an acrylic stylus to "touch" the interface. For the sensor, we use an electric conductivity sensor to detect the difference between oil and water. The user holds the stylus, and if the tool moves from the oil layer to the water, the user feels the existence of a solid interface between the two liquids (Figure 8).

The sensor consists of two metallic wires, and measures the electric conductivity between them. This sensor is small enough to install on the tool tip and works in real time (Figure 9).

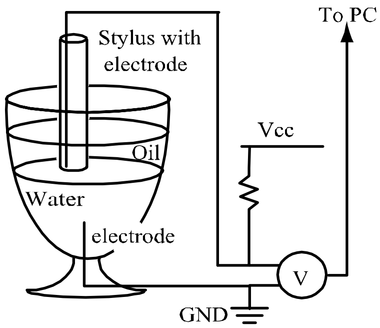

Figure 9 The structure of the sensor for detecting water

5. Discussions

The experiments we described in section 4 show that the SmartTool enables us to touch sensory information. However, it also indicates that maintaining the sensor accuracy would be a significant problem for the SmartTool. In our system, the sensors are on the tool tip. Therefore, the sensor itself makes contact with many kinds of materials, which means there is a possibility of breaking the sensor. In addition, we have to consider the residue which accumulates around the tool, preventing the sensors from sensing accurately.

In the experiment described in section 4.1, we use an optical sensor just for detecting the egg yolk. Of course, this sensor by itself would not be appropriate for a real human, but the SmartTool concept is still applicable. For example, by using the 5-Aminolevulinic Acid (ALA), which is often used in Photodynamic Therapy (PDT) and Photodynamic Diagnosis (PDD), we can distinguish tumor cells from normal cells [10]. That acid concentrates on tumor cells and fluoresces. By using an optical sensor to detect that fluorescent light, the system could detect the tumor. The system could then generate repulsive force from the normal cell for protection, and attractive force towards the tumor cell for guidance. Furthermore, if we want to distinguish live organs, Fiber-Based Fourier Transform Infra-red Spectroscopy would be useful.

6. Conclusion

In this paper, we proposed a new system for the augmented reality of haptics, the SmartTool. The SmartTool sends the information from its sensors to the human through haptic sensation. It enables us to touch the sensory information. Then we described the prototype system we made, and the two experiments using the prototype system.

7. Acknowledgement

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