

VR-based Exoskeleton System for Rehabilitation

Siam Charoenseang
 Institute of Field Robotics
 King Mongkut's University
 of Technology Thonburi
 Bangkok, Thailand
 siam@fibo.kmutt.ac.th

SarutPanjan
 Institute of Field Robotics
 King Mongkut's University
 of Technology Thonburi
 Bangkok, Thailand
 sa_panjan@hotmail.com

1. Introduction

Recent studies have reported that stroke is a common cause of death in the world [1]. There are more than 700,000 stroke patients in Thailand each year [2]. Normally, results from the stroke such as muscle weakness, unsmooth muscle contraction, neural loss to balance the body's movement and muscle coordination, give the patients with the difficulties for living [3]. This paper proposes a prototype of VR-based exoskeleton system for rehabilitation those patients.

2. System Overview

Fig. 1. shows the configuration of the proposed system. This system consists of a hand exoskeleton device which is used to generate force feedback to the user. The exoskeleton also sends finger's angles and receives braking angles from the main computer. Markers are used to track the positions and orientations of virtual objects and user's hand. Video camera is used to receive video image from the real environment. Camera is mounted on LCD glasses display [4] which is used to show the graphics in the same view of user's. Graphics is updated by the physics engine using the Bullet software library [5].

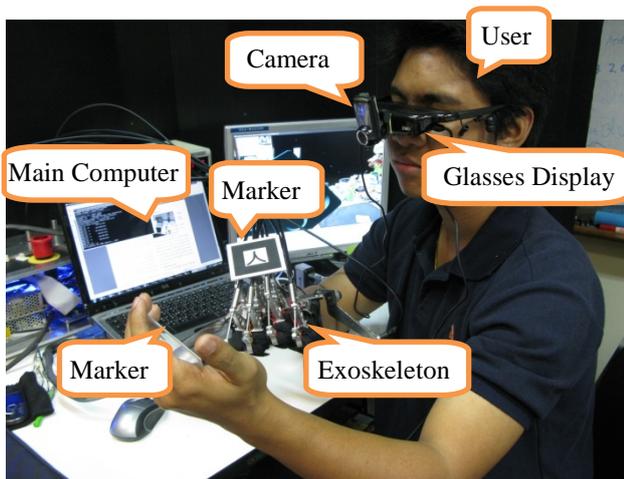


Fig. 1. System Overview

3. System Components

The system consists of two main components which are hardware and software components. Hardware includes an exoskeleton device with controller, an LCD glasses

display, a video camera, force sensors, and markers. Software includes graphics manager and vision manager.

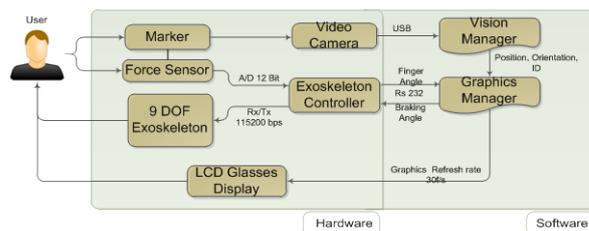


Fig. 2. System Components

In Fig. 2. the system receives video image from the video camera, does image processing to find target's positions and orientations, and generate computer graphics superimposed on video image. It also sends force feedback in form of braking angles to all motors on exoskeleton device.

3.1 Exoskeleton Device

Exoskeleton device is used to generate force feedback to a user. It receives commands from the main computer through the exoskeleton controller for controlling its motors. The controller also receives sensed forces from strain gauges for adjusting tensions of the cables. Object manipulation by hand basically, thumb finger use 2 DOF rotate about X and Z axes but index to little fingers use 3 DOF rotate about Z axis. The last joint of index to little fingers cannot be controlled independently. Rotation of the last joint depends on the previous joint's rotation. Hence, mechanical structure of the proposed exoskeleton device is designed so that mechanism of index to little fingers exoskeleton are designed can generate 2-DOF force feedback per finger. To simplify the mechanical structure exoskeleton of thumb finger, this device can generate only 1-DOF force feedback at the fingertip. Computer graphics of virtual fingers are designed with 2 DOFs for thumb finger and 3 DOFs for index to little finger as shown in Fig 3. In addition, the movements of virtual fingers are updated correspondingly to real finger's. Physics engine uses forward kinematics from "Equation (1)." to calculate the position and orientation of each finger from the D-H parameters table 1 and 2. [6]

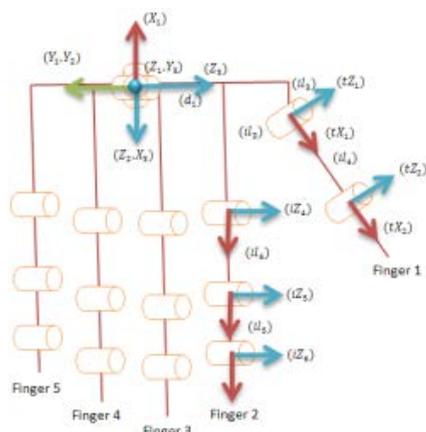


Fig. 3. Frames and axes of hand exoskeleton

$${}^{i-1}T_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i & 0 & a_{i-1} \\ \sin \theta_i \cos \alpha_{i-1} & \cos \theta_i \cos \alpha_{i-1} & -\sin \theta_i & -\sin \alpha_{i-1} d_i \\ \sin \theta_i \sin \alpha_{i-1} & \sin \theta_i \sin \alpha_{i-1} & \cos \theta_i & \cos \alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Table 1 Finger no.1's DH-parameters

link	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	Offset	θ_1
2	90	0	0	θ_2
3	-90	0	0	θ_3
4	45	tl_3	d_4	θ_4
5	0	tl_4	0	θ_5

Table 2 Finger no.2-5's DH-parameters

link	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	Offset	θ_1
2	90	0	0	θ_2
3	-90	0	0	θ_3
4	0	il_3	d_4	θ_4
5	0	il_4	0	θ_5
6	0	il_5	0	θ_6

3.2 VR Software

Video captured by the Logitech 2 MP Portable Webcam C905[7] resolution is 640x480 pixels and graphics refresh rate is 30 frames per seconds. The vision manager applies the ARToolkit software library [8] to locate markers and send the marker's position and orientation to the graphics manager.

Graphics manager is responsible for rendering virtual objects and virtual hand on a marker using OpenGL as shown in Fig. 4. and 5. Bullet physics engine included in the graphics manager is used to detect collisions and calculate reaction force from virtual hand's manipulation.

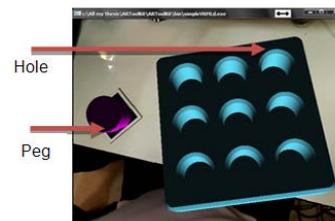


Fig. 4. Virtual objects in physics simulation

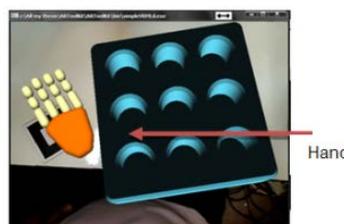


Fig. 5. Virtual hand in physics simulation

4. System Experiments

There are two experiment sets implemented in this proposed system. The first experiment is used to explore the maximum force feedback provided by the exoskeleton device. First, the user wears the exoskeleton to do grasping while the motors are set to hold their original positions. The exoskeleton controller then queries the maximum forced from strain gaged.

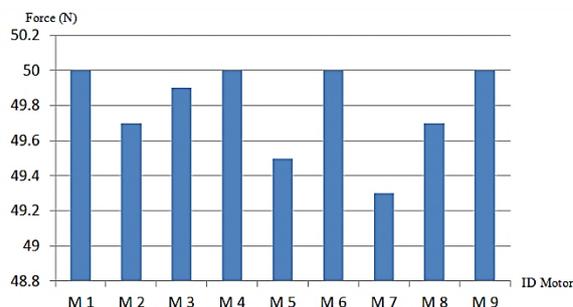


Fig. 6. Maximum force feedback from motors

In Fig.6.the horizontal axis represents motor IDs and the vertical axis represents forces exerted on each joint. The results show that exoskeleton device can generate maximum force feedback up to 50 N.

This second experiment is set to test the virtual object assembly task. In this experiment, 10 users are asked to use the proposed exoskeleton device to manipulate the virtual objects in the real environment. The goal of this virtual assembly task is to put virtual pegs in holes with/without force feedback effect. All virtual objects with physics simulation are augmented on the real markers and users can/cannot receive force feedback while they manipulate the virtual objects as shown in Fig. 7-9. The operation time of each user is recorded. The results from this experiment show that the users spend

less time with average of 18.9% while using force feedback system.

the exoskeleton's performance with physiotherapists and stroke patients.

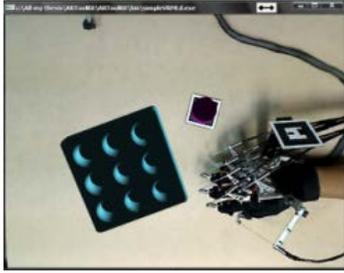


Fig. 7. Before grasping virtual object.

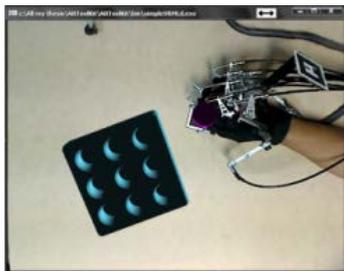


Fig. 8. Grasping virtual object.



Fig. 9. Virtual object in the hole.

5. Conclusions

This research proposed a prototype of virtual reality with force feedback system for rehabilitation. Exoskeleton device was designed and built to generate 9-DOF force feedback to the user's hand. The total weight of this exoskeleton device is about 427 grams. This device can generate with maximum forces up to 5N for each finger. Virtual objects in physics simulation can be superimposed on the tracked real markers. Graphics refresh rate is about 25 frames per seconds. The proposed system will be set to help the stroke patient to map between the visual and hand motor movement in sensorimotor hand therapy. Several rehabilitation protocols can utilize this proposed system to provide the courses of training to the patient. In the training, the user can use the hand exoskeleton to manipulate virtual objects with force feedback in the real environment. This provides more realistic to improve the training's performances. The next step of this research is to verify

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