

**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

<b>μ-IMU</b>	Micro Inertial Measurement Units
<b>ACSM</b>	American College of Sports Medicine
<b>ADC</b>	Analog Digital Converter
<b>ADP</b>	Adenosine Diphosphate
<b>ARC</b>	Automatic Memory Counting
<b>ATP</b>	Adenosine triphosphate
<b>BLE</b>	Bluetooth Low Energy
<b>BP</b>	Blood Pressure
<b>bpm</b>	beats per minute
<b>CCS</b>	Code Composer Studio
<b>CO<sub>2</sub></b>	Carbon Dioxide
<b>Cr</b>	Creatine
<b>CR</b>	Cardiac rehabilitation
<b>CRPs</b>	Cardiac Rehabilitation Programs
<b>CU</b>	Charging Unit
<b>ECG</b>	Electrocardiogram
<b>GPS</b>	Global Positioning System
<b>HR</b>	Heart Rate
<b>HR<sub>max</sub></b>	Maximum Heart Rate
<b>HR<sub>reseve</sub></b>	Reserved Heart Rate
<b>HR<sub>rest</sub></b>	Rest Heart Rate
<b>IDE</b>	Integrated Development Environment
<b>IDF</b>	International Diabetes Federation
<b>IMU</b>	Inertial Measurements Unit
<b>IR</b>	Impulse Response
<b>LED</b>	Light Emitting Diode
<b>LTI</b>	Linear Time Invariant
<b>MCU</b>	Micro Controller Unit
<b>MET</b>	Metabolic Equivalent
<b>MSB</b>	Most Significant Bit

<b>N<sub>2</sub></b>	Nitrogen
<b>O<sub>2</sub></b>	Oxygen
<b>PCr</b>	Phosphocreatine
<b>Pi</b>	inorganic Phosphate
<b>Psi</b>	Pounds per Square Inch
<b>PU</b>	Portable Unit
<b>RKHS</b>	Reproducing Kernel Hilbert Space
<b>RMS</b>	Root of Mean Square
<b>RQ</b>	Respiratory Quotient
<b>SC</b>	Serial Clock
<b>SD</b>	Serial Data
<b>SISO</b>	Single Input Single Output
<b>SMD</b>	Surface Mounted Devices
<b>SS</b>	Stable Spline
<b>TA</b>	Tri-axial Accelerometer
<b>TCA</b>	Tri-Carboxylic Acid
<b>TI</b>	Texas Instruments
<b>UART</b>	Universal Asynchronous Receiver Transmitter
<b>USB</b>	Universal Serial Bus
<b>USCI</b>	Universal Serial Communication Interface
<b>VCO<sub>2</sub></b>	Volume of Carbon Dioxide
<b>VE</b>	Ventilation
<b>VO<sub>2</sub></b>	Oxygen Uptake
<b>VO<sub>2max</sub></b>	Maximum Oxygen Uptake
<b>VT</b>	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<sup>2</sup>. 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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