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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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

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 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.

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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.

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Content

List of Figures

List of Table

Acronyms and Abbreviations

Units of Measure

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

Acronyms

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

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