

**ADVANCED ASSISTIVE CONTROL STRATEGIES
FOR SMART HOSPITAL BEDS**

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A thesis submitted in partial fulfilment of the requirements for the
Degree of Doctor of Philosophy



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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I, Huy Hoang Nguyen, certify that the work in the 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.

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Table of contents

CHAPTER 1 . INTRODUCTION.....	1
1.1 PROBLEM STATEMENT	1
1.2 AIMS OF THESIS	5
1.3 CONTRIBUTIONS.....	6
1.4 STRUCTURE OF THESIS	7
1.5 PUBLICATIONS RELATED TO THESIS	8
CHAPTER 2 . LITERATURE REVIEW.....	9
2.1 HOSPITAL BEDS	9
2.1.1 Definition, structure and classification	9
2.1.2 Advantages and disadvantages.....	11
2.2 SMART HOSPITAL BEDS.....	13
2.2.1 Definition and current research.....	13
2.2.2 Advantages and disadvantages.....	16
2.3 ADVANCED CONTROL FRAMEWORK.....	17
2.3.1 Operator detection approaches.....	17
2.3.2 Operator-following strategy	20
2.3.3 Advanced low-level control	21
2.4 DISCUSSION	31
CHAPTER 3 . OPERATOR DETECTION METHODS FOR THE TRACKING FUNCTION OF SMART HOSPITAL BEDS.....	34
3.1 INTRODUCTION.....	34
3.2 SMART HOSPITAL BED STRUCTURE.....	35

3.2.1	Bed frame	35
3.2.2	Sensor system.....	36
3.2.3	Control devices.....	37
3.2.4	Power supply system.....	38
3.2.5	Motors and actuators	39
3.2.6	Wheels.....	39
3.2.7	Air mattress	40
3.3	OPERATOR DETECTION METHODS	41
3.3.1	Feature extraction.....	41
3.3.2	Gaussian distribution method.....	44
3.3.3	Neural network classification method.....	45
3.4	OPERATOR-FOLLOWING STRATEGY	50
3.5	EXPERIMENTAL RESULTS	52
3.5.1	Operator detection performance.....	53
3.5.2	Operator following performance.....	57
3.6	DISCUSSION	61
CHAPTER 4 . AN OPTIMAL MULTIVARIABLE PID CONTROL STRATEGY FOR SMART HOSPITAL BEDS.....		63
4.1	INTRODUCTION.....	63
4.2	MULTIVARIABLE DYNAMIC MODEL.....	64
4.2.1	Mathematical model.....	64
4.2.2	Parametric identification process	68
4.3	OPTIMAL MULTIVARIABLE PID CONTROL STRATEGY	70
4.3.1	Stage 1: Triangular Diagonal Dominance decoupling.....	71
4.3.2	Stage 2: Optimal PID control.....	72

4.4	RESULTS.....	74
4.4.1	OMPID controller design.....	74
4.4.2	Experimental results.....	79
4.5	DISCUSSION	87
CHAPTER 5 . INTELLIGENT MULTIVARIABLE CONTROL STRATEGIES		89
5.1	INTRODUCTION.....	89
5.2	ADVANCED OPERATOR-FOLLOWING CONTROL STRATEGY.....	90
5.2.1	Neural network based operator detection.....	92
5.2.2	Operator-following strategy	92
5.2.3	Neural multivariable low-level control	93
5.3	OPTIMAL MULTIVARIABLE NEURAL NETWORK CONTROL	94
5.3.1	Stage 1: Two-phase diagonal decoupling technique.....	94
5.3.2	Stage 2: Optimal neural network control design.....	95
5.4	RESULTS.....	101
5.4.1	OMNN controller design.....	101
5.4.2	Experimental results.....	109
5.5	DISCUSSION	117
CHAPTER 6 . CONCLUSION AND FUTURE RESEARCH DIRECTIONS ...		119
6.1	CONCLUSION	119
6.2	FUTURE RESEARCH DIRECTIONS.....	122
APPENDIX A. ARITIFICIAL NEURAL NETWORKS.....		124
APPENDIX B. AUTONOMOUS NAVIGATION ROBOT - TURTLEBOT		132
REFERENCES.....		137

List of figures

Figure 2.1: Mechanical hospital bed (Audrey 2016)	10
Figure 2.2: Semi – electric hospital bed (Drivemedical 2015)	11
Figure 2.3: Electric hospital bed (Stryker 2013a)	11
Figure 2.4: Zoom Motorised Drive System (Stryker 2013b).....	14
Figure 2.5: IntelliDrive Powered Transport System (Hill-Rom 2014)	14
Figure 2.6: I-Drive Power TM System (Linet 2013b)	15
Figure 2.7: The bed wheelchair system (Panasonic 2009).....	16
Figure 3.1: The smart hospital bed system	36
Figure 3.2: The sensor system: the encoder (Encoder 2016),	37
Figure 3.3: The central control system: the KTA 198 board (Oceancontrols 2009), the motor controller (RoboteQ 2015), the Phidget 8/8/8 board (Phidgets 2012) and the laptop.....	38
Figure 3.4: The DC motor (NPC 2011) and actuators (Linak 2016)	39
Figure 3.5: The wheel system	40
Figure 3.6: The air mattress	40
Figure 3.7: Laser data processing procedure:	42
Figure 3.8: Feature determination	43
Figure 3.9: Neural network structure	45
Figure 3.10: The hospital bed system and the target for tracking.....	52
Figure 3.11: Distribution of the two data sets	53
Figure 3.12: The Boundary B_{WG}^W with $\theta^G = 0.2, 0.15, 0.1, 0.05$	55
Figure 3.13: The Boundary B_{GH}^G with $\theta^H = 0.2, 0.15, 0.1, 0.05$	55
Figure 3.14: Demonstration of the operator-following task.....	59

Figure 3.15: Trajectory of the hospital bed and operator	60
Figure 3.16: Linear velocity of the hospital bed and operator	60
Figure 3.17: Angular velocity of the hospital bed and operator	61
Figure 4.1: The smart hospital bed system	65
Figure 4.2: Step response of the smart hospital bed dynamics	70
Figure 4.3: Optimal Multivariable PID control scheme.....	71
Figure 4.4: Optimal PID control method for a velocity subsystem	72
Figure 4.5: Decoupled models with TDD decoupling technique.....	76
Figure 4.6: Root Locus plots for the linear velocity subsystem.....	77
Figure 4.7: Closed-loop step responses of controllers with initial and optimal parameters	78
Figure 4.8: Root Locus plots for the angular velocity subsystem.....	78
Figure 4.9: Closed-loop step responses of controllers with initial and optimal parameters	79
Figure 4.10: The smart hospital bed travels on the granite surface	80
Figure 4.11: The open loop and closed-loop response of the hospital bed system with $v_d = 1 \text{ m/s}$; $\omega_d = 1 \text{ rad/s}$	80
Figure 4.12: The closed-loop response of the hospital bed dynamics being controlled by OMPID control with $v_d = 0.4 \text{ m/s}$; $\omega_d = 0.4 \text{ rad/s}$	81
Figure 4.13: The closed-loop response of the hospital bed dynamics being controlled by OMPID control with $v_d = 0.6 \text{ m/s}$; $\omega_d = 0.6 \text{ rad/s}$	82
Figure 4.14: The closed-loop response of the hospital bed dynamics being controlled by OMPID control with $v_d = 0.8 \text{ m/s}$; $\omega_d = 0.8 \text{ rad/s}$	82
Figure 4.15: The closed-loop response of the hospital bed dynamics being controlled by OMPID control with $v_d = 1 \text{ m/s}$; $\omega_d = 1 \text{ rad/s}$	83
Figure 4.16: The smart hospital bed travels on various environmental conditions: .	84

Figure 4.17: System outputs of the smart hospital bed being controlled by OMPID control with $v_d = 1 \text{ m/s}$; $\omega_d = 1 \text{ rad/s}$ in the case of travelling on the carpet surface	85
Figure 5.1: Advanced operator-following control strategy.....	91
Figure 5.2: Optimal multivariable neural network control structure for a smart hospital bed	94
Figure 5.3: Optimal neural network control structure.....	96
Figure 5.4: Neural network control structure.....	97
Figure 5.5: Opened-loop of the decoupled transfer matrices $P_{DD}(s)$, $P_{1DD}(s)$ and $P_{2DD}(s)$ using the diagonal decoupling technique.....	103
Figure 5.6: System outputs of three representational sub-systems $P_{DD}(1,1)$, $P_{1DD}(1,1)$ and $P_{2DD}(1,1)$ these being controlled by $ONNCv$	106
Figure 5.7: System outputs of three representational sub-systems $P_{DD}(2,2)$, $P_{1DD}(2,2)$ and $P_{2DD}(2,2)$ these being controlled by $ONNC\omega$	109
Figure 5.8: Comparison between OMNN control approach and OMIPD control approach.....	110
Figure 5.9: The closed-loop response of the hospital bed dynamics being controlled by OMNNC with $v_d = 0.4 \text{ m/s}$; $\omega_d = 0.4 \text{ rad/s}$	111
Figure 5.10: The closed-loop response of the hospital bed dynamics being controlled by OMNNC with $v_d = 0.6 \text{ m/s}$; $\omega_d = 0.6 \text{ rad/s}$	111
Figure 5.11: The closed-loop response of the hospital bed dynamics being controlled by OMNNC with $v_d = 0.8 \text{ m/s}$; $\omega_d = 0.8 \text{ rad/s}$	112
Figure 5.12: The closed-loop response of the hospital bed dynamics being controlled by OMNNC with $v_d = 1 \text{ m/s}$; $\omega_d = 1 \text{ rad/s}$	112
Figure 5.13: Output responses of the smart hospital bed being controlled by OMNNC with $v_d = 1 \text{ m/s}$; $\omega_d = 1 \text{ rad/s}$ in the case of travelling on the carpet surface	114

Figure 5.14: Trajectory of the hospital bed and operator	116
Figure 5.15: Linear velocity of the hospital bed and operator	116
Figure 5.16: Angular velocity of the hospital bed and operator	117

List of tables

Table 3.1: Experimental results of the Gaussian Distribution Method.....	56
Table 3.2: Mean values of training, validation and testing results utilising four algorithms.....	56
Table 3.3: Best performance of NN based operator detection using four algorithms.....	57
Table 3.4: Comparisons of mean values and best performances of testing results for two proposed classification algorithms.....	57
Table 4.1: Output performance of the linear velocity subsystem (on the granite surface).....	83
Table 4.2: Output performance of the angular velocity subsystem (on the granite surface).....	84
Table 4.3: Output performance of the linear velocity subsystem (on the carpet surface).....	85
Table 4.4: Output performance of the angular velocity subsystem (on the carpet surface).....	86
Table 4.5: Output performance of the linear velocity subsystem (on the cement surface).....	86
Table 4.6: Output performance of the angular velocity subsystem (on the cement surface).....	86
Table 5.1: Results of NN-LM based operator detection algorithm.....	92
Table 5.2: Output performance of the linear velocity subsystem (on the granite surface).....	113
Table 5.3: Output performance of the angular velocity subsystem (on the granite surface).....	113
Table 5.4: Output performance of the linear velocity subsystem (on the carpet surface).....	114

Table 5.5: Output performance of the angular velocity subsystem (on the carpet surface).....	115
Table 5.6: Output performance of the linear velocity subsystem (on the cement surface).....	115
Table 5.7: Output performance of the angular velocity subsystem (on the cement surface).....	115

List of Abbreviations

2D	: 2-dimensional
ANN	: Artificial neural network
DC	: Direct current
DSP	: Digital signal processing
DV	: Disparity vectors
FN	: False negative
FP	: False positive
G	: Girth
GaRBF	: Gaussian radial basis function
GDM	: Gaussian distribution method
GDX	: Gradient descent with momentum
H	: Height
HJB	: Hamilton-Jacob-Bellman
HSV	: Hue, saturation and value
IAV	: Inscribe Angle Variance
IMM	: Interacting multiple model
LM	: Levenberg Marquardt
LRF	: Laser range finder
MLP	: Multilayer perceptron
NN	: Neural network
OFV	: Optical flow vectors
OMPID	: Optimal multivariable proportional integral derivative
OMNNC	: Optimal multivariable neural network controller
ONN	: Optimal neural network
ONNC v	: Optimal neural network controller for linear velocity subsystem
ONNC ω	: Optimal neural network controller for angular velocity subsystem
OPID	: Optimal proportional integral derivative
P	: Proportional
PD	: Proportional derivative
PID	: Proportional integral derivative
RBF	: Radial basis function

RANSAC	:	Random sample consensus
RP	:	Resilient backpropagation
SCG	:	Scaled conjugate gradient
<i>Sen</i>	:	Sensitivity
<i>Spec</i>	:	Specificity
TDD	:	Triangular Diagonal Dominance
TP	:	True positive
TN	:	True negative
UTS	:	University of Technology Sydney
W	:	Width

Abstract

The intention of employing hospital beds is to bring comfort to the hospitalised people and support the clinical staff in patient-care activities. Over many years, hospital beds have been upgraded from simple beds created by crude stretchers to smart beds equipped with various advanced functionalities such as motorised wheels and an intelligent steering system. With these features, patient transportation becomes much easier and safer than before. In addition, the number of manual handling tasks and injuries of nurses in relation to the transfer of patients are significantly reduced.

However, a drawback of the current smart hospital beds is that their steering systems are controlled by human users. In recent years, the increasing number of people being hospitalised (especially obese patients) has led to work overload problems for nurses. Stress, exhaustion and distraction of staff are some of the effects of the nursing work overload problem. These are also major factors causing unpredictable risks for both patient and medical staff during transportation within hospitals.

An integration of an operator-following function not only allows the smart hospital bed to deal with the problem of human control but also creates an innovative solution in terms of patient transport. To achieve this, a 3-stage operator-following control strategy is required for the bed system. In the first stage, the operator is identified by the utilisation of a target detection algorithm. In the second stage, based on the information obtained relating to the operator, operator-following controllers generate desired velocities for the smart hospital bed. In the final stage, a low-level controller drives the bed system to track the desired velocities.

In relation to operator detection, two approaches, consisting of the Gaussian Distribution Method (GDM) and the Artificial Neural Network (ANN), are investigated and developed for the smart hospital bed. Technically, the GDM classifier is based on a threshold condition of a Mahalabonis distance between a testing point and the training data set. On the other hand, the ANN classifier is based

on a construction of a neural network model through a training procedure. The experimental results show that the operator detection performance of the Neural Network - Levenberg Marquardt (NN-LM) method is better than that of the GDM method (92.41% sensitivity and 89.8% specificity vs 91% sensitivity and 88.5% specificity).

In terms of the low-level control, two approaches including an Optimal Multivariable Proportional Integral Derivative (OMPID) control method and an Optimal Multivariable Neural Network (OMNN) control approach are introduced and designed for the smart hospital bed. In theory, the OMPID control algorithm is a combination of a Triangular Diagonal Dominance (TDD) decoupling technique and an Optimal Proportional Integral Derivative (OPID) control design. Meanwhile, the OMNN control strategy combines a two-phase diagonal decoupling technique and an Optimal Neural Network (ONN) control design. Real-time implementation indicates that the OMNN controller drives the smart hospital bed to track the desired velocities with higher accuracy, smaller overshoot, shorter rise time and settling time than the OMPID controller.

From the results obtained from the operator detection algorithms and the low-level control algorithms, an advanced operator-following control strategy is developed for the smart hospital bed. This is a combination of the neural network based operator detection method, the Proportional Integral Derivative (PID) based operator-following strategy and the intelligent multivariable low-level control approach. The Levenberg-Marquardt (LM) learning algorithm is chosen to train the neural network classifier. Two PID controllers are utilised to minimise the distance and angle error between the operator and the bed system. The Optimal Multivariable Neural Network control strategy takes the responsibility of stabilising the overall system under the effect of uncertainties. The experimental results serve to show that the operator-following performance of the smart hospital bed using the advanced operator-following control strategy is more stable and efficient than that of the bed system without the proposed approach.