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Design of an accurate end-of-arm force display system based on wearable arm gesture sensors and EMG sensors

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ABSTRACT

Most upper limb rehabilitation patients are still hard to feel the accuracy force they have imposed in the end of arm after a systematic upper limb rehabilitation. In order to provide an accurate end-of-arm force for those disabled people, a force display system based on wearable arm gesture sensors and Electromyographic (EMG) sensors is designed and given in this paper. The wearable arm gesture sensors and EMG sensors are specially placed to detect the arm gesture and the EMG signal of the arm, and a force sensor is used to measure the force and verify the force display effect. In order to control the rehabilitation arm move slowly at a constant speed, the kinematic model of the upper arm is analyzed. A special experiment platform is established so as to get the simultaneous data of end-of-arm force and the arm gesture and EMG signal, then the Generalized Regression Neural Network (GRNN) is brought in to catch the relationship between them. A group of horizontal movement experiment and vertical movement experiment are designed specially and verify the feasibility and effectiveness of the system. The result shows that the information fusion based on GRNN for this system could accurately display the end-of-arm force.

1. Introduction

Nowadays, many disabled people and old people have a dyskinesias problem with their arms caused by stoke or an unfortunate accident [1,2]. As the improvement of robot skill and medical technology, many effective therapies [3,4] are brought in to try to solve the arms' dyskinesias problem, especially the special rehabilitation training for the disabled arm, and many rehabilitation robots [5] with different structure and function have been designed and took into the application.

Colombo [6] presented two rehabilitation robot devices for the upper limb, including a one degree of freedom wrist manipulator and a two degree of freedom (DOF) elbow-shoulder manipulator, and an admittance control strategy is given to control the robot move smoothly with a mean velocity. Chen [7] presented an assistive control system with a special kinematic structure of an upper limb rehabilitation robot based on the NTUH-ARM. Three rehabilitation modes including active mode, assistive mode and passive mode are conducted to help the impaired limb move and do the rehabilitation exercise. Xu [8] presented control strategies for an upper-limb rehabilitation robot based on the BARRET WAM, including a fuzzy-based PD position control strategy under the passive recovery exercise to control the WAM Arm stably and smoothly to stretch the impaired limb to move along predefined trajectories, and a fuzzy logic regulator in the active motion mode to adjust the desired impedance between the robot and impaired limb to generate adaptive force in agreement with the change of the impaired limb's muscle strength.

Although some of the upper limb rehabilitation robot could positively make the arms recovered with much flexibility and controllability, however, the arms are still impossible to be healed as a regular arm of a normal person, and the new problem which always occurs after the arm upper limb rehabilitation was completed is that the rehabilitation patients are still hard to accurately feel how much force they have used in the end of the impaired arm, and they could not almost handle an object stably. Therefore, in order to solve the force display problem for the rehabilitation patients, an accurate end-of-arm force display system is designed in this paper based on information fusion with arm gesture and

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Fig. 1. Body sensors network kit.

EMG signal. A lot of information fusion approaches [9–11] have been presented by the researchers all over the word, and some of them are put into application and works well. In this paper, GRNN is chosen to fuse with arm gesture and EMG signals because it has a great advantage in nonlinear mapping ability and learning rate.

The remainder of this paper is organized as follows. First, Section 2 describes the system architecture, including the wearable arm gesture sensors part, wearable EMG sensors part and the force measurement and display part. Kinematic model of the upper limb is established in Section 3, and information fusion approach based on the GRNN is described in Section 4. In Section 5, experiments platform is specially designed and described, and the comparison between the force derived by the force display system and the real force is given, and at last conclusion is given in Section 6.

2. System architecture and analysis

In order to provide an accurate end-of-arm force for the disabled people, especially for those who have completed upper limb rehabilitation but still could not have the accurate sense of force in the end of arm, a force display system is established, including the wearable arm gesture sensors part, wearable EMG sensors part and the force measurement and display part.

2.1. Wearable arm gesture sensors part

Wearable arm gesture sensors part is constituted of an arm sleeve, a short glove, and three-dimension (3D) angle sensors, and other auxiliary components, as shown in Fig. 1. The arm sleeve and the short glove are designed as an open circle and could be easily fastened, and it is portable and suitable almost for every adult people. The 3D angle sensors are placed on the different position individually to detect the angles of different part of the arm, as shown in Fig. 2. Therefore, it is easy to get the eulerian angles of the upper arm, forearm and the hand.

The core device of the 3D sensor is ADXL362(Analog Device). It's ultralow power, 3-axis MEMS accelerometer. It can provides 12-bit output resolution. Measurement ranges of ±2 g, ±4 g, and ±8 g are available, with a resolution of 1 mg/LSB on the ±2 g range.

2.2. EMG sensors part

EMG signal is a compositive superposition of many muscle motor unit action potentials from both time and space domain, and reflect the status of neuromuscular function. EMG signal is a kind

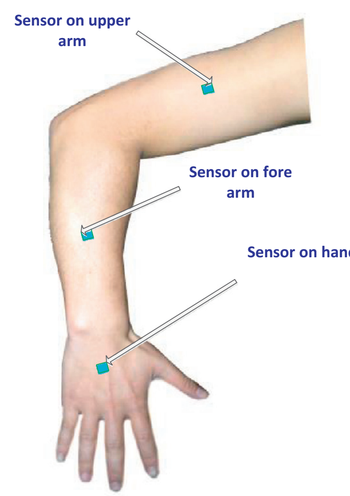

Fig. 2. Arm gesture sensors distribution.

Fig. 3. EMG sensors.

of quite weak signal with range from 100 to 5000 μV. Every EMG sensor has three poles, including '+', 'GND' and '−', and the difference of every two near poles is 6 mm, as shown in Fig. 3.

The structure diagram of the conditioning circuit of the EMG sensor is shown in Fig. 4. The voltage gains of the two amplifiers, A1 and A2, are set as 15 and 40 respectively. The high-pass filter (cut-off frequency: 10 Hz) is used to remove the direct current component from the signal. The low-pass filter (cut-off frequency: 500 Hz) is used to eliminate the high-frequency noises. The voltage gains of these two filters are about 1.3. The notch filter is used to reduce the 50 Hz power-line interference. Since the input range of the data collector is from 0 to 3 V, we design the level-rising circuit to make the voltage of the signals greater than 0 V.

A group of two EMG sensors are attached and clinged to the skin of fore arm, and have enough contact area with fore arm. EMG signal captured by the EMG sensors is a time series signal which can describe the characteristics of the hand action after necessary