Design and Implementation of Assistive Devices for Poststroke Rehabilitation of Hand and Fingers[1]

Kevin Kao
Department of Mechanical Engineering,
National Central University,
32001, Taiwan

Jheng-Jie Huang
Graduate Institute of Biomedical Engineering,
National Central University,
32001, Taiwan

Min-Chun Pan
Department of Mechanical Engineering,
National Central University,
32001, Taiwan;
Graduate Institute of Biomedical Engineering,
National Central University,
32001, Taiwan
e-mail: pan_minc@cc.ncu.edu.tw

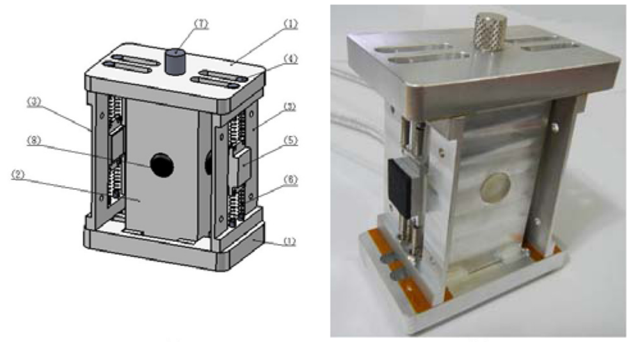
1 Background

Cerebrovascular disease also known as stroke remains the third among the top ten leading causes of death in Taiwan. Patients with stroke usually get some physical dysfunction like disability, hemiplegia, or contracture that makes them lose quality of life. The patients usually need to face a long rehabilitation process and employ various assistive devices. The main function of assistive devices is to improve or maintain the patient's act ability. For stroke patients to restore their hand function for fine movement is relatively difficult. A traditional aid "splint" can prevent joint deformities effectively. Besides, in recent years, a variety of dynamic auxiliary gloves were developed [1,2] that used elastic structure to help patients train their fingers like bend, stretch, and grasping ability. These aids can help patients to recover hand function effectively but lack of signal measurement and feedback for recording and quantifying hand exertion.

This technical brief aims to design (1) tip-pinch and (2) grip strength measurement devices that combine flexible-force-sensor (FlexiForce Sensor) with assistive devices, and (3) a thumb opposition sensing device. These assistive devices with sensing feedback can quantify physical activity levels and help physicians assess the effectiveness of rehabilitation. Additionally, these developed sensing and assistive devices are combining with virtual reality games. They can make the rehabilitation process further interesting, enhance the patients' motivation on the tasks, and eventually increase the rehabilitation performance.

2 Methods

Three assistive devices of both the rehabilitation and effectiveness evaluation for stroke patients' hand and fingers were designed. These relatively dedicated movements are grip, tip pinch, and thumb opposition, respectively. To the purpose of the assistive devices fulfilling the functionality, the mechanism of hands' and fingers' movement was first investigated. The physical design of the devices were drawn by using SolidWorks 3D®, and the signal conditioning for sensing feedback of each device was laid out through OrCAD®. As to the sensing elements, piezoresistive force sensors were employed for grip and tip-pinch strength assistive devices, and finger-ring switches were used in the design of thumb opposition sensing device.



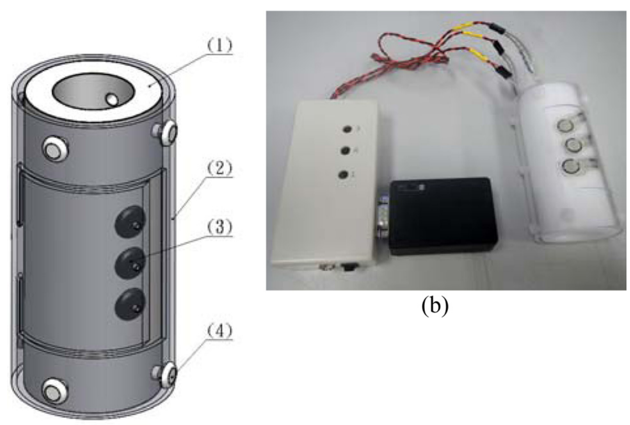
(a) (b)

Fig. 1 Tip-pinch strength measurement device: (*a*) mechanism drawing, and (*b*) built-up device

2.1 Tip-Pinch Assistive Device. Figure 1(*a*) shows its mechanism drawing. The tip-pinch width, 30 or 40 mm, can be adjusted by turning the width block (indicated as (2) in the drawing) dependent upon the size of a patient's palm. While in test, both the thumb and the forefinger pinch the side rubber pads to squeeze piezoresistive force sensors. This makes the tip-pinch strength picked up, as shown in Fig. 1(*b*) the built-up device. Further, the device can be made of acrylic to be comfortable to use.

2.2 Grip Assistive Device. As shown in Fig. 2(*a*), the mechanism drawing shows the grip strength measurement device, which is composed of two hand-held pipes. An acrylic pipe cut and inserted by a 66×45 mm elastic layer comprises the outer hand-held pipe. Three piezoresistive force sensors are mounted on the inner wall of elastic layer. The inner handling pipe is made of acrylic. When palm-grip exerts on the elastic layer, therefore, the strength is transmitted to the three sensors and measured. Figure 2(*b*) shows the built-up device along with its signal conditioner.

2.3 Thumb Opposition Sensing Device. Figure 3 illustrates the device together with its conditioning and indication units. Here, finger rings equipped with copper chips were employed as the detecting elements. The copper chip of the thumb ring is connected to the anode of a 3 V battery, and each of those of other



(a) (b)

Fig. 2 Grip strength measurement device: (*a*) mechanism drawing, and (*b*) built-up device along with its signal conditioner

[1]Accepted and presented at the Design of Medical Devices Conference (DMD2014), Minneapolis, MN, April 7–10, 2014.

DOI: 10.1115/1.4027032
Manuscript received February 21, 2014; final manuscript received March 3, 2014; published online April 28, 2014. Editor: Arthur G. Erdman.

Copyright © 2014 by ASME

Downloaded From: http://medicaldevices.asmedigitalcollection.asme.org/ on 07/22/2014 Terms of Use: http://asme.org/terms

Fig. 3 Thumb opposition sensing device

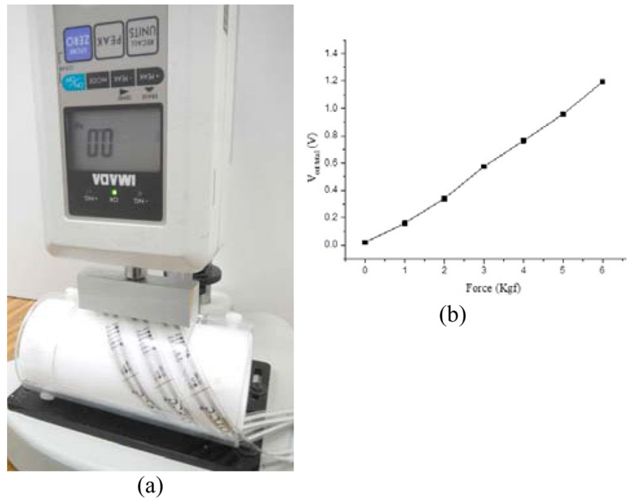


Fig. 5 Calibration of grip strength measurement device: (*a*) calibration setup, and (*b*) relation of exertion force and output voltage

finger rings is serially connected to a light-emitting diode (LED) and then to the cathode of the battery. Therefore, while the thumb touches a finger, it makes a close loop and causes the LED to illuminate. Meanwhile, a 3-V signature will be transmitted to a mainframe computer as a record through XBee wireless transmission.

3 Results

This section shows the validation of three constructed assistive devices. An electronic thrust instrument was employed to calibrate tip-pinch and grip assistive devices, respectively. The thrust instrument exerts a force from 1 to 6 kgf, increasing every unit kgf to each side of the tip-pinch strength device, as shown in Fig. 4(*a*). Figures 4(*b*) and 4(*c*) illustrate the relationship of output voltage versus exertion strength for two sensors. It is noted that the sensitivities for the device with FlexiForce-1 and FlexiForce-2 are 1.224 kgf/V and 1.250 kgf/V, respectively.

Likewise, the electronic thrust instrument equipped with a wide thrust head exerts a force from 1 to 6 kgf, increasing every unit kgf to the grip assistive device, as shown in Fig. 5(*a*). This obtains a relationship between exertion force and output voltage with a sensitivity of 5.05 kgf/V (Fig. 5(*b*)). It is noted that the sensitivity for the grip device is around four times of those for the tip-pinch device, which results from the varied signal conditioners although the same type of FlexiForce sensor was used. Generally the grip strength is much larger than tip-pinch strength for the same person. Further, the actual range of force sensing can be adjusted by the used signal conditioner.

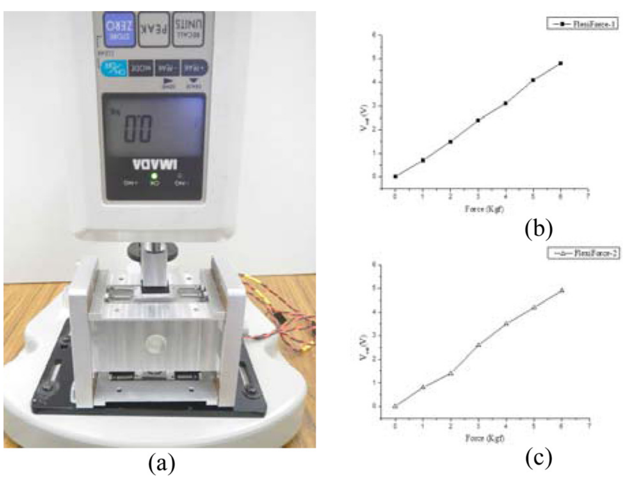


Fig. 4 Calibration of tip-pinch force measurement device (*a*) calibration setup. Relation of output voltage versus exertion force and sensor: (*b*) FlexiForce-1, and (*c*) FlexiForce-2.

Fig. 6 Test of thumb opposition sensing device

Figure 6 shows the test of the thumb opposition device. It is noted that while the thumb touches pinkie, an LED lights as two connecting copper chips make the circuit a closed loop. Meanwhile, a 3-V signature is wirelessly transmitted to the computer as a record of the correct task.

4 Interpretation

For stroke patients, to recover delicate movement of hand and fingers is more challenging than that of upper extremity. Thus, assistive devices that enable enhancing patients' motivation on the task are demanding. To the end, the study designed and implemented tip-pinch and grip assistive devices as well as a thumb opposition training device. Their functions have been validated through calibration processes. Further, virtual reality games with designated scenarios are being designed and incorporated in to these devices, therefore, to complete the design of assistive device system for the rehabilitation of hands and fingers.

References

[1] Laura, C. M., Ricardo, R.-T., Arno, H. A. S., and Julius, P. A. D., 2009, "A Wrist and Finger Force Sensor Module for Use During Movements of the Upper Limb in Chronic Hemiparetic Stroke," IEEE Trans. Biomed. Eng., **56**(9), pp. 2312–2317.

[2] Elizabeth, B. B., Iian Black, R. J. H., and Peter, S. L., 2011, "Hand Spring Operated Movement Enhancer (HandSOME): A Portable, Passive Hand Exoskeleton for Stroke Rehabilitation," IEEE Trans. Neural Syst. Rehabil. Eng., **19**(4), pp. 391–399.

Downloaded From: http://medicaldevices.asmedigitalcollection.asme.org/ on 07/22/2014 Terms of Use: http://asme.org/terms