

# **Monitoring and Control of the Cardiovascular System During Indoor Exercise**

A thesis written by

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under the supervision of

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in fulfilment of the requirements of the degree of

**Doctor of Philosophy**

Faculty of Engineering and Information Technology

University of Technology Sydney, Australia

2012

## **CERTIFICATE OF AUTHORSHIP/ORIGINALITY**

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# Abstract

The increase in obesity and diabetes is of great public health, social and economic concern worldwide. Modern treadmill systems can provide effective, safe and practical indoor exercise for the consumption of extra energy. However, an uncontrolled treadmill can cause excessive exertion on the cardiovascular system. To avoid excessive cardiovascular stress, an efficient way of monitoring and controlling of exercise strength is to regulate treadmill speed and/or gradient to stimulate the exerciser's heart rate following a predefined profile.

In this thesis, an automated treadmill system has been developed, which includes wireless portable ECG and tri-axial accelerometer sensors, and a Labview based control module. Based on this automated system, efficient rate detection techniques have been developed by using the pitch estimation method. Different types of multi-loop integral control configurations have been proposed and implemented to regulate the heart rate and/or step rate by manipulating treadmill speed and/or gradient. These control structures have been placed under real time testing which includes Single-Input Single-Output (SISO), Multiple-Input Single-Output (MISO) and Multiple-Input Multiple-Output (MIMO) control by using the established Labview module. It has been found that MISO control is the most efficient method, and would be effective in making the treadmill exercise more reliable and safer in rapidly tracking the heart rate profile to achieve desired exercising outcome. For this reason, this thesis also proposes the concept of Multi-loop Integral Controllability (MIC) and proves the existence of multi-loop integral controllers which can obtain unconditional multi-loop stability of the Two-Input Single-Output automated treadmill system.

The benefit of our automated control system includes assisting patients in post-cardiac attack rehabilitation and therapy to safely control the heart rate to follow a suitable profile. This reduces the need for supervision by medical professionals. Furthermore, in athletics and fitness applications, an automatic control system can allow users to optimize their training intensity.

# Acknowledgements

First and foremost I would like to convey my many thanks to the remarkable people who provide support, motivation, knowledge, friendship and love on my journey to pursuit a Ph.D.

Special recognition must be given to my supervisor, Dr Steven Su for his expertise, supervision and unconditional encouragement throughout the course of this project. I am particularly grateful for his wisdom that has inspired me to be a life-long learner and a passionate seeker of knowledge, and for his always being the first subject to test our new setup instrumentations, even though some of them were quite tough. I thank him with the deepest of respect.

I would like to express tremendous gratitude towards my colleague Andrew Zhang for the great discussions about the research and help in many cases. I also acknowledge the support received by Sam Cheng and Sam Chui for taking time to give insights into my thesis, as well as give me some suggestions for the research.

I am indebted to all of the volunteer subjects, who have given their precious time to participate in the experiment and helped me to collect the data. Special thanks to Basil Turk and Luis Dolores who were always willing to help out when I needed subjects for testing.

I wish to acknowledge the important support from Australian Postgraduate Scholarship which enabled me to pursue my higher degree at University of Technology Sydney.

Finally and most importantly, I would like to thank my family - my mother Chunchun Zhang for her care and being backbone during this period of my life. Thanks also go to my relatives in China. Without their eternal love and support, I would not be who I am today.

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# Acronyms and Abbreviations

## Units of Measure

<b>hr</b>	Hour(s)
<b>km/h</b>	Kilometres per hour
<b>min</b>	Minute(s)
<b>m</b>	Meter
<b>sec</b>	Second(s)

## Acronyms

<b>2ISO</b>	Two Inputs and Single Output
<b>ACF</b>	Autocorrelation Function
<b>AMDF</b>	Average Magnitude Difference Function
<b>BPM</b>	Beats Per Minute
<b>DAQ</b>	Data Acquisition
<b>DIC</b>	Decentralized Integral Controllability
<b>DUS</b>	Decentralized Unconditional Stability
<b>ECG</b>	Electrocardiograph
<b>GAS</b>	Globally Asymptotically Stable
<b>GUI</b>	Graphical User Interface
<b>HR</b>	Heart Rate
<b>HRC</b>	Heart Rate Controlled
<b>Kp</b>	Proportional Gain
<b>Ki</b>	Integral Gain
<b>Kd</b>	Derivative Gain
<b>LES</b>	Locally Exponentially Stable
<b>MISO</b>	Multi-Input Single-Output

<b>MIMO</b>	Multi-Input Multi-Output
<b>MIC</b>	Multi-loop Integral Controllability
<b>NI</b>	National Instruments
<b>PC</b>	Personal Computer
<b>PID</b>	Proportional Integral Derivative
<b>PPM</b>	Paces per Minute
<b>RMS</b>	Root Mean Square
<b>SISO</b>	Single-Input Single-Output
<b>SPM</b>	Steps per Minute
<b>SR</b>	Step Rate
<b>TA</b>	Tri-axial Accelerometer
<b>UTS</b>	University of Technology Sydney
<b>VI</b>	Virtual Instrument