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Robotic Surgery Improvement: Novel Robotic Arm Model

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Abstract

Robotic surgery began by utilizing technologies from microsurgery, leading to 7-degree freedom robotic arms such as Da Vinci System. These robotic surgeries aim for precise, fast, and safe surgery compared to the original surgeries. However, 3 main problems emerged from the current robotic surgery system: size, cost, and malfunction. Size leads to other complications, and my model provides a solution for such complications. Research on JSTOR, Google Scholar, PubMed, and robotic surgery company websites, resulted in 21 articles, of which 12 were utilized as references in this paper. My model significantly decreases the size of robotic surgery by combining mechanical methods and parts from microsurgical robots. The attachment of a robotic arm to the operating table fulfilled my goal of solving current complications, which is decreasing the size, cost, and malfunction rate.

I. Introduction

The history of robotic surgery began with the concept of telepresence. Combining telemanipulation, which is for microsurgery, with telepresence made a concept of remote surgery, which would be the base for robotic surgery. Additionally, an orthopedic image-guided system developed by Hap Paul, DVM, and William Bargar, MD, enabled visual imaging systems in robotic surgery. As computer-assisted surgeries began to evolve, with the imaging system and computer-assisted technologies applied to robotic surgery, the size of robotic surgery systems increased continuously. While robotic surgery uses similar technologies that are being applied in microsurgery, combining the two fields of study would further enhance robotic surgery. For instance, ZEUS and Da Vinci systems, which are the most widely known surgical robots, currently showed that long-distance procedure is possible by improving the transfer rate of information significantly. They can reproduce the surgeon's hand movement almost completely by giving 7 degrees of freedom to the robotic arm.[1] However, there are limits to increasing such freedom of degree. As robotic surgery enabled long-distance remote surgery and developed continuously, complications emerged, based on the extravagant size of the device. Robotic surgery provides fast and accurate surgery and my model would further emphasize these advantages while improving current complications that exist.

II. Background

As the market size of robotic surgery is estimated to increase rapidly from USD 4.4 billion to USD 18 billion in 10 years, a novel approach to development is inevitable to follow up and boost the developing speed. There are mainly three parts of the system, a surgeon console, 4 robotic arms, and an imaging system. Each part of the system has increased in size since the first robotic surgery took place in 1985. The first robotic surgery system was PUMA 560, which was 56 kg in mass. Currently, the Da Vinci System increased its mass by about 971%, which is 544 kg.[2] My model does not improve the freedom of degree or enhance the technological precision of the surgery directly, however, it resolves the complications emerging based on the extravagant size of the system. The enhancement also indirectly increases the efficiency and speed of the procedure.

To solve such problems, utilizing microsurgical technologies is a promising solution. Robotic surgery also was able to develop by using telemanipulation from microsurgery in the early history of robotic surgery. Since they have similar usage and structure, utilizing some technologies from microsurgery seems inevitable. Microsurgery is a type of surgery that mostly uses a robotic system for small vessels or tissues to operate a surgery in small incisions that is not visible to the human eye. Microsurgery is mostly used in neurosurgery, oral and maxillofacial surgery, and plastic surgery, which requires precision just as robotic surgery does.

<figure 1> Three devices used in robotic surgery.

<figure 2> MUSA microsurgery robotic system

The MUSA robot contains similar components to Da Vinci robotic system but is smallerand simpler. They are both used in similar surgeries while the MUSA system with a narrower range; however, MUSA eliminates the complication Da Vinci system currently contains, which is by decreasing the size. The picture above shows the basic component of microsurgery: fourrobotic arms attached to the sliding plane of the table(1). Four arms (2) also can contain different kinds of types of equipment such as forceps, scissors, and irrigators; and each arm can easily change the equipment they hold. Applying this to my robotic arm model, the attaching table (1) will be placed next to an operating table where the patient lies, or directly connected to it. Instead of using one table plate for four of the robotic arms, attaching two plates to each side of the operating table would provide a wider approach range of incisions to the surgeon. In other words, part 3 would not be used in my model. Then the attachment part in my model from the picture would be attached to the table. Robotic arms (2) that couldchange their types of equipment can be applied to robotic surgery. This brings the advantageof changing the robotic arms frequently with less cost. Microsure robotic surgery system is between $400,000 to $65,000, which is a fifth of the Da Vinci System. Applying the advantagesthe MUSA system brings to robotic surgery would greatly decrease the size and cost of the robot.

III. Complications in the Current Robotic System.

The majority of currently available surgical robots are too large in size. Only a smallspace is left for people when the robots fully enter the room.[5] Also, these robots require movement. They can not consistently stay in the same operation room but has to be stored temporarily in another place before the surgery. Every time the operation requires a robot assistant, the devices should move into the operating room. While moving the instruments, small vibrations or impacts could damage the device. It also spends unnecessary time, possiblydelaying the surgery by 20 minutes. Also, If any malfunction happens in the robot, the surgeonis unable to find out the origin due to its vast size. Due to the size, malfunction also happens often during the surgery, which leads to severe consequences. The sufficient size of the robotthen leads to an increase in cost, which burdens the patients.

The robotic arm itself costs about 2 million dollars.[3] The majority of hospitals are not able to afford such expensive equipment despite the advantages robotic surgery brings, also preventing investments and industrial development of robotic surgery. Additional repairs and upgrades would expend more money than just the equipment since parts for repair are rare and expensive also. The cost seems unrealistic to most hospitals and to the patients. If the robotic system maintains its costly expense, practical use and further development of roboticsurgery would face challenges.

Malfunction actually happens commonly during robotic surgery. From 2000 to 2013 when robotic surgery was used, a total of 144 deaths, 1,391 patient injuries, and 8,061 device malfunctions were reported robotic surgery, according to a study published in PLOS One in 2016. [4] Also, there are some rare cases in which the surgery led to severe injury to the patients. 55 percent of the malfunction was due to device failure and operation setup issues. [6] While robotic surgery requires skilled surgeons and a good environment, constant malfunctionhinders the primary purpose of robotic surgery and provides risks to the patients. [7]

IV. Proposed model

Attaching robotic arms to each side of the operating table will prevent current complications, which are based on the size of the instruments. Attaching instruments to the table solves such problems and brings more advantages: a decrease in size, cost, andmalfunction rate.

A. Size

Current equipment for robotic surgery takes up a redundant amount of space. Three parts of the equipment would restrict the number and freedom available for surgeons, and nurses to enter the operation room freely. Attaching the robotic arm to each side of the operating table significantly decreases the volume of equipment. The overall plan is to attach the four robotic arms that are actually involved in the procedure to the sides of the table and install the remaining parts under the table. For example, the Steris Amsco 3080 chair has a height of about 44 inches. By calculating the dimension under the table, about 666000 cubic centimeters are available. At least one of the pieces of equipment could go under such a surgical table. While today's surgical room is already crowded enough, this would provide more space for people in the operating room.[8] Also by decreasing the volume of the equipment, the equipment would now be in the operating room permanently since it is fixed to the table, preventing unnecessary movements. Originally, equipment was required to move from place to place, mostly to operating rooms, and set up the equipment to proceed.[9]

During such movements, equipment was damaged and the malfunction rate increased. However, reducing the volume and designating a particular operating room for robotic surgery could prevent unnecessary movements and prevent malfunction. This also increases the speed of robotic surgery since it requires less time to set up the equipment.[10]

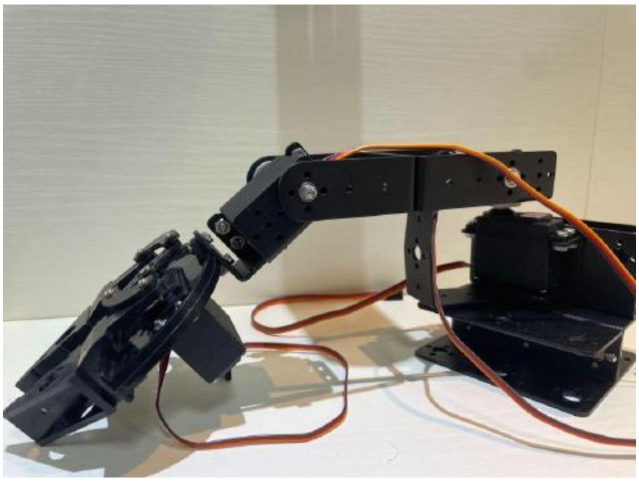
B. Cost

Semi-permanent attachment of robotic surgery instruments also decreases the cost of surgery. The instrument itself costs 2 million dollars.[11] Not only this burdens the buyer, or the hospital, but also is a burden for patients who possibly will use this technology. To improve accessibility for people and to enhance the development of the industry, reducing such a burden seems crucial. The attachment of instruments would significantly decrease the overall expense of surgery. By reducing the size of the instruments, fewer parts are used to make, repair, and operate the robot. This would directly decrease the cost of robotic surgery. When hospitals operate robotic surgery, the main expense mostly happens in repair. This is because most parts are rare and not often produced. As mentioned earlier, this model can reduce the malfunction rate and the parts used in the model. By decreasing the volume and number of parts required, the cost of repair would drop. The cost of producing the instrument would also drop as the volume decreases. If the producers or factories take less burden than before, more devices could be made with the remaining budget, therefore enhancing the production itself.

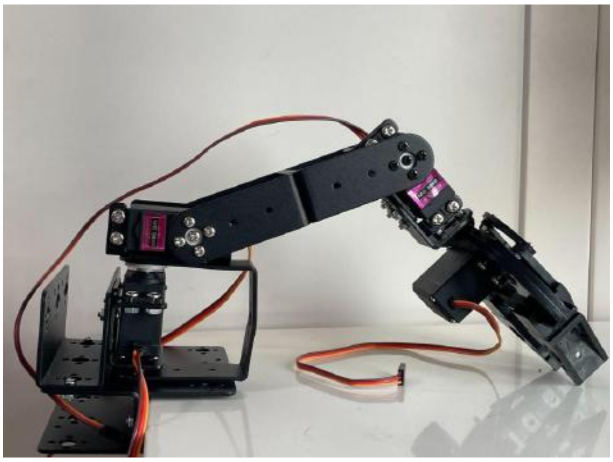
C. Malfunction

Attaching the instruments to the table also reduces the malfunction rate. The main reason malfunction happens is due to the size and movement of the device. Large volume requires more parts, which more likely increases the probability of malfunction rate. More parts would make the device complex, requiring more accuracy in movement. However, improving the accuracy of software has limits. The size of the current instrument also creates difficulty for movement. If the instruments are attached to the table, there is no need to move the device, solving the entire problem. This problem is troublesome since the movement of the robot directly increases the probability of malfunction. While those instruments are moved from place to place, small vibrations or impact that inevitably happens might harm the device. It might dislocate some part of the device, or impact the transmission of 3D video during operation, which both influences operation directly.

V. Implementation



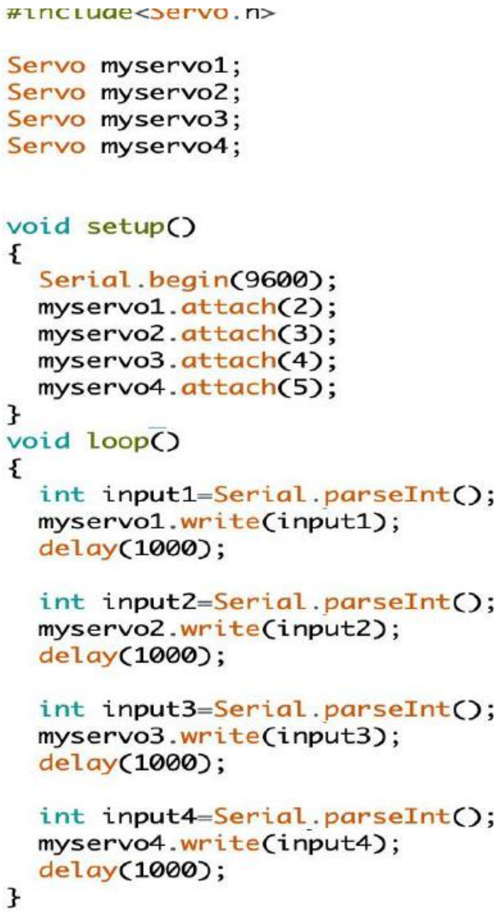
<figure 3> 4 degree abstract model



<figure 4> Model Attached to a table to represent surgery setup

In order to achieve such a goal, the combination of technology between microsurgery and robotic surgery seems inevitable. One of the problems in robotic surgery was the size of the device, and microsurgical robots such as MUSA from Microsure are much smaller in size, weight, and dimension.[12]

The robotic arm in both my abstract model and in MUSA contains a similar number of freedom of degree. The picture below shows a simple code to control my 4-degree robot’s movement.



```
#include<Servo.h>

Servo myservo1;
Servo myservo2;
Servo myservo3;
Servo myservo4;


void setup()
{
  Serial.begin(9600);
  myservo1.attach(2);
  myservo2.attach(3);
  myservo3.attach(4);
  myservo4.attach(5);
}
void loop()
{
  int input1=Serial.parseInt();
  myservo1.write(input1);
  delay(1000);

  int input2=Serial.parseInt();
  myservo2.write(input2);
  delay(1000);

  int input3=Serial.parseInt();
  myservo3.write(input3);
  delay(1000);

  int input4=Serial.parseInt();
  myservo4.write(input4);
  delay(1000);
}
```

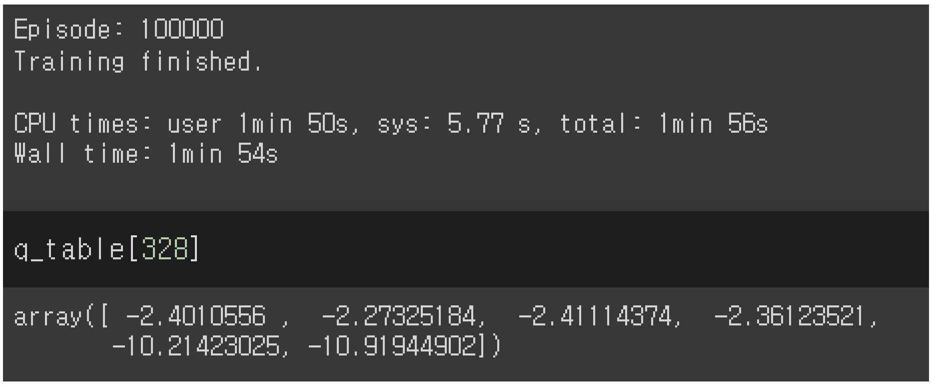
<figure 5> codes

The input ‘int intput1=Serial.parseInt()’ would be received as the surgeon’s movement in reality, and the output and control of the motor ‘myservo1.write(input1);’ is represented in such a way since it is an abstract code and model. This simplistic movement and code would prevent malfunction while transmitting the information from the surgeon to the robot, which happens often in the current robotic system due to its complexity.

VI. Adopting AI

Linear control used to control a robot is performed without considering the remaining elements, so it is difficult for a robot with strong nonlinearity to obtain satisfactory performance to control. Strict control is a nonlinear control technology that complements the uncertainty of the system, and shows high performance when controlling the robot[13]. Sliding mode control is one of the frequently used toughness control methods due to its simple structure. This control method greatly increases the gain value and can be used even if the dynamic characteristics of the control target are not accurately known, but shaking occurs due to the sign function and the high control gain. Reinforcement learning is a learning method that finds policies that maximize expected rewards through the experience of agents. This method gives the robot artificial intelligence when performing tasks so that it can assemble parts under vision data and reaction force or computes the counter-mechanics of robot armswith difficult and complex shapes.

Among reinforcement learning algorithms, Q-learning is a basic reinforcement learning algorithm that determines policies according to value through array-type Q-table, and has the advantage of being easy to implement due to its simple structure[14]. In this research, I propose an algorithm to adopt Q-learning to surgery robotic arm. I conducted a simlation evaluation of Q learning and got result of Q -table values. In <figure 6> and <figure 7>, the learning was implemented with 5X5 grid which has one each R, Y, G, B on it. The arm start withrandom location, go to the destination, drop a object, and go back to the start location.



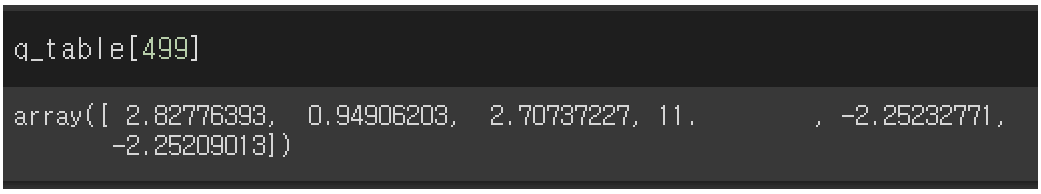
```
Episode: 100000
Training finished.

CPU times: user 1min 50s, sys: 5.77 s, total: 1min 56s
Wall time: 1min 54s

q_table[328]

array([ -2.4010556 ,  -2.27325184,  -2.41114374,  -2.36123521,
       -10.21423025, -10.91944902])
```

<figure 6> Simulated Q table



```
q_table[499]

array([ 2.82776393,  0.94906203,  2.70737227, 11.        , -2.25232771,
       -2.25209013])
```

<figure 7> Simulated Q table where index is 499

VII. Conclusion and future works

Instruments used currently in robotic surgery have some flaws: size, cost, and malfunction. Attaching the robotic arm simplifies these problems. Once the instrument is installed, unnecessary movements are minimized, and permanently stays in the operation room. This also decreases the size of the instrument, enabling more space and view for surgeons. Although the surgery would use instruments for 3D vision, still this installation could prevent malfunction possibility that occurs during movement. As mentioned before, a high proportion of errors reported during robotic surgery comes from the malfunction of the instrument, and when such an error happens, patients could get severe injuries. Since the device has a relatively low volume and size, less number of mechanical parts would be used, generally decreasing the malfunction rate. Fewer parts used in the instrument not only prevent injuries but also make the equipment cheaper. Attaching four robotic arms to each side of the chair would provide great advantages. The parts that were used originally would go under the chair. Even though the arm itself is attached to the chair's side, much other hardware is required to connect the surgeon and the robot for precise operation. The solution clearly brings many advantages and benefits to improve the current system.

Furthermore, in this paper, the q learning algorithm was evaluated in a synthetic environment. I would conduct an expriment with my real robot arm (it should be developed to get user input of 3 parameters) in the future work.

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Instructor’s comment:

In my capacity as his research paper mentor, I have overseen his intellectual and emotional development over the course of two years, and he is, without a doubt, one of the most competent students I have come across in my career.

He is just the kind of driven, engaging, and curious student that will help make your classroom a lively environment and safe place to take intellectual risks. His research paper is the product of long hours of discussions and deliberations on providing an embedded method for surgery robot. Even though he was not familiar with those fields at that time, he left no stone unturned, questioning everything from door placements and line formations to exit strategies and frequency of drills. He is not afraid to voice his concerns or questions and possesses the higher- order thinking skills needed to shed light on unexplored facets of a problem. He successfully adapted the Arduino system and the proficiency of his proposition has been proven in the paper. He always has a unique angle and perspective on any given topic, and I have consistently walked away from our interactions energized and impressed.

97/100

The research paper is well-organized, and successfully adapted Sean’s thoughts on the research paper. Attaching the robotic arm to the table is an intellectual solution, supported by strong and firm analysis and explanation.