Human-in-the-loop wearable robot optimization for squatting

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***Abstract*—Wearable robots have been introduced to occupational workers to assist work. These devices have usually adopted a generic assistance strategy, which does not fit on each user. In this work, it is pursued to develop a personalized assistance method in repetitive squatting tasks with an Ankle-Foot Orthosis (AFO). We will use the Human-in-the-Loop (HIL) optimization of AFO with physiological signals to optimize the AFO control parameter set. In this optimization process, metabolic estimation from muscle synergies is adopted for enhancing optimization speed and minimizing the dimension of signals. We first validated the muscle synergy as a proxy measure of the metabolic cost. Based on our initial results for the personalized assistance method with muscle activities, Human-in-the-loop optimization step will proceed.**

Keywords*— *Exoskeleton, Ankle Foot Orthosis, Squat, Muscle Synergy, Metabolic estimation, Human-in-the-loop Optimization

I. Introduction

The wearable robot technology, such as an exoskeleton, has emerged and been expected to boost users' performance [1,2]. Notably, it is promising not only in a physically demanding area but also in tedious and repetitive workspace, such an area where workers repetitively lift and squat. However, the general assistance methods applied to the conventional wearable robots do not perfectly fit individual users, so the need for personalized assistance methods is inevitable. Human-in-the-loop (HIL) optimization quenches our thirst for personalized assistance [3]. Nonetheless, conventional cost measure in HIL optimization, metabolic cost, challenges the optimization due to its slow sample speed and delay. To surmount these drawbacks, muscle activities were introduced to estimate metabolic effort [4], and synergies were adopted to minimize the dimension of the muscle activity signals [5].

The lift-related work can be assisted lumbar or hip exoskeletons as well as ankle exoskeleton [6]. The goal of this research is to optimize AFO control parameters for each user using physiological signals, including muscle synergies and metabolic estimation.

II. Methods

This research can be distinguished into two distinct steps. The first step is parameter identification, and the second step is the HIL optimization step, as shown in Fig 1.

In the parameter identification step, muscles synergy weight matrix (W_h, W_r, W_{rh}) and metabolic estimate parameters are identified(τ, β, t_{delay}) shown in Fig 1. (a). W_h, W_r, W_{rh} respectively stand for human muscle synergy, robot synergy, and human-robot synergy matrix. $\tau, \beta,$ and t_{delay} is the rise time constant, rise/decay ratio, and time delay of EMG signals. In this step, subjects are required to squat two times for 2 min with 5 min rest in between. We collected muscle activity (EMGs) data from eight muscles, metabolic cost, ankle angle data. After data acquisition, muscle synergy(W_h) and robot synergy (W_r) are acquired by the non-negative matrix factorization algorithm (nnmf). Human-robot synergy matrix(W_{rh}) is obtained by ridge regression from W_h, W_r [5]. Also, the metabolic estimate parameters are searched by using a metabolic-estimate transfer function with muscle synergies and Patternsearch function in Matlab toolbox [4].

In the Human-in-the-loop Bayesian optimization step, we optimize the level of torque for each individual by optimizing the torque gain parameter, $\boldsymbol{\Theta}$ by minimizing expected metabolic cost, estimated from muscle synergy.

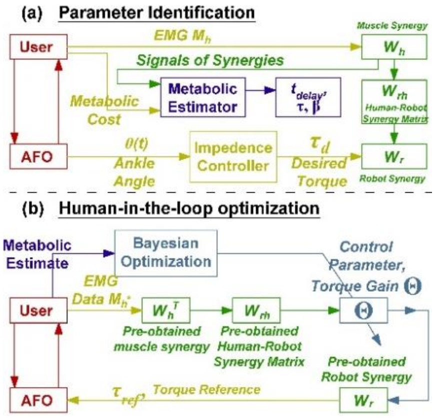
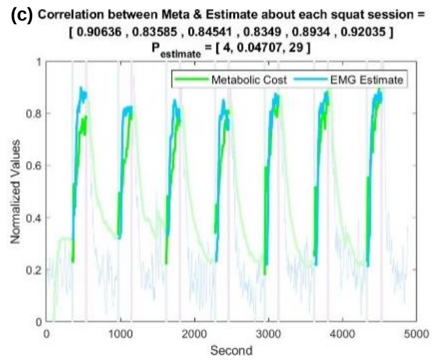


Fig 1. Diagrams of two identical steps in this experiment.

(a) is parameter identification step which searches for the following:
1) synergy matrix W_h, W_r and human-robot-synergy mapping matrix W_{rh},
2) metabolic estimate parameters.

(b) is HIL optimization step to find optimal parameter θ minimizing metabolic estimate



(c) An experiment to compare metabolic estimate and metabolic cost during squat tasks. A subject was required to alternatively do 7min rest and 3 min squat tasks. The green line is metabolic cost, and the blue line is metabolic estimate with synergies. The pale straight lines are the start and end time of squat tasks, and the pale curves are total trajectories of metabolic cost and estimate.

III. Result & Future Work

Fig 2 is the result of an experiment to compare metabolic cost and metabolic estimate from muscle synergies. The test was conducted with seven squat tasks for 3min with 7min rest in between. The blue line and green line are the metabolic cost and the metabolic estimate during each squat task. The lowest correlation between the measure and estimate is 0.835, and the highest one is 0.92. It means the metabolic estimation is quite decently done. In the future, we will proceed to the HIL optimization step and discuss the outcome during Dynamic Walking 2020.

[1] K. Miura et. al., "The hybrid assisted limb (HAL) for Care Support, a motion assisting robot providing exoskeletal lumbar support, can potentially reduce lumbar load in repetitive snow-shoveling movements," *J. Clin. Neurosci.*, 2018.

[2] C. A. Lotz et. al., "The effect of an on-body personal lift assist device (PLAD) on fatigue during a repetitive lifting task," *J ELECTROMYOGR KINES.*, 2009.

[3] Y. Ding et. al., "Human-in-the-loop optimization of hip assistance with a soft exosuit during walking," *Science Robotics.*, 2018.

[4] O. M. Blake and J. M. Wakeling, "Estimating changes in metabolic power from EMG," *SpringerPlus*, vol. 2, no. 1, 2013..

[5] M. Hamaya et. al., "Exploiting Human and Robot Muscle Synergies for Human-in-the-loop Optimization of EMG-based Assistive Strategies," *ICRA.*, 2019.

[6] S. Hwang et. al., "Lower extremity joint kinetics and lumbar curvature during squat and stoop lifting," *BMC Musculoskelet.*. 2009.

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