Metabolic Cost Estimation using Dual Unscented Kalman Filter and Gaussian Mixture Model

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Introduction

- By increasing assistive robotic devices[1] for increasing human's locomotion, The performance evaluation methods are needed such as metabolic cost [2].
- **The metabolic cost** is the amount of the energy demand to perform a certain given task [3].

- The challenges of measuring metabolic cost
  - ✓ **Time delay** [4] because of the mitochondrial dynamics
  - ✓ **Noisy** in respiratory measurement [5]
  - ✓ **Long measurement time** [5] : at least five minutes to obtain a reasonable estimate per testing condition.

- The purpose of the paper is **to minimize the metabolic cost estimation time** as well as **provide high confidence in the measurement.**
- We proposed two algorithms, Dual Unscented Kalman Filter(Dual UKF) and Gaussian Mixture Model(GMM)

Methodology

A. Dual Unscented Kalman Filter (Dual UKF)

- Dual UKF
  - ✓ No need linearization (improves stability)
  - ✓ Simultaneously estimates model parameters and state
- Dynamic model

$$Y = a\left(1 - e^{-\frac{t}{\tau}}\right) + a_0$$

  - τ : the rate of change in time constant
  - a_0: metabolic cost in standing position
  - a : initialized underlying metabolic cost using ten initial data

B. Gaussian Mixture Model (GMM)

- GMM
  - ✓ Data driven and model-free algorithm
  - ✓ Based on prior modeling and Normal-Inverse-Wishart(NIW) distribution
- Linear-Gaussian dynamics

$$P(x_{t+1}|x_t, u_t) = N(f_{xt}x_t + f_{ut}u_t + f_{ct}, F_t)$$

  - ✓ Use GMM to add the posterior information about the system to estimate
  - ✓ Trained the model using the limited number of respiratory data points.
  - ✓ The model is used to predict complete metabolic estimation for a single mode

C. Evaluation

- Used previously collected metabolic data(N=7), 4 conditions
- Calculated the maximum error between the true metabolic cost(two minutes average of five minutes data) and the estimated metabolic cost using a limited data set for each algorithm.

Results

A. Dual Unscented Kalman Filter

Table 1. Maximum error results with different time and data points using Dual UKF

	All	2min	1.5min	30 samples	20 samples
Max Err	1.6%	4.3%	4.7%	6.1%	8.4%

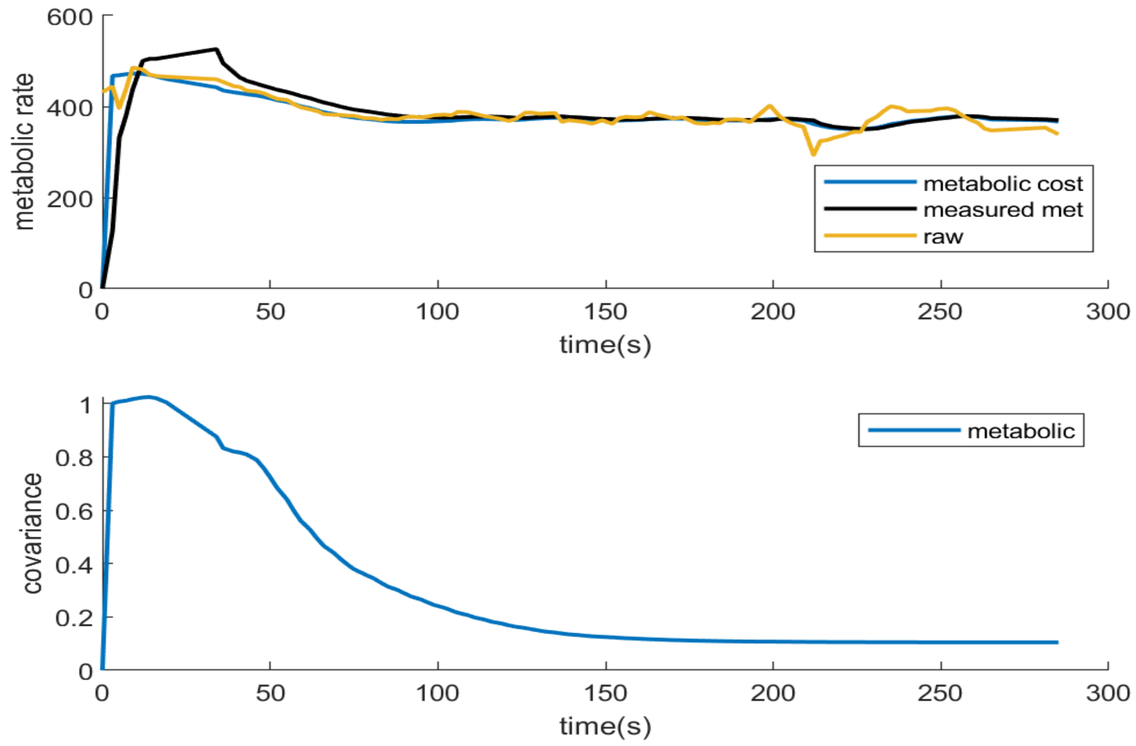

Fig. 1 Metabolic estimation of Subject 1 in 4th condition with 5min data based on Dual UKF

B. Gaussian Mixture Model (GMM)

Table 2. Maximum error results with different data points using GMM

	50 samples	30 samples	20 samples
Max Err	2.2%	3.0%	7.7%

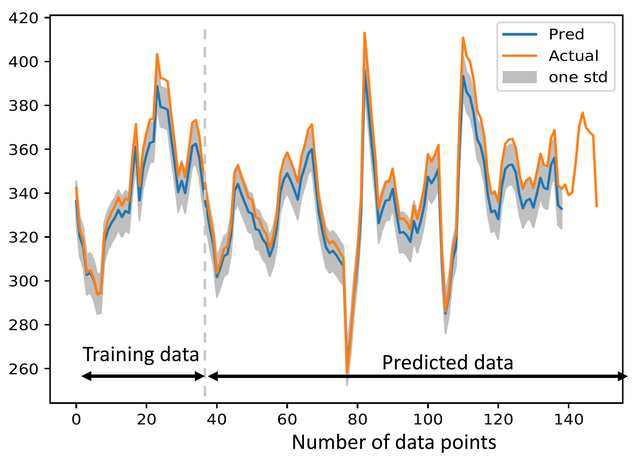

Fig. 2 Metabolic estimation results with 30 given data points using GMM

Discussion

- We could **reduce metabolic cost estimation time using both Dual UKF and GMM algorithm.**

	Advantages	Disadvantages
Dual UKF	No need training data	Larger error
GMM	Smaller error	Need training data

- Future work UKF : optimizing model uncertainty, noise, covariance matrix
- Both algorithms could be used to optimize assistance method in real-time with further improvement

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