ROBOTIC NEUROSURGERY: AN ACTIVE VISION GUIDED ROBOTIC ARM FOR ENDOSCOPIC AND BONE DRILLING MANEUVERS

By

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DEDICATION

"To My Family"

To my parents, En Awang Bin Ahmad and Puan Ainon Kamarian Bt Md Ali, thank you for giving me good education and support until today. My appreciation goes to my wife, Khairani Idah Mokhtar and my lovely daughter, Maisarah for being patience all this while. Not forgotten, to my in-laws En Mokhtar Bin Hassan and Puan Wan Hasnah Bt Wan Ismail, for taking care of my daughter when I'm not around.

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ABSTRAK

Penggunaan robot di bidang perubatan telah bermula satu dekad yang lalu. Neurosurgeri merupakan salah satu daripada bidang perubatan yang mempelopori penggunaan robot. Tujuan kajian ini adalah untuk menghasilkan satu program dengan menggunakan perisian V+ dan mencipta pemegang yang berkebolehan untuk memegang pengerudi dan endoskop serta menilai keupayaan dan ketepatan robot melakukan pembedahan asas neurosurgeri seperti mengerudi tulang dan pergerakan endoskopi. Kajian ini terbahagi kepada dua bahagian iaitu penebukan tulang dan pergerakan endoskopi. Di bahagian penebukan tulang, sebaik selesai proses pengimejan, koordinat sasaran akan ditentukan. Tangan robot (bersama dengan pengerudi lubang) akan dirangsang dan dibawa kearah sasaran. Daya kemasukan pada tangan robot diletakkan pada tahap minima agar pengerudi lubang dapat berhenti apabila menyentuh plastersin. Setelah lubang dibuat, tangan robot akan diarah bergerak jauh dari sasaran. Sebanyak 30 lubang akan dilakukan di lima kedudukan yang berbeza (*supine*, duduk, condong ke kiri/kanan, *prone*). Untuk bahagian pergerakan endoskop, tangan robot akan diarah untuk mengecam sasaran. Seterusnya, tangan robot akan dirangsang dan bergerak kearah sasaran dan memasukkan endoskop ke dalam lubang. Atas arahan, tangan robot akan digerakan ke dalam dan keluar. Di kedudukan *supine*, kejituan yang dicatatkan adalah 1.0mm dengan nilai ulangan diantara 0.04 mm ke 0.17mm. Masa untuk menebuk adalah diantara 13.1 ke 14.3 saat. Sementara di posisi duduk, kejituan yang dicatatkan berada diantara 0.1mm ke 1.0mm dengan nilai ulangan berada diantara 0.10 mm ke 0.92mm. Masa untuk menebuk pula berada diantara 6.6 saat ke 10.5saat. Di kedudukan condong ke kiri, kejituan yang

dicatatkan ialah 1.0mm dengan nilai ulangan diantara 0.03 ke 0.12 mm sementara di kedudukan condong ke kanan, kejituan yang dicatatkan berada diantara 1.0mm ke 2.0mm, dengan nilai ulangan sebanyak 0.10mm. Masa untuk menebuk bagi kedudukan condong ke kiri adalah 14.0 ke 15.4 saat manakala 12.5 ke 13.0 saat untuk kedudukan condong ke kanan. Di posisi *prone* pula, kejituan yang dicatatkan adalah 0.5mm ke 1.0mm dengan nilai ulangan diantara 0.08mm ke 0.31mm. Masa yang diambil untuk menebuk adalah diantara 9.0 ke 16.6 saat. Bagi pergerakan endoskopi, ketepatan yang dicatatkan adalah di antara 0.3mm ke 1.0mm dengan nilai ulangan sebanyak 0.31mm ke 0.77mm. Endoskop berjaya dimasukkan ke semua sepuluh lubang. Secara ringkasnya, walaupun dengan beberapa limitasi, robot ini didapati dapat melakukan pembedahan asas neurosurgeri. Tetapi banyak pengubahsuaian serta kajian yang lebih terperinci perlu dilakukan.

Robotic Neurosurgery: An Active Vision Guided Robotic Arm For Endoscopic And Bone Drilling Maneuvers

ABSTRACT

Surgical robots have been appearing in the operating room over the past decade and neurosurgery was one of the pioneer in this area. The aims of this study were to create a program using V+ module and to design a suitable end effector capable of holding bone perforator and endoscope. In addition, the ability and accuracy of the robot performing bone drilling and endoscopic maneuvers were assessed. The study was divided into two parts which were bone drilling and endoscopic maneuvers. In bone drilling section, immediately after image processing, the coordinates of the target were determined. The robotic arm (together with bone perforator) was simulated and driven to the target. The insertion force by the robot was placed at minimal as to allow the bone perforator to stop once it hit the plasticine. After a burr hole was made, the robot was instructed to move away from the target. A total of 30 burr holes were performed at 5 different positions (supine, sitting, right and left lateral, and prone). In endoscopic maneuver section, the robot was initiated to recognize the targeted burr hole. The robotic arm was simulated and driven to the targeted burr hole and placed the endoscope into the burr hole. On command, the robot was instructed to move forward (insertion) and outward. A total of ten burr holes were examined. In supine position, the accuracy was 1.0mm with the repeatability value ranged from 0.04mm to 0.17mm. Time taken to do burr holes was in the range of 13.1 to 14.3 seconds. In sitting position, the accuracy ranged from 0.1mm to

1.0mm with the repeatability ranged from 0.10mm to 0.92 mm and time taken to perform burr holes ranged from 6.6 to 10.5 seconds. In left lateral position, the accuracy was 1.0mm with repeatability of 0.03 to 0.12 mm and in right lateral position, the accuracy ranged from 1.0mm to 2.0mm with repeatability of 0.10mm. Time taken to drill in left and right lateral was in the range of 14.0 to 15.4 seconds and 12.5 to 13.0 seconds respectively. In prone position, the accuracy ranged from 0.5mm to 1.0mm with repeatability of 0.08 to 0.31 mm and the time taken to drill was in the range of 9.0 seconds to 16.6 seconds. For endoscopic procedure, the accuracy ranged from 0.3mm to 1.0mm with repeatability of 0.31mm to 0.77mm and the endoscope was able to be inserted into all 10 burr holes. In summary, the present robotic arm has the ability to perform basic surgical procedures although there were some limitations. Further study is needed to refine the robotic system.

Chapter 1:

1.0 INTRODUCTION

The use of robots in operation theatre has been appearing in the last few decades (Howe and Matsuoka, 1999). Robots have been used in general, cardiac and orthopaedic surgery (Howe and Matsuoka, 1999, Mohr et al., 1998, Chapman et al., 2001). In neurosurgery, the clinical used has been limited to stereotactic procedures and endoscopic maneuvers, although brain is a unique organ and well suited for robotic application (Louw et al., 2004).

A robot, at its most basic level should consists the following components: mechanical devices which consist of a wheeled platform, arm or any parts capable of interacting with its environment, sensors which receive signals from internal (robot) and external (environment) sources and a system which acts like a "brain", capable of integrating and transforming the signals and instructs the robot to perform appropriate tasks(Niku, 2001, Nathoo et al., 2005)

Robots are designed and controlled by the computer systems. It is designed in such a way that the robot is able to carry out any task that can be programmed simply by altering the program.The movements of the robot are controlled via the controller which is a specialized computer containing specific programs that interpret the input and allow motions. The controller will constantly monitor the external sensors (Niku, 2001).

Many surgical robots are robotic arms designed in different shapes and sizes. The arm is developed in a way that the end effector and sensor are capable of performing tasks. It may resemble human arm and based on this anthropometric, the robot is allowed to be positioned in a variety of ways. Each joint has 1 degree of freedom (DOF). A robotic arm with 3 degree of freedom mean that the robot is capable of moving in three different ways: left and right, forward and backward and up and down. Majority of the working robots have 6 degrees of freedom (Nathoo et al., 2005)

The main purpose of creating robot is to assist and extend human capabilities and not to replace human surgeons. There are advantages and disadvantages of using robots in surgery. Table 1.0 summarizes the strengths and limitations of human and robot.

Concerning the strength, robots have the ability to work continuously without experiencing fatigue, tremor or boredom and they are stable (Mc Beth et al., 2004). The surgeon's physiological tremor of 40 μm can be reduced to 4μm by using a robotic system (Nathoo et al., 2005).They resist to radiation and infection . Robots are able to perform work in hazardous environment (Satava, 2004).

Robots have good geometric accuracy and have repeatable precision at all times unless something goes wrong to them. They can process multiple stimuli simultaneously whereas human can only process single active stimulus (Sutherland et al., 2003).

The disadvantage of robots include poor judgement. They are unable to judge or think like human. They lack the capability to respond to emergency situations unless the safety mechanism has been programmed in the system (Howe and Matsuoka, 1999). They also have poor hand-eye coordination and limited dexterity. At present, most of the surgical robots are limited to relatively simple procedures (Nathoo et al., 2005). Robots are expensive. They are costly due to the initial cost of equipment and installation (Niku, 2005).

There are huge differences between medical and industrial robots. Medical robots are used in medical settings for patients and concern human life while industrial robots are operated in factories for product. Therefore, the safety issues of medical robots are more stringent and critical. The other different is that, industrial robots are required to be placed in isolated cell with safety interlocks, preventing people from directly interact with the robot. On the other hand, medical robots require direct contact with the patient and surgeon (Fei et al., 2001).

According to Duchemin et al. (Duchemin et al., 2004), in order to achieve certain standard safety certification, it is necessary to classify all medical devices according to four classes:

Class I: small degree of risk

Class IIa: medium degree of risk

Class IIb: high potential of risk

Class III: very serious potential of risk.

Obviously, by comparison, industrial robots belong to the last two categories (classes IIb and III), therefore making them so different from medical robots.

Table 1.0 : Summary of the strength and limitations of human and robot

Humans	Robots
<u>Strengths</u>	<u>Strengths</u>
Strong hand- eye coordination	Good geometric accuracy
Dexterous (at human scale)	Stable and untiring
Flexible and adaptable	Can be designed for a wide range of scales
Can integrate extensive and diverse information	May be sterilized
Able to use qualitative information	Resistant to radiation and infection
Good judgement	Can use diverse sensors (chemical, force, acoustic etc
Easy to instruct and debrief	
<u>Limitations</u>	<u>Limitations</u>
Limit dexterity outside natural scale	Poor judgment
Prone to tremor and fatigue	Limited dexterity and hand eye coordination
Limited geometric accuracy	Limited to relatively simple procedures
Limited ability to use quantitative information	Expensive
Large operating room space requirement	Technology in flux
Limited sterility	Difficult to construct and debug
Susceptible to radiation and infection	

Adapted from Howe and Matsuoka: Robotic for Surgery. *Annu Rev. Biomed Eng.* 1999; 211-240

1.1 ROBOTIC SYSTEM IN OTHER SPECIALITIES

1.1.1 _ORTHOPEDIC SURGERY

Orthopedic is one of the specialties that uses robot in some of its surgical procedures. Bones as compared to soft tissues are easier to manipulate and distort little during cutting. These make the application of image-guidance relatively easier. The areas that received greatest interest are hip and knee replacement and spinal fusion and other areas which are under way include craniofacial reconstruction and fracture treatment (Adili, 2004) .

The development of ROBODOC system starts in mid 1980s. In Europe, ROBODOC system is commercially available. However in the United States, the system is still undergoing FDA approval. As compared to the manual procedure, this system provides two advantages. Firstly, the clinical trials have shown that the femoral pocket is accurately formed and secondly, the preoperative CT scan images used to map the bone-milling procedure as a preparation to the system, provide the surgeon the opportunity to optimize the implant size and placement (Bargar et al., 1998).

1.1.2 GENERAL AND CARDIAC SURGERY

Minimally invasive procedure in general surgery involves making small incisions through the abdominal wall. The incision allows the instrument to be inserted and acts as a pivot so that the instrument can move freely inside the body (Wang et al., 1998).

Autonomous robots that utilize imaging data for guidance are not suitable for these applications, simply, because the high variety of skills needed to manipulate the deformable soft tissue. However, a surgeon-controlled teleoperated robot is promising. This system allows the surgeon to orientate the instrument even in difficult angle and also work at smaller scale as compared to hand-held instruments (Mack, 2001, Cohn et al., 1996).

Robotic system has been used in cardiac surgery. With the support of a new-generation articulated coronary stabilizer, cardiac surgeon is able to execute a completely endoscopic coronary artery bypass grafting without thoracotomy (Casula et al., 2003, Loulmet et al., 1999, Chitwood et al., 2001).

Garcia-Ruiz et al. (Garcia-Ruiz et al., 1997) in their study concluded that the use of robotic enhancement technology has led to better result in coronary artery bypass anastomoses in plastic model and also enhanced the precision, dexterity and reduced fatigue.

1.1.3 UROLOGY

In mid 1990s, the Automated Endoscopic System for Optimal Positioning (AESOP) was introduced into laparoscopic urology. This system was updated with 2000 version and has been shown to be accurate either by voice activation controlled, hand controller or foot pedals. It has been used as part of the standard operating system for laparoscopic radical prostatectomy (RP) and has been shown to reduce operating Time (Dasgupta and Challacombe, 2004).

Another kind of robots that are used in urology are da Vinci ™ (Intuitive Surgical Corp., Sunnyvale, CA) and Zeus ™ (Computer Motion, CA) (Dasgupta et al., 2005). Sung and Gill assessed and compared the two systems in performing various urologic laparoscopic procedures in acute porcine models. They found that robotic laparoscopic procedures were effectively done using either da Vinci or Zeus systems. However, the operative times were shorter and intraoperative technical movements were more intuitive with da Vinci system (Sung and Gill, 2001).

1.2 ADEPT COBRA 600

Adept Cobra 600 robot is a SCARA robot with 4 joints as depicted in Figure 1.1. Joints 1,2 and 4 provide rotational movements and joint 3 moves in translation. Joint 1, is also referred to as the shoulder has motion limited to ±105 degrees. Joint 2, which also referred to as the elbow has motion limited to ±150 degrees. Joint 3, allows vertical translation of the quill with the maximum stroke of 210mm. Joint 4, also referred as the wrist allows ± 360 degrees rotational movement. The Adept Cobra Robot uses the Adept MV (MV 5 or MV 10) controller and power cassis PA4 or compact controller. Table 1.1 summarizes the Adept Cobra Robot Specifications.

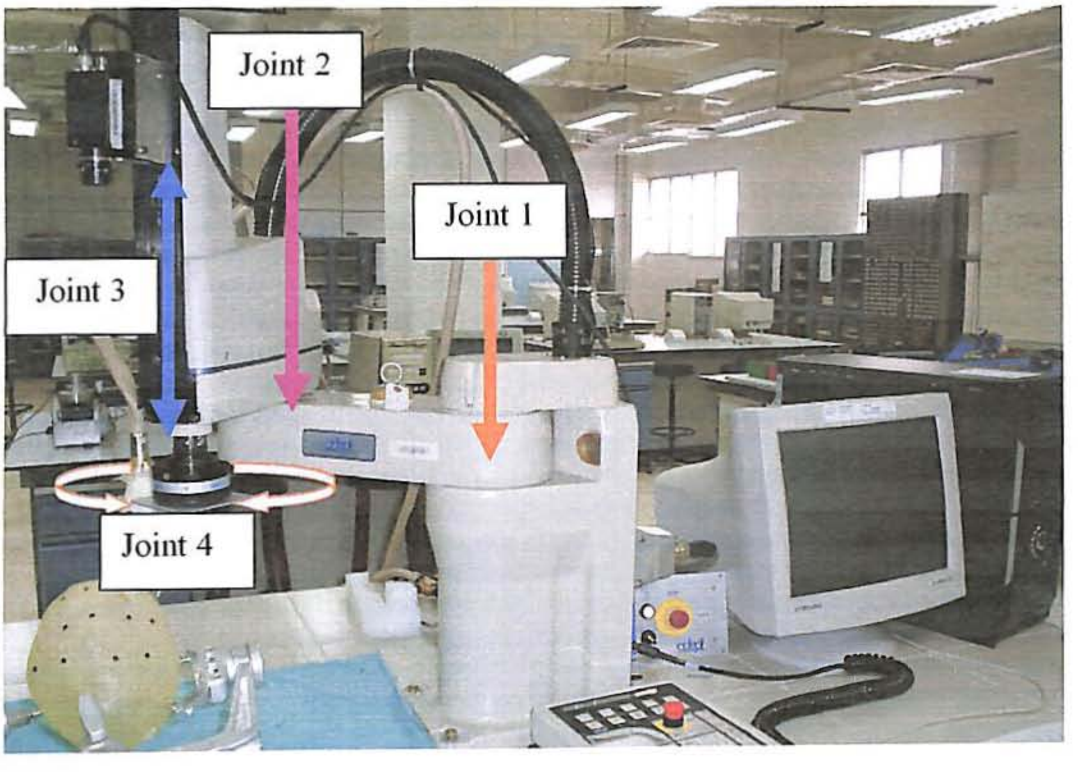

Figure 1.1: Adept Cobra 600 Robot