BioMetal Glove

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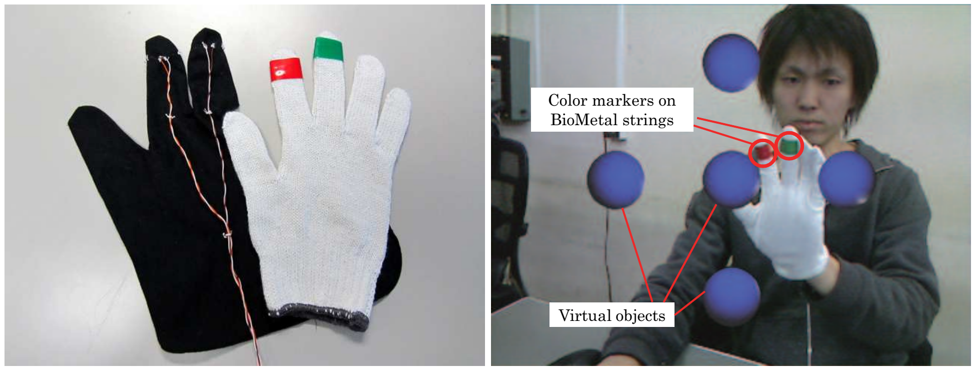

Figure 1: *(Left) Thin and light BioMetal strings are stitched to the fingertips of a black glove. A user wears the black glove under a white glove with color markers. (Right) Presenting contact sensation of virtual objects with BioMetal glove. The contact between the markers and the virtual objects are detected with calibrated stereo cameras.*

Abstract

We propose a new haptic device for rendering contact sensation of virtual objects in camera-based Augmented Reality (AR) environments. Haptic feedback can help a user to intuitively sense virtual objects. For vision-impaired users, it also means a transfer from optical information observed in the cameras to haptic information. In our system, the contact between the virtual objects and the user's hand is detected with cameras. Therefore, when presenting the contact sensation, optical markers on the hand should not be occluded from the cameras so as to avoid disturbing the estimation of 3D position and posture of the hand. To fulfill such a requirement, we used BioMetal, a promising and versatile light and thin material that shrinks when electric current is applied, which provides the haptic feedback. Strings of BioMetal were stitched onto our proposed BioMetal glove. Because BioMetal does not shrink instantly when energized, a major challenge is how to deal with the time lag. We address this problem by setting buffering regions for pre-heating the BioMetal strings.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities

Keywords: contact sensation, augmented reality, BioMetal

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1 Introduction

We explain here the manipulation of virtual objects with the user's hand in Augmented Virtuality (AV) and Augmented Reality (AR) systems. AV is realized by capturing the position and posture of the user's hand by using special devices. The position of the virtual objects is changed according to the position and posture of the user's hand. On the contrary, AR is realized by displaying virtual objects in "real world" images captured with cameras [Klein and Murray 2007]. In AR, the position and posture of the hand are captured with cameras, and the virtual objects are manipulated in the coordinate space of the real world. In other words, a virtual hand manipulates virtual objects in a virtual world in the AV environment, while in the AR environment, a real hand in the real world manipulates virtual objects in the real world. AR provides a sense of existence of virtual objects more effectively than AV.

Conventional AR systems have been applied to annotate information to real objects. Mobile phones with cameras have been commonly used for this purpose. Previous AR studies have mainly addressed how to visually display the virtual objects.

In this paper, we propose a new method to present virtual objects haptically in AR. Users can easily feel the depth of virtual objects with a contact sensation from them. Depth information is difficult to display only with visual feedback. Another benefit is that users with impaired vision can feel the virtual objects in the AR environment with the information captured by cameras presented as haptic feedback. Our method aims to recognize the posture and position of hands with cameras and to present the virtual objects according to the posture and position visually and haptically. Because the device for presenting contact sensation should not occlude the hand from the cameras, it must be small and thin. Conventional contact sensation devices cannot be used in such a camera-based AR system. We propose the use of *BioMetal* [BioMetal®], a metal actuator, for making the contact sensation device. The BioMetal shrinks when it is energized. We used the BioMetal to form a glove by winding BioMetal strings on the fingertips. Power cables are put on the back of the hand. The glove is thin and wearable. We call it a *BioMetal Glove*.

2 Related Works

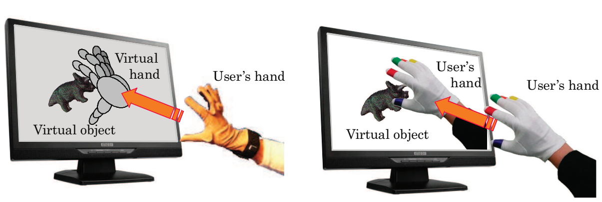
CyberTouch[CyberTouch™] and CyberGrasp[CyberGrasp™] developed by Immersion Corporation provide contact sensation or reaction force from virtual objects. CyberTouch presents the contact sensation with 3-cm-long vibrators on the fingertips. CyberGrasp has an exoskeleton with controlled wires on it. It provides force feedback through the wires. Both devices are so large that they may disturb the estimation of hand posture from captured images when used in a camera-based AR environment. In addition, they do not have position sensors. Additional special-purpose devices are required to detect a collision between the hand and the virtual objects.

Sandor et al. [Sandor et al. 2007] installed visual feedback into a haptic feedback system. Several visual markers are set on a haptic feedback device and a head-mounted display (HMD). Calibration between them is done with the markers. The users can interact only with the virtual objects that are located near the haptic device, and only with a pen-style device. In addition, since the system includes the haptic device, HMD, markers and position trackers, it is very large and cannot be moved.

Aoki et al. [Aoki et al. 2009] proposed a light contact sensation system using small coils. The small coils pull wires on the fingertips to provide haptic feedback. The device is wearable and weighs only 1.4 g, enabling moving users to interact with virtual objects haptically. Minamizawa et al. [Minamizawa et al. 2008] also proposed a contact sensation system with small motors. Scheibe et al. [Scheibe et al. 2007] adopted Shape Memory Alloy (SMA) to present contact sensation. The system was confirmed to be valid for a driving simulator. These systems are achieved not only with coils or SMAs, but also with additional position markers like LEDs or magnetic markers. Although the position markers are indeed light, the receivers for them are not light and wearable. Moreover, although LEDs present the relative positions to the observing cameras, the change in position of cameras has not been considered. In addition, none of those systems take into consideration the fact that the devices would visually occlude the hands. In fact, there was no trial to introduce contact sensation for a camera-based AR system.

3 Presenting Contact Sensation for AR

Before describing the proposed system, let us first clarify the requirement for presenting the contact sensation in AV and AR environments. As shown in Figure 2, the requirement for AR is different from that for AV.



(a) Augmented Virtuality (b) Augmented Reality

Figure 2: *The difference between AV and AR. Requirements for contact sensation devices are different in AV and AR environments.*

In the AV environment, as shown in Figure 2(a), the 3D position and posture of the hand are often captured by special-purpose devices such as data gloves or magnetic position sensors instead of cameras. A virtual hand is displayed in a virtual environment. The contact is detected by testing the collision of the virtual hand and the virtual object in the virtual world, while presenting the visual and haptic feedback accordingly. Since the virtual object is manipulated by the virtual hand rather than the real hand, the size of haptic devices does not have to be considered. Actually, a larger size is desirable in order to provide a guide for calibrating the position sensors to the posture sensors. Once the calibration is done, the position sensors can no longer be moved. Moreover, it is difficult for the user to feel the virtual objects as real ones since the contact is calculated based on the positions of the virtual hand and the virtual objects.

In contrast, in the AR environment (Figure 2(b)), the 3D position and posture of the hand are often calculated with images from cameras, because AR requires the position and posture of the hand relative to the cameras. Video-see-through HMDs or PDAs make it possible to display the virtual objects on a real hand from the viewpoint of the user. Color glove [Wang and Popovic 2009] and Handy AR [Lee and Höllerer 2007] are two typical examples of such systems. Both systems, however, do not provide any haptic feedback. When introducing haptic feedback to such camera-based systems, we need to be careful to avoid visually occluding the hand by the gloves or devices for tracking the hand.

4 Virtual Object Manipulation with Stereo Camera

Figure 3 depicts how to achieve manipulation of virtual objects in an AR environment using the proposed BioMetal glove. BioMetal is a kind of SMA. It tolerates repetitive shrinkage and stretch and works quickly compared to other SMAs. It is also used as an artificial muscle of a robot.

The virtual objects are manipulated with colored fingertips. The positions of the fingertips are estimated using calibrated stereo cameras. We calibrate the stereo cameras with Zhang's method [Zhang 2000]. The contact between the virtual objects and the hand in the real world can be detected since the calibration makes it possible to project the real coordinates on the virtual coordinates. The contact is presented both visually and haptically. Haptic feedback is achieved through the shrinking of the BioMetal strings.

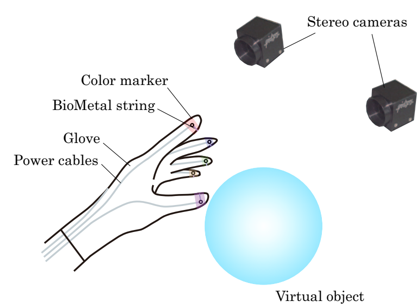


Figure 3: *Manipulation of virtual object with user's hand in camera-based AR environment. Color markers indicate 3D positions of fingertips to stereo camera, and BioMetal strings present contact sensation.*

Each fingertip is colored with a marker in a unique color. Each of the stereo cameras detects the colored regions in its own image. HSV color system is adopted to detect the regions. The detected regions are labeled, and the center of each colored region with the maximum size indicates the 2D position of the corresponding fingertip. The 3D position of the fingertip is calculated with the calibrated stereo cameras. Although some previous systems used a single camera to estimate the position [Wang and Popovic 2009], we adopted stereo cameras to achieve more accurate 3D positions. The depth in particular can be much more accurately estimated when the stereo cameras are used.

5 Design of BioMetal Glove

5.1 Physical Characteristics of Biometal

BioMetal is a kind of light and noiseless SMA. One disadvantage of BioMetal is that its response to energization is slow. A time lag occurs with both shrinkage and stretching. We solve this problem by providing a buffering region to the virtual objects and the details are described in Section 5.3. Figure 4 represents the thermal responsiveness of the BioMetal.

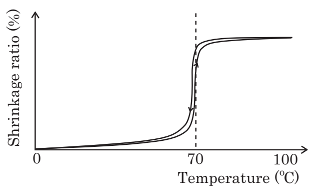


Figure 4: *Thermal responsiveness of BioMetal. Biometal drastically shrinks and strecthes in the vicinity of* $70\ ^\circ\mathrm{C}$.

The BioMetal shrinks when heated. Energization at 150 mA initiates a heating to $70\ ^\circ\mathrm{C}$ and a shrinkage of 4% of the natural length. A spring style BioMetal string shrinks 50% with the same energization. Air cooling causes the BioMetal to stretch. Thinner BioMetal string heats and cools more quickly than thicker types.

In our implementation, the energization was done using a TUSB-ADAPIO device by Turtle Corporation [TUSB-ADAPIO]. We were able to control the energization from $0V$ to $2.5V$ in increments of $0.1V$.

5.2 Installation of BioMetal Strings

The BioMetal strings were stitched onto a glove, as depicted in Figure 5. The terminals attached to the strings are fixed to the glove. When the strings are shrunk, the contact sensation is presented on the palmar region of the fingertips. Since the strings and terminals are light and thin, they do not prohibit the hand from being captured by the cameras.

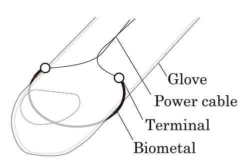


Figure 5: *Design of BioMetal Glove.*

We limited the energization to $3V$, and the temperature of the BioMetal strings were controlled to be under $80\ ^\circ\mathrm{C}$. In addition, since BioMetal has low thermal conductivity, users are hard to sense its heating. To avoid burn injuries, we placed a piece of cloth between the BioMetal strings and the fingertips. Rubber sheets are safer, but we chose cloth since rubber sheets would restrict the free movement of the user's fingers. Optical markers can be put on the BioMetal strings directly, or on an additional glove covering the BioMetal glove. This makes it possible to present the contact sensation without occluding the hand from cameras. The lengths of the strings were set to $3cm$ empirically. Shrinkage and stretching take longer when long strings are used, whereas the feedback is insufficient for the contact sensation when short ones are used. For each string, a pair of power cables is required to connect the string to the TUSB-ADAPIO unit. The cables were positioned on the back of the hand.

5.3 Buffering Region for Quick Response

As shown in Figure 6, to eliminate the time lag caused by the slow response of BioMetal to energization, we proposed covering the virtual objects with a buffering region. When the fingertips of the user enter the region, low energization is provided to pre-heat the BioMetal strings. Pre-heated BioMetal strings can then shrink quickly when fully energized at the moment the user touches the virtual object. Since the ratio of shrinkage against energization depends on the air temperature, the pre-heating energization is tuned by testing in an actual environment. When the air temperature is $20\ ^\circ\mathrm{C}$, we pre-heated the BioMetal strings to about $60\ ^\circ\mathrm{C}$ with 100 mA current. A $3cm$ string shrunk within 0.5 second with the buffering region, while it takes 0.8 second without the buffering region.

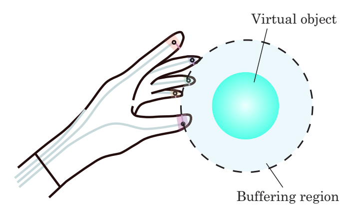


Figure 6: *Buffering region to compensate for slow response of BioMetal strings.*

A possible alternative is to compensate for the slow response by setting the level of energization to be inversely proportional to the distance between the fingertips and the virtual objects. This method can avoid presenting false contact sensation when the fingertips are far from the virtual objects. However, it is difficult to implement due to the thermal characteristics of the BioMetal. The BioMetal suddenly shrinks when it is heated above a threshold level. Therefore, we cannot control it as a smooth function of distance. As a solution, we adopted binary energization, which is controlled by testing whether the fingertips have entered the buffering region.

Although the setting of the buffering region is effective for overcoming the slow shrinkage, it cannot solve the problem of slow stretching. We need a method to cool the heated BioMetal instantly. One possible way is to cover the BioMetal strings with refrigerant. However, devices implemented in such a way tend to be large [Mascaro and Asada 2003]. We did not adopt such a solution so that we could keep the system simple.

6 Experimental Results

We conducted a user study to investigate whether the BioMetal glove is valid for presenting the sensation of virtual objects. For the task, we asked subjects to find the virtual ball that had contact sensation out of five virtual balls (Figure 1). Stereo cameras were installed on the display monitor. The subjects had to try to touch the virtual balls while watching the monitor. Four of the balls did not present visual feedback even if the subjects' fingers reached the balls. In the experiment, the BioMetal strings were attached to the fingertips of the forefinger and middle finger of the glove. Although we could have attached strings to all five fingertips, we used only two of them to keep the glove compact and light, since the main purpose of the current experiment was to test the validity of BioMetal for presenting contact sensation.

The ball with the contact sensation was randomly selected from the five balls. The subjects were five university students. We analyzed the number of correct selections by the subjects. We also asked the subjects to answer the following questions on a scale of 1 to 5 – "5: agree very much," "4: agree," "3: neutral," "2: disagree" and "1: disagree very much."

Q1: The glove is easy to wear.

Q2: The glove allows free movement of the fingers and hand.

Q3: I can feel the contact sensation with the balls.

Q4: I can easily recognize the ball with contact sensation.

Q5: I feel the balls exist in the real world.

Q6: I want to use the glove in the future.

We obtained an accuracy rate of 88% – 22 correct answers from 25 trials for the selection of the ball with the contact sensation. No user gave two or more incorrect answers. The accuracy rate suggests that the BioMetal glove is effective for presenting contact sensation.

The results of the questionnaire are shown in Figure 7.

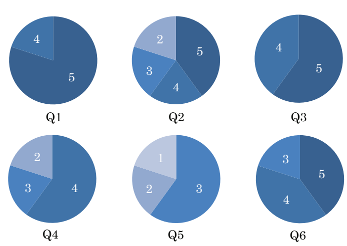


Figure 7: *Results of questionnaire.*

The answers of all subjects for Q1 were "agree very much" or "agree," and four out of five subjects answered "agree very much" or "agree" to Q2. Therefore, we can conclude that the BioMetal glove was easy to wear, and the glove did not make it difficult to move the hand.

All subjects agreed to Q3. This means that the BioMetal glove succeeded in presenting the contact sensation. On the other hand, the score for Q4 was lower than that for Q3. The users have to focus their attention in order to sense the contact sensation. The problem can be partially solved by having larger areas of the fingertips covered by BioMetal strings. The slow stretching of the BioMetal strings also contributes to the problem. Although we succeeded in compensating for the slow shrinkage with the buffering region around the virtual objects, we should also refine the system to respond quickly when the hand and the virtual objects are detached.

Most of the subjects answered "neutral" or "disagree" to Q5. This means that our system still lacks immersiveness. A more refined AR environment, such as a system using HMDs, should produce a higher score.

The score for Q6 was high, which gives good prospects for this research.

7 Conclusion and Future Works

We proposed a new method for presenting contact sensation in an AR environment. A major requirement for the contact sensation device in camera-based AR systems is to avoid occluding the 3D posture and position of the hand from the cameras. We achieved this with our proposed BioMetal glove.

In the future, we plan to improve the buffering region technique to alleviate the slow response of the BioMetal as. Currently, the buffering region was set only to solve the slow shrinkage problem, and the problem of the slow stretching remains unsolved. This makes it difficult for users to sense virtual objects since the contact sensation was presented even when the users' hand was detached from the virtual objects. The importance of solving the slow stretch problem was brought out through subject experiments. Another solution is to connect the two ends of the string to additional strings to be energized when a fingertip is detached from the virtual object. The shrinking of the additional strings would pull the two ends of the string in the opposite directions and hence, result in the stretching of the string. By pre-heating the additional strings, we can achieve quick stretching of the string. Predicting the contact from the posture and position of the user's hand in a time sequence may also help to solve the problem.

Another future goal is to refine the system from a hardware perspective. More strings covering all the fingertips and other areas of the hand would present more detailed contact sensation, which is expected to be effective for sensing the shapes of virtual objects and manipulating them in an AR environment.

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