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Human-in-the-loop werable robot optimization for squat

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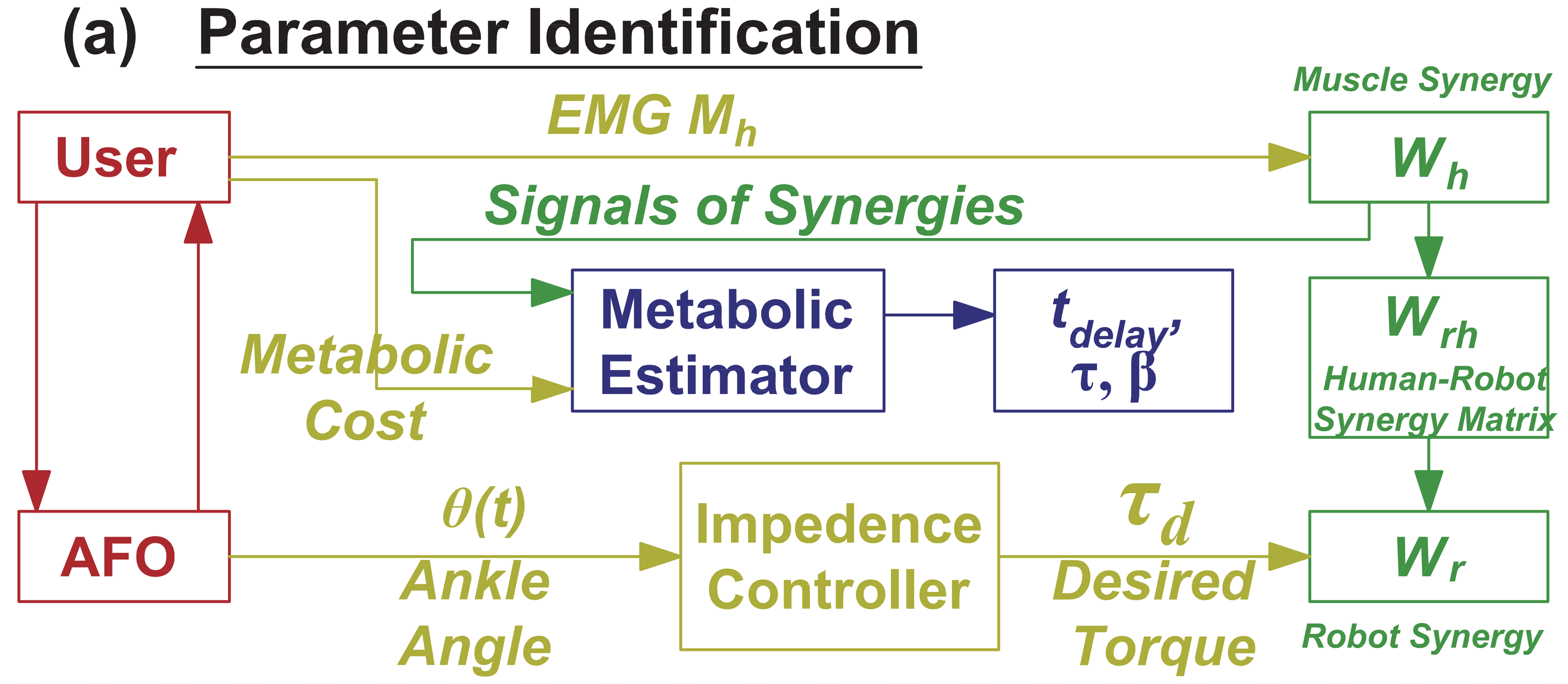
Introduction

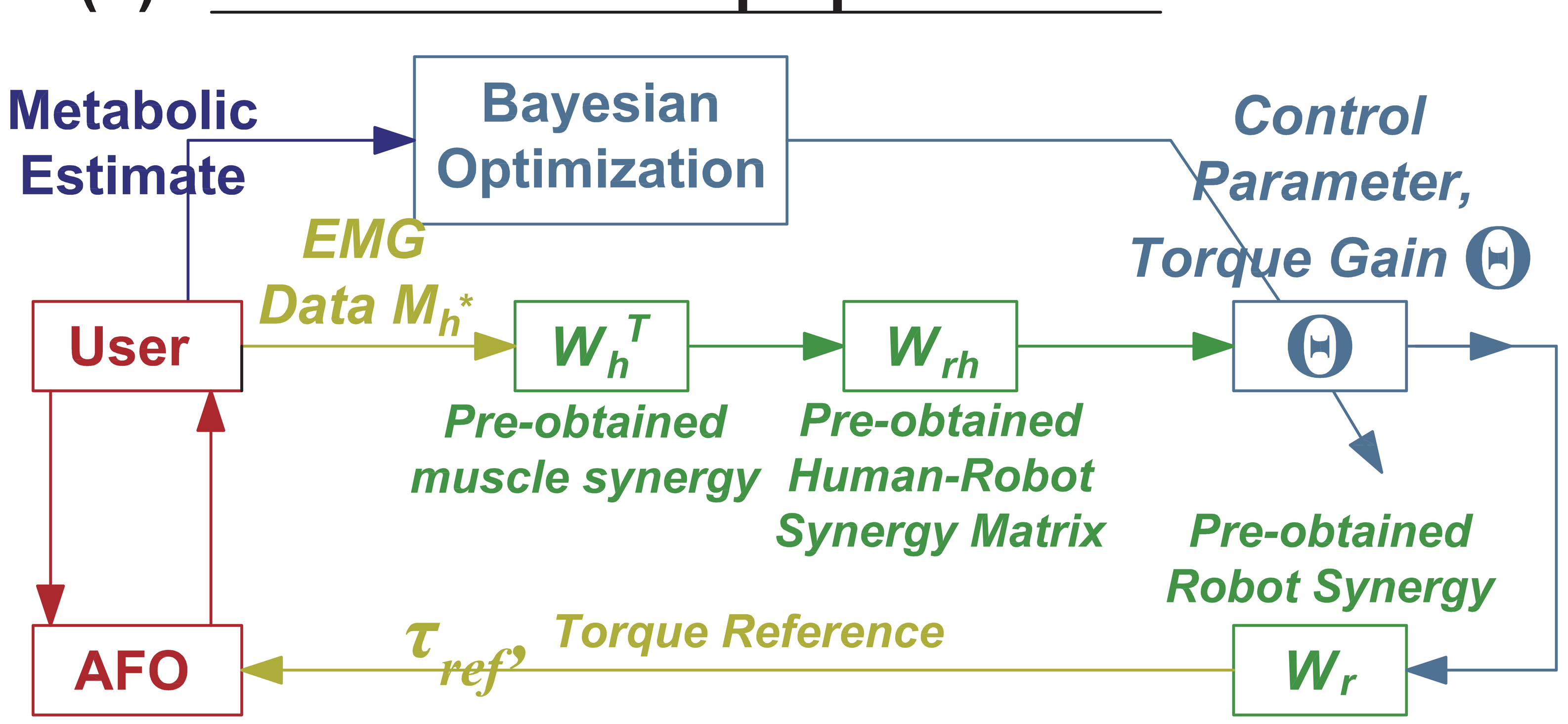
- Human-in-the-loop optimization(HIL) methods have been used to optimally assist and maximize users' performance [1, 3].
- Metabolic cost is used to evaluate the performance of the assistance, but has disadvantages of slow sampling rate and delay.
- Metabolic esitmate using EMG signals can be utilized to overcome these shortcomings [2].
- Lift-related studies have mainly focused on hip and knee assistance. However, it is revealed that Ankle joint also engages in squat tasks [4].
- In this paper, we suggest optimal squat assistance method with AFO using physiological signals, such as muscle synergies and metabolic estimate.

Methodology

(a) Parameter Identification



(b) Human-in-the-loop optimization



- The research can be splited into 2 main steps.
- In "parameter Identification" step, subjects were instructed to do a few squat tasks, and then parameters of synergies and metabolic estimate are searched
- In "Human-in-the-loop" step, on the basis of the searched parameters, control parameter, torque gain Θ, is searched by minimizing metabolic estimate.

Parameter Identification - Synergy

- 8 muscles are measured :
  Rectus femoris (RECT), Tibialis anterior (TA), Soleus (SOL), lateral Gastrocnemius (GAS), Vastus medialis oblique(VMO), Vastus lateralis oblique (VLO), Biceps femoris (BICE), and Semitendinosus (SEMI)
- Given signals from either muscles or torque, synergies are identified using Non-negative matrix factorization,

$$M = WC$$

where M is either EMG signals or desired torque trajctory, W is synergy weight matrix, and C is the signal of the synerges.

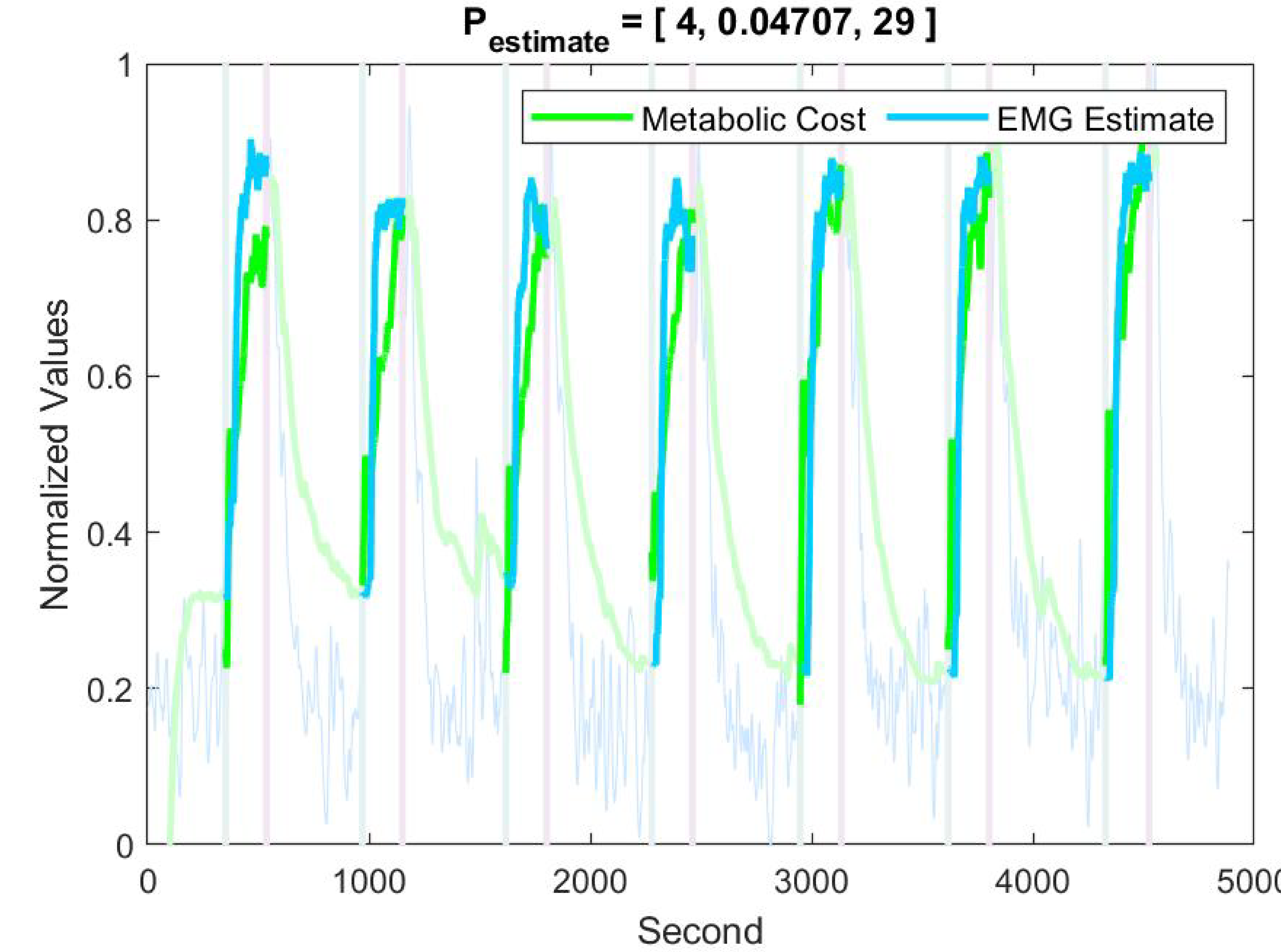
Parameter Identification - Metabolic Estimate

- Metabolic estimate transfer function is the following [2] :

$$\frac{d}{dt}(P(t)) + \left[\frac{1}{\tau}\left(\beta + [1-\beta]EMG(t-t_{delay})\right)\right]P(t) = \frac{1}{\tau}EMG(t-t_{delay})$$

where τ, β,t_{delay} are rise time constant, rise/decay ratio, and time delay of emg signals.
- Instead EMG signals, muscle synergies are adopted as input.
- Pattern search function in Matlab toobox is used.

Correlation between Meta & Estimate about each squat session = [0.90636 , 0.83585 , 0.84541 , 0.8349 , 0.8934 , 0.92035]
$P_{estimate}$ = [4, 0.04707, 29]



- Experiment to compare metabolic cost and metabolic estimate during squat was conducted.
- A subject was required to squat 3 min and rest 7 min alternatively and 7 squat tasks were done.
- The green line is metabolic cost, and blue line is the estimate.
- Correlation values suggested on the top shows how they are similar to each other for the first six squat tasks.

Future Work

- Still design and adjust details in the HIL optimization step.
- Plan to conduct all the step in near future.

Reference

[1] Y. Ding and M. Kim et. al., "Human-in-the-loop optimization of hip assistance with a soft exosuit during walking," Science Robotics., 2018.
[2] O. M. Blake and J. M. Wakeling, "Estimating changes in metabolic power from EMG," SpringerPlus, vol. 2, no. 1, 2013..
[3] 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.
[4] S. Hwang et. al., "Lower extremity joint kinetics and lumbar curvature during squat and stoop lifting," BMC Musculoskelet.. 2009.