Finger angle estimation using musculoskeletal model on thumb and index finger

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Abstract. Prosthetic hand control system usually controls finger using pattern recognition from surface ElectroMyoGraphy (EMG) signal from the forearm, as most of the finger muscles are located in the forearm with small tendon connected to the skeletal system. However, pattern recognition is not the same method as muscles control the hand and finger, this lead to a limitation in postal and long-time training is required for each subject. All finger provide benefit to daily life but 50 percent of all hand functions are made possible by the thumb and index finger. Therefore, due to the complexity of forearm muscles, this research will limit on thumb and index finger. The method proposed using sEMG from muscles and simple movement of flexion and extension to estimate equilibrium position and stiffness with one degree of freedom (DOF) for each finger call musculoskeletal model. Our research interesting in using the same principle of the musculoskeletal model to estimate equilibrium position and stiffness of thumb and index finger separately by measure position in 3-dimensional space. The result will be confirmed by measure position, force and EMG of the subject simultaneously.

1. Introduction
A large number of researchers are studies on building prosthetic hand finger to replicate actual hand and finger using Surface Electromyography (EMG) signal as control signal to provide some degree of freedom for amputee [1]. The study [2] suggested the use of biomechanical models to predict force at the thumb-tip based on sEMG signals and link the connection between muscles sEMG signal amplitude to force amplitude. The study [3] provide great example of sEMG measurement on forearm using di-pole sEMG sensor.

This paper will provide further research in the field of thumb and index finger position and estimation, the preliminary experiment setup to measure the characteristic of thumb and index finger muscles, which use in the proposed model. In the experiment, the sEMG signal is considering as muscles contraction and motion of all finger is simplify into flexion and extension motion. The statistical data of each data is correlation coefficient and root mean square error.

2. Methodology

2.1. Musculoskeletal Model
According to [3] the location of sEMG sensor should be identified via the anatomy and general muscles location in the human forearm. Therefore, the research starts from select interesting muscles
pair contract in opposite direction of flexion and extension and relatively large to acquired best signal to noise ratio. Thumb has four muscles in total connect and provide force to the skeletal structure, however, in this paper, the muscles that provide flexion-extension motion and locate in forearm area is selected as Flexor pollicis longus muscle (FPL) and Extensor pollicis brevis muscle (EPB). Likewise, index finger has seven muscles in total connect and provide force to the skeletal structure, however, in this paper, the muscles that provide flexion-extension motion and locate in forearm area is selected as Flexor digitorum superficialis (FDS) and Extensor digitorum (ED). The location of muscles is confirmed by measure sEMG signal while asking the subject to move the finger in flexion and extension motions. The location is adjusted multiple time until a reasonable signal to noise ratio of the subject is acquired, in case of some accident reduce the signal to noise ratio between the experiment, the data of particular experiment is rejected and the subject is asked to repeat the experiment again.

The musculoskeletal model is the developed version of Mykin model [4] use to reduce the complexity of finger musculoskeletal structure; the model is represented by one degree of freedom joint for flexion and extension. Two muscles flexor and extensor connect to the joint via tendon and force of each muscle are controlled by muscles activations and joint angles as shown in figure 1. In actual anatomy, finger joint consists of more than one muscles and multiple support muscles for stabilization, they work as an independent group and provide almost uniform motions for flexion and extension of the finger [5]. In this paper, the flexion muscle is referred as Muscle 1 and extension muscle is referred as Muscles 2.

![Figure 1. Structure of musculoskeletal model.](image)

2.2. Joint Torque, Equilibrium Points and Stiffness

The torque of each muscle represented by muscles contraction, string constant, and length of muscles, which separate between flexor and extensor. The torque of said joint is expressed by adding up torque of flexor and extensor as shown in equation (1) [6], where torque in the flexion direction is expressed as the positive value.

$$\tau = \sum_{i=1}^{2} a_i (k_{ui} + k_{ui}u_i)(l_{ui} + l_{ui}u_i - a_i \theta)$$  \hspace{1cm} (1)

The parameter $a_i$ denotes moment arm of muscle $i$; $k_{ui}$, $k_{ui}$, $l_{ui}$, $l_{ui}$, parameters (all in positive values) to define the characteristics of muscle $i$, $\theta$ indicate the joint angles, where angle in flexion is expressed as positive. Signs for moment arm are expressed as follows to indicate the effects resulting from the difference in position of the muscles: $a_1 > 0$, $a_2 < 0$ [6].

Equilibrium point of the joint is calculated by solving equation (1) for the joint angle that $t = 0$. Equilibrium points are defined as the angles at which torque generated by muscles is just balanced to stop when no external forces are applied to the joints as shown in equation (2) [6].

$$\Theta_{eq} = \frac{\sum_{i=1}^{2} a_i (k_{ui} + k_{ui}u_i)(l_{ui} + l_{ui}u_i)}{\sum_{i=1}^{2} (a_i)^2 (k_{ui} + k_{ui}u_i)}$$  \hspace{1cm} (2)
3. Experiment Setup
The experiment performed on 10 subjects age 21-28, male, right-handed with an average age at 25.2. Subjects were given a command by stimulus program show the preferred action on the screen which 2.5 meters away. The motion of fingers is captured by Optitrack with Baseline Upper Body + Fingers (33), the markers are placed on proximal interphalangeal joints of thumb finger, distal interphalangeal joints of the index finger, and proximal interphalangeal joints of index finger according to human anatomy. Surface EMG sensors with local reference were placed on Flexor Pollicis Longus, Flexor Digitorum Superficialis, Extensor Pollicis Brevis, and Extensor Indicus. The data from both device is synchronized and store using LSL (lab streaming layer) system from GitHub. Each subject perform at least 10 trials with 5 trials for variable estimation and 5 trials for verification choosing randomly. In each trial, the calibration period is set at the start of the trial to reduce noise. Each trial consists of resting, small flexion, max flexion, max extension motion as shown in figure 2.

4. Result
The estimate angle is compare with measure finger angles in time serial as shown in figure 3. The result of this experiment is shown using box-and-whisker plot with root-mean-square-error (RMSE) and statistic data of correlation coefficient between estimated fingers angle and fingers angle recorded by motion capture. Correlation coefficient and RMSE are calculated separately with each subject and shown on figure 4.

5. Discussion
The result show correlation between surface EMG signal and thumb, index finger angle estimated by musculoskeletal model using appropriate parameter of muscles. The wireless EMG sensor and optical motion capture was used to ensure maximum freedom of motion while measuring finger angle and EMG signal, simultaneously. Two possibilities appear from this experiment. First, prostatic arm control using EMG signal to control finger directly without pattern recognition. Second, the control not limit only position, the musculoskeletal model also show force using the same parameter.
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7. Reference
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