Detection System Design of the Glenohumeral Joint Motion Information

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Abstract: Due to the complex coupled motion of shoulder mechanism, design the guiding movement rule of rehabilitation robot generally lack of the glenohumeral (GH) joint motion information. This study focused on development detection system design of the GH joint motion information. In this paper, the detection system incorporates the detection mechanism and measurement system. Design of the detection mechanism includes model of the shoulder complex, configuration as well as structure design of the detection mechanism. Design of the measurement system includes hardware selection and software development. Straight after, detection system was integrated. Then, test and analysis was presented. The results show the detection system can measure and present the GH joint motion information in real time. It provides a method to obtain the movement information of the GH joint, and has practical significance for shoulder function simulation and ergonomics.

1 INTRODUCTION

With the aggravation of aging and traffic accidents happen frequently, more and more patients with upper limb motor dysfunction. To repair upper limb injury, rehabilitation training equipment is more and more popular. Due to most of the joints movements of the upper limb need to be based on the glenohumeral (GH) joint motion, obtainment the GH joint motion information is very important to design the structure of upper limb rehabilitation training equipment and is of practical significance to ensure the rehabilitation training effect of the affected limb (Kirsch, 2001; Kiguchi, 2011).

The GH joint is one of the joints in the shoulder complex and the shoulder complex is an especial complicated and correlative system (Tobias, 2009), which results in extremely complex GH joint movement. Although many researchers have studied the coupled motion of the shoulder complex, only a small amount of quantitative information on the GH joint is available in the existing literature (Yang, 2005). Thus, to find a method to quantize the daily movement information of the GH joint is necessary. In this paper, the motion information detection system of the GH joint is developed, which provides a method to obtain the movement information of the GH joint, and can obtain and present the GH joint motion information in real time.

2 DETECTION SYSTEM DESIGN

2.1 Model of the Shoulder Complex

To obtain the motion information of the GH joint, it is necessary to understand the shoulder complex due to the GH joint is one of the joints in the shoulder complex. Generally, the shoulder complex consists of the shoulder girdle and the humerus, and the humerus connects to the scapula of shoulder girdle through the GH joint (Klopčar, 2006). The shoulder girdle includes three bones (the scapula, sternum, and clavicle) and three joints (the sternoclavicular (SC), scapulothoracic (ST), and acromioclavicular (AC) joints). As shown in Figure. 1. The GH joint is composed of the humeral head and the glenoid cavity of the scapula, which is usually equivalent to a spherical joint, and the kinematics of the AC, ST, and SC joints are not clear (Yang, 2005); Thus, it is difficult to understand the motion characteristics of the GH joint relative to the sternum.

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Theoretically, all of the joints and bones of the shoulder complex that exhibit 6-degree of freedom (DOF) are particularly complex. Practically speaking, some researchers, who are just looking for an equivalent kinematic structure considering the overall motion characteristics, do not wholly replicate the shoulder complex. The mechanistic theory of joint physiology is helpful for understanding the shoulder complex kinematics (Maurel, 2000; Lenarčič, 2006; Tondu, 2006).

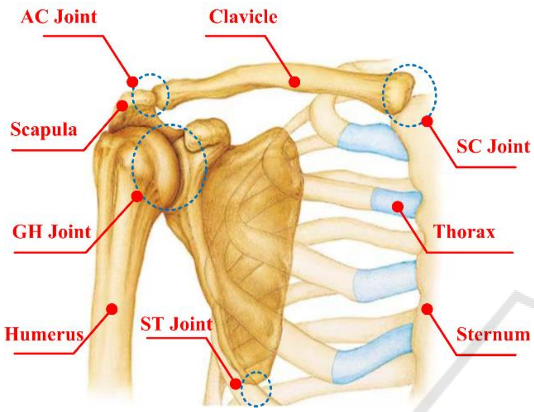


Figure 1. Anatomy of the shoulder complex.

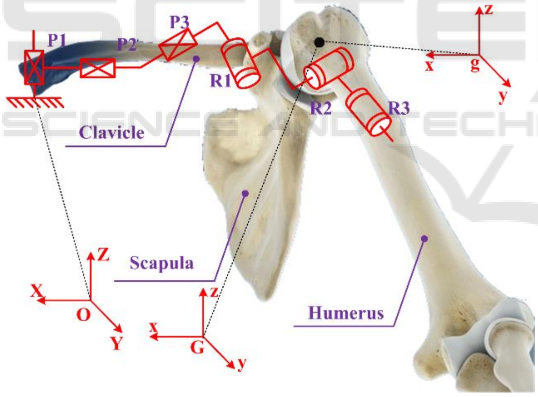


Figure 2. Mechanism model of the shoulder complex.

For the GH joint has three revolute DOFs with the axes intersecting vertically in the GH joint center as well as moves with the functional relevance of the shoulder girdle during humeral movements and according to the knowledge of theoretical mechanics, the general motion of a rigid body can be decomposed into translation following any of the base points and rotation relative to the base point. Thus, the shoulder girdle is assumed to be a platform. The mobile reference frame is established on the shoulder girdle, and the origin of the mobile reference frame is G. Relative to the global coordinate system: O-XYZ, the G point has three translational DOFs. The fixed connection coordinate frame is established on the humerus head, and the origin, represented by g is a point on the humerus head coincident with the GH joint center. Relative to the mobile reference frame, the humerus has three rotational DOFs with the axes intersecting vertically in the g point in space. In this way, a generalized GH joint with floating center (i.e., a 3-DOF spherical joint with floating center, whose center displacement variable relative to the sternum is coupled with its rotation) has been presented, as shown in Figure. 2.

2.2 Detection Mechanism Design

2.2.1 Mechanical Analysis of DOF

According to the model of the shoulder complex, the GH joint possesses six DOFs (three rotation and three translation). In order to completely track the GH joint, the detection mechanism possess three vertical orthogonal translational joints and three rotational joints with the axes intersecting vertically in GH joint center. From the view of the theory of mechanism, the DOF of the detection mechanism meets the requirements.

2.2.2 Structure Design of the Detection Mechanism

The self-tracking mechanical system includes horizontal tracking mechanism, vertical tracking mechanism that includes a pulley mechanism, and wearing mechanism, which are presented in figure. 3. The function of the self-tracking mechanical system can be able to fully track the motion information of the GH joint. The following are the description of horizontal tracking mechanism, vertical tracking mechanism, and wearing mechanism in details.

Horizontal tracking mechanism poses two DOFs, which is mounted on the support plate. It consists of two interconnected guide strip slide mechanism which are equivalent to prismatic joints and tracks the GH joint displacement variable in the horizontal plane(two guide strip slide mechanism has sufficient range of motion to track the horizontal motion of the GH joint).

Vertical tracking mechanism poses one DOF, which is mounted on the horizontal mechanism. It consists of one guide strip slide mechanism and a pulley mechanism. The guide strip slide mechanism tracks the GH joint displacement variable in the vertical axis direction, which has sufficient range of motion to track the vertical axis direction motion of the GH joint. The pulley mechanism can balance the gravity of the vertical guide strip slide mechanism.

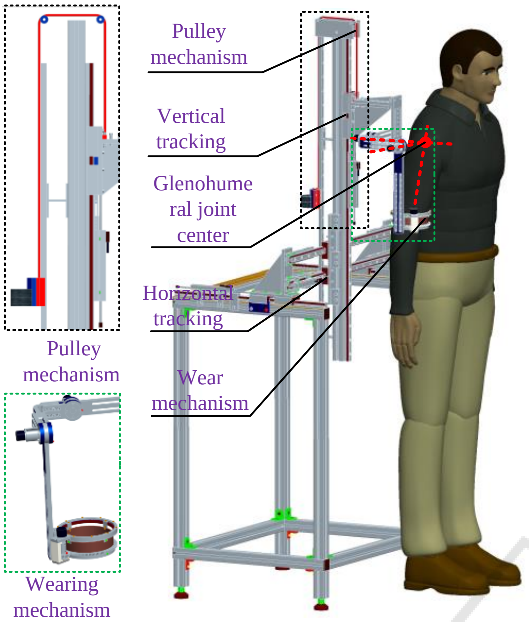


Figure 3. Detection mechanism

Wearing mechanism has three revolute DOFs with the axes intersecting vertically in the GH joint center, which is mounted on the vertical mechanism. It consists of three revolute joints which are connected to each other and is to track three-dimensional rotation of the GH joint.

2.3 Measurement System Design

Figure. 4 is the measurement system schematic diagram, which includes the hardware and software.

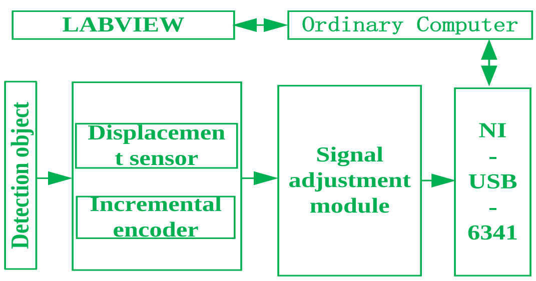


Figure 4. Diagram of measurement system

2.3.1 Hardware of the Measurement System

The hardware mainly includes three displacement sensors (NS-WY-02), three incremental encoders (CFZ2124-3600-06-14F), signal adjustment module, and a collection card of NI-USB-6341. The function of the displacement sensor is to obtain the displacement variable of the GH joint in three dimensions. The incremental encoder is to obtain the angle motion information of the GH joint during humerus rotation movement. The signal adjustment module is to adjust the weak signal of the sensors and the incremental encoders. The NI-USB-6341 is to obtain the adjustment signal which can be transmitted to the ordinary computer via USB port, the actual components are presented in figure. 5.

Figure 5. Diagrams of components

2.3.2 Software of the Measurement System

The displacement sensor outputs voltage signal and the encoder outputs digital signal. Thus, this detection system needs to detect three channels of analog voltage signals, three channels of digital signals, and the six channels of signals are required for synchronous acquisition. The collecting information of the three encoders use three counters as well as the information of the three displacement sensors and synchronous acquisition is a conventional collection.

Using LABVIEW to develop the underlying application, specific programming principle is as follows: First of all, establishment three-way analog input channels collect voltage signal and establishment a three-way counter signal acquire encoder Angle. Using the data line of the error message to arrange the parallel execution sequence and the counter to synchronize the trigger signal. The analog input channel and counter acquisition channel are set to the same sampling rate and synchronization trigger counter clock source, so as to realize synchronization of all signal acquisition.

2.4 Detection System Integration

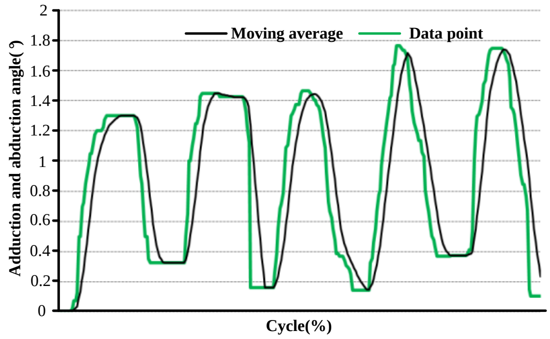
Combined with the data measurement system described in the above section, the rotation information of the GH joint can be obtained through the connection of the encoder, coupling, and the detection mechanism; the translation information of the GH joint can be acquired through the connection of the displacement sensor and the detection mechanism. Then, the GH joint motion information detection system is obtained.

Figure 6. System integration.

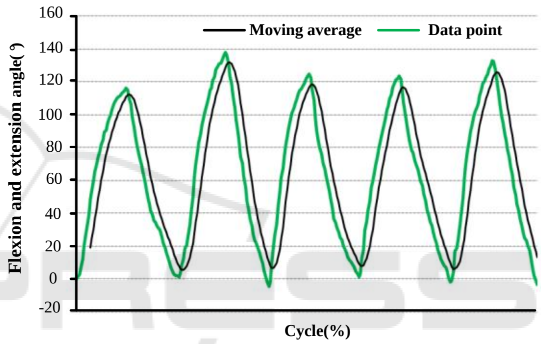
The whole system starts from the tested object and converts it into electrical signal through the sensor and encoder. After the signal conditioning module, the signal is sent to the data acquisition card (NI-USB-6341) for collection and then process by the software. The data curve in the acquisition process is displayed on the monitor in real time. The structure diagram of measurement system and detection system integration is shown in figures. 4, 6.

3 TEST AND ANALYSIS

The prototype of the detection system is shown in Figure. 6. At the beginning of the test, the tester weared the detection mechanism and the experimenter made the wearing device's three rotational joints with the axes intersecting vertically in GH joint center. Then, the tester rotated humerus complete the flexion and extension movement in five cycles, and the detection system presented and recorded the GH joint motion data. One set of data was described below: Tester (age 26 years; height 179 mm; weight 82kg; arm length 551.5mm) made humerus complete the flexion/extension movement in five cycles. Experimental results, which are the GH joint motion data during flexion/extension movement in five cycles, are shown in Figure.7.



(a)



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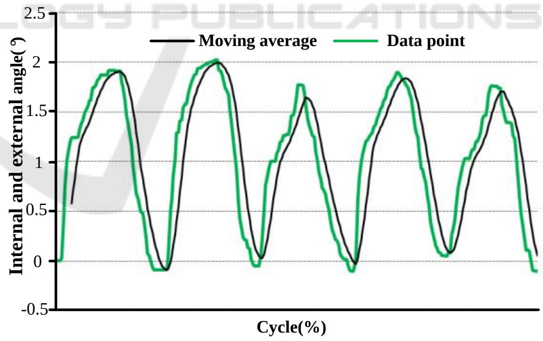
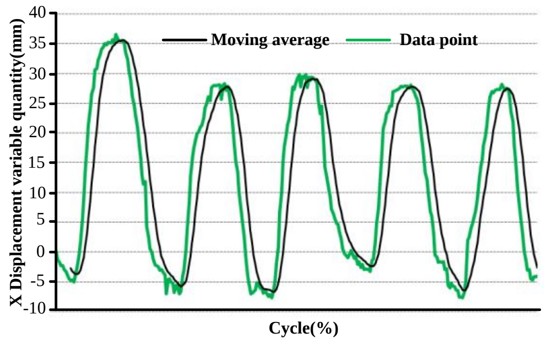
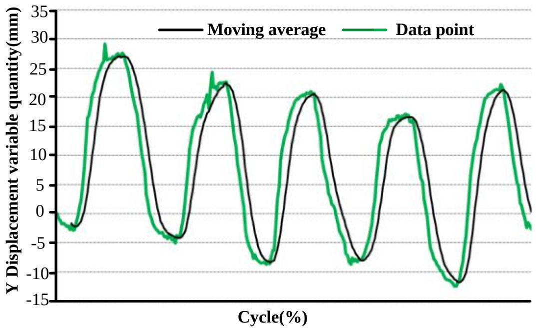


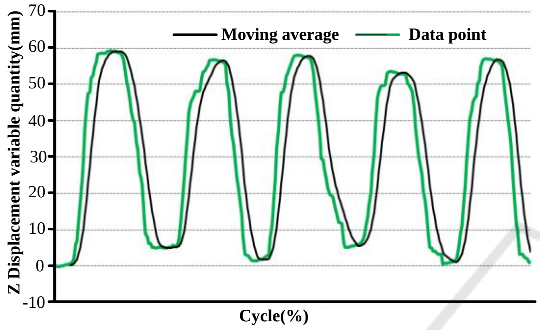
(c)



(d)



(e)



(f)

Figure 7. Diagrams of the GH joint motion information relative to the sternum during humeral natural flexion and extension rotation in five cycles: (a) humeral adduction and abduction rotation angle, (b) humeral flexion and extension rotation angle, (c) humeral internal and external rotation angle, (d) *X* of the GH joint displacement variable, (e) *Y* of the GH joint displacement variable, (f) *Z* of the GH joint center displacement variable.

Fig. 7 shows the green curves (black lines is the moving average) for the tester performing humerus flexion/extension nature movement in five cycles and the angle range is about 120°. The movements of the GH joint in three dimensionsin (adduction/abduction, flexion/extension, and internal/external) and the GH joint center displacement variable in the X, Y, and Z directions are observed, which are presented in (a), (b), (c), (d), (e), and (f), respectively. During the nature flexion/extension movement of the humerus, a small amount of adduction as well as abduction and internal as well as external movement occurs with the lifting process. This phenomenon is normal during the natural flexion/extension movement of the humerus, because it is impossible for the humerus lifting process to completely guarantee in the sagittal plane. However, the GH joint center displacement variable large and regular in the X, Y, and Z directions confirmed the coupled motion of the shoulder complex. Subsequently, a great deal of tests and analyses were performed, the above similar results are also presented.

4 CONCLUSIONS

In this paper, a kinematic model of the shoulder complex (3-DOF GH joint with floating center) was proposed. Then, a detection system was designed. Real-time GH joint motion information was obtained, which confirmed the rationality of the shoulder complex model and detection system.

It provides a method to obtain the movement information of the GH joint and the detection system can obtain the fundamental motion data of human shoulder motion. Which has practical significance for shoulder function simulation and ergonomics.

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