University of Technology Sydney

Faculty of Engineering & Information Technology

Modelling, Regulating and Controlling Cardiovascular Responses by using Wearable Sensors

A thesis submitted for degree of

Doctor of Philosophy

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Certificate

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This research is supported by the Australian Government Research Training Program Scholarship.

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List of Abbreviation

µ-IMU	Micro Inertial Measurement Units
ACSM	American College of Sports Medicine
ADC	Analog Digital Convertor
ADP	Adenosine Diphosphate
ARC	Automatic Memory Counting
ATP	Adenosine triphosphate
BLE	Bluetooth Low Energy
BP	Blood Pressure
bpm	beats per minute
CCS	Code Compose Studio
CO_2	Carbon Dioxide
Cr	Creatine
CR	Cardiac rehabilitation
CRPs	Cardiac Rehabilitation Programs
CU	Charging Unit
ECG	Electrocardiogram
GPS	Global Positioning System
HR	Heart Rate
HR_{max}	Maximum Heart Rate
HR_{reseve}	Reserved Heart Rate
HR_{rest}	Rest Heart Rate
IDE	Integrated Development Environment
IDF	International Diabetes Federation
IMU	Inertial Measurements Unit
IR	Impulse Response
LED	Light Emitting Diode
LTI	Linear Time Invariant
MCU	Micro Controller Unit
MET	Metabolic Equivalent
MSB	Most Significant Bit

N_2	Nitrogen
O_2	Oxygen
PCr	Phosphocreatine
Pi	inorganic Phosphate
Psi	Pounds per Square Inch
PU	Portable Unit
RKHS	Reproducing Kernel Hilbert Space
RMS	Root of Mean Square
RQ	Respiratory Quotient
SC	Serial Clock
SD	Serial Data
SISO	Single Input Single Output
SMD	Surface Mounted Devices
SS	Stable Spline
TA	Tri-axial Accelerometer
TCA	Tri-Carboxylic Acid
TI	Texas Instruments
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus
USCI	Universal Serial Communication Interface
VCO_2	Volume of Carbon Dioxide
VE	Ventilation
VO_2	Oxygen Uptake
VO_2max	Maximum Oxygen Uptake
VT	Ventilatory Threshold

Abstract

Physical exercise has significant benefits for humans in improving the health and quality of their lives, by strengthening the functions of their cardiovascular and respiratory systems. However, it is very important to control the intensity of the exercise within the capability of the individual to maximize the efficiency of the exercise and ensure the safety of the exercises.

The maximal rate of oxygen uptake (VO_{2max}) and Heart Rate (HR) are the important determinants of cardiovascular fitness and health status; their measurements can help in cardiac diseases detection.

In this thesis, we first developed two reliable and valid wearable exercise monitoring systems by using TI e Z430-Chronos watch as well as iPhone App, which can control the exercise intensity through audio stimulations and audio command to improve cardiovascular fitness of various exercisers.

Various exercises including treadmill exercise and stair climbing were performed under the monitoring and controlling of the developed wearable devices together with the portable gas analyzer, K4b^2. Based on experimental data, we applied the non-parametric model to investigate the dynamics of Heart Rate (HR) response to stairs exercise status. The self-designed application provides a reliable technique to record HR data and to present safe and understandable exercise instructions. The protocol of the experiment guarantees a continuously monitoring of HR. The identification result of different period numbers are compared, and the models, which includes three types of parametric models and one nonparametric model, are also presented.

In conclusion, the developed portable monitoring systems, exercise protocols, and HR models have great potential to accurately predict and regulate the dynamic cardiorespiratory response to moderate strength exercise, promote safer exercise and guide the cardiac patient's during the outpatient cardiac rehabilitation phase.

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