

論文 / 著書情報
Article / Book Information

題目(和文)	関節剛性に基づく筋骨格モデルから指の平衡位置推定に関する研究
Title(English)	A Study on Estimation of Equilibrium Position of Finger from Musculoskeletal Model Based on Joint Stiffness
著者(和文)	何梓遜
Author(English)	Zixun He
出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第12479号, 授与年月日:2023年3月26日, 学位の種類:課程博士, 審査員:小池 康晴,金子 寛彦,SLAVAKIS KONSTANTINOS,吉村 奈津江, 葭田 貴子
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第12479号, Conferred date:2023/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

(博士課程)
Doctoral Program

論文要旨

THESIS SUMMARY

系・コース : Department of, Graduate major in	情報通信 ライフエンジニア リング	系 コース	申請学位 (専攻分野) : Academic Degree Requested	博士 Doctor of	(Philosophy)
学生氏名 : Student's Name	何 梓遜		指導教員 (主) : Academic Supervisor(main)	小池 康晴	
			指導教員 (副) : Academic Supervisor(sub)		

要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

When using prosthesis or exoskeleton devices, it is important to reflect the user's intention to the movement of the device, and many methods for reflecting the user's intention using electromyography (EMG) have been studied. However, since the forearm contains various muscles related to hand and wrist motion, it is difficult to estimate finger motion from the EMG. At the same time, the estimation of finger joint angles during grasping movements while accounting for the interaction between the human body and the environment remains a challenge. Recently, classification of wrist movement patterns using muscle synergy has been shown to be more predictive than results using EMG. Therefore, it is expected that muscle synergy can be used to estimate motion intention more accurately than EMG. The aims of this study are : (1) propose an independent component analysis(ICA)-based muscle co-extraction method to solve the crosstalk problem of EMG for more accurate prediction of finger motions. (2) propose a method for estimating the actual finger force based on the equilibrium position and stiffness of the finger joints for estimating finger angles during grasping.

In the first experiment, the main objective was to assess whether using muscle synergy extracted from ICA data was a more accurate predictor of finger movements than EMG. In this study, ICA was used to decompose the raw EMG signals collected from 32-channel EMG electrodes and then extract the muscle synergy (ICA-Synergy) and used to estimate the angle of the finger or wrist through the Musculoskeletal model (MSM). The performance of ICA-Synergy based MSM (Synergy-MSM), MSM, Linear Regression Model (LRM) and Support Vector Regression (SVR) was compared in estimating the angles of the metacarpophalangeal (MCP) joints of the index, middle and thumb. Since different numbers of independent components affect muscle synergy, the optimal number of extracted independent components must be confirmed. To solve this problem, we calculated the correlation coefficients between each IC and finger motion data. Then the 2-16 ICs with the highest correlation coefficients were selected to extract muscle synergy to generate and find the best model of Synergy-MSM, Synergy-LRM, and Synergy-SVR. Then, the estimated and measured angles of each model were compared. Then, after comparing the prediction and measurement angles of each model, the prediction performance of Synergy-MSM (mean CC=93.0%, mean NRMSE=10.7%) was confirmed to be higher than the other three models. The results suggested that ICA-Synergy can estimate finger movements more accurately than IC or EMG due to (1) ICA can separate the signal crosstalk from neighboring muscles and find a better signal source. (2) Muscle synergy extracted from multiple muscle activities can represent motor commands better than IC, resulting in a model with better predictive performance. Moreover, ICA-Synergy is also achieved excellent performance in classical regression models.

Since MSM ignores the interaction forces generated when grasping an object, it is difficult to accurately estimate the angle of the finger during grasping motion. To overcome this problem, the main goal of the second experiment was to develop a method to estimate the actual finger angle and grasping force when grasping an object based on the estimated equilibrium position and stiffness of the finger from MSM. In this study, the equilibrium point hypothesis was used to establish an equation between the actual position of the finger, the equilibrium position and the joint stiffness during grasping of an object. Although the equilibrium position cannot be observed directly during grasping motion, the equilibrium position is measured qualitatively using the unloading reflex experiment in this study. After that, the proposed Synergy-MSM was used to estimate the equilibrium position, torque and stiffness of the grasped object, and then the actual angle of the finger was calculated. In order to evaluate the performance of the proposed method, the angles and torques of

the fingers were estimated for each of the three grasping motions under two different force production patterns. The results indicated that the estimated values of the MCP angle and torque of the index finger and thumb had high similarity to the measured data, and the estimated stiffness was also consistent with the characteristics of finger force production during grasping motion.

In summary, this study proposes an ICA-based muscle synergy extraction method and introduces it to MSM to estimate finger angles. The extracted muscle synergy after separating the overlapping muscle activities using ICA was shown to significantly improve the accuracy of finger angle estimation. In addition, this study proposed a method to estimate the MCP joint angle of the finger during grasping an object using Synergy-MSM to estimate the joint stiffness and torque. This method can simultaneously estimate the torque and angle of the finger and is expected to be used to develop control methods for simultaneous position and stiffness adjustment, to increase the dexterity of the prosthesis.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

注意：論文要旨は、東工大リサーチリポジトリ(T2R2)にてインターネット公表されますので、公表可能な範囲の内容で作成してください。

Attention: Thesis Summary will be published on Tokyo Tech Research Repository Website (T2R2).

(博士課程)

Doctoral Program

東京工業大学

Tokyo Institute of Technology