Analysis of resolution of elbow joint rotation with visual information

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Abstract

When we control a force-display system, some problems always happen. One of the problems is how fast and accurately it moves after it receives a control command.

One of the methods of the improvement of the problem can be given as the improvement of the accuracy of the force-display system itself, for example, improving the stiffness and the output of actuators. However, in the cases, it has the drawback of lost of the reality in other side because of it being bigger.

Another method of the improvement of the problem can be given as the improvement from an operator side. It can be said that there can be a method of the investigation of the perception ability of human being, because the error of the force-display system is accepted if an operator can't perceive it.

The level of the quality of a imaginary sense decreases if the accuracy of the force-display system is rough, and of course, the operator feels the incongruity if it decreases to less than the level of standard. However, we don't know the level of the quality which human being feels the incongruity. In other words, it isn't cleared how accurately human being perceives the accuracy of the force-display system. We can clear an acceptable range of the error of the force-display system if we can clear how accurately he perceives his own conditions and moves his own body.

In this study, we pay attention to the problem of how accurately a human operator discriminates displayed senses from the force-display system, and verify the acceptable range of the error of the force-display system from the results of the experiments. We investigate the perception sense of the position of the human operator with the purpose of control of the force-display system. There are several senses of the position perception, for example, the perception of the distance and the angle of rotation of joints and so on. In this study, we investigate the perception of the angle of rotation of an elbow joint. Then we deal with the elbow joint as intimate relation from several joints with the force-display system, and did some experiments and verified their results. We also did the combined experiment of an elbow and a wrist and verified their results to investigate relation between the joint of the elbow and that of wrist.

Key words: Virtual Reality, Force-Display, Joint of Elbow, Joint of Wrist

1.Introduction

Virtual reality enables to have an illusion to be in imaginary environment but our being in real one. It is necessary to display much more imaginary senses to sense organs of an operator as possible to have an illusion to be in the imaginary environment. But the operator feels awkward if the imaginary senses displayed were contradictory. That is displayed the imaginary senses are need to be united each other.

Many researches for the development of the system, which is able to display the sense of sight or hearing have been reported, but compared with them, the system is able to display the sense of force and little. Without displaying the sense of force, the system would lose reality because of lack of some information (weight, hardness, shape and so on). It is necessary to display the sense of force for being lost in the imaginary environment. Recently, it is important to display the sense of force, and the research on this field is focused on. The system, which displays the sense of force on imaginary world, is called “force-display”. Some of methods of force-display have been developed.

1) Master arm
2) Joy stick [1]
3) Wire [2]
4) Wearable hand (glove)[3]
5) Wearable arm [4]

But, each system has the problem need to improve.
1) Too large-scale
2) Have a limit of degree of freedom
3) Small movable range
4), 5) Unable to display weight of imaginary object

Although, the research of virtual reality with force feedback have been done with taking advantage of their features.

In this study, our purpose is to develop a light and compact system, so that operators lost in imaginary environment. However, this system cannot be enough rigidity, force and speed of response due to the design specifications. The defects bring out error to this system. However, it has not been cleared how human perceive this error. If we find the accuracy of the perception of speed and force of a human sense organ, we see allowable quantity of the error of the system.

Many researches have been done with human sense for developing making an agreeable imaginary environment. Yoshizawas[5] pays attention to the fact that a human being judges it only by the limited information of a difference of sight of both eyes when the depth of the solid image is perceived. They cleared that when each is separately exists, a human being can perceive an actual object and an imagination object. Ifukubes[6] turned fixed quantity of the error that a somato sensory system could be permitted and utilized for development virtual reality system. They cleared that the recognition of human being of the deviation in the front direction was more difficult than that in the back direction. Ishikawas[7] did the experiment of the adaptation between the information on the sight and touch. As a result, they cleared that senses were unified well by sight's indicating touch movement. Kurokawas[8] investigated how human movement changes when a sight target changes on a high-speed location movement, and cleared that it isn’t a little influence when an angle is greatly being adjusted, but a big influence appears when it changes to a grade to adjust small from the grade when an angle is greatly being adjusted.

In this way, it can't be said that a human sense and the ability which human unifies them are perfect. Then we investigated the error of human sense of spatial position to see allowable quantity of an error of a virtual reality system. We focused on the angle of the rotation of an elbow. Then, We did an experiment to investigate relations with it and the information on the sight and so on.

This paper is organized as follows: in section 2, we investigated the angle perceptible resolution of an elbow joint in different conditions. Then we model an error mechanism of the elbow joint. Section 3 shows the control scheme of an angle in the force display system using the allowable error of the elbow joint, followed by the control results. Section 4 shows the case of a wrist joint. Section 5 shows the analysis of the combined case of the elbow and a wrist joint. This paper is concluded in Section 6.

2.Experiment 1: Analysis of Allowable Error Resolution of Elbow Joint

In Experiment 1, we measured an angle of the rotation of an elbow when examinee rotated his elbow, and investigated the error between the measured angle and target one. The experiment procedure is done as follows.

A total of 5 students (4male, 1female) participated in the experiment. The mean age was 23.4 years (range: 21 to 25). All examinees set an angle measurement device (which is developed for measuring angle of the rotation of the elbow) to their left-arm, rotated their elbow to several targets of angle with their spontaneous timing.

We set up following conditions on this experiment.
1) Set seven targets (0, 15, 30, 45, 60, 75, and 90 degree) at random
2) Rotated elbow 50 times each target

3) Rotated elbow with and without visual information

4) Rotated vertically without fixation of joint of shoulder (Figure 1), vertically (Figure 2) and horizontally (Figure 3) with fixation

Because, 1), 2) we need many data of each angle to compare average of all examinees' data with personal and to investigate standard deviation of measurement result of examinees' and personal.

3) To investigate the influence of the visual information.

4) To investigate the influence of the way of rotation and posture.

Fig. 1 Experimental Setup (1)

Fig. 2 Experimental Setup (2)

Fig. 3 Experimental Setup (3)

Figure 4 and Figure 5 are the average of the measurement angle of the whole examinees in each condition (vertically without fixation, vertically with fixation, horizontally with fixation). Figure 4 is the case of the experiment of the rotation of the elbow with the visual information. Figure 5 is the case of without the visual information. The vertical axis in the graph is a measurement angle, and the horizontal axis is the target angle.

From Figure 4, in the case of with the visual information, measured angle was almost equal to the target on each target degree, though they exceeded a little angle. On each condition, (rotated vertically without the fixation of joint of shoulder, vertically and horizontally with the fixation) an influence by the difference in the condition isn't seen in the measurement result. From Figure 5, the measurement angles were greater than the angle of the target in all the angles except for 0 and 90 degree. Because we thought that 0 and 90 degree are thought to be comparatively easy to distinguish for the human being [9], it was natural that the measured angle was almost the target on each target degree on 0 and 90. Except for 0 and 90 degree, the case when the examinees measured without the visual information have a bigger error of the perception of the angle than the case when the examinees measured with the visual information in all the angles. The error of the perception became biggest in 15 degree, and it decreases gradually to 75 degree. The point to which it should pay attention is that a difference appears in the case of the fixation of the shoulder joint and no fixation. The case when it was moved without fixation was a bigger error of the perception of the angle than the case when it was moved with the fixation. From the above, when human being rotate his elbow with visual information, the sense of the space position resolution of the elbow joint doesn't take an influence by the posture, but when without the visual information, the sense of the space position resolution of the elbow joint loses correctness, and it knows that an influence is taken in the posture and the way of the rotation of the joint of the elbow as well.

Figure 6 and Figure 7 are the average of the standard deviation of the measurement angle of the whole examinees in each condition. Figure 6 is the case of with the visual information. Figure 7 is the case without the visual information. The vertical axis in the graph is a standard deviation, and the horizontal axis is a target angle.

This result is obtained in the same way as the case of the measurement angle. The case when it was moved without the visual information was more difficult to rotate to the examinees' own target than the case when it was moved with the visual information. However, about the posture, unlike the case of the angle measurement, the fixation of the joint of the shoulder joint has a greatly influence in the target angles from 15 to 60 degree on both conditions with and without visual information.

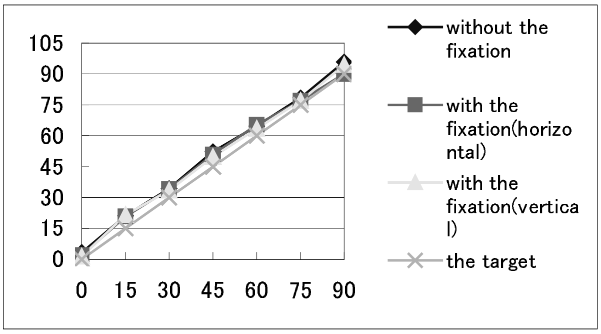

Fig. 4:Average of the measured angles with the visual information among five examinees for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

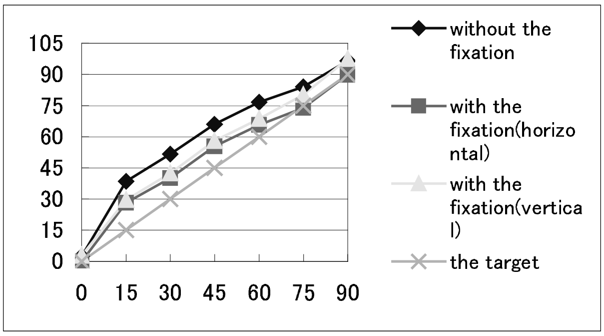

Fig. 5:Average of the measured angles without the visual information among five examinees for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

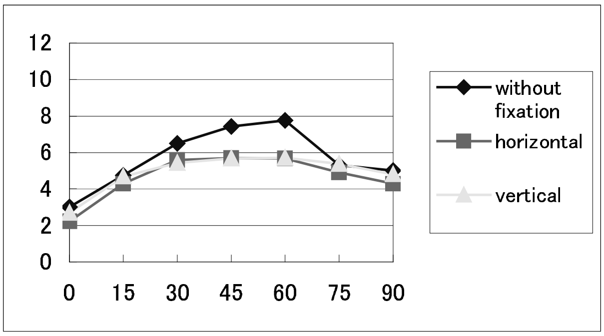

Fig. 6:Average of the measured standard deviation with the visual information among five examinees for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

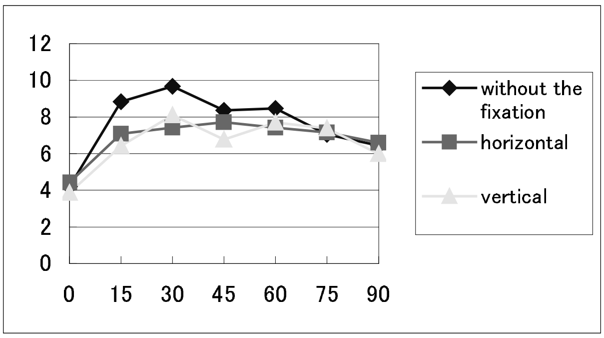

Fig. 7:Average of the measured standard deviation without the visual information among five examinees for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

Here, the cause that the errors of the rotation of the elbow become as big as the little angle is verified. It can be regarded about a human arm as Y and Z (Figure 8), and the change rate of θ due to the slight change of X by the rotated elbow was examined from equation (1).

The vertical axis in Figure 9 is K (equation (3)) ,which is a term to show a change rate of equation (2), and the horizontal axis is θ. We investigated how much the change rate of θ changed when Y and Z were supposed an upper arm part and a former arm part and the ratio of the length was changed.

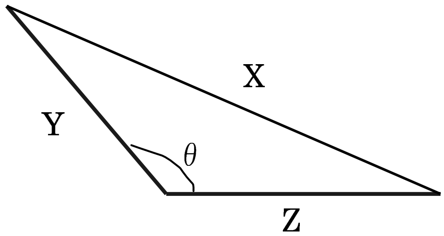

Fig 8: Model of imaginary arm

$$\Delta\theta = \left(Y^2 + Z^2 - 2XY\cos\theta\right)\cdot \Delta X / XY\sin\theta \quad \text{........ (1)}$$

$$K = \left(Y^2 + Z^2 - 2XY\cos\theta\right) / XY\sin\theta \quad \text{........ (2)}$$

Figure 9 shows that as the ratio of the former arm part and the upper arm part becomes big, the change rate of θ becomes big, and that the change rate of θ is as high as θ is small, when X changed slightly. It knows that the angle of the rotation of the elbow changes greatly, when an arm is moved only a little, as the angle of the rotation of the elbow is small, and as a former arm part mores longer than the upper arm part. Figure10 shows the value, which was got by multiplying the value of K by the value of each angle. This is similar to the result of this experiment. So, it can be considered that this change rate of θ has relations with the error of human sense of spatial position.

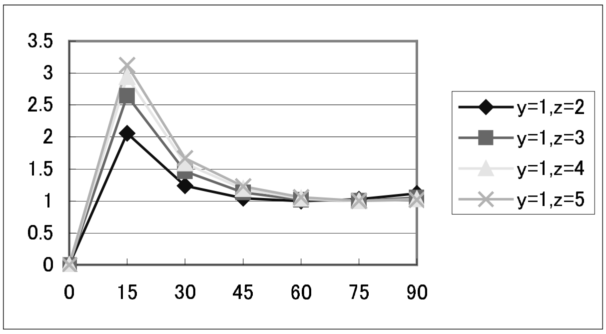

Fig. 9:Change of the sensitivity for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

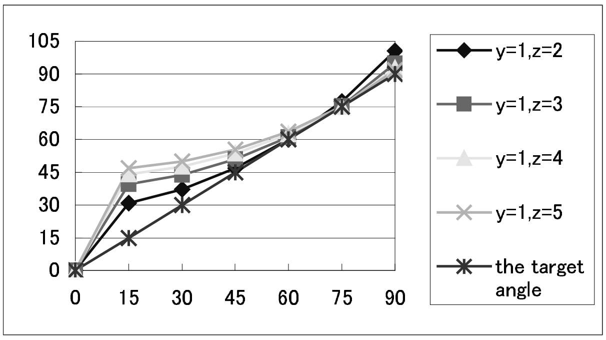

Fig. 10:The graphs which are multiplied target angle and change of sensitivity for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

3.Experiment 2: Angle Control Utilizing Angle Perception Error

In Experiment 2, we displayed imaginary arm on the screen of HMD (Head Mounted Display) to the examinees (Figure 11). For the elbow, the angle of the rotation is different from that of the actual one is indicated on the screen. Then the quantity of the error was increased gradually, and examined which condition to feel a sense of incongruity for examinees. The way of the presentation of the angle is following. From the result obtained from the experiment 1 without the visual information on each condition, the graph interpolated between the 6th-type crossing the origin like equation (3). For example, Figure 12 is result of experiment 1 (no fixation, without visual information) and the graphs (which made by making the difference between the measured and the target angle change) before interpolation in the sixth-type equation. The reason why we complemented the graph in the sixth-type is the reason is to connect the measured six points smoothly.

Among 0 and 90 degrees, a target angle was used for getting the change of the measurement angle, because they don't take the influence of the visual information and posture so much. By this, the angles' connections with the front and back become smooth. And we could make it that the environment in which a sense of incongruity was little was prepared for the examinees.

$$Y = \alpha X^6 + \beta X^5 + \gamma X^4 + \varsigma X^3 + \xi X^2 + \zeta X \qquad \text{........ (3)}$$

A total of 4 students (3 male, 1 female) participated in the experiment. We asked the examinees if they feel incongruity as displayed a magnified angle of the equation with a certain degree.

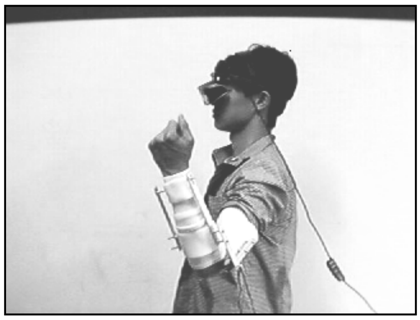

Fig. 11: Experimental Setup (4)

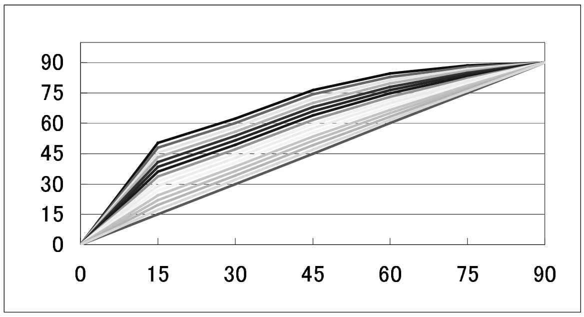

Fig. 12: Examples of the approximated formula of Fig. 5

—Examinee A——————————
without fixation···1.4times
with fixation (vertical)···1.1times
with fixation (horizontal)···1.4times

—Examinee B——————————
without fixation···1.4times
with fixation (vertical)···2.1times
with fixation (horizontal)···2.0times

—Examinee C——————————
without fixation···1.5times
with fixation (vertical)···1.8times
with fixation (horizontal)···1.2times

—Examinee D——————————
without fixation···1.4times
with fixation (vertical)···1.2times
with fixation (horizontal)···1.5times

Fig. 13: The results of Experiment 2

Figure 13 is the results that we obtained on this experiment, when we asked examinees whether it felt the sense of incongruity against the movement of the imaginary arm on the screen. On the condition without fixation, the average of feeling a sense of incongruity was 1.425 times. Though the error of the angle of the rotation of the elbow is biggest on this condition in experiment 1, the examinees didn't feel a sense of incongruity against the angle in spite of greatly bigger one than that of the average on experiment 1. In addition, it was about the same result in the whole examinees. Without the fixation of the joint of shoulder, it can be said that the sense of the space position resolution loses correctness. On the condition with the fixation, when rotated the elbow horizontally, the average of feeling a sense of incongruity was 1.55 times. When rotated the elbow vertically, the average was 1.525 times. On this condition, the considerable difference was seen between the examinees. However all examinees didn't feel the sense of incongruity against the angle on experiment 1 on all conditions. It is much easier to set up the illusion by being lost the correctness of the space position resolution by thinking of an imaginary arm the examinees' one.

4.Experiment 3: Wrist Angle Analysis

In Experiment 3, we measured angle of the rotation of the wrist when an examinee rotated his wrist, and investigated the error measured and target angles in the same way as the case of Experiment 1. The following explains experimental methods.

1 student (male) participated in the experiment. His age was 26 years. The examinee had the lever of the experiment device (Figure 14), which was developed for measuring angle of the rotation of the wrist by making use of three-dimensional position sensor with his left hand. He rotated his wrist to several targets of angle with his spontaneous timing. We set up following conditions on this experiment in the almost same way as Experiment 1.

1) Set four targets (0, 20, 40, and 60 degree) at random
2) Rotated wrist 50 times each target
3) Rotated wrist with and without visual information
4) Rotated horizontally

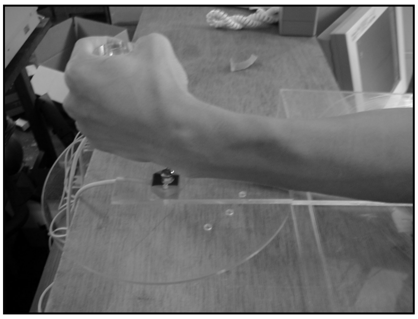

Fig. 14: Experimental Setup (5)

Figure 15 shows the average of the measurement angle of the examinee in two conditions (in the case of with and without visual information). The vertical axis in the graph is a measurement angle, and the horizontal axis is the target angle.

From Figure 15, in the case of with the visual information, the measured angle was almost same as the target degree, though they exceeded a little target angle in the same way as the case of Experiment 1. And in the case without the visual information, the measurement angles were greater than the target angle in all the angles except for 0 and 60 degree. Because we thought that 0 degree is thought to be comparatively easy to distinguish for the human being in the same way as the case of Experiment 1,and about 60 degree, it can be thought that a big error doesn't happen easily for the reason of nearly limit of the angle of the rotation of wrist. The case when examinee measured without the visual information occurred a bigger error of the perception of the angle than the case when examinees measured with the visual information in all the angles. The error of the perception became biggest in the 15 degree, and it decreases gradually to 60 degree.

From the above, when human being rotate his wrist with the visual information, the sense of the space position resolution of the joint of the wrist doesn't take an influence, but when without the visual information, the sense of the space position resolution of the joint of the wrist loses correctness in the same way as the case of joint of the elbow in Experiment 1.

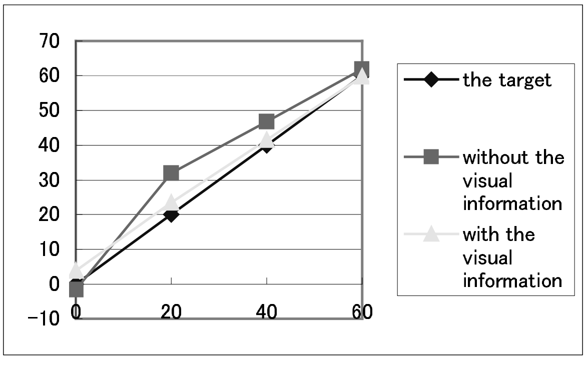

Fig. 15: Average of the measured angles with and without the visual information of the examinee for the four target angles 0, 20, 40 and 60 degree

Figure 16, is the average of the standard deviation of the measurement angle of the examinee with and without the visual information. The vertical axis in the graph is a standard deviation, and the horizontal axis is the target angle.

As a result, in the same way as the case of the measurement angle, the case when it was moved without the visual information was more difficult to rotate to the examinee's own target than the time when it was moved with visual information. This result is also in the same way as the case of the joint of the elbow in Experiment 1.

From the above, it can be said that characteristics of the joint of the wrist is similar to that of the joint of the elbow.

However, it is necessary to do some experiments further in order to prove these results because we didn't do the experiments about more than one examinee and other postures in Experiment 3. We will do some experiments further from now on.

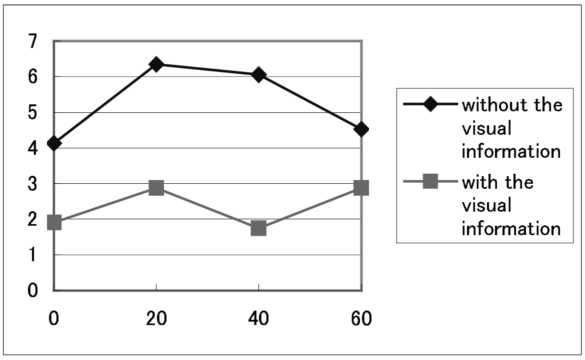

Fig. 16: Average of the measured standard deviation with and without the visual information of the examinee for the four target angles 0, 20, 40 and 60 degree

5.Experiment 4: Combined of Elbow and Wrist

In Experiment 4, we measured an angle of the rotation of the elbow when examinees rotated their elbow with fixation of the wrist in a certain fixed. In other words, we did experiment which is the same as Experiment 1 with fixation of the wrist. The following is to say explain experimental methods.

1 student (male) participated in the experiment. His age was 26 years. He is the same person in Experiment 4.

The examinee had the lever of the experiment device (Figure 17), which was developed to measure the angle of the rotation of the wrist by making use of three-dimensional position sensor with his left hand. And he rotated his elbow (with fixation of the wrist in a certain fixed) to several targets of angle with his spontaneous timing.

We set up following conditions on this experiment in the almost same way as Experiment 1

1) Fixation of the wrist (0, 20, 40, and 60 degree)
2) Set seven targets (0, 15, 30, 45, 60, 75, and 90 degree) at random
3) Rotated elbow 50 times each target
4) Rotated elbow with and without visual information
5) Rotated horizontally

Fig. 17: Experimental Setup (6)

Figure 18 shows the average of the measurement angle of the examinee in each condition (in the case of fixation of the wrist) with and without the visual information. The vertical axis in the graph is a measurement angle, and the horizontal axis is the target angle.

From this result, the case when it was moved without the visual information was more difficult to rotate to the examinee's own target than the time when it was moved with the visual information in the same way as the case of Experiment 1, though the difference isn't large.

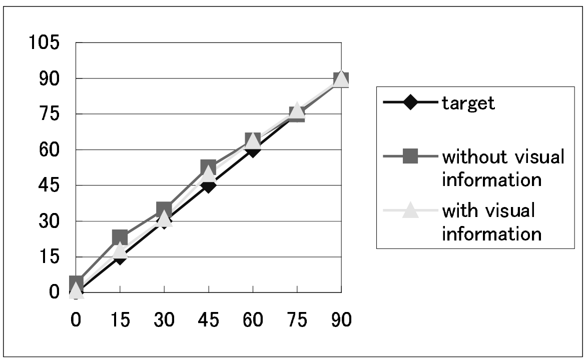

Fig. 18:Average of the measured angles with and without the visual information for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

From Figure 19, in the case of without the visual information, the measured angle was almost same as target angle in each target though they exceeded a little target angle in the same way as the case of Experiment 1. The point to which it should pay attention is that the more bigger the angle of the joint of the wrist was, the correctly measured angle was. As the reason, it can be thought that the ratio of the former arm and the upper arm changed by the rotation of the joint of the wrist (cf. Figure 9).

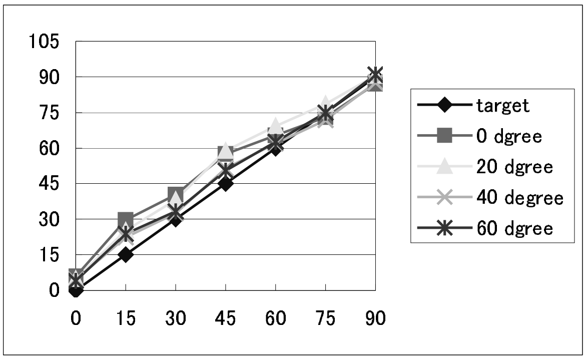

Fig. 19:Average of the measured angles with and without the visual information for the seven target angles 0, 15, 30, 45, 60, 75 and 90 degree

However, since we didn't do the experiments for more than one examinee and other postures in this Experiment, as the case of Experiment 3, it is necessary to do some experiments further in order to prove these results. As the future works, we have to do some experiments further from now on.

6.Conclusion

The following things cleared by the result of the experiment on this research.

1. The force-display system lets an operator have an illusion by operating the visual information.

2. There is the difference on the quantity of illusion due to the difference and the change of the operator's posture.

3. There is the difference in the quantity of illusion between individuals.

4. The force-display system is allowed to have bigger the error to display a small angle than that of a big angle.

5. The force-display system is allowed to have an error when it displays a same angle several times.

6. The force-display system lets an operator have an illusion by display bigger angles than an actual angle of the elbow joint.

7. The force-display system lets an operator have an illusion by display bigger angles than an actual angle of the wrist joint.

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