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# Development of VR-STEF System with Force Display Glove System

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## Abstract

For functional training, however it is important to evaluate the motion functions of trainee, traditional evaluations have problems on subjectivity. We aimed to quantitatively and objectively recreate clinically relevant motion function evaluations by VR technology; to use data gained from traditional evaluations and to computerize evaluation. We also aimed to consider a gap between robotic and conventional rehabilitation. In this paper, we reported virtual glove and VR-STEF systems that are able to recreate a Simple Test for Evaluating Hand Function, STEF.

**Keywords:** Virtual Reality, Glove, Rehabilitation, Functional Test, Passive force display

## 1. Introductions

### 1.1. Importance of evaluating motion function of upper limbs

Many advanced countries have a high proportion of elderly people. In Japan, typically, the number of elderly in low-grade need of "support" or "care 1" among seniors over the age of 75 grows more rapidly than whole number of elderly over the age of 65 [1]. The reasons for the higher proportion are feebleness, falling, fractures or some sickness in joints, which are associated with deterioration of physical function because of aging. Therefore, evaluations of physical functions and addressing the issues of maintaining or recovery of functions are necessary part of treatment to decrease the nombers of elderly who are bedridden or needing care. Evaluations are also necessary as a way to increase the number of elderly participating in social activities.

Also for disabled, rehabilitation along with medical treatment is needed to recover function [2]. Evaluation during functional training is an indispensable part of the process; understanding the patient's manifestation, designing an intervention plan, and then checking its effect [1].

As discussed above, realizing rehabilitation with a preventive approach and supporting independence that negates the needing care are thought to be tasks of great importance. The movements of the upper limbs are complicated and various, and indispensable for daily activities such as for eating and operating appliances; therefore, their evaluation is especially important.

### 1.2. Problems of conventional functional evaluation methods for upper limbs

There are many methods that are widely used clinically for functional evaluation of the upper limbs, and which target hemiplegia; Brunnstrom's test [3], SIAS (Stroke Impairment Assessment Set), Motricity Index [4], Fugl-Meyer method [5] and so on. Those evaluations are made by watching subject's responses when therapists instruct orally or manipulate directly. Thereby, evaluations will naturally vary according to the subjectivity of therapists, so that subjects cannot be measured objectively or quantitatively.

On the other hand, using apparatus, such as applied robotic technology or virtual reality (VR), for upper limb rehabilitation or evaluation is well researched. We also have developed a 3-D exercise machine for upper limbs, EMUL, (cf. Fig. 1) [6] and applied it clinically [7], which aims to evaluate quantitatively and bio-feedback to trainee. On the other study, Krebs and Hogan of MIT have developed MIT-MANUS tah has a 2-D linkage mechanism [8], and have commercialized it for rehabilitation of cerebral infarction patients. Jack and Burdea et al. have applied the RMII force feedback glove [9] and a CyberGlove [10] in finger rehabilitation for stroke patients [11].

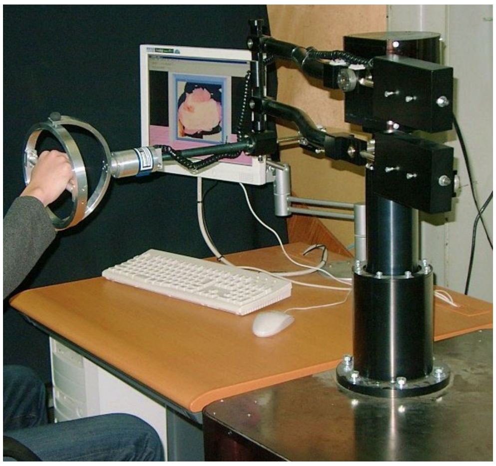


Figure 1: 3-D Exercise Machine for Upper Limbs, EMUL

However, their methods for evaluation differ vastly from conventional ones. That makes it difficult to use stored and databased clinical evaluation data. Additionally, doctor confidence is not high because the simple effects of experience are considered. The introduction of rehabilitation robots might be delayed in clinical situations by this gap in the levels of comprehension.

### 1.3. STEF

The STEF ( Simple Test for Evaluating Hand Function, cf. Fig. 2 ) suggested by Kaneko [12] is widely used for clinical evaluations of hemiplegia in Japan. It was developed and generalized to easily and objectively evaluate motion function, especially quickness, of upper limbs.

The STEF consists of 10 sub tests. On a stage 800(W)× 400(D)× 35(H) [mm], a subject grasps test objects in order, moves each one to its ordered position, and then releases it. Objects are generalized into 10 kinds and have different shapes, weights and materials ( cf. Fig. 3 ). In each sub test, the time consumed is converted into a score of 1 to 10 points on an evaluation measure constructed with data of 100 able bodied persons. Summarized scores of sub tests are used in evaluation. The degree of impairment is checked by age group against a score sheet derived from data of 1,205 able bodied persons who were 3 to 90 years old. The maximum score is 100. Each upper limb is evaluated independently.

However, with STEF, unified evaluations can only be made by time consumed in exchange for easy and short time tests. Therefore, the problem remains that evaluations of behavior, like how test objects are grasped or how upper limbs are moved, vary according to subjectivity of therapists, and then evaluations cannot be done adequately objectively and quantitatively.

Figure 2: STEF

### 1.4. Purpose of this study

As noted, there is still some gap between robot and conventional rehabilitation on evaluation methods and their result; so that it is difficult to apply robot rehabilitaion in clinical settings. However, even with conventional methods, adequately objective and quantitative evaluations cannot be carried out. This study suggests a method that comes between robotic and conventional evaluations, and discuss its effectiveness. From this, we aim to gain an insight into how evaluations with rehabilitation robots will be applied in practical clinical treatments.

Figure 3: Tools of STEF

We consider that among the conventional evaluation methods STEF is relatively suitable for objective and quantitative evaluations. Therefore, we recreated STEF utilizing VR technology with a force display glove that can represent the sensation of grasping and is set at the endeffect part of a 3-D rehabilitation robot for the upper limbs like EMUL. It is expected that standard data of STEF is available for application to VR-STEF evaluations. Additionally, it is expected that more quantitative evaluations can be undertaken; measuring grasping posture and force of subject's fingers with sensors of the glove, and also measuring trajectory of hand position with sensors of the rehabilitation robot. As yet, there are no rehabilitation systems that can evaluate functions of whole upper limbs in 3-D space, including a conventional clinical evaluations.

In this paper, we report the development of a novel force display glove system and the construction of VR-STEF using EMUL.

## 2. Specifications of VR-STEF

Fig. 4 shows an image of "VR-STEF," which includes the glove system we aimed to develop. Basic specifications are introduced as follows:

- Use Conditions:
  The force display glove is attached to the end part of EMUL mentioned in the previous section. For their evaluation, subjects sit on a chair and make their evaluation. Subjects wear the glove in their right hand for testing that hand.
- Subjects:
  Hemiplegic, dystonic or ataxia patients with stroke sequelae, spinal cord injured patients, Parkinson's disease patients and so on.
- Elemental behavior:
  Virtual objects, as spheres or cubes, whose shapes or sizes are different, are displayed on the CRT. Moving

the hand wearing the glove causes the hand and fingers displayed on the CRT to move similarly. When virtual objects on the screen are grasped, reaction forces are generated to the hand and fingers in the glove.

- Evaluation Items:
  The degrees of recovery of the hand and fingers, as a range of motions, gripping patterns, etc., are evaluated from bending angles and the magnitude of the gripping forces measured with the glove. Motion functions of the upper limbs are also evaluated by the time expended and by the trajectory of the hands as measured by EMUL.

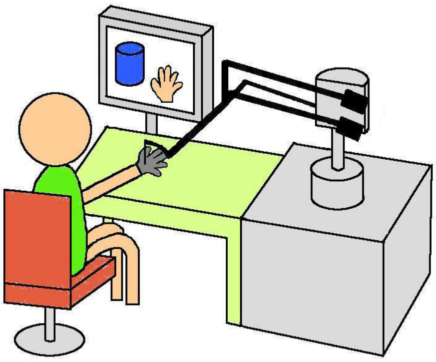


Figure 4: Outline of VR-STEF

## 3. Development of New VR Glove

### 3.1. Problems in Conventional VR Gloves and Guidlines on Development of New Glove

The VR-STEF needs a force display (VR) glove. Most commercialized sensor or force display gloves, for example, CyberGlove [10] or CyberGrasp [13] produced by Virtual Technologies Co., aim to precisely measure position or orientation of hand and fingurs, or to represent fine force sensations. However, because of their construction it is not so easy to set them up; as well they are very expensive. Therefore, they are not really applicable for use in clinical treatment.

The force display glove used in this study does not require such precise measurement or force display ability; rather, it has characteristics of safety, inexpensive, and is easy to set up, and to be manageable in a way that does not hinder training or actual examinations. Other many gloves or ”glove-like” systems that have sensors and/or force display ability have already appeared [14]. However, few gloves have been developed in the view as ours.

### 3.2. Features of the Passive Force Display Glove

The passive force display glove (PFDG) as shown in Fig. 5 was developed in accord with the above guidlines. Table 1 has the specifications of the PFDG, and its features are as follows:

- For easy procurement and setting up, the PFDG has a commercially manufactured working glove made from polyurethane fiber. Parts are glued to the glove and reinforced with Velcro.
- Displayed force is generated by electromagnetic brakes. A passive type system is included for safety [15, 16]. Wire–pulley systems transport the force through brakes to the fingers. A torsion spring is set to the axis of each brake to maintain tension in the wires.
- In each finger part, a rotatable part is set between PIP (proximal interphalangeal) joint and DIP (distal interphalangeal) joint, so that displaying force affects the finger almost normally. A roller is set above the finger between PIP joint and MP (Metacarpophalangeal) joint to prevent the wire from interfering in movement of the finger and to make movement of the wire smooth.
- To measure the bending angles of the fingers, mini potentiometers are fixed to the brake axes. Bending sensors, whose resistance varies according to their curvature, are also set at the backs of the MP joints, except for that of the thumb; one is also attached at the palm side of the MP joint.
- A sheet type force sensor (NITTA Co.) is set on each finger to measure grasping forces. The sensor sheet contacts finger cushion.
- The wrist part of the PFDG has a joint connecting to EMUL as shown in Fig. 6. The brakes of the PFDG are fixed on this connecting part. Weight compensation of the PFDG including the brakes is accomplished by EMUL. Other 3-D force display systems may be used in the same way.
- Wearing the PFDG feels relatively easy, however, ungloving feels difficult because the glove is fit to the hand.
- The cost of the PFDG main unit is around $4,500, which is much less than the $23,000 cost of a CyberGlove.

## 4. Estimation of Joint Angles

Using the PFDG, the joint angle of each finger is estimated from $\theta_p$ [deg], the rotating angle of the potentiometer from

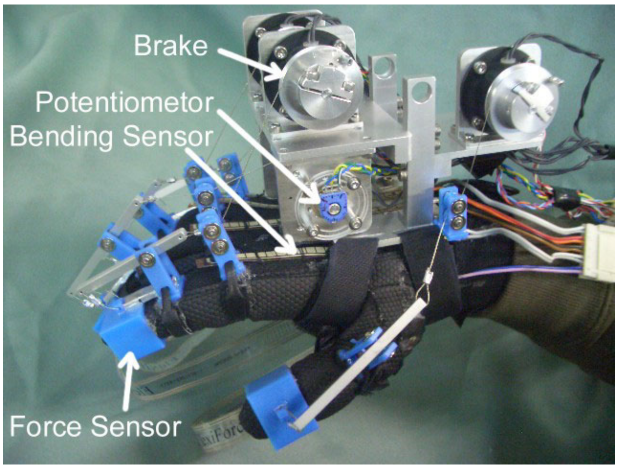


Figure 5: Passive Force Display Glove

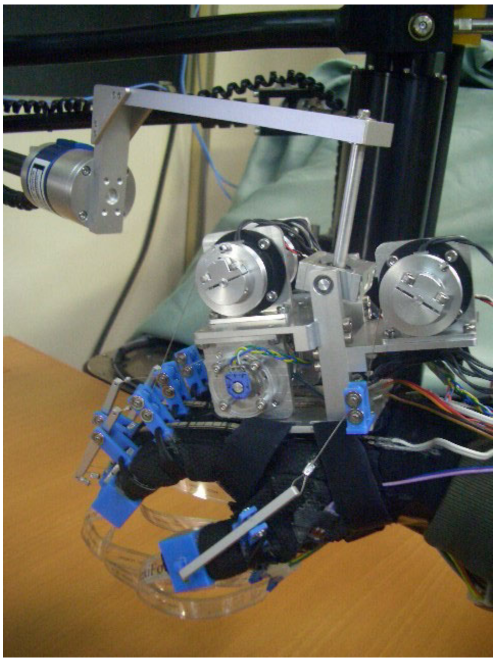


Figure 6: Connecting with EMUL

its initial position, and $\theta_b$ [deg], the bending angle of the bending sensor.

Here, PIP joints and MP joints of from the first to the fourth fingers are measured as the way of this section. DIP joint and MP joint of thumb are also measured. Each DIP joint of from the first to the fourth fingers moves in flexion synkinesis with the PIP joint, so that the angle will be estimated from the PIP angle. Displacement of the PIP angle of the thumb is given as zero because its movement is so little. In this study, only opposition is considered and lateral pinch is neglected.

Now, an angle of a MP joint is defined $\theta_1$ [deg], angles of PIP joints of from the first to the fourth fingers and DIP joint of thumb are given as $\theta_2$ [deg] as shown in Fig. 7. The initial status ($\theta_1 = \theta_2 = 0$) is the case all fingers are stretched straight.

Table 1: Specifications of Force Display Glove

| | |
|---|---|
| Weight | 700 [g] (except a jointing part) |
| Max. Force to measure | 29 [N] |
| Measurable joint angle | $\theta_1, \theta_2$: 0∼70 [deg] |
| Accuracy | $\theta_1$: $\pm 2.2$ [deg], $\theta_2$: $\pm 2.5$ [deg] |
| Displayable size of sphere | 25 [mm] (Min. radius) |

The bending sensors at MP joints directly measure $\theta_1$.

$$\theta_1 = \theta_b \tag{1}$$

$\theta_2$ can be estimated by the relation between $\theta_p$ and $\theta_b$ when a PIP joint is bent by given angle, and then can be written as follows:

$$\theta_2 = f(\theta_p, \theta_b) \tag{2}$$

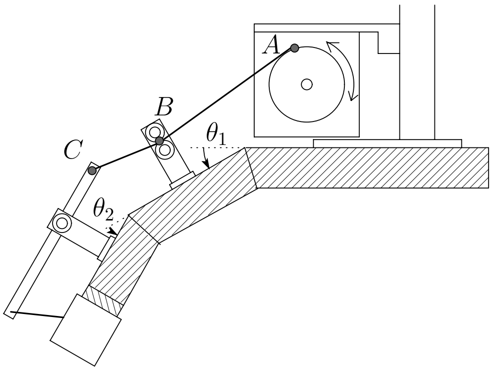


Figure 7: Finger Part

## 5. Representing Spheres

### 5.1. Control Algorithm

Spherical grip, gripping style of grasping a ball, is recognized by the PFDG and then an adequate force is displayed by the PFDG to represent the ball. An operator bends a finger and touches a sphere that has its center on an axis under the operator's palm ($OPR$) as shown in Fig. 8. Where, the radius of the sphere is $r$ [mm], the length of the outer part the finger contacting the sphere (thick lines in Fig. 8) is $l$ [mm] and thickness of the finger ($SQ$) is $t$ [mm]. Values of $l$ and $t$ are given as constant. DIP angles except for that of the thumb are assumed not to be used for determination of gripping.

The angle of the area where the finger touches the sphere, $\angle POQ$, equals an angle between a line that is an extension of the back of the hand ($AR$) and the fingertip ($BS$), that is, $\theta_1 + \theta_2$. It is assumed that the outer part of the finger can be approximate a circular arc, its length can be written

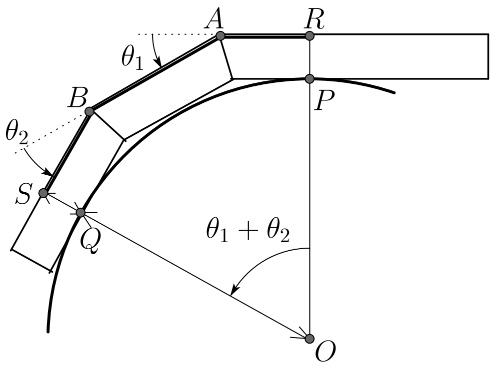


Figure 8: Displaying a Ball

as follows:

$$L = 2\pi(r + T) \times \frac{\theta_1 + \theta_2}{360} \tag{3}$$

Then, the radius of contacting sphere, $r$, is calculated as Eq. (4).

$$r = \frac{l}{2\pi} \times \frac{360}{\theta_1 + \theta_2} - t \tag{4}$$

When the radius of the sphere to be displayed is $r_{ref}$, energizing the brakes makes the operator feel the sphere if $r$ satisfies the following inequality:

$$r \leq r_{ref} \tag{5}$$

When the posture of the hand does not satisfy Eq. (5) or values of the force sensors at the fingers decline under thresholds, brakes are set to OFF. Also, assuming that in the case of spherical gripping the operator's grips of $\theta_1$ and $\theta_2$ are similar, the operator is detected as failing to grasp when he/she grips in another way as only $\theta_1$ changes.

On the PFDG, estimating errors of measuring are $\delta\theta_1 = \pm 2.2$ [deg], $\delta\theta_2 = \pm 2.5$ [deg], the mean error of $r$ can be estimated at $\delta r = \pm 3.9$ [mm]. Because the spheres used in STEF obviously vary in size, the PFDG is considered to have adequate precision for use in VR-STEF.

### 5.2. Experiments Representing Spheres

Using the PFDG, experiments representing some spheres were carried out. Radii of the spheres were 65 [mm] (Large), 45 [mm] (Medium), 30 [mm] (Small). A picture while displaying a large ball is shown in Fig. 9, one while displaying a small ball is shown in Fig. 10.

Some data on the first finger when the large sphere was displayed are shown in Fig. 11. The figure indicates that $\theta_1 + \theta_2$ reached the desired angle $\theta_{ref}$ calculated from $r_{ref}$ by bending the finger, and then the brake turned into ON, thereby angles stopped changing. Because the operator kept gripping while the brake was ON, values of the force sensor kept increasing. However, after he/she relaxed his/her force, the brake turned to OFF. The threshold of the force sensor of the finger set up 10 [gf].

Figure 9: Gripping a Ball (L)

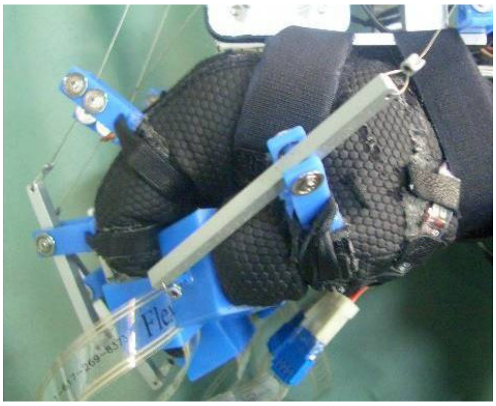


Figure 10: Gripping a Ball (S)

Each speres (S·M·L) were represented. Comparison of results is shown in Fig. 12. In each case, brakes turned into ON when the angles had reached each desired angle. Therefore, it clarifies that distinction among the different size of the spheres were realized.

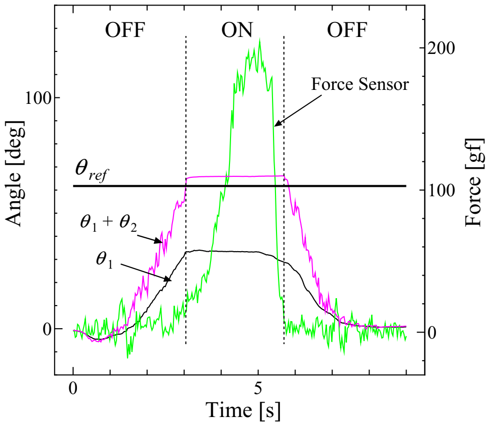


Figure 11: Results of the Case of the Ball (L)

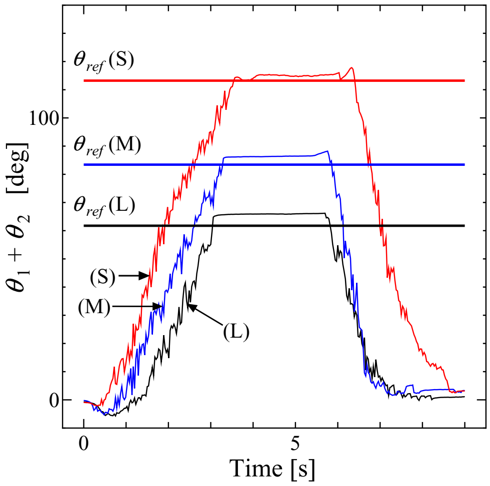


Figure 12: Comparison of Gripping Balls

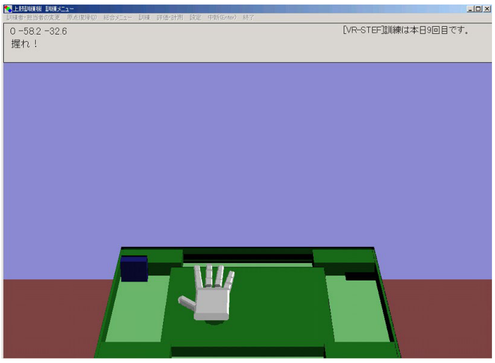
## 6. Softwere for VR-STEF

Fig. 13 shows a graphic presentation of the VR-STEF software under development.

The items displayed are a floar, the starting point for the evaluation used only when the sofware begins, a “hand mark” equivalent to the hand and fingers of the subject, the objects to be moved, and the start and the goal position for the objects. Objects and the hand mark are painted different colors in grasping condition from other conditions. A palm and fingers are drawn for the hand mark. Objects, walls around the evaluation space and the floor generate reaction forces by spring coefficient. As well, loads affect downward according to mass of objects.

Ten kinds of objects are represented and sequenced the same as for real STEF; large balls, medium balls, large blocks, medium blocks, medium cubes, medium disks, small cubes, large flat plates, small disks, small balls and pins. Where, large flat plates are, in actual STEF, pieces of cloth. While here we use large flat plates, in actulal STEF pieces of cloth are used. For this report, flat plates have been substituted for easy constructing. Each start and goal position for the objects is set at the same position in actual STEF. The floor height and the evaluation starting point can be changed by the user from items in the menu page. This enables evaluations suitable for the different conditions of vairous subjects’.

While various data along with the time expended in the evaluation can be received, it is under consideration how to feed them back to estimators or subjects.



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[VR-STEF]訓練は本日9回目です。

Figure 13: Preliminary Image of VR-STEF

## 7. Conclusion and Discussion

In this paper, we detailed our development of a passive-type force display glove system (PFDG) as part of the construction of a VR-STEF system; that is, STEF presented by VR technology. Specifications and features of the PFDG were explained. It was also explained that the PFDG system was able to display virtual balls classified into their size with the spherical grip style. This result indicates the feasibility of representing objects of VR-STEF. At last, status of development of VR-STEF software was reported.

Other aspects of the study measure conditions utilizing sensor gloves or rehabilitation robots while subjects perform STEF with actual STEF items. However, it will be hard to grasp objects with the gloves as easily as can be done without gloves, so that the result could differ from those evaluated with ordinal STEF. However, while VR-STEF may have the same risks of difference, it also has the possibility to achieve the same evaluation results as with conventional STEF in respect to the motion functions of subjects, by improvements in the hardware and software associated with the glove system. Additionally, VR-STEF has the advantage of being a rehabilitation system for the upper limbs that can carry out clinical treatments consistently from evaluation to training without needing additional measuring devices. The VR-STEF also has the advantage of quantitative indices for motion function evaluations.

The PFDG can connect to not only EMUL but also other 3-D force display systems like PHANToM if the connecting part is reconstructed. Users can choose the force display system according to cost, working area, generative force or other factors.

In future work, we will improve our VR-STEF system through pilot experiments, and undertake clinical evaluations. From this, we will be able to predict how well we can fill the gap that now exists between conventional and robot rehabilitation.

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