A Smart Wheelchair System using a Combination of Stereoscopic and Spherical Vision Cameras

By

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Certificate of Authorship / Originality

I, Jordan Son Nguyen, certify that the work in this thesis has not previously been submitted for a degree, nor has it been submitted as part of the requirements of a degree, except as fully acknowledged within the text.

I also certify that this thesis has been written by me. Any help that I have received in my research work and in 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.

Signature of Candidate

November 2012

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Table of Contents

List of Figures

List of Tables

Nomenclature

1D	1-Dimensional
2D	2-Dimensional
3D	3-Dimensional
AB	Able-Bodied
ADC	Analog-Digital Converter
AWF	Automatic Wall Following
BCI	Brain-Computer Interface
CAN	Controller Area Network
CCD	Charge-Couple Device
CCW	Counter-Clockwise
CNS	Central Nervous System
CPU	Central Processing Unit
CW	Clockwise
CWA	Collaborative Wheelchair Assistant
DAQ	Data Acquisition
DLL	Dynamic Link Library
DOS	Disk Operating System
DP	Door Passing
EEG	Electroencephalograph
FM	Fundamental Matrix
FN	False-Negative
FOV	Field Of View
FP	False-Positive
FPS	Frames Per Second
GOA	General Obstacle Avoidance
GPIO	General-Purpose Input/Output
GPS	Global Positioning System
GUI	Graphical User Interface
HMC	Head-Movement Controller
HIS	Hue/Saturation/Intensity
HFOV	Horizontal Field Of View
IEEE	Institute of Electrical and Electronic Engineers
IR	Infrared
LED	Light-Emitting Diode
LIS	Locked-In Syndrome
NI	National Instruments
NSW	New South Wales
PC	Personal Computer
PCB	Printed Circuit Board
PFM	Potential Field Method
PGR	Point Grey Research
POC	Proof Of Concept
QUEST	Quebec User Evaluation of Satisfaction with Assistive Technology
RGB	Red/Green/Blue
RRCS	Royal Rehabilitation Centre, Sydney
RSU	Rehabilitation Studies Unit
SAD	Sum of Absolute Differences
SCI	Spinal Cord Injury

SD	Standard Deviation
SLAM	Simultaneous Localisation And Mapping
TFT	Thin-Film Transistor
TIM	Thought-controlled Intelligent Machine
TIM-VPH	Thought-controlled Intelligent Machine – Vector Polar Histogram
TN	True-Negative
TOF	Time-Of-Flight
TP	True-Positive
USB	Universal Serial Bus
UTS	University of Technology, Sydney
VFF	Vector Force Field
VFH	Vector Field Histogram
VPH	Vector Polar Histogram
WCCP	Wheelchair Centre Point

Abstract

Reports have shown growing numbers of people who fall into the categories of the elderly or those living with some form of disability. Physical and functional impairments are broad-ranging across these groups and the causes are numerous, including strokes, spinal cord injury, spina bifida, multiple sclerosis, muscular dystrophy, and various degenerative disorders. Rehabilitation technologies are a solution to many of these impairments and aim to improve the quality of life for the people who require them. Smart wheelchair developments, in particular, have the purpose of assisting those with mobility disabilities. Providing independence in mobility can have many significant benefits to the users in their daily lives, including improved physical, cognitive, confidence, communication, and social skills.

Unfortunately for many, particularly those with tetraplegia (partial or total loss of functionality through illness or injury to all four limbs and torso), there is a serious lack of options available for adequately and safely controlling mobility devices such as wheelchairs. There are few options for hands-free controlling wheelchairs, and furthermore, there are no accessible options for intelligent assistance from the wheelchair to make hands-free control easy and safe. This is a serious issue since the limited hands-free control options available can be difficult to use, resulting in many accidents. There are also new control technology devices emerging in research, such as brain-computer interfaces (BCIs), which could potentially provide an adequate means of control for many people who cannot use currently commercial options, but require intelligent assistance from the wheelchair to make use of such a system safe.

In this thesis, the design and development of a new smart wheelchair, named TIM, is introduced to address these issues. The TIM smart wheelchair was created with the intention of providing intelligent assistance during navigation for any hands-free control technology, both currently commercial and new devices produced in research. This aims to vastly improve the options available to the people who are in need of such smart wheelchair developments.

A method of utilising stereoscopic cameras for adaptive, real-time vision mapping is presented in this thesis, as cameras are increasingly becoming a more accessible and inexpensive form of artificial sensor. The mapping process in this method involves acquisition from the left and right stereo pair of cameras, which then undergo a range of image pre-processing techniques before being stereo-processed, which includes matching and correlation algorithms, to produce a disparity image. This disparity image contains depth information about the scene, which is then converted into a 3-dimensional (3D) point map, placing all mapped pixels of the environment, and features within, into a 3D plane. Unnecessary information, such as the floor and everything above the maximum height of the TIM smart wheelchair, is removed and the remaining data extracted into a 2-dimensional (2D) bird's eye view environment map. This mapping representation assists the wheelchair in the later steps of making intelligent navigational decisions based on the relative placement of objects in the environment.

Wheel encoders on the drive wheels are also acquired during operation, and odometry change calculations are performed to facilitate the ability of the system to 'remember' mapped object points that have passed outside the vision range. This is performed frequently to construct a real-time environment map, and to remember the placement of objects that have moved out of the range of vision, in order to further avoid collisions. This is particularly useful for static environments and creating maps of the static object placements within. A wheel parameter correction process was also employed to increase the accuracy of this mapping process and successfully reduce the errors associated with drive wheel specifications, which in turn can affect the mapping process based on the wheel encoder information. Correction of these parameters helped optimise the 'memory mapping' process and reduce skewing and accumulative errors in the maps.

A process for intelligent stereo processing parameter selection was designed, as the quality of disparity images, and hence the quality of environmental-mapping, is heavily dependent on the stereo processing parameters, which may work well when set for one environment but produce problems in another. The differences that affected performance between environments were found to mostly be the lighting conditions which resulted from the varying types of environments. As such, this proposed method involves classifying environmental categories in real-time, based on image data available, and adapting the parameters accordingly. The environment types were separated into four categories to account for most encountered environmental situations, being 1) 'General Illumination Contrast', 2) 'Extreme Illumination Contrast', 3) 'Consistent Dark', and 4) 'Consistent Bright'. The proposed method successfully allowed classification in real-time of the environment categories and adaptation of the stereo processing parameters in accordance, producing a system that can change its settings 'on the fly' to suit the environment the wheelchair is navigating through.

Limited vision and trouble with dynamic objects were found to be downfalls with the stereoscopic vision, so to address these, methods of utilising a spherical vision camera system were introduced for obstacle detection over a wide vision range. Spherical vision is an extension of monoscopic cameras, producing 360º of panoramic vision. A strategy to utilise these panoramic images is presented, in which the images are separated into segments and 'Traffic Light' zones. The segments display different areas of the image representing the allocated areas around the wheelchair. The 'Traffic Light' zones within the segments are separated into three categories: 1) Red, meaning an obstruction is present around the wheelchair, 2) Yellow, indicating to take caution as an object is nearby, and 3) Green, meaning there are no objects close to the wheelchair in this segment. Image processing techniques have been assembled as a pre-processing strategy, and neural networks are used for intelligent classification of the segmented images into the zone categories. This method provides a wider range of vision than the stereoscopic cameras alone, and also takes into account the issue of detecting dynamic obstacles, such as people moving around.

A unique combination of the stereoscopic cameras and the spherical vision cameras is then introduced. This combination and system configuration is biologically inspired by the equine vision system. Horses inherently have a large vision range, which includes a wide monocular vision range around and a binocular vision overlap ahead of the horse. In accordance with this effective vision system, the camera configuration on the TIM smart wheelchair was modelled similarly and advanced software integration strategies then followed.

A method for advanced real-time obstacle avoidance is presented, which utilises algorithms in research, such as Vector Field Histogram (VFH) and Vector Polar Histogram (VPH) methods, and adapts them for use with the specified camera configuration. Further improvement upon the algorithms for this application provides safer obstacle avoidance during navigation in unknown environments, with an added emphasis on making automated navigational decisions towards areas with more available free space. Speed and manner of obstacle avoidance is dependent upon the placement spread of objects in an environment and how close they are to the wheelchair during navigation.

Finally, the combination and integration of the automated guidance and obstacle avoidance capabilities of the wheelchair with hands-free control technologies are introduced. The aim of the TIM smart wheelchair system was to effectively provide safe navigation with automated obstacle avoidance in a manner that ultimately executes the user's intentions for travel. As such, a head-movement control (HMC) device and a brain-computer interface (BCI) device are both separately integrated with the TIM smart wheelchair, providing a display of two new options for hands-free control.

Experimental studies were conducted using these two control devices separately, to assess the performance of the TIM smart wheelchair, as well as its ability to carry out user's navigational intentions safely and effectively. Eight able-bodied participants trialled the system, including four male and four female, with ages ranging from 21 to 56 years old. All of these able-bodied participants have not previously had any experience operating a wheelchair. In addition, two male tetraplegic (C-6 to C-7) participants also completed the experimental study, aged 20 and 33. Both tetraplegic participants are wheelchair users, so these experiments were of great importance. The same tasks applied to all, and included navigating obstacle courses with the use of the head-movement control system and the brain-computer interface for control. Experiment runs were conducted for each control system with automated navigational guidance assistance from TIM, and repeated for some capable participants without the assistance from TIM. This process was also conducted in two types of obstacle courses, being 1) a 'Static Course' and 2) a 'Dynamic Course', requiring different types of challenges in obstacle avoidance. This provided results to assess the performance and safety of the TIM smart wheelchair in a range of environments and situations.

Evaluation of the results displayed the feasibility and effectiveness of the developed TIM smart wheelchair system. This system, once equipped with a unique camera configuration and reliable obstacle avoidance strategies, was able to successfully allow users to control the wheelchair with research-produced hands-free interface devices and effectively navigate safely through challenging environments. The TIM smart wheelchair system is able to adapt to people with various types and levels of physical impairment, and ultimately provide ease-of-use as well as safety during navigation.