MuscleVR: Detecting Muscle Shape Deformation Using a Full Body Suit

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ABSTRACT

The research proposes a full body suit to detect muscle shape deformations. The suit consists of a stretchable sensor composed of a photo reflector (made up of a photo transistor and an infrared(IR) LED) and a spring. The photoreflector is embedded in the spring. When the spring is not stretched, the emitted IR light will reflect back to the phototransistor. However, when the spring is stretched, some of the emitted IR light can flow out through the aperture of the spring, reducing the light reflecting back to the transistor. Therefore, the more the spring is stretched, the less the amount of light would be detected. Here, a virtual reality(VR) system that can synchronize avatar bodies with users' muscle shape deformations.

KEYWORDS

stretchable sensor; muscle shape deformation; phototransistor; spring

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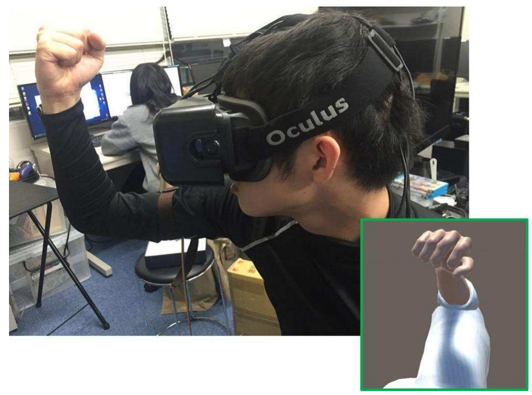

Figure 1: *A snapshot of muscle deformation VR*

1 INTRODUCTION

In the virtual environment, ownership of avatars is being developed to provide immersive experiments by reflecting the physical properties of users. In many previous VR studies, each joint angle of the body was reflected by sensors, such as three-dimensional motion capture devices, depth sensors, and data gloves.

However, users in real environments have many physical properties, such as expressions and muscle bulges, in addition to joint angles, and by reflecting the physical properties of the users to the avatars, a sense of ownership of avatar in the virtual environment improves.

Various sensors have been developed for measuring human conditions in general, such as sensors that measure displacement exclusively (i.e., a strain gauge). Although highly accurate measurement is possible, the measurable amount of displacement is limited due to mechanical restrictions. Also, there is a conductive rubber which changes its resistance value by applying pressure. However, since it reacts sensitively to temperature changes, accurate measurement is difficult.

In particular, many sensors obtain biological information. The myoeletric potential or electromyography(EMG) sensor acquires the activity state of muscle fiber by measuring electric potential. However, EMG is limited by the position of the electrodes, contact condition and, skin conductance of the users, making it difficult to obtain an index, such as displacement amount, that is easily reflected in an avatar.

Therefore, we propose an expansion sensor to comprised of a photo reflector and a spring as a device for measuring

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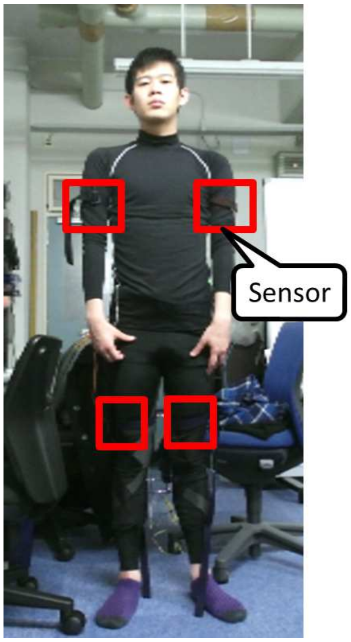

Figure 2: *Snapshot of Muscle VR Suit*

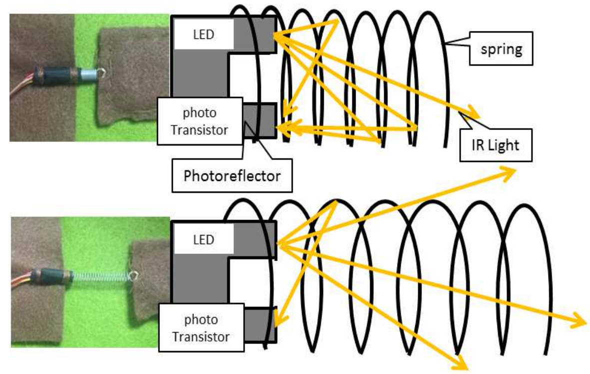

Figure 3: *The relationship between elongation of the spring and amount of leaked light*

body swelling. Figures 1 and 2, show the concept image of body swelling measurement using the proposed method of this study. The proposed expansion sensor optically measures the elongation and contraction of the spring from the inside, and by selecting a spring with high elasticity, large displacements can be measured. The measurement property can be freely customized by changing the spring constant.

In this study, the characteristics of the proposed expansion and contraction sensor are confirmed, and it is shown that it is possible to measure physical expansion by creating a belt-like device. In addition, measurements synchronized with the EMG sensor that are generally used in motion analysis were performed and the temporal correspondence relationship examined. Multiple applications for belt-shaped devices were created, attached to limbs, and interlocked with Microsoft Kinect sensor to manipulate the motions of avatars in the VR environment according to the movements of the real environment, to expand the application of muscles.

2 RELATED WORKS

As a method of acquiring physicality, Kiyama measured the movement of the arm of a person and synchronized the length avatar[2]. In [6], Xu measured the physical condition, reducing the influence of clothes, but this method took time to scan. It is difficult to reflect physical information in real time. For sensor measuring elongation, a strain sensor made of carbon nanotubes was proposed by Grett et al.[1], and a sensor using optical fibers was proposed by Yamada et al.[7]. In addition, Moravez et al. focused on the fact that the strain sensor can measure the deformation of skin and the human body and used a strain sensor as a breathing sensor [3]. Wilson et al. sensed changes in cloth by sewing copper wire into the cloth [4]. This can be replicated at low cost, but the sensor itself cannot stretch to a large extent. It is unsuitable for motion analysis.

For a sensor made of flexible material, research that enables stretch sensing on a plane by combining Sretzi's elastic cloth and a photo reflector has been conductor [5]. By passing IR light emitted from the photo reflector through the cloth, sensing was performed by utilizing increases and decreases in reflected light according to the extent of expansion and contraction of the fabric. These changes combined with the photo reflector are based on the measurements of our research. These can be made at low cost, and it is expected that measurements can be easily realized for optical measurement.

Therefore, in our system, the motion of the user's body is acquired by motion capture and expansion of the body to a suit measured by attached sensors.

3 STRETCH SENSOR

3.1 Measurement principle

The expansion sensor proposed in this research acquires IR light reflected from a photo reflector installed in a spring. When the spring expands, a gap is generated. As shown in Figure 3, when the amount of extension of the spring increases, the amount of light leaked from the photo reflector installed in the spring increases. As the amount of leaked light increases, reflected light returning to the light-receiving portion of the photo reflector decreases. By observing the changes in the reflected light, the degrees of expansion and contraction can be measured. Changing the length and material of the spring requires the spring to be extended accordingly. By changing the characteristics of the spring, it is possible to customize the stretchability in accordance with the parts to which the expansion sensor is attached and, the assumed body movement.

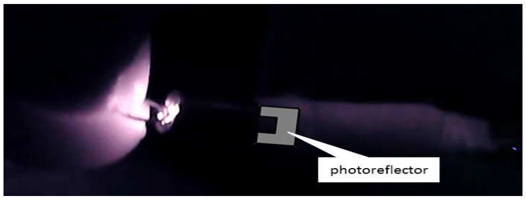

Figure 4: *How to leak IR light when the spring is not stretched*

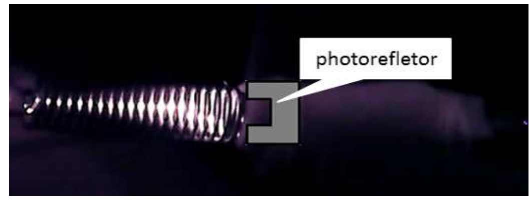

Figure 5: *How to leak IR light when the spring is stretched*

Next, a method of leakage of IR light emitted from the inside of the spring is described. Figures 4 and 5 were photographed through a filter that shuts off visible light when the expansion sensor expands. Figure 5 illustrates that IR light leaks when the spring is stretched.

In Figure 4, IR light leaks from the side opposite of the photoreflector, which is influenced significantly by the tip of the spring. However, when looking at how the light leaks in Figure 5, the IR light leaks close to the photoreflector, and the infrared light on the tip side of the spring was small. Even when the tip of the spring was covered, the IR light was leaked from the side, although the IR light leaking from the tip of the spring. Thus there is less restriction on what is attached to the tip of the spring.

In Figure 5, it is not that the light reaches the whole extended spring, but that the light has not reached the side of the tip of the spring. What is important to change in the sensor value is elongation near the photoreflector. It is necessary to take this into consideration at the time of measurement.

3.2 Hardware

Figure 6 shows a configuration of the proposed expansion sensors, which is made by combining a photo reflector and a spring. By connecting the terminal of the photoreflector and the substrate by extending the copper wire from the base, it is possible to install the spring without changes to the charatritics of the spring. The positions of the photoreflector and the spring can be fixed by sewing them. Since the spring is metal, it is necessary to cover the terminal portion of the photoreflector with an insulator to avoid shortening. The proposed sensor was made into a felt arm band. Figure 7 shows the stretching sensor stitched to the felt. The tip was connected to a micro controller unit (MCU; ArduinoPro Mini). To reduce delays in the experimental setup, wired implementation was developed, making it possible to create a wireless sensing system by connecting the MCU to a PC by Zigbee or Bluetooth.

3.3 Use cases

When using the expansion sensor, it is necessary to fit it according to the direction in which the measurement object expands. To measure the degree of expansion of the muscles of the arm based on the thickness of the arm, we arranged the direction of the spring to be vertical to the direction of the arm. If the expansion of the joint is to be measured, the direction of the spring of the expansion sensor may be positioned parallel to the direction of the arm. In this way, it is possible to selectively use expansion and contraction sensors for each scene and to simultaneously measure the body swelling of multiple parts. By knowing the respective correlations, it is possible to analyze the information about motion in the real environment. Our system can visualize muscular expansion within the VR environment and increase the motivation for exercise and its own physical information. Figure 8 shows a trial training with HMD. The deformation of muscles can be augmented in the VR environment.

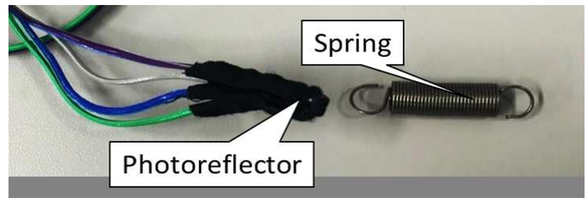

Figure 6: *Structure of stretch sensor*

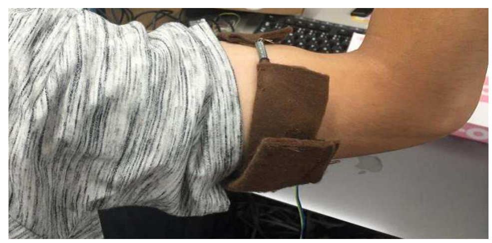

Figure 7: *Installation example of stretch sensor*

4 EXPERIMENT

4.1 Reproducibility of the stretch sensor

When measuring expansion and contraction using an extension sensor, the sensor must return the same value for the length of the spring. Therefore, we investigated the difference between the length measured when extending the spring and the length measured when the spring contracts. In the experiment, a measuring device, as shown in Figure 9, was used, and 20 mm was measured at intervals of 1 mm of spring elongation. Measurements were made at 0 mm, 1 mm, 2 mm and so on, up to 20 mm and then extended to 20 mm, 19 mm, 18 mm ... 0 mm before contraction.

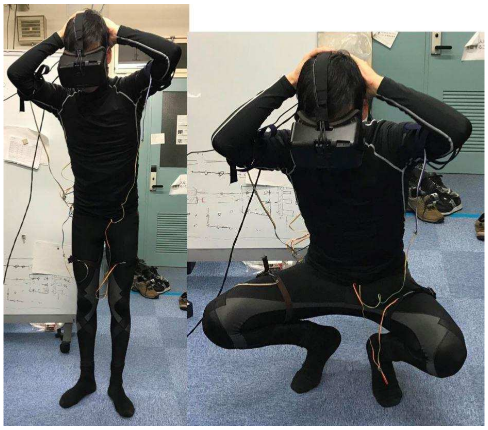

Figure 8: *Training assist with HMD*

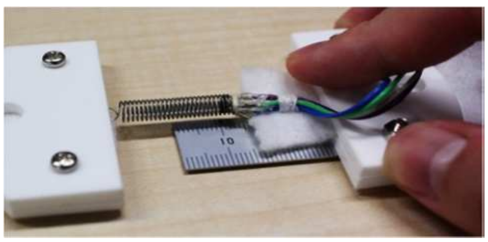

Figure 9: *Experiment on elongation and contraction of the elastic sensor*

The experimental results are shown in Figure 10. The graph shows a phenomenon in which the sensor value increases when the spring is extended and decreases when the spring is released. The vertical relationship of sensor values do not reverse before or after the extension of the spring.

Additionally, the hysteresis phenomenon occurs, and it can be evaluated by the sensor values for either elongation or contraction, with the length of the extension of the spring linked to the sensor value.

4.2 Changing spring type

One of the parameters of the expansion sensor is the spring coefficient, which varies depending on the springs material and natural length. Therefore, when changing the material and natural length of the spring, experiments were conducted on the difference in values that can be acquired by the extension sensor. In this experiment, springs of nichrome plasted steel (20 mm, 30 mm) and stainless steel (20 mm) were used. In addition, similar to the process in Section 4.1, measurements were taken up to 20 mm.

In Figure 11, shows that when the spring type was changed, the value differed. The result was almost linear until 12 mm, but after this, the inclination was gentle, because the amount of light leaking from the spring decreased with length. In the case of extending the spring (15mm-), it was found that the

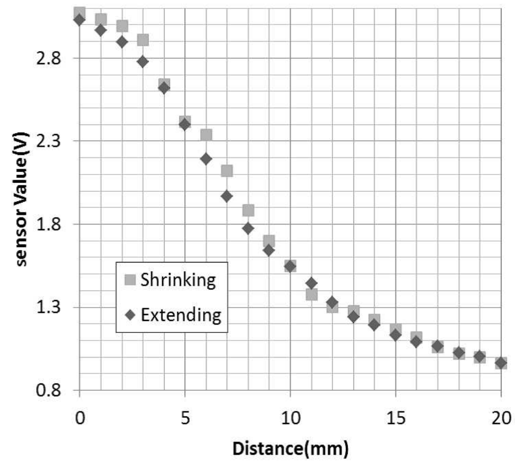

Figure 10: *Relationship between direction of extension and contraction of the spring and sensor values*

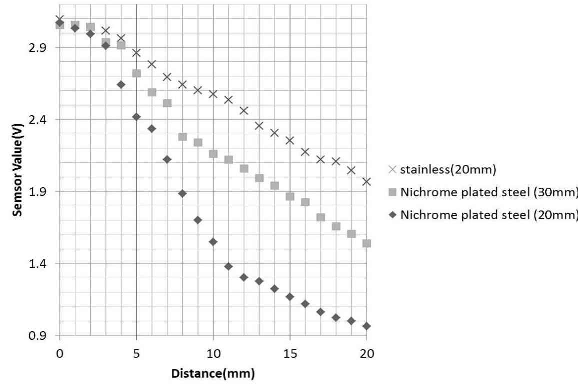

Figure 11: *Results of changing spring type*

graph can be represented by making the approximate function not a linear function but a quadratic function.

4.3 Comparative experiment changing the circumference

It is possible to measure the expansion sensor according to the circumference of the body by adjusting the length. Therefore, even if there are physical differences between the arm and the thigh, it can be worn according to the user. Therefore, when installing the expansion sensor, we examined how the sensor value changes with changing lengths around the winding object. In the experiment, the expansion sensor was wrapped around the object, fixed on one side, and stretched by 20 mm for measurement. A spring of nichrome-plated steel wire (30 mm) was wrapped around a cylindrical object with diameter of R = 54 mm, 66 mm, 97 mm, and 126 mm.

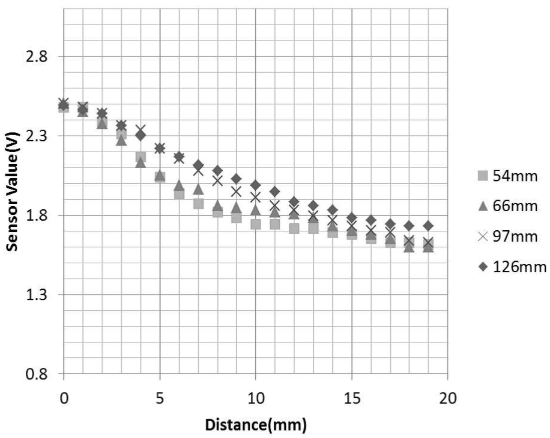

Figure 12: *Comparison between curve stretching and linear stretching of 20 mm nichrome-plated steel wire*

The results of the experiment are shown in Figure 12. Four types of measurements showed that all the results could be measured linearly. Also, a small amount of sensor value blur was observed until the spring was extended to 10 mm. Additionally, as the spring was stretched, the difference in each length gradually decreased.

4.4 Synchronous measurement from the EMG and stretch sensor

When the muscle was moving, we observed changes in myopotentials due to excitation of the muscle fibers. Afterward, expansion was observed as a result of actual muscle activity. Experiments were conducted on whether this process could be observed with a stretch sensor and an EMG sensor.

As shown in Figure 13, the EMG sensor and the expansion sensor were attached to the arm, and the measurements from the two sensors were performed in synchronization. In this experiment, measurements were made under two conditions: instantaneously applying force to the muscle and instantaneously. Also, the microcontroller used in this experiment was an Arduino Pro mini, and a Bitalino EMG sensor was used for the EMG test. The experiment was conducted at a frequency of 200 Hz.

Figure 14 shows the results when instantaneously putting muscles to work. The graph shows that the expansion sensor reacts immediately after the EMG sensor starts reacting, and then, the value of the expansion sensor returns when the myoelectric potential sensor value decreases. By combining the myoelectric sensor and the expansion sensor, the muscle moved after the change in the myoelectric potential.

Figure 15 shows the results when sustaining muscle emphasis. The graph shows myogenic potential violently fluctuated because expansion and contraction of the belt attached to the arm can be measured, the peak of the physical shape change in the body due to the muscle activity, which was difficult for the myoelectric sensor to measure.

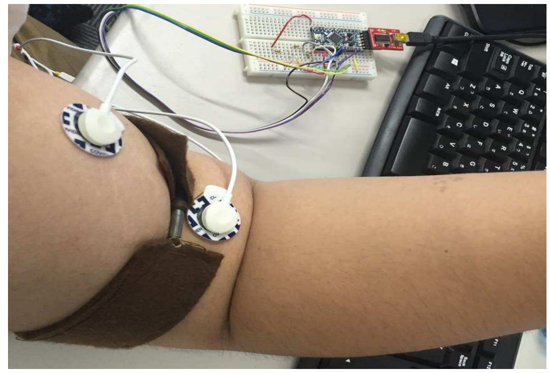

Figure 13: *Synchronous measurement of the myoelectric sensor and telescopic sensor*

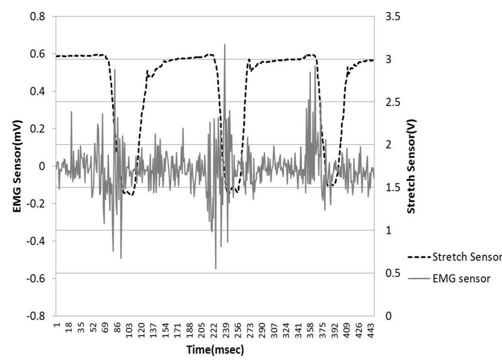

Figure 14: *Instantaneously applying force to the muscle*

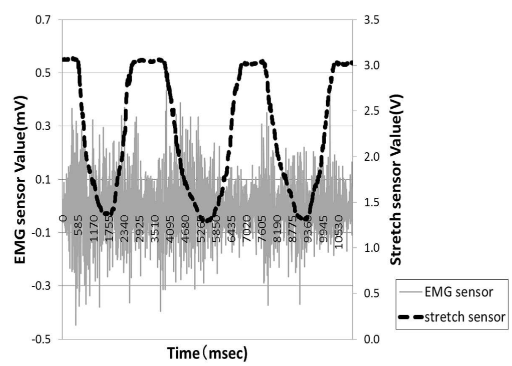

Figure 15: *Force is continuously applied to the muscle*

5 INITIAL TRIAL IN VR ENVIRONMENT

The expansion sensor created in this study was attached to the main part of clothing, and the data set of each exercise was acquired. We also created an application that reflects physical information on the avatar using clothes fitted with sensors.

We got a data set of arms in two positions: bend (FIgure 16) and stretching (Figure 17). When bending the arms,

Figure 16: *Arm bending behavior*

Figure 17: *Bending and stretching motion of leg*

the subjects were asked to tense their muscles while bending their arms.

In Figure 18, the sensor value reacts even when the arm is bent without applying force, and the sensor value further changes when a force is applied in that state. In this way, it is possible to acquire an unexpected expansion of the body, and it is also possible to acquire the difference in degree of expansion in case of further consciousness. This can be attributed to the fact that the left hand responds in spite of bending and stretching the legs in Figure 19. The reason for this is that the left hand has moved during bending and stretching. The reason why the initial values of the plurality of sensors are different is that the winding condition of each part is different. Although we are evaluating with raw data this time, it is necessary to normalize when creating a robust application.

Next, we created an application that projects the information obtained from this sensor onto the avatar in the VR environment. In this application, joint angles are acquired by using the Kinect sensor, and physical inflation information is acquired with the sensor of this research. Figure 20 is

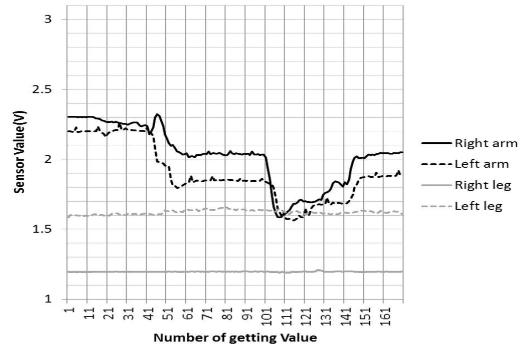

Figure 18: *Data set of arm bending*

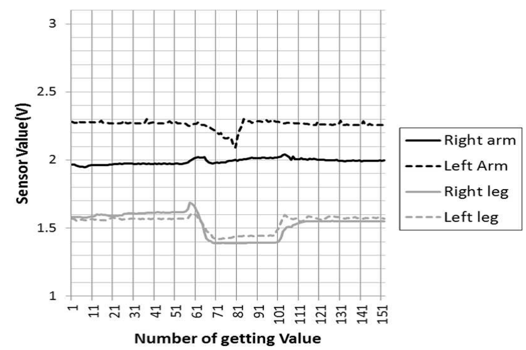

Figure 19: *Data set of bending and stretching motion of leg*

a snapshot of the application; the avatar also works according to the movement of a person in the real environment. Furthermore, it is understood that the body of the avatar also expands according to the state of the real environment. In Figure, 21 the arm of the avatar is expanding by bending the person's right arm and applying force. In Figure 22, by raising the left foot, you can see that the muscles are expanding and that the left foot of the avatar is also expanding. By moving the body and applying force, you can see that the joint angle and the inflation information of each part are reflected by the avatar.

6 DISCUSSION

In experiment 4.2, despite showing the same length, the sensor values were different because the amount of light leaked varied depending on the differences in natural length and the degree of the gap opening of the spring and the material, even if the elongation of the spring was the same. For the nichrome-plated spring's 20 mm expansion sensor, if the length was set ahead to some extent, the change in the sensor value weakened. This is because the amount of leakage of light decreased after a certain length, and furthermore, it was influenced by external light, and it was difficult to capture the change in the amount of reflected light. When reflecting the muscle on the avatar, it is better to implement

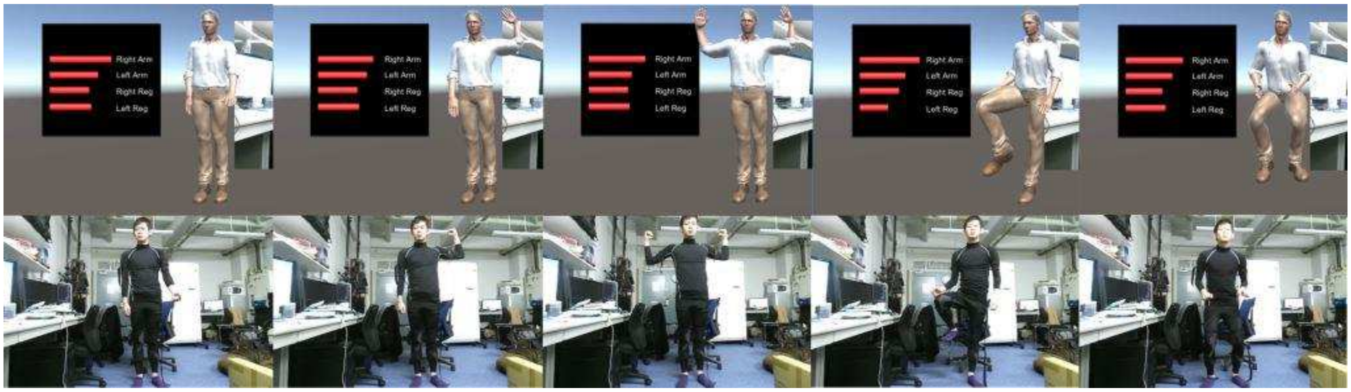

Figure 20: *Sequential images of deformation*

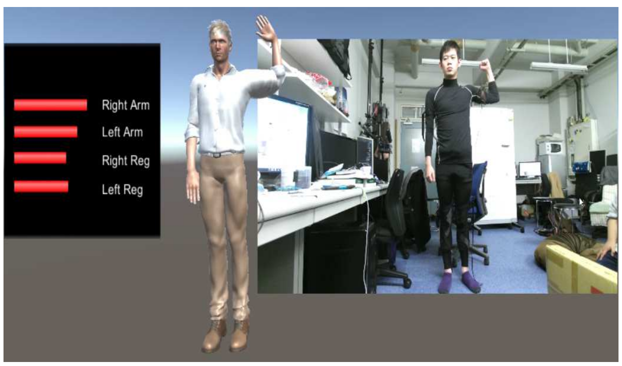

Figure 21: *Bending right arm on virtual environment*

Figure 22: *Bending left leg on virtual environment*

this sensor with a multidimensional function instead of a simple linear function.

In experiment 4.3, the sensor value when the elongation length was 0 mm (natural length), was lower than the other experimental results. This is thought to be caused by the distortion of the spring when winding the stretch sensor on the object and the gap between the springs generated at that time. However, as a use application of the expansion sensor, there was no significant influence because it was mainly wrapped around the body, and no large deviation was observed in the initial value. The difference was measured to 10 mm elongation in the same experiment, but the error was small because there was no significant influence if calibration was carried out during actual use.

In experiment 4.4, it was found that the responses of the EMG and expansion sensor may be different. Since EMG acquires a change in myoelectric potential, it is not affected by the delay until muscles actually expand, and it is possible to acquire muscle change. On the other hand, in the case of an expansion sensor, it is possible to acquire a physical shape maintenance, such as swelling of arms occurring when an arm is bent without applying force. In this way, with the expansion sensor, it is possible to acquire an unconscious expansion of the body, which is difficult to obtain by EMG.

7 LIMITATION

Although the expansion sensor uses the IR light of the infrared ray irradiated from the photo reflector, the intensity of the reflected light obtainable by the sensor also affects the reflection coefficient inside the spring. The influence of the reflection characteristics inside the spring on the measurement need to be investigated in the future.

Since this measurement method uses IR rays, when it is used outdoors, it is also affected by ambient light such as the sun. Furthermore, when infrared light was used in a motion capture system or the like, it received IR light from the motion capture system. To make it possible to use the sensor in various situations, it is necessary to implement a robust device and signal processing to prevent disturbance.

There was a difference in the extreme curvature between extension with a straight line depending on the length of the spring and the case of extending along the curve. There is no problem when it can be approximated by a straight line, such as the swelling of the arm, but there is a possibility that it may be a problem when examining the joint angle of the finger. In the case of extreme curvature, it is necessary to prepare another evaluation method or to make the diffusivity of light inside the spring as uniform as possible.

In a virtual environment, we have a limited field of view by HMD. In order to better understand our muscle movement, our system can provide a third person view in VR.

8 CONCLUSION

In this paper, we proposed a sensing method to measure muscle shape changes by combining a highly customizable photo reflector and a spring as a means of measuring physical expansion in a user's body for VR. By correlating the sensor value and the elongation of the stretch sensor, the experiment was validated. The time series expansion of the muscle linked with the activity of the muscle fiber was observed by the proposed sensors and EMG sensor. In addition, expansion of the user's muscles can be reflected in the avatar in the virtual environment by the proposed system.

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