Development of a quantitative evaluation method in occupational therapy exercise for upper limb motor function rehabilitation

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ABSTRACT

Rehabilitation exercises required to sustain a motivation amongst patients and demands a quantitative in rehabilitation field. In this study, we developed a measuring equipment for upper limb motor function rehabilitation using optical sensor to improvise these problems. This system consisted of an optical sensor device, a personal computer and automatic calculated software for upper limb position. The measuring equipment was designed to measure the optical sensor position and movement length during the task of sanding movement and wiping movement. The movement positions were calculated based on the motion captured by optical sensors. We found that the accuracy of the optical sensor trajectories was similar in all actual measured value. These results are proposed to be very beneficial in the development of rehabilitation training programs and evaluation methods for patients who needs upper limb motor functions.

Keywords: *Stroke, hemiplegia, upper limb rehabilitation, upper limb motion, measurement system, occupational therapy.*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-03-28
Accepted for publication: 2017-05-18
Published: 2018-01-31

Introduction

Medical devices and technology in occupational therapy exercise has been progressed every year to provide the best possible options for patient and health care professionals [1]-[7]. The development of medical devices was designed to benefit all genders including young and older population to improve the quality of life. Recent years, the increasing demanding in the market to target elderly population has shown remarkably exciting [8]-[11], [16]-[19].

The elderly population in the society has been introduced to several interesting policies and programs in developing and developed countries [3, 4]. One of the program recommended was motor and recovery function amongst elderly. This is due to increase awareness of motor disorder and cognitive impairment in cerebrovascular disease that develops a high proportion in the aging society [7].Conventional motor function training and function recovery assessment methods depend on the subjective evaluation and observation from physicians, physical therapists and occupational therapists [8].The demanding of quantitative evaluation is an essential in medical rehabilitation field to rule out further objective and specific rehabilitation training.

Sanding and desk wiping movement is commonly training practice for patients who requires upper limb motor function rehabilitation [13-15]. The training volumes involved the standard procedures called out by occupational therapist and the patient will try to fulfil every procedure required. The scores will be given based on the efforts shown by the patients and required a lot of motivation and time consuming. This session has been reported leads to exhaustion amongst professional health care and patients [13]. This evaluation lacks of justification onset of degree and there is no indicator to shift for the next training.

The purpose of the sanding movement evaluation in occupational therapy is to facilitate for muscle training. A lot of movement requires in order to perform this task. In this study, a quantitative measured has been proposed to measure the parameter of repetitive numbers of work and the moving distance used in each patient per evaluation of the training effect.

Desk wiping movement is a training to expand the range of motion of the elbow and shoulder joints of the patients [13].In tradition practice, the occupational therapists assessed the extension of the range motion in training subjectively [13]. There has been little quantitative analysis of these range of motion. In this study, we also proposed to evaluate the desk wiping movement by determining the range of motion of joint in upper limb, simultaneously record and illustrate the trajectory motion during the training session. The figure demonstrated the sanding and wiping movement has been explained in details in Figure 9 in this paper.

We developed a device system that capable of measuring the sanding movement and desk wiping movement without constraint the normal physical training session. Later, we presented the basic experiments that carried out amongst patients to measure the total movement of several training model during the sanding and wiping movements using the optical sensor which developed in the upper limb measurement system as an occupational therapy approaches. This paper also provides the information about the experiments conducted using a measurement model with assuming the upper limb operating range to acquire an objective and quantitative evaluation method for the training effect.

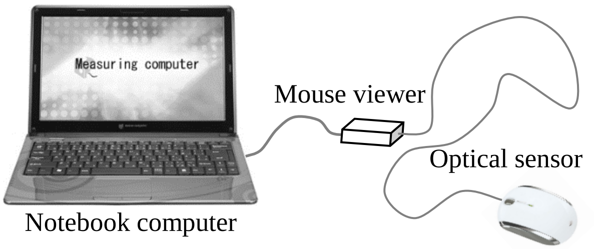
System overview

Optical sensor based measurement system

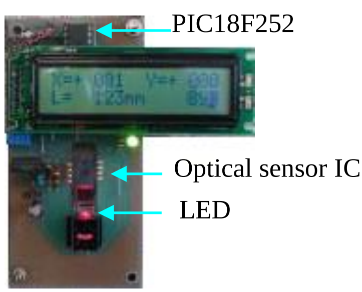
Figure 1 illustrated the image of the novel optical sensor measurement system device for the upper limb movement function. This system comprises of four essential modules which are an optical sensor device, a personal computer, a measurement control algorithm and a system control software. The optical sensor core module consisted of a LED, an optical sensor IC, a measurement software and a LCD display. We improved an optical mouse kit consist of optical sensor (ADNS-5030) and related parts manufactured by AVAGO Technologies to develop a plane movement measuring device. The specifications of the optical measuring device as shown in Table 1. Figure 1 (b) illustrates the entire optical sensor module, and Figure 1 (c) demonstrates the optical sensor IC. This IC has special features which are not just an optical sensor but also has a built-in CPU, Digital Signal Processing (DSP) capability, and also has the capability of mutual communication with external components. There is a small hole in the centre of the bottom surface, and there is a secondary surface of the optical sensor in the back of it, and the image focused by the lens is microscopic surface images. Light passes through the optical path inside the plastic and illuminates the desk surface.

All parts of this optical sensor is shown as in Figure 2. The ADNS-5030 IC is based on Optical Navigation Technology, which measures changes in position by optically acquiring sequential surface images or frames and mathematically determining the direction and magnitude of movement. The ADNS-5030 contained an Image Acquisition System (IAS), a Digital Signal Processor (DSP), and a four wire serial port. The IAS acquires microscopic surface images via the lens and illumination system. These images are processed by the DSP to determine the direction and distance of motion. The DSP calculates the Δx and Δy relative displacement values. An external microcontroller reads the Δx and Δy information from the sensor serial port. The microcontroller then translates the data into PS2, USB, or RF signals before sending them to the host PC.

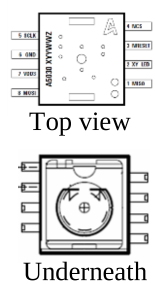
The optical sensor IC autonomously acquires information on the surface of the desk. If the sensor moves, the IC will detect the movement changes and calculate each position from the information captured, however if the sensor is not move, the IC will recognize that the position information captured remains the same as before the static condition. The sensor IC automatically compares the information of the time before and after in the IC, if there is movement changes detected in the information, then the sensor will output the information of total movement, which is the total movement in the x and the y direction of the sensor. If there is no movement detected, the total movement data is not output then it will activate the energy saving mode where the LED reduced the brightness.



(a) Overview of the system



(b) Optical sensor



(c) Optical sensor IC

Figure 1: Optical sensor system for upper limb rehabilitation

Table 1: Optical mouse kits specification list

Part name	Contents
ADNS－5030 (Sensor)	Optical sensor IC
ADNS－5200 (Chip)	Light emitting diode holder
HLMP－ED80 (LED)	Red light emitting diode
ADNS－5100(Lens)	Optical sensor IC holder with

	rectangular lens
ADNS－5100(Lens)	Optical sensor IC holder with circular lens

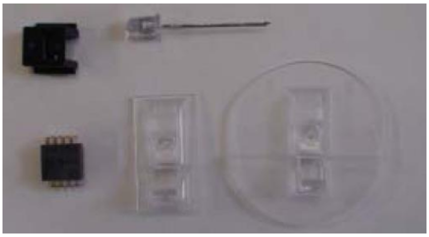


Figure 2: Optical sensor hardware

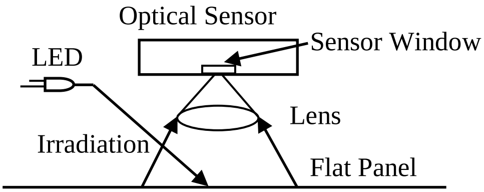


Figure 3: The principle operation of the optical sensor on the surface of the table

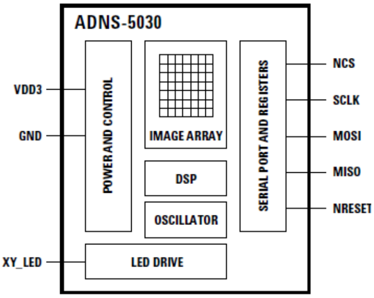


Figure 4: Block diagram circuits of ADNS-5030 optical sensor

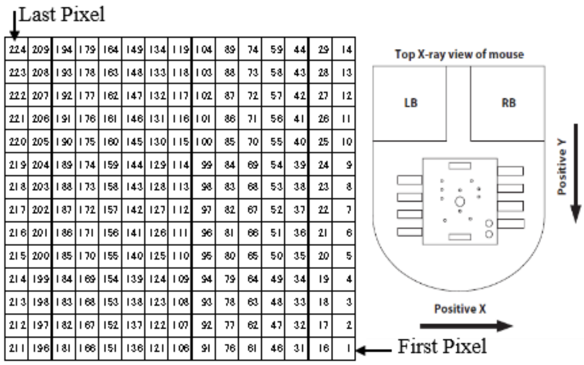


Figure 5: Physical Pixel Address Map – readout order of the array

In this system, the sensor IC able to detect the total movement and also possible to change the several physical quantities obtained as output from the measurement. Moreover, an operating command to control the behaviour of the sensor can be coded to the sensor IC. The distance from lens reference plane to tracking surface specified to approximately 2.4 mm ± 0.4 mm with an accuracy less than 1 mm. If the error of this interval becomes large, the high accuracy measurement values may not be obtained. Figure 3 demonstrates the LED illuminates the desk surface from an oblique direction. In the intervals of 2.4 mm, the LED are designed to illuminate a small area of the desk surface beneath the lens. Thus, if this interval is too short, the irradiation position is on the left side where the position just under the lens. On the contrary, if the interval is too long, it will shift to the right side, subsequently precise adjustment is necessary. Figure 4 illustrates block diagram internal circuit of the optical sensor IC. The DSP is the built in two-dimensional image sensor. In Figure 5 illustrates the pixel arrangement in two-dimensional image detected by the sensor. The horizontal axis and the vertical axis is 15 pixels each.

Principle operation of optical sensor

The measurement system based on optical sensor consists of an optical sensor part, a control part, a LCD and a battery part. From the automatic control of optical sensor IC, the LED turns on and off automatically. If the sensor IC is moving, the LED is lit up in the continuous ON state, and if the sensor IC stopped moving, the LED is lit in the energy saving mode.

Measurement and operation method

Figure 6 indicates the procedure of measurement and operation using the optical sensor. The measuring device based on the optical sensor IC sequentially output the total movement in x and y direction where each Δx, Δy has positive and negative values. However, when the sensor IC is not moving or stopped, there is no data transmission from the sensor IC. The sensor IC will determine all the process either it stopped or in operation. If it is in motion mode, it will transmit out the total movement from the time of the previous total movement. The sensor IC will transmit the data to the PIC. The calculation of total summation movement in the x direction from the start movement to the final movement defined as the total sum of x from the left to the right direction. The calculation of total summation movement in the y direction obtained from the total of final movement defined as the total sum of y in the vertical direction.

From the Pythagorean Theorem, the consecutive output of the total movement (Δx, Δy), and the total of each small movement calculated as in Equation (1).

$$\Delta = \left((\Delta_x)^2 + (\Delta_y)^2\right)^{1/2} \tag{1}$$

The moving path length, L obtained from a consecutive sum, ΣΔi of the total small movement, Δi.

Figure 7 illustrates a calculation method of a path length. The initial point as the starting point, then continuously move the measuring device translated to the trajectory of the measured path length. From the Pythagorean Theorem, the total movement in the x and y directions detected from the optical sensor IC then calculated the total of small linear movement segments, which is integrated to find the total path length to the end point. Measured values along a curve like as in a circle will consider as the sum of the inner straight lines, then resultant in an error.

Figure 8 illustrates a calculation method of the area surrounded by the closed curves. For the area calculation, we adopted the Heron's formula, which is the formula for finding the area from triangle with three sides. Let a, b, c be the length of three sides of the triangle, the area, A of the triangle as stated in Equation (2).

$$A = \sqrt{s(s-a)(s-b)(s-c)} \tag{2}$$

Here, s is the semi perimeter of the triangle as in Equation (3),

$$s = \frac{1}{2}(a+b+c) \tag{3}$$

Always set the start point as one vertex of a triangle and also as the origin of X and Y coordinate system. For instance, two consecutive points transmitted from the optical sensor IC moving along the locus as the residual of the two vertices of a triangle. The coordinate values（x_{i-1}， y_{i-1}）and （x_i， y_i ）of the two vertices are given by two consecutive sets of data（$Sum\ x_{i-1}$ ， $Sum\ y_{i-1}$）and （ $Sum\ x_i$， $Sum\ y_i$ ）. Let a as the leading edge and c be the trailing edge.

$$a_i = \sqrt{\left(Sum\,x_i^{\,2} + Sum\,y_i^{\,2}\right)} \tag{4}$$

$$c_i = a_{i-1} = \sqrt{\left(Sum\,x_{i-1}^{\,2} + Sum\,y_{i-1}^{\,2}\right)} \tag{5}$$

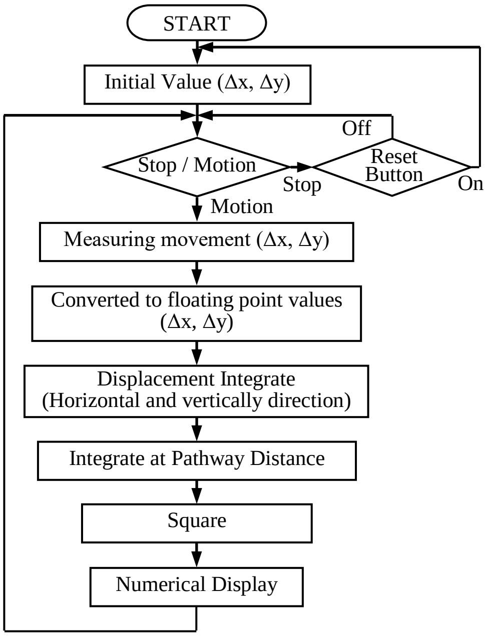


Figure 6: Procedure in measurement work flow

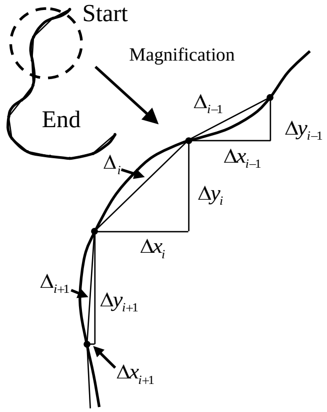


Figure 7: Calculation method of route length

The residual side bi along the trajectory is a small line segment. Here, bi = Δi where the length of three sides is determined, from the Equation (2) and (3), the area of the small triangle is determined, and then calculated the total area as the integration of all the area of the small triangle. These hypotheses are illustrated in Figure 8.

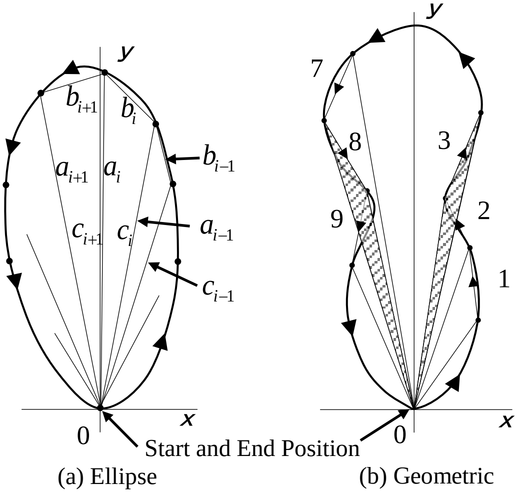


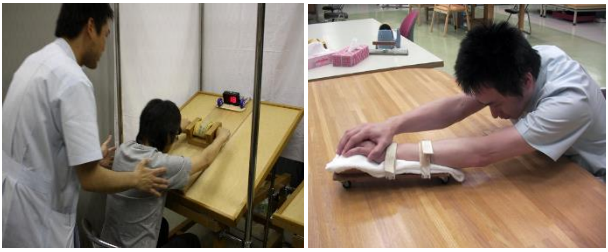
Figure 8: Calculation methods of area in the case of an ellipse and geometric shape

In Figure 8 (a), the locus is assumed as the counter clockwise movement from the start point as illustrated in the example figure. On the other hand, as shown in Figure 8 (b), the trajectory of a general figure is not necessarily moving in one direction. Side 1, side 2, side 7, and side 9 are moving counter clockwise, however sides 3 and 8 are moving clockwise. The geometric shape of locus also can be determined by using Heron's formula to obtain the total area. A small triangle area when the side b is oriented in the counter clockwise direction defined as a positive value. Whereas, a small triangular area where the side b has a clockwise direction defined as a negative value. As aforementioned defined, the final locus in any closed curve can be obtained by the total area of the small triangle using the Heron's formula by consecutively summing up the area within the closed surface.

Evaluation Experiment

Figure 9 illustrated the sanding and wiping movement usually performed for motor function rehabilitation in occupational therapy. The sanding movement training as illustrated in Figure 9 (a), and the wiping movement training as demonstrated in Figure 9 (b).

There was various rehabilitation training carried out in occupational therapy. However, in our study, we only emphasis on the sanding and wiping movement using our novel optical sensor in the basic experiments performed to measure the total movement in the rehabilitation training.



(a) Sanding movement (b) Wiping movement

Figure 9: Rehabilitation of motor function in sanding and wiping movements

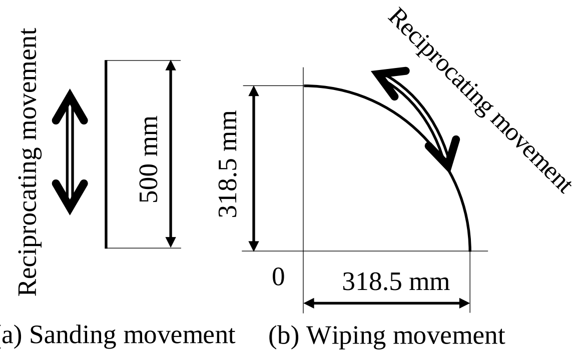


Figure 10: Basic experiment in distance measurement; (a) sanding movement, (b) wiping movement

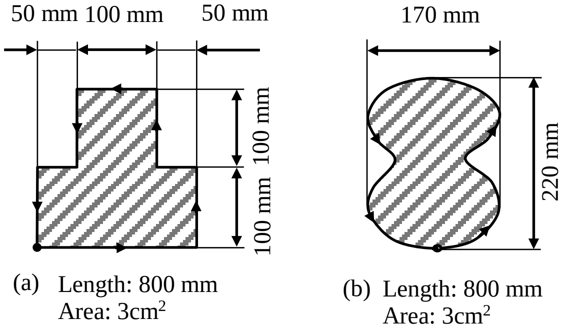


Figure 11: The evaluation method of locus length and the total area resulting from the locus

During the sanding movement training, the reciprocating movement at a distance of 500 mm in the operation area where the measured value and the value obtained from the novel optical sensor were compared and verified. The experimental setup during the sanding movement as presented in Figure 10 (a). As demonstrated in Figure 10 (b), during the wiping movement the measured value and the value obtained from the measurement system were compared in the working distance of 500 mm on the desk. The sanding and wiping movements performed repeatedly in ten times. We used a guide lines to accurately trace during measuring the actual figure.

Furthermore, desk wiping movement is a training to enlarge the range of motion of the joint in every patient's elbow and shoulder, however in training evaluation, it can be easily evaluated through determining the working distance and the movement area in order to quantify the operation area as the measurement carried out using a figure as exposed in Figure 10 and 11.

Experimental result

We conducted basic experiments using our novel measurement system during the sanding and desk wiping movements to verify the accuracy of the measured values at the time of movements. Figure 12 illustrates the trajectory movement and the position of the optical sensor while tracing the profiles as demonstrated in the sanding movement as in Figure 10 (a) and Figure 10 (b) the wiping movement during the rehabilitation session. Figure 12 (a) showed the trajectory of the sanding movement where the horizontal axis X presence 0 as the reference as well as the maximum position error of the left and right is 2 [mm]. In the extension movement, the trajectory profile of reciprocating motion from 0 to 500 [mm] illustrated on the Y axis. Figure 12 (b) indicates the trajectory profile of the optical sensor during the wiping movement. The maximum position error from the presented guideline is 2 [mm]. It was almost similar to the measured distance if comparing the measured distance mapping from the position of the optical sensor.

Results of locus length during the sanding and wiping movement measurement experiments as illustrated in Figure 13. Approximately 1% error existed when measuring the linear movement distance of 500 [mm] on the desk, about 6 [mm] error approximately in measured value of 494 [mm] from the actual measurement was confirmed. The locus length during the wiping movement can be measured as well as in the sanding movement. It was confirmed that the percentage error of 1.4% existed in the measured value of 492[mm] with about 8[mm] error from the actual value.

Using the figure as demonstrated in Figure 11, calculation of the total movement area resulting from the locus as an evaluation method for the wiping movement. The results of locus area measurement experiments in rectangle and geometry model as presented in Figure 14. In the rectangle model, the locus area measurement experiment indicated an error of about 2.9 cm^2 directed to the 1% of percentage error. The locus area measurement error of the geometric model demonstrated error about 2.9 cm^2 which directed to 1.2% of percentage error.

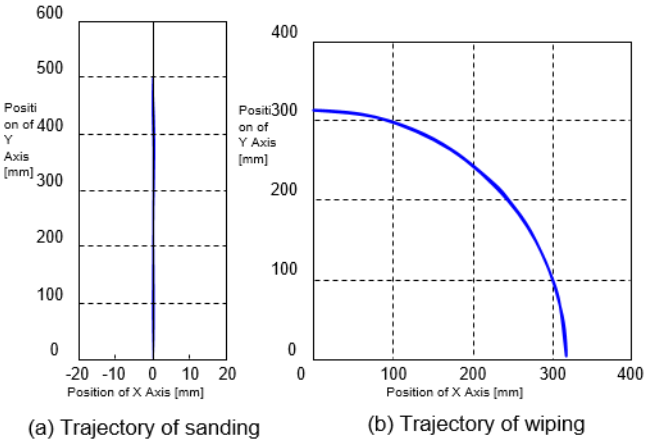


Figure 12: Profiles of the trajectory of sanding (a) and wiping (b) movement in the rehabilitation session

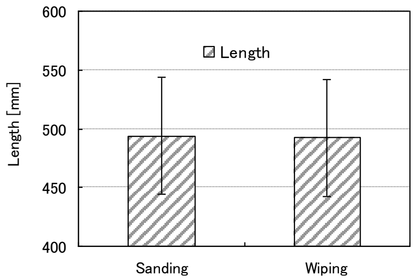


Figure 13: Result of the experiment for locus length during the sanding and wiping movement

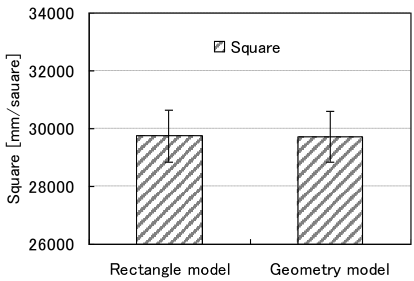


Figure 14: Result of the experiment for locus area in rectangle and geometry model

Discussion

We confirmed that the movement and the measurement executed of our novel optical sensor during the basic experiments of sanding and desk wiping movement in occupational therapy not restricted the normal rehabilitation training. The experimental result revealed an error from the measured value about 1% of percentage error. However, if compared to the number of movement measured at the medical site and the evaluation method based on eye measurement, the measurement using our device system is more objective and quantitatively evaluated.

Meanwhile, Lee et al. who is the researcher and developer of the upper limb motor function rehabilitation system, evaluates it using motion speed, distance and error to recognize the behaviour of the upper limb movement function [1]. Moreover, even in clinical practice for patients with motor impairment disorder, they used the movement distance and the motion pattern to objectively analyse and investigate the progress of the motor function recovery, the mechanism of recovery and the changes occurred to the paralyzed side of the body of the patients [2][3]. During the sanding and wiping movement training evaluated using our system, it is easy to obtain movement distance and error, objectively evaluated the total training capacity and movement area.

The Quantitative evaluation method of our novel optical sensor capable to monitor the progress level of the training and the task improvement easily, thus it expected to improve the patient motivation due to the system feed back to the patient. Moreover, the effect of the quantitatively evaluation feedback received from the movement training which linked to the patient's nervous system, secondarily generated the somatosensory sensation, and feasible to promote function regenerative such as improvement of synaptic transmission efficiency and promotion of axonal outgrowth.

Conclusion and Future

We have developed an innovative device capable of measuring the total movement for sanding and desk wiping movement which is usually implemented in the conventional occupational therapy. More objective and quantitative training evaluation method emphasis to easiness and effectiveness of assessment in upper limb motor function rehabilitation training, thus we developed the measurement system device that capable to quantitatively evaluate the training level of every patient.

As a result of the distance measurement experiment, both the sanding and wiping movement revealed about 1% of percentage error and in sanding movement was about 6 mm, whereas in the wiping movement about 7.5 mm an error existed from the actual measurement value was confirmed. Based on the locus area measurement of the rectangle model, the error existed was about 2.9 cm^2 which was around 1.1% of percentage error, as well as the locus area measurement of the geometric model the error occurred was about 2.9 cm^2 which was nearly 1.2% of percentage error. Therefore, it was suggested that it is effective for quantitative assessment and quantification of patient's training level at clinical site.

In the future, it is necessary to improve the design of our developed measuring device system and need to consider in various point of views before conducting any clinical trials on the targeted subjects.

Acknowledgment

The authors would like to express their sincere appreciation to Mr. Honda, the occupational therapist from Hyogo Prefectural Rehabilitation Centre for his enthusiastic guidance and many constructive ideas throughout this research.

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