UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Development of Monitoring, Modelling and Control Systems for Human Physiological Assessment with Wearable Devices

by Hairong Yu

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Steven Su

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Declaration

I, Hairong Yu, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Physiological signals play vital roles in studying the mechanism of human body reaction during exercise and human kinetics assessment. This thesis develops a wearable exercise monitoring system to monitor and regulate human cardiorespiratory responses to moderate exercise. To describe the relationship between the body's physiological reactions and the exercise, the modelling approach has been extensively explored in a range of applications. In this thesis, the cardiorespiratory signal responses to the exercise phase are comprehensively analysed through the means of different modelling approaches. A non-parametric kernel based modelling approach has been proposed to address the complexity of the model dynamics. This thesis also develops a novel Inclination based Calibration method to address the static nonlinear modelling problem for the calibration of the sensors in an Inertial Measurement Units.

The non-parametric model is the preferable method when the system structure information is insufficient, or the system is too complex to be described by a simple parametric model. Hence, the non-parametric modelling method with kernel-based regularisation is developed to estimate the physiological signal response to the exercise phase during different types of exercise. The kernel selection and regularisation strategies are discussed, and a series of simulations are performed to compare the fitness, sensitivity and stability of different kernels.

For detecting the exercise phase, the innovative in-field calibration method for the portable tri-axial sensor is developed to calibrate the Inertial Measurement Units data. Based on the fact that the angle between the local gravity and magnetic field is invariant, this thesis proposed a new in-field calibration approach, called Inclination Based Calibration, which can reliably estimate the model parameters of the sensor with a simple linear Least Square estimator. Based on optimal experimental design, a 12-observation Icosahedron experimental

scheme has been performed for micro Inertial Measurement Units. Both the calibrated results and the simulation comparison demonstrate the effectiveness of the proposed method.

This monitoring and control system could comprehensively study human kinetics and cardiorespiratory mechanism and help to make assessments. Some general approaches for physiological signal processing and modelling, parameters estimation, sensor calibration and experiment protocol control are proposed in this work. The effectiveness and benefits of different modelling approaches are demonstrated by a range of means. This system could be applied in strategic exercise design, athletic assessment, exercise enhancement and health monitoring.

Publications

The contents of this thesis are based on the following papers that have been published, accepted, or submitted to peer-reviewed journals, conferences and book chapters.

Journal Papers:

1. Hairong Yu, Lin Ye, Ganesh R. Naik, Rong Song, Hung T. Nguyen, Steven Su*, "Nonparametric Dynamical Model of Cardiorespiratory Responses at the Onset and Offset of Treadmill Exercises." *Medical & biological engineering & computing*, vol. 56, no. 12, pp. 2337-2351, June 2018.

2. Hairong Yu, Lin Ye, Ying Guo, Steven Su*, "An Innovative 9-Parameter Magnetic Calibration Method Using Local Magnetic Inclination and Calibrated Acceleration Value", *IEEE Sensors Journal*, doi: 10.1109/ JSEN. 2020. 2995876, May 2020.

3. Lin Ye, Ahmadreza Argha, Hairong Yu, Branko G. Celler, Hung T. Nguyen, Steven Su*, "Dynamic Characteristics of Oxygen Consumption.", *Biomedical engineering online*, vol. 17, no. 1, pp. 44, December 2018

4. Lin Ye, Ying Guo, Lei Dong, Hairong Yu, Hung Nguyen, Steven Su*, "A Fast-Converge, Real-Time Auto-Calibration Algorithm for Triaxial Accelerometer." *Measurement Science and Technology*, vol. 30, no. 6, pp. 065010, February 2019.

5. Hairong Yu, Lin Ye, Hamzah M Alqudah, Kairui Guo, Branko G. Celler, Rong Song, Steven Su*, "Prediction of Cardiac-respiratory Response to Treadmill Exercise by Using Non-Parametric Modelling with Stairs Exercise based Kernel Characterization", under submission to *IEEE Transactions on Biomedical Engineering*, 2020.

6. Hairong Yu, Lin Ye, Rong Song, Yuxi Luo, Hamzah M Alqudah, Steven Su*, “Oxygen Consumption Response to Stair Exercise by Non-parametric Modelling", under review at *Biomedical Physics and Engineering Express*, 2020.

7. Hairong Yu, Lin Ye, Ying Guo, Steven Su*, “An Effective In-Field Calibration Method for Triaxial Magnetometers based on Local Magnetic Inclination", under review at *IEEE Transactions on Instrumentation and Measurement* , 2019.

Conference Papers:

1. Hairong Yu*, Kairui Guo, Hung T. Nguyen, Steven Su, “The Classification for “Equilibrium Triad” Sensory Loss based on sEMG Signals of Calf Muscles.” *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, July 2017.

2. Kairui Guo, Hairong Yu*, Rifai Chai, Hung Nguyen, Steven W. Su, “A Hybrid Physiological Approach of Emotional Reaction Detection Using Combined FCM and SVM Classifier.” *2019 41th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, July 2019.

3. Kairui Guo*, Henry Candra, Hairong Yu, Huiqi Li, Hung T. Nguyen, Steven W. Su, “EEG-based Emotion Classification using Innovative Features and Combined SVM and HMM Classifier.” *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, July 2017.

4. Yao Huang, Rong Song*, Wenhui Chen, Hairong Yu, Ahmadreza Argha, Branko G. Celler ,Steven Su, “The Effects of Different Tracking Tasks on Muscle Synergy through Visual Feedback.” *2019 41th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, July 2019.

5. Kairui Guo*, Hairong Yu, Yunzhu Chen, Rong Song, Steven W. Su “Puzzle-based Automated Upper Limb Functional Electrical Stimulation Strategy Using EMG Connectivity Analysis.” *2020 42th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, July 2020.

Book Chapters:

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