Low cost real-time finger flexion strength measurement system

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Abstract. Human grip strength is important in carrying out daily activities. However, the grip strength may be decreases or affected due to aging or diseases. Thus, hand exercising ball is invented as a rehabilitation device in order improve the physical grip strength. The commercial hand exercising balls comes with different stiffness which are soft, medium and hard without quantitative data. In the rehabilitation, diagnosis and intervention should be done quickly and accurately. The data are crucial for therapist to evaluate and determine the suitable treatment for the patients. A low cost real-time finger flexion strength measurement system is developed to measure the forces required to squeeze the hand exercising balls with different stiffness. The prototype is able to measure the subjects’ grip strength from four fingers without the thumb. Data collected from 10 subjects (6 healthy subjects and 4 patients) with different gender, age, height, weight and health status. The force required to grip the hand exercising ball range from 7.71N to 79.11N for soft ball, 12.80N to 104.08N for medium ball and 19.35N to 165.82N for hard ball

1. Introduction
Hand is the most active part of human body in daily life, and finger flexion is so important to allow someone to hold the handset, carrying bags and baskets, hold the mug etc.

Studies had shown that grip strength has a high correlation with age where the grip strength will decrease gradually due to aging [1]. The reducing of grip strength will begin from approximately 30 years old based on the cross-sectional and longitudinal studies [2]. Study showed that the grip strength have an average decrement 0.5 % to 1 % annually after age of 30 [3]. In certain cases, people may loss their hand movement ability due to accident such as stroke. In such cases, grip strength can be used as a measurement of the degree of impairment in respect to neuromuscular or neurological disabilities suffered after trauma or surgery [4]. In addition, grip strength also served as a good indicator of an individual physical state, especially in an elderly population [5]. Grip-strength measurement has also correlated with various clinical tests [6, 7].

Exercise had been implemented into the treatment of large number of medical disorders[8]. A combination of strength training, aerobic exercise and flexibility exercises can help to reduce medication dependence while maintaining functional independence of the patients [9]. Therapeutic hand exercising ball has been invented as a device for the patients to retain or improve their affected grip strength by constantly gripping it in the palm which can increase their muscle performance [10]. The flexible and spongy therapeutic hand exercising ball is used to exercise the hand muscles and joints by repetitive gripping.
There are few types of therapeutic hand exercising balls can be found in the market. The most common shapes of the ball are the spherical shape and egg shape (Figure 1). Egg shape is chosen in this study because it conforms to the human hand.

Manufacturers had produced hand exercising balls with a variety of stiffness to accommodate various treatment levels. However, the stiffness of the balls is normally categorized as strong, medium and soft, this may lead to controversy because different manufacturers have different standard of strong, medium and soft. The physical therapists had to decide which stiffness should be used for the patients based on their experience. This may have negative impacts for inexperienced physical therapists if they use the wrong stiffness. This not only will affect the effectiveness of the treatment, but also may further injure the muscle of the patients.

According to Guyatt, the measurements of the effectiveness of a physiotherapy intervention should be valid, responsive and interpretable [11]. In the rehabilitation and physiotherapy center, any diagnosis and intervention should be done quickly and accurately [12]. The accurate data are crucial for physical therapist to evaluate their patients and provide suitable treatments or interventions.

Thus, quick and accurate measurement of hand grip strength is crucial for physical therapist to evaluate their patients’ performance and then suggest a suitable treatment or interventions for them.

2. Prototype

Flexible filament type force sensors, Interlink FSR 402 are selected due to its high accuracy, fast response time, high consistency, long lifespan and low cost.

The size of the hand exercising ball is small to be gripped firmly using four fingers only; hence the thumb force is not been included this study. Figure 2 shows the standard gripping pattern used to hold the hand exercising ball, it can be seen that the thumb is not pressing or touching any part of the ball. Thus, the sensors are placed at the tip of index, middle, ring and little fingers which contributed most of the gripping force.

The sensor is fixed on the elastic rubber which can be secured on finger with Velcro tape. The elasticity of the rubber allows the sensor to be fixed on any size of finger (Figure 3).
Figure 3. Sensor placement. (a) Fingers place on the elastic rubber with sensors. (b) The elastic rubbers are wrapped around the finger and secured with Velcro tape. (c) Sensors secured on the finger tips

The circuit design of the force sensor is shown in Figure 4. The system is power up with a 9V battery, and connects to computer via Arduino Uno. Two LED feedback is added to attract the attention of children, the first LED will light up when first threshold value been achieved, then both LED will light up when second threshold been achieved (Figure 5).

Figure 4. Circuit Design of the system

Figure 5. LED feedback. (a) No LED light without force. (b) Red LED light up when first threshold achieved. (c) Both LED light up when second threshold achieved

Study of Haidar showed that the dominant hand of the subjects has higher maximum grip strength than the non-dominant hand [4]. Grip strength was found to be closely correlated with the position of elbow and shoulder [13]. As recommended by American Society of Hand Therapists, the subject will flex their elbow at 90 degrees and rest their hand on table / chair arm / on the lap when performing the hand gripping exercise. Soft ball is put at horizontally on the palm and subject will fully flex their 4 fingers to apply maximum force on the ball repeatedly in 30 seconds. 5 minutes rest time is provided before the subject continues with middle stiffness and hard ball. Average of three maximum forces of each trial will be calculated.
A real-time display on monitor shows the force result and the maximum force will display at the end of each trial, as shown in Figure 6.

![Figure 6. Real-time result for 1 trial](image)

3. Data collection
The system has tested on 6 healthy subjects and 4 patients with different gender and age. The sensors are placed onto the fingers of dominant hand of the subject and the forces exerted onto the therapeutic hand balls with different stiffness are recorded. The gender, age, height and weight of the subjects are shown in Table 1 and Table 2.

### Table 1. Normal subject information

| Subject | Gender | Age | Height | Weight |
|---------|--------|-----|--------|--------|
| 1       | Female | 23  | 165cm  | 44kg   |
| 2       | Female | 58  | 160cm  | 55kg   |
| 3       | Male   | 23  | 171cm  | 50kg   |
| 4       | Male   | 25  | 170cm  | 75kg   |
| 5       | Male   | 60  | 171cm  | 80kg   |
| 6       | Male   | 7   | 115cm  | 18kg   |

### Table 2. Patient subject information

| Subject | Gender | Age | Height | Weight | Disability          |
|---------|--------|-----|--------|--------|---------------------|
| 7       | Female | 19  | 163cm  | 55kg   | Learning disability |
| 8       | Male   | 11  | 145cm  | 38kg   | Learning disability |
| 9       | Male   | 14  | 155cm  | 44kg   | Hydrocephalus       |
| 10      | Female | 14  | 157cm  | 40kg   | Apert Syndrome      |

The 4 fingers full flexion gripping force for each subject is summarized in Table 3.

The system success to capture the gripping force created by 4 fingers full flexion, except subject 10 whose suffer with Apert syndrome unable to bend her hand, therefore no gripping force been recorded.
Table 3. Result

| Subject | Soft Ball (N) | Medium Ball (N) | Hard Ball (N) |
|---------|---------------|-----------------|---------------|
| 1       | 28.97         | 29.29           | 39.21         |
| 2       | 36.69         | 46.97           | 45.08         |
| 3       | 37.33         | 61.91           | 64.13         |
| 4       | 67.40         | 104.08          | 165.82        |
| 5       | 79.11         | 94.91           | 102.32        |
| 6       | 16.15         | 19.45           | 20.35         |
| 7       | 17.88         | 20.58           | 35.65         |
| 8       | 7.71          | 12.80           | 20.00         |
| 9       | 12.36         | 17.27           | 19.35         |
| 10      | -             | -               | -             |

4. Discussion Conclusion

The developed low cost real-time finger flexion gripping strength measurement system able to collect data from various age group, gender, healthy subjects and patients.

![Gripping force result for soft, medium and hard stiffness ball.](image)

The results showed that the grip force increases as the stiffness of the hand exercising balls increases from soft to hard. The force required to grip the hand exercising ball range from 7.71N to 79.11N for soft ball, 12.80N to 104.08N for medium ball and 19.35N to 165.82N for hard ball. Generally, adult male has higher average grip strength than adult female. Patients have relatively lower grip force compared to healthy subjects. Subject 4 (male, bodybuilder) has the highest average grip force which is 165.82N and subject 9 (patient with hydrocephalus) has the lowest average grip force which is 19.35N. On the other hand, the elderly male and female has higher grip force than the adult male and female.

Overall, the result obtained from this study is much lower than standard grip force recorded from healthy subject. This may due to the lack of thumb force in measurement. According to the fingers force sharing analysis done by Quaine [14], thumb force has a contribution of approximately 100N. Hence, this explained why the experimental results show much lower reading than other studies.

5. Conclusion

This study success to develop a low cost real-time finger flexion strength measurement system, which is light weight and portable, it is also a user friendly system which required minimum setup time. This system able to measure the gripping force regardless of age, gender, size of finger and health status of subject.
6. Limitation and future work
The system only able to measure 4 fingers reading without thumb, it is recommended to top up another sensor at thumb in the future. The system may modify to include the finger extension strength for further rehabilitation purpose. Current system had been provided with visual feedback, however, sound feedback like buzzer or alarm may introduce to improve the attention of subject, and this may also benefit to the subject with vision impairment.

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