DESIGN AND DEVELOPMENT OF A FLEXIBLE ROBOTIC ARM VISION SYSTEM FOR ORTHOPEDIC ROBOT

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DECLARATION

I hereby declare that the materials in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

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LIST OF ABBREVIATION

°	Degree
CAD	Computer Aided Design
CCD	Charge-Coupled Device
cm	Centimetre
DC	Direct current
DMS	Danger Monitoring System
F	Far
FL	Fuzzy Logic
FSARS	Fail Safe and Auto Recovery System
GUI	Graphical User Interface
HS	High speed
I^2C	Inter-Integrated Circuit
LED	Light Emitting Diode
LS	Low speed
m	Metre
mm	Millimetre
M	Medium
MS	Medium speed
MSB	Most Significant Bit
N	Near
OAS	Obstacle Avoidance System
OTOROB	Orthopaedic robot
PIC	Programmable Integrated Circuit
QEI	Quadrature Encoder Interface
RAM	Random Access Memory
RPM	Revolutions per minute
SPI	Serial Peripheral Interface

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ABSTRAK

Salah satu masalah utama dan terbaru yang membelunggu hospital di Malaysia adalah masalah kekurangan pakar atau pakar bedah, terutamanya di kawasan luar bandar. Pakar bedah khusus yang tidak mencukupi di kawasan-kawasan itu terutamanya dalam bidang ortopedik menyebabkan lebih banyak kematian di kalangan pesakit disebabkan oleh kekangan masa. Sistem robot mudah alih yang dikenali sebagai OTOROB telah direka dan dibangunkan untuk membantu pakar bedah untuk hadir secara maya di kawasan itu bagi menghadiri pesakit. Sistem robot mudah alih tersebut memerlukan lengan robotik yang fleksibel untuk memeriksa pesakit yang dikawal dari jauh oleh pakar bedah. Lengan robot yang fleksibel dengan sistem penglihatan sebagai efector akhir telah direka, dirumuskan dan diuji pada masa nyata. Sebelum pembangunan prototaip, pemodelan maya lengan robot dilakukan mengunakan perisian Solidworks. Model yang direka telah disimulasi dan dianalisis untuk mengkaji kesesuaian reka bentuk. Keputusan simulasi membuktikan bahawa reka bentuk berkenaan sesuai untuk dibangunkan. Kemudian, prototaip yang dibangunkan telah diuji kebolehulangan, dan ujian kelinearan untuk menentukan kawalan pergerakan lengan robot. Analisis kelinearan dan sudut pergerakan lengan robot menunjukkan ralat kurang daripada 5% kesilapan. Perisian pengawalan lengan robotic (GUI) telah dibangunkan untuk mengawal lengan robot dan mendapatkan data dari lengan robot mengenai orientasi dan kedudukan. Logik kabur dilaksanakan dalam sistem kawalan keselamatan untuk artikulasi lengan robot. Sistem keselamatan lengan robot terdiri daripada Sistem Pemantauan Bahaya (DMS), Sistem Pengelakan Rintangan (OAS) dan Sistem Gagal Selamat dan Pemulihan Sendiri (FSARS). DMS yang dikawal system logic kabur diuji dan dinilai. Hasil kajian menunjukkan bahawa DMS mampu menilai and menunjukkan tahap bahaya di sekeliling lengan robotik kepada pengguna melalui GUI dengan tanda-tanda amaran dan kedudukan halangan. Kemudian, OAS memberikan maklum balas kepada halangan mobil dan statik di sekeliling lengan robot. Lengan robot didapati mampu mengelakkan halangan menghampiri secara autonomi melalui kawalan logik kabur. FSARS lengan robot adalah tertakluk kepada pelbagai keadaan kegagalan, dan sistem membuktikan bahawa pengunaan sistem pemulihan berjaya. Akhirnya, sistem penglihatan dinilai dengan menganalisis sistem pencahayaan pengelihatan menggunakan perisian Matlab. Integrasi sistem lampu LED meningkatkan kejelasan visual yang diperolehi melalui kamera video. Kawalan lancar lengan robotik dan juga rutin keselamatan melalui logik kabur telah menambah baikkan keseluruhan artikulasi lengan robotik.

ABSTRACT

DESIGN AND DEVELOPMENT OF A FLEXIBLE ROBOTIC ARM VISION SYSTEM FOR ORTHOPAEDIC ROBOT (OTOROB)

One of the main and recent problems in Malaysian hospitals is the lack of surgeons and specialists, especially in rural areas. Insufficient specialised surgeons in such regions particularly in the niche of orthopaedic causes more fatalities and amputees due to time constrain in attending the patients. Broken limbs due to accidents can be treated and recovered. But severed blood vessels results in blood loss and leads to amputation or even worst fatalities. A mobile robotic system known as OTOROB is designed and developed to aid orthopaedic surgeons to be virtually present at such areas for attending patients. The developed mobile robotic platform requires a flexible robotic arm vision system to be controlled remotely by the surgeon. To be present virtually is still insufficient if clearer view is not obtained. Thus, a flexible robotic arm with vision system as end effector is designed, developed and tested in real time. Prior to the development of the prototype, virtual modelling of the robotic arm is done in Solidworks. The designed model is simulated and analysed to study the suitability of the design. The simulation results proved that the design is applicable. Then, the developed prototype is subjected to repeatability, and linearity tests in order to determine the movement control of the robotic arm. The robotic arm linear and angular movements resulted in less than 5% of error. A Graphical User Interface (GUI) is developed to control the robotic arm and obtain data from the robotic arm regarding the orientation and position. Fuzzy logic is implemented in the control system to provide safety for the robotic arm articulation. The safety systems of the robotic arm consist of Danger Monitoring System (DMS), Obstacle Avoidance System (OAS) and Fail Safe and Auto Recovery System (FSARS). The fuzzy controlled DMS system was tested and evaluated. The results prove that the DMS is capable of conveying danger level surrounding the robotic arm to the user through GUI with warning indication and obstacle positions. While, the developed OAS, responded to the approaching and static obstacle around the robotic arm. The robotic arm is capable of avoiding approaching obstacle autonomously via fuzzy control. FSARS of the robotic arm was subjected to various failure circumstances and the system executed the recovery system successfully. Finally, the vision system was evaluated by analysing the vision lighting system using Matlab software. The integration of LED lighting system improved the visual clarity obtained through the video camera. The smooth control of the robotic arm coupled with the safety routines improved the overall articulation of the robotic arm.

CHAPTER 1

INTRODUCTION

1.1 Robot

The advancement of human civilization aside from those core elements such as agriculture, trade, transportation, architecture, mathematics, science, politics, and astronomy has brought human kind into a new era of sophisticated and modern living. The use of tools and "know-how-to-make" ability of human marked the beginning of technology, or the science of engineering which have brought mankind into a new era of highly sophisticated and advance civilization, where in this 21st century robotics play a major role (Mitsuishi *et al.*, 2007).

The early development of robot can date back to 12th century AD, such as the Automata of Al-Jazari, which is a self-operating machine and Leonardo Da Vinci's humanoid automaton in the 15th century (Vijay Kumar, 2010). Since then robots also evolved on the path of human civilization until the development of the world most advanced humanoid robots like ASIMO by Honda and TOPIO by Tosy Robotics. Automata of Al-Jazari and ASIMO are shown in Figure 1.1.

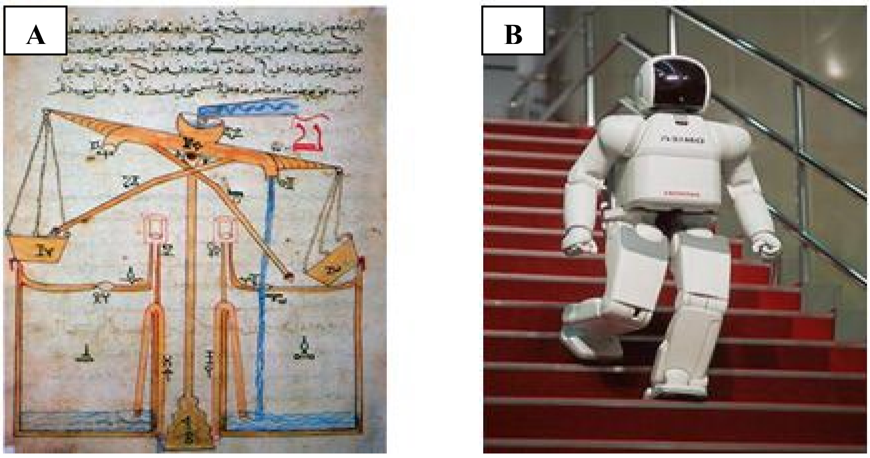

Figure 1.1: Sketch of Automata of Al-Jazari (A) and ASIMO the humanoid robot by Honda (B)

Source: (A) www.wikipedia.org/wiki/Al-Jazari and (B) asimo.honda.com/products

A robot in modern world according to Robot Institute of America is an automatic, reprogrammable, multifunctional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of variety of tasks (Robot Institute of America, 1975). While, Broadbent *et al*. (2009) described a robot as a very powerful computer with equally powerful software housed in a mobile body and able to act rationally on its perception of the world around it. Robots were initially used in the automation sector to replace human labours for handling repetitive and simple tasks reliably, with the objective of cost reduction (Haydars and Levent, 2007).

Besides that, wide application of robots include deployment in dangerous and hazardous work spaces which are potentially dangerous to humans, such as underwater, underground, space and other extreme environments (Park *et al*., 2006). The usage of robots can be traced in almost every field ventured by humans, from household robots such as vacuum cleaner robots to bomb disposing robots in military operations and NASA Spirit Rover for Mars exploration.

However, the new trends in robotics research have been denominated by service robotics because of their general goal of getting robots closer to human social needs, especially in the areas such as medical robotics, rehabilitation robotics, field robotics, construction robotics and humanoid robotics (Garcia *et al*., 2007).

1.2 Medical Robotics

Medical robotics refers to robotic systems applied within the domain of health care which evolved from multidisciplinary field of science and engineering involving topics from mechanical engineering, electrical engineering, materials science and computer science (Wang *et al*., 2006).

Initial surgical robotic systems in the 1980s employed general-purpose industrial manipulators, either directly or with minor modifications (Taylor and Stoianovici, 2003). The designed robotic system often shares its working area with operators or medical staff and has a close interaction with the patient (Vilchis *et al.*, 2003).

According to Kanade *et al.* (2006) and Taylor (2006), the term medical robotics has often been construed to refer strictly to surgical procedures. However due to its indefatigability, accuracy, and repeatability, robotic technology is increasingly affecting the entire healthcare sector through advances in surgery, diagnosis, preoperative planning, postoperative evaluation, chronic assistive devices, acute rehabilitation, hospital logistics and scheduling, long-term follow-up and quality control.

Medical robotics also extensively improves existing medical procedures to be less invasive and produce fewer side effects that would result in faster recovery times and improved worker productivity, improve risk-benefit, cost-benefit ratios and reduced medical errors (Okamura *et al.*, 2010). The major niche in medicine that employs robotics is surgical and interventional robotics. The development of surgical robots is motivated by the desire to enhance the effectiveness of a procedure by coupling information to action in the operating room or interventional suite and transcend human physical limitations in performing surgery and other interventional procedures (Wang *et al.*, 2006). The earlier surgical robots were used in neurosurgery and orthopaedic surgery as the anatomic landmarks provided convenient, fixed and accurate points of registration by the computer (Hong *et al.*, 2006).

The Zeus and da Vinci robots are robots with master-slave configuration where the surgeon controls the surgery and a set of positioners and camera-control equipment that is mounted on the operating room table are used effectively in telesurgery (Butner and Ghodoussi, 2003; Mitsuishi *et al.*, 2007). Surgical robots such as the da Vinci surgical system and Zeus surgical system shown in Figure 1.2, are beginning to realize their potential in terms of improved patient outcomes.

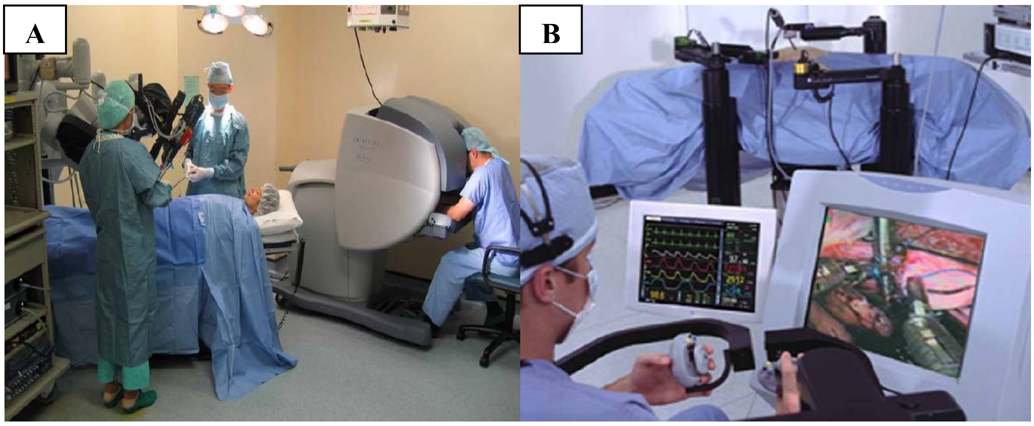

Figure 1.2: The Da Vinci (A) and Zues (B) surgical robots

Source: (A) www.davincisurgery.com and (B) www.allaboutroboticsurgery.com

The other types of health care robot that are widely used in medical field are the telemonitoring robots. Normally, a telemonitoring robot is controlled by a remote doctor for telerounding in hospitals which employs two ways audio visual communication with patients. This type of robots, for instance Remote Presence-7 (RP7) by Intouch Inc., were successfully used as telehealth system and become a new modality for doctor-patient interactions, particularly in areas where access to medical expertise is limited (Bartneck *et al*., 2010). Figure 1.3 shows the RP7 robot during telerounding check on a patient in Shawnee Mission Medical Center, Kansas City.

Figure 1.3: Telerounding by a remote doctor using RP7 robot in Shawne Mission Medical Centre, Kansas City

Source: www.intouchhealth.com/produts/rp-7/

The development of surgical and telemonitoring robots in medical field is targeted to overcome human resource shortages and improve health care services. Moreover, robotic assistive limbs and rehabilitation robots are widely used to assist patients to lead a better life. For instance, robotic prosthetic devices aim to emulate the missing limb or other body part through replication of many joints and limb segments and seamless neural integration that provides intuitive control of the limb as well as touch feedback to the patient with missing limbs (Wang *et al.*, 2006). Robot assisted recovery and rehabilitation reduces recovery period of the patient and reduces trauma.

1.3 Research Motivation

The increase of road accidents is related to the rapid growth in population, economic development, industrialisation and motorisation encountered by the country (Nizam Mustafa, 2005). According to Abdul Rahman *et al.* (2005) injuries due to road traffic accidents are the third cause of admission and the fifth cause of death in Malaysian government hospitals in 2003, where traffic accidents in Malaysia have been increasing at the average rate of 9.7% per annum over the last three decades. Table 1.1 presents road accidents statistic from year 2003 to 2010, released by Road Safety Department, Ministry of Transportation (MOT).

Table 1.1: Road accidents statistics from year 2003 to 2010

Year		2003	2004	2005	2006	2007	2008	2009	2010
Total Accidents		298,653	326,814	328,268	341,232	363,319	373,047	397,330	414,421
Type of Injury	Death	6,286	6,228	6,188	6,287	6,282	6,527	6,745	6,872
	Critical	9,040	9,229	9,397	9,254	9,273	8,866	8,849	7,781
	Light	37,415	38,631	31,429	19,884	18,444	16,901	15,823	13,616

Source: Road Safety Department, Malaysian Ministry of Transportation

Studies also revealed that the number of fatalities (death within 30 days after accident) also increased due to serious injuries (Nizam Mustafa, 2005). Malaysia as a developing country, has introduced various campaigns, safety regulations and technological implementation to prevent road accidents rate. Measures taken to deliver efficient treatment and healthcare services to victims particularly in remote/