ORIGINAL ARTICLE

Adaptive neuro-fuzzy sliding mode control of the human upper limb during manual wheelchair propulsion: estimation of continuous joint movements using synergy-based extended Kalman filter

Mohammad Mahdi Rusta[1] · Seyyed Arash Haghpanah[1] · Sajjad Taghvaei[1] · Ramin Vatankhah[1]

Abstract

Wheelchair upper limb exoskeletons can present a revolutionary approach to aid individuals with neuromuscular disorders in their daily tasks, which require two primary factors, i.e., estimating the human intention to decrease human–robot interactions and generating the adaptive optimal control signals. Therefore, firstly, this study aimed to propose an adaptive neuro–fuzzy sliding mode controller to generate the optimal control signals, in which and an adaptive optimal multi-critic-based neuro-fuzzy system was designed to tune the control gains of the sliding mode controller according to the changes in the joint torques and tracking errors. Secondly, a neural network model was designed as a measurement function in the structure of an extended Kalman filter to infer the human's continuous movement intention, which was trained to establish a comprehensive relationship between inputs, i.e., joints' kinematics and pushrim force, and outputs, i.e., electromyography features. Data acquisition relied on Biometrics Ltd.'s DataLink software and hardware, including surface electromyography and electrogoniometer sensors, while a force sensor system was designed for pushrim force acquisition. The features were extracted using the nonnegative matrix factorization method. The results of the proposed controller were compared with two of the newest control strategies for position-tracking in the wheelchair upper limb exoskeleton robotic system, i.e., proportional derivative–based fuzzy sliding mode control and a fuzzy-based nonsingular terminal sliding mode control structures, which both used the sliding mode control approach with different proposed sliding surfaces to generate the required control signals and also used the neuro-fuzzy system to improve the performance. For the proposed measurement model, the results were compared with the linear regression model and the adaptive neuro-fuzzy inference system, which are two of the most used classification methods. The results affirmed the efficacy of the proposed controller as a robust and accurate control structure for trajectory tracking, both in the absence and presence of disturbance, thereby underscoring its potential for practical applications in manual wheelchair propulsion. Furthermore, the findings underscored the proposed measurement model's robustness and adaptability, making it a promising tool for estimating continuous joint movements in rehabilitation and assistive applications.

Keywords Sliding mode controller · Neuro-fuzzy system · Extended Kalman filter · Neural network

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1 Introduction

Manual wheelchairs (MWs) are crucial assistive devices for over 90% of the 65 million manual wheelchair users (MWUs) worldwide [1]. However, the repetitive movements in manual wheelchair propulsion (MWP) can impose excessive loads on the upper limb muscles, reducing efficiency and causing musculoskeletal pain [2, 3]. Therefore, MWUs are always prone to upper limb pathology and clinical rehabilitation.

Neuro Fuzzy Manual

Rajkumar Roy,Mario Köppen,Seppo Ovaska,Takeshi Furuhashi,Frank Hoffmann

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