SMART EMG SLEEVE FOR MUSCLE TORQUE ESTIMATION

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In this study, the smart EMG sleeve is developed. Through integrating the wearable EMG device, the smart EMG sleeve become more comfortable, therefore the user will not feel the existence of electrodes. The proposed EMG sleeve can measure the EMG and movement of arm and the new kind of fabric electrode is also developed to reduce the drawback of traditional electrodes. The fabric electrodes can provide very comfortable feeling for user. In order to transfer the raw EMG to useful information, the Kalman filter is also introduced, then the relationship of filtered EMG and biceps torque are calculated. The proposed smart EMG sleeve not only measure the EMG signal, but also estimate the torque and can be used in homecare and exercise.

1. Introduction

There are many diseases to cause the movement disability; therefore they need to have rehabilitation in hospital. On the other hand, it is a large population of exercise in the modern era. The need to monitor the muscle performance is increased dramatically. Traditional EMG monitor is too huge to use in the outside and the traditional electrode is very uncomfortable for user. In 2015, the wearable device has been the hottest word, there are some research already develop the wearable EMG device [1, 2, 3, 4]. They already overcome the inconvenience of wired EMG device. But this study try to integrate the wearable EMG device to become more comfortable smart cloth, therefore the user will not feel the existence of electrodes. Beyond this idea, the novel EMG sleeve is proposed to measure the EMG and movement of arm and new kind of fabric electrode to reduce the drawback of traditional electrodes. So the following application can go out the hospitals into sport and homecare area.

2. Methods and experiments

2.1. Fabric electrodes

For the low EMG signal, the Silver knitting fabric electrode with low resistance is designed. The property is shown as Table 1. To test the performance of fabric electrode, the resistance of 10 cm interval was measured 3 times and under three condition: 1. Measure the resistance of dry electrode directly; 2. Measure the resistance after putting fabric electrode into acid liquid 24 hours and placing in the shade to dry; 3. Measure the resistance after putting fabric electrode into alkali liquid 24 hours and placing in the shade to dry according ISO105-E04. The result shows the maximum resistance is below 16.8Ω in all testing. It is good enough to measure the EMG signal.

Table 1. The resistance of 3 types of conductive fabric.

Fabric Electrode	Values
yarn	
Fabric electrode	
Yarn	Silver filber 70d/34f
Dry fabric	1.2±0.1Ω
acid liquid	14.7±2.1Ω
alkali liquid	6.5±0.8Ω

2.2. System architecture of EMG and motion module

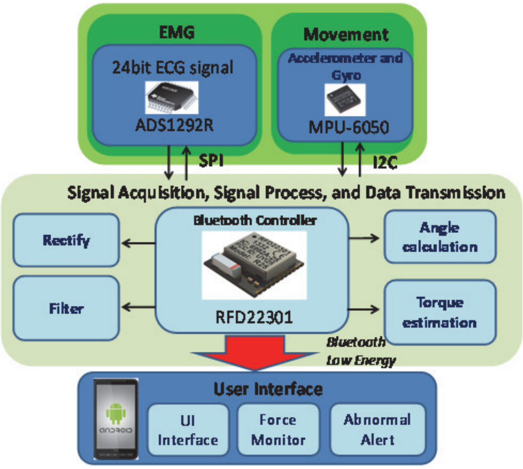

Figure 1. The system architecture of wearable EMG module.

The 24-bit ADC ADS1294 (TI, Dallas, TX, USA), gyro & accelerometer MPU-6050 (InvenSense Inc., Sunnyvale, CA, USA) are integrated together to become a wearable EMG sleeve and the system architecture of EMG sleeve is showed as Figure 1. The textile electrodes will sense the EMG and the 24-bit ADC is chosen for biceps and triceps EMG sensing. The 16-bit 6-axial accelerometer and gyro is chosen for movement detection. The module also includes the low energy Bluetooth module for wireless transmission and it can be driven by a small 1632 button battery. For long time monitoring, it is designed as a light and wearable device. The user can put the device on the sleeve by buttons easily. Through the cell phone application, the EMG and movement signal can be showed for users in real time.

2.3. *User interface*

In order to measure the EMG and movement, TTRI developed the elastic textile electrode and integrate the fabric electrodes into smart sleeve, shown as Figure 2(a). EMG of antagonist muscles and movement is sensed by the fabric electrode on the sleeve. There are two fabric-based electrodes on each muscle bally. The electric contacts between the fabric-based sensor and the Bluetooth controller are achieved by metallic buttons. The overall of smart sleeve is showed in Figure 2(b).


(a) (b)

Figure 2. Configuration of smart sleeve and interface: (a) the designed smart sleeve; (b) the wearable smart sleeve.

2.4. *Kalman filter for muscle strength estimation*

The EMG signal can be used to estimate the muscle torque and muscle fatigue. However, it is not easy to analyze and transform EMG into torque directly because the EMG signals are time-variant and non-stationary and the movement signal will also affect the EMG signal. In order to solve those problems, the EMG raw data will be filtered by 20Hz high-pass and 400Hz low-pass filters. Then, the Kalman filter is used to preprocess the rectified EMG signals. After filtering by the Kalman filter, the linear Regression will be used to estimate the elbow torque via the stable EMG signals. The following shows how we utilize the Kalman filter to obtain the estimated muscle strength. Because the muscle strength does not change rapidly, the state-space model for muscle strength is simply set as Eq. (1). The measurement model describes the relationship between the measurements and the process state is defined as Eq. (3). x_k is the state estimation variable of muscle strength and w_k is the process noise. $z_k \in \Re^1$ is the measurement muscle strength and $v_k \in \Re^1$ is the measurement noise form EMG electrodes.

$$x_k = x_{k-1} + w_k \tag{1}$$

$$z_k = x_k + v_k \tag{2}$$

Here, w_k and v_kv are assumed to be white, independent and have normal probability distribution.

$$p(w) \sim N(0, q) \tag{3}$$

$$p(v) \sim N(0, r) \tag{4}$$

The $q \in \Re^1$ is the process noise covariance matrix and $r \in \Re^1$ is the measurement noise variance. They might change with each time step. The procedure for discrete Kaman filter of muscle strength estimation is to predict the state variable under the last state estimation in the time-update cycle and adjust the state variable according the measured muscle strength in the measurement-update cycle.

Time update

$$\hat{x}_k^- = \hat{x}_{k-1} \tag{5}$$

$$p_k^- = p_{k-1} + q \tag{6}$$

Measurement Update

$$k_k = k_k^-(p_k^- + r)^{-1} \tag{7}$$

$$\hat{x}_{\mathrm{k}} = \hat{x}_k^- + k_k(z_k - \hat{x}_k^-) \tag{8}$$

$$p = p_k^- - k_k p_k^- \tag{9}$$

Here, $\hat{x}_k^- \in \Re^1$ is the prior state estimate of muscle strength at step k and $\hat{x}_k$ is the posteriori state estimate of muscle strength at step k given measurement muscle strength z_k. $p_k^- \in \Re^1$ is the priori estimate error variance and $p_k \in \Re^1$ is the posteriori estimate error variance. The k_k is the gain to minimize the posteriori error variance p_k.

2.5. Linear regression and experiment procedure

The angle of forearm and gravity direction be caculated by forearm accelerometer. The elbow torque will be calculated by the angle, arm of force, and the weight of dumbbell, showen as Eq. (10). The subject was instructed to move his forarm from 0 to 90 degree under 0lb, 5lb, 10lb and 15lb dumbell and the four EMG signal, two 3-axial accelerometers, and 3-axial gyros was record. The sample rate of EMG is 1000Hz and the accelerometers and the gyros are 125Hz. We will use the calculated torque and filtered EMG to find the relationship of elbow torque and the filtered EMG signal of biceps through linear regression. τ_{biceps} is the estimated torque of biceps, $m_{dumbbell}$ is the mass of dumbell, m_{forarm} is the mass of forearm, g is the gravity and equal to 9.8 m/s^2, the L is the forcearm of dumbell and elbow, and the L_c is the mass center of forearm.

$$\tau_{biceps} = m_{dumbbell} \cdot g \cdot L \cdot \sin\theta + m_{forarm} \cdot g \cdot L_c \cdot \sin\theta \qquad (10)$$

3. Results and conclusions

The results of EMG signal processing is shown as Figure 3. Through the rectify and the filtering, the filtered EMG signal is clear, the variation is changed according to the elbow torque. The regresion are applied in the test of lifting 0lb, 5lb, 10lb, 15lb, and all. The black line is the overall result and therefore we can estimate the torque through the regression equation. From 0lb to 15lb, the stepness become lower, it is because the nonlinear property of EMG. When the EMG signal is become larger, the generated torque will increase slower. Thorough experiment, it shows the smart sleeve can not only detect the EMG, angle, and torque, but also the muscle torque is also estimated by the kalman filter and linear regresion. The torque information can be use to let the user know the muscle condition and the user can adjust their exercise program to make the exercise more efficient.

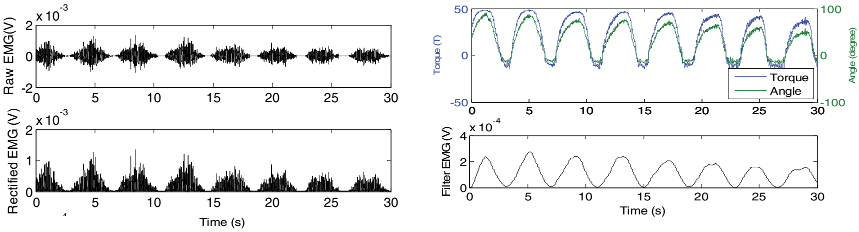

Figure 3. The EMG, torque, and angle signal processing.

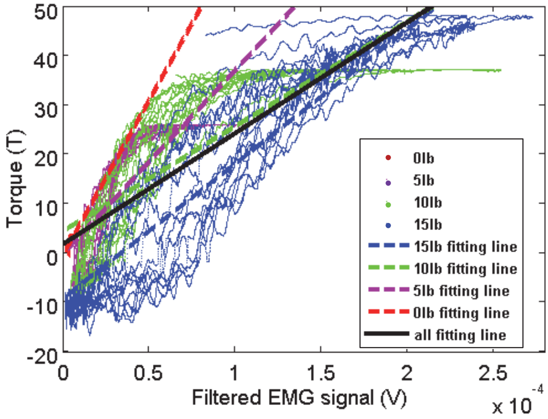

Figure 4. The relationship between filtered EMG signal and elbow torque.

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