Measurement of the arm movement using arm support system with three-dimensional acceleration sensor

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Abstract:

Development of technologies for people with disabilities is necessary to improve the quality of life of elderly people in the future aging society. A light compact arm balancer with three-dimensional acceleration sensors accomplishes that goal. This device particularly features a motion analysis system. Results of experiments show that the program ascertains the speed from the acceleration sensor input. The system has an actual operating principle that is simple and reliable.

1. Introduction

Looking to the emergence of a future aging society, development of welfare and nursing care equipment aimed at improving the quality of life (QOL) of elderly people and disabilities has been sought. [(1)~(3)] Along with the aging population, elderly people and those with disabilities who find it difficult to move their own arms independently because of cerebrovascular damage, bone fracture, or other reasons have been increasing. A new arm movement support device has been developed for elderly people and those with disabilities: the "arm balancer". [(4)] It supports arm movements of those whose muscles are weakened by cerebrovascular damage, bone fracture, amyotrophic lateral sclerosis (ALS), or other reason.

Welfare and nursing care equipment as represented by the "arm balancer" are used as assistance devices. Although qualitative assessment of the ease of use of this device by users was conducted through a questionnaire study, movements of users themselves while using the welfare and nursing care equipment have not been assessed. Healthcare professionals often point out that no system exists to assess beneficial effects on rehabilitation by which a patient with restricted joint contracture and with a limited range of arm reach can increase the arm reach distance and move arms with independent control after rehabilitation.

This study was conducted to construct a system for the quantitative assessment of user movements by measuring acceleration and speed while the user is using the "arm balancer" movement support device. The actual movements of the user are measured using small three-dimensional acceleration sensors. If this system is used with the "arm balancer", then acceleration and speed measurements conducted when arms are moving will be possible. The effects of rehabilitation in terms of how much the patient is improved can be assessed quantitatively and can be used to create a database.

2. Composition of the Arm Balancer

The "Arm-Balancer" consists of the joints and the link and the gas springs. This is a very simple structure. Figure 1 shows the constitution of the "Arm-Balancer". Figure 2 shows the using of the "Arm-Balancer". Table 1 shows specification of the Arm Balancer.

The arm-balancer constitutes of the support arm that protects the wrist part and the swing arm that protects the elbow. The main support part is attached to a direct motion guide that is capable of sliding front and back in a range of about 300mm. Due to rotational joint, the support arm can turn up and down and the and the swing arm can turn horizontally. The gas spring is introduced in the support arm and swing arm to acquire the arm-assist. Apart from the support arm, the combinations of the other parts are formed differently; as a result, right hand specifications can as well be applied on the left hand.

The arm balancer supports three-dimensional operation. Arm actions over a wide area are possible, such as sophisticated writing action and actions associated with drinking coffee while holding a cup, as shown in the figure. The assist force of the arm balancer is a force by which the arm and the wrist are lifted vertically by a gas spring. Therefore, a force against the assist force is necessary when

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swinging down the arm and the wrist. According to the gas spring specification, the design specification of the assist force is 10 N for the arm component and 5 N for the wrist component.

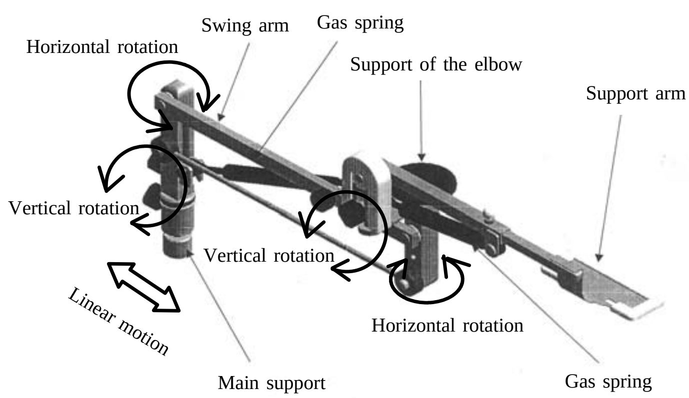


Fig. 1 Composition of the Arm Balancer

Fig. 2 The Arm Balancer in use

Table 1 Specification of the Arm Balancer

Item	Specification
Motion	Main support liner motion Swing arm Vertical rotation Horizontal rotation Support arm Vertical rotation Horizontal rotation
Actuator	Gas spring
Width／ Height	350mm／ 225mm
Support／ Weight	10N(arm)／ 5N(wrist)
Weight	20N

3. EXPERIMENTS

3-1 Experimental device

Figure 3 portrays a schematic view of the movement measurement system of the "arm balancer" produced for this study. A three-dimensional acceleration sensor (KXM52-1050; Akizuki Denshi Co.) was mounted at the elbow part of the "arm balancer." A circuit board for relaying information was used so that wiring could be identified easily. Acceleration when the "arm balancer" is actuated is output in the form of voltage. Then, analog data are converted to digital data by a RT-DAC/USB (Realtek Semiconductor Corp.). The data are input to the PC and voltage data are converted to acceleration data. These processes were performed using a software program. MATLAB simulink (The MathWorks, Inc.) was used for conversion processing. Using RT-DAC/USB, the sampling frequency was set to 20 ms, which enables real-time processing. Outputs from the three-dimensional acceleration sensor include many noise components. Therefore, high-frequency component noises were removed using a low-pass filter having a cutoff frequency of 5 Hz. Voltage data passed through the low-pass filter were converted to an acceleration unit. This acceleration was subjected to integral treatment to calculate the speed. If acceleration is integrated here as it is, then the integral value of acceleration, i.e. speed, will diverge in plus infinity in several milliseconds because of the low-frequency noise of the acceleration sensor. Therefore, the program was devised so that the measurement is reset to zero at the leading edge and trailing edge of the integral value to prevent its divergence in plus infinity.

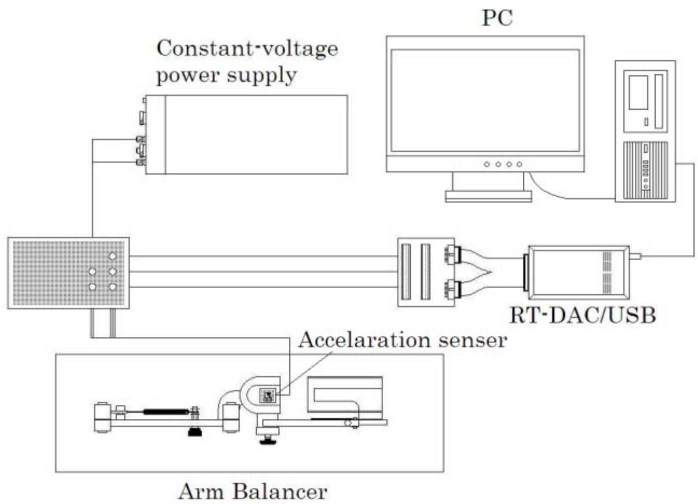


Fig 3 Experimental device.

2.2 Experimental Method

A three-dimensional acceleration sensor (KXM52-1050; Akizuki Denshi Co.) was mounted at the elbow part of the "arm balancer" to collect acceleration data. Figure 4 shows rehabilitation aspects of a so-called sanding movement. With this rehabilitative exercise, a box with a handle is moved forward and backward, then right and left (x-direction, y-direction) two-dimensionally on a table to alleviate joint contracture and to extend the movement range over time.

Figure 4 shows a facility used exclusively for sanding movement at the university hospital. When the patient performs this movement at home, he observes such a movement that the upper surface of a large table such as a dining table is cleaned using a towel or dishcloth. Experiments were performed under the following conditions to simulate the sanding movement. To assess how much the patient recovered his functions after rehabilitation by continuing such sanding movements, an upper limb functional test after cerebral stroke and a simplified upper limb functional test were conducted. Assessment items of these tests are the patient's reach distance, picking up balls or coins, and the time the patient must use to move a cube. Measurement of how far the patient can reach can be performed easily using a measuring stick or a ruler. However, measurement of the speed during each movement is not easy. Therefore, the time for doing a series of movements such as moving a cube five times is measured. In this study, we assessed speeds at which it is difficult to take measurements. To move the arm at a constant speed is collaborative work done by the musculoskeletal system and nervous system of human movements. For that reason, it is extremely important.

Fig. 4 The sanding movement

A three-dimensional acceleration sensor (KXM52-1050; Akizuki Denshi Co.) was mounted at the elbow part of the arm balancer. Figure 5, which depicts a top view of the arm balancer, shows that it performs a linear movement and rotational movement. Motion analysis is performed using the acceleration sensor.

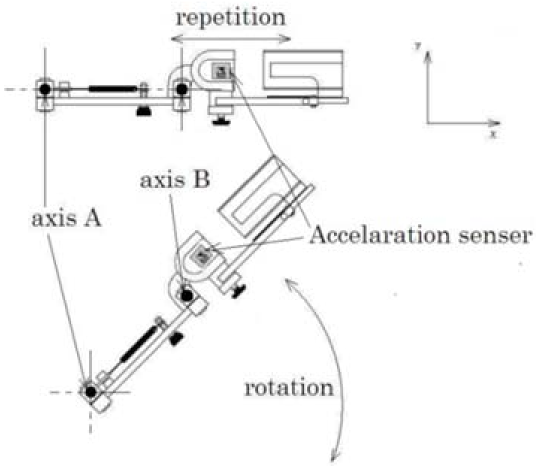


Fig. 5 Experimental Motion of the Arm Balancer

For linear movement, as shown in Figure 6, the arm balancer body was reciprocated 300 mm in the y-axis direction at a constant speed and measurements were taken for 20 s. Experiments were performed under two conditions: 2 s for one reciprocation and 4 s (half speed of the former).

Rotational movements were reciprocated at an angle of about 160° at a constant speed and measurements were taken for 20 s. Experiments were performed under two conditions: 2 s for one reciprocation and 4 s for one reciprocation (half speed of the former)

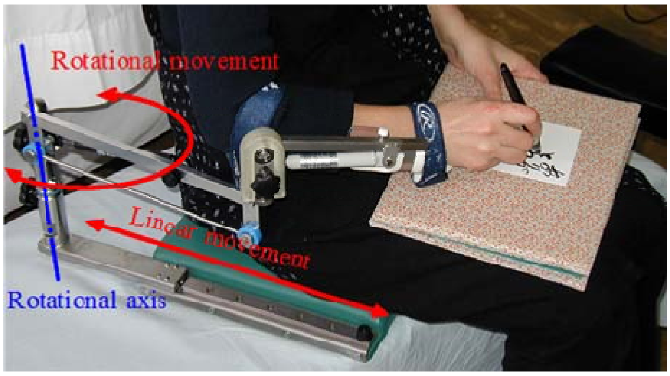
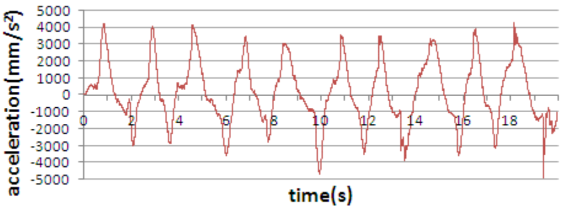


Fig. 6 Motion of the Arm Balancer

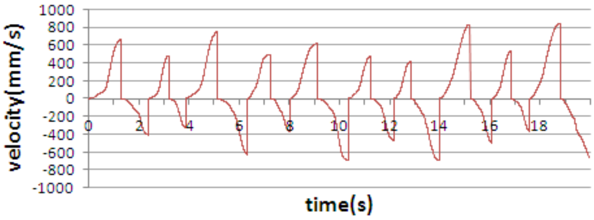
4. RESULTS OF EXPERIMENTS

4.1 y-axis measurement of linear movement

Figure 7 shows measurements, acceleration and speed on the y-axis when the arm balancer performed linear movements, with 2 s for one reciprocation. The graph of acceleration and speed show that positive values and negative values are repeated alternately, thereby indicating reciprocating movements.



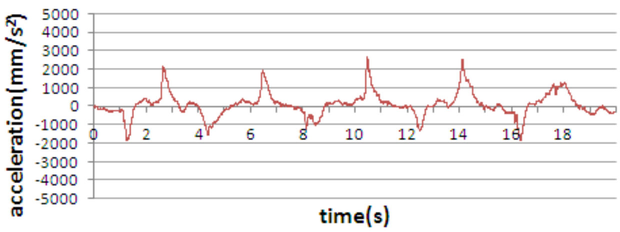
(a) Acceleration on the y-axis



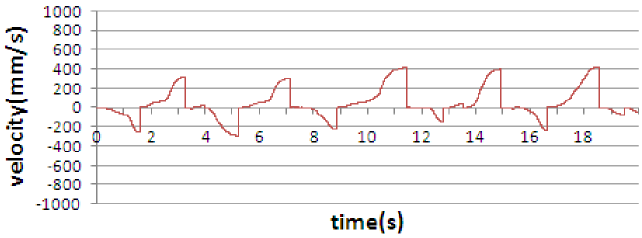
(b) Speed on the y-axis

Fig. 7 Linear movements (2 second for one reciprocation)

Figure 8 presents results of experiments in which one reciprocation took 4 s. It is known that as compared with 2 s for one reciprocation, all numerical figures are smaller and the number of reciprocations is halved.



(a) Acceleration on the y-axis

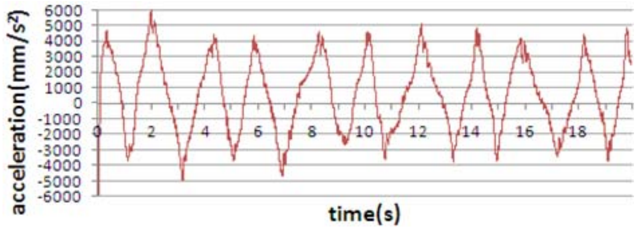


(b) Speed on the y-axis

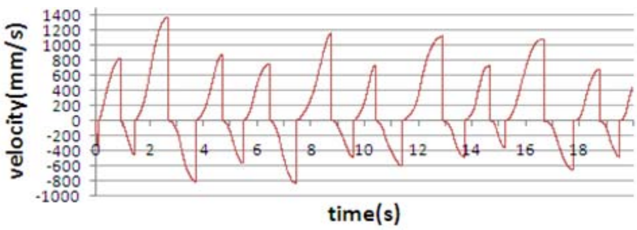
Fig. 8 Linear movements (4 second for one reciprocation)

4.2 x-axis measurement of rotational movement

Figure 9 shows measurements, acceleration and speed on x-axis when the arm balancer performed a rotational movement at 2 s for one reciprocation. Each value repeats rising and lowering, thereby indicating repeated reciprocating movements.



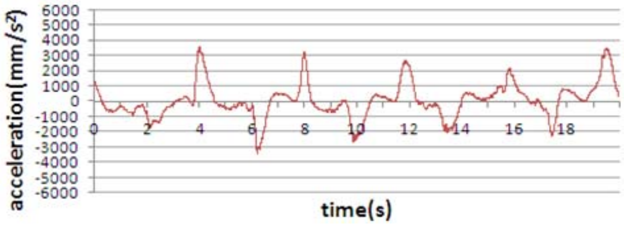
(a) Acceleration on the x-axis



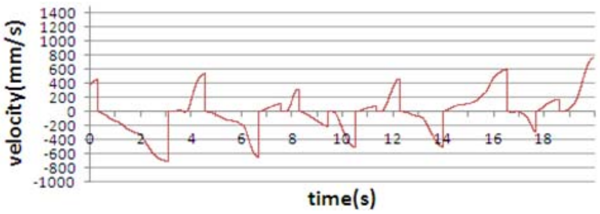
(b) Speed on the x-axis

Fig.9 Rotational movements (2 second for one reciprocation)

Figure 10 presents data obtained when one reciprocation took 4 s. The response was apparently smaller than when data taken when one reciprocation took 2 s. The maximum speed and maximum acceleration are nearly half. The graph shows that actual movements can be sensed.



(a) Acceleration on the x-axis

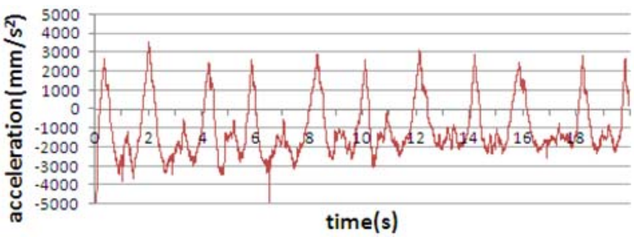


(b) Speed on the x-axis

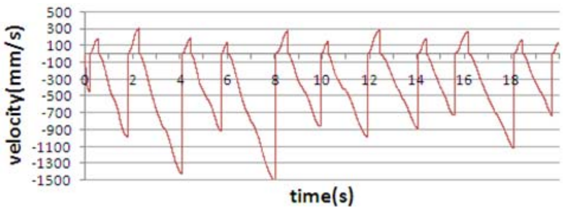
Fig.10 Rotational movements (4 second for one reciprocation)

4.3 y-axis measurement of rotational movement

Figure 11 presents measurements, acceleration and speed on the y-axis when the arm balancer performed rotational movement, with 2 s for one reciprocation. Each value repeats rising and lowering, thereby indicating repeated reciprocating movements.



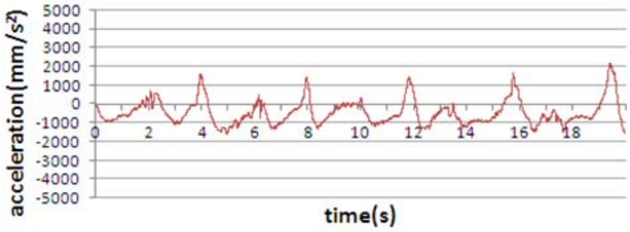
(a) Acceleration on the y-axis



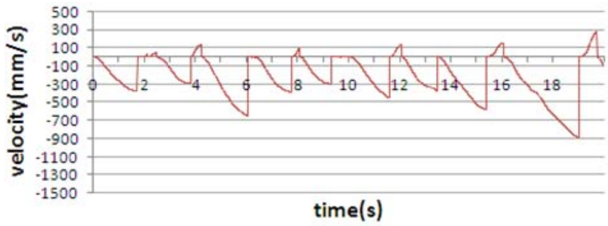
(b) Speed on the y-axis

Fig.11 Rotational movements (2 second for one reciprocation)

Figure 12 shows y-axis data taken when one reciprocation took 4 s. As compared with data taken when one reciprocation took 2 s, data are nearly half and it is understood that actual movements can be read from the graph.



(a) Acceleration on the y-axis



(b) Speed on the y-axis

Fig.12 Rotational movements (4 second for one reciprocation)

5. DISCUSSION

According to the speed of the data shown in Figure 7(b) and Figure 8(c) obtained from the present experiment, the average of speed of one peak is approximately 300 mm/s. These are data obtained when moved actually 300 mm in 1 s. It is therefore considered that the analytical system we established is reliable. Furthermore, it is understood from the graph that one reciprocation took 2 s in Figure 7 and 4 s in Figure 8.

Although it is presumed from the data of rotational movement that both the x-axis and y-axis show reciprocating movements, it is difficult to read the trajectory of actual movements from the data. Numerical figures of speed and acceleration on the y-axis are mostly in the negative direction rather than in the positive direction. This is regarded as attributable to significant influences of centrifugal force generated by rotational movement. Although greater speed entails greater influence of centrifugal force, it is considered that the actual movement speed of the user for using the rehabilitation equipment is not so fast. Therefore, whether or not centrifugal force should be examined remains as a theme for future study.

Measurement of the speed allows verification that the patient can move at a certain speed and that continued rehabilitation leads to improvement. Moreover, measurement of acceleration enables detection of arm trembling during rehabilitation movement. The difference of acceleration and the difference of speed can be ascertained based on the experiment results. It is considered that these might be used as a method of quantitative assessment.

6. Conclusions

In this study, the author specifically examined an "arm balancer" arm movement support device using a link mechanism for elderly people and disabilities. The objective of the study is to take data measurements so that this device can be used as rehabilitation equipment and to check effects by rehabilitation quantitatively. Results of the experiments reveal the findings presented below.

1. A measurement system of arm balancer was constructed.
2. Measurement of the speed from the acceleration sensor is possible.
3. Measurement of the speed and acceleration enables quantitative measurements of effects by rehabilitation using the arm balancer.
4. The trajectory of actual movements at rotational movement is only slightly read from the data alone.
5. With rotational movement exceeding a certain speed, the influence of centrifugal force is significant. However, when used for rehabilitation, the influence of centrifugal force should be examined as a future theme of research.

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