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Development of a Gaze Controlled Robotic Surgical Camera

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DEVELOPMENT OF A GAZE CONTROLLED ROBOTIC SURGICAL CAMERA

By

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THESIS

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of Wayne State University,

Detroit, Michigan

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Approved by:

Advisor Date

Co-Advisor Date

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Dedication

To my late father, Padmanaban Sivadasan

Acknowledgements

My sincere gratitude goes to my advisor, Dr. Darin Ellis for introducing to me to the world of human factors, supporting my studies and providing his extensive knowledge whenever needed. I appreciate the advice Dr. Abhilash Pandya provided me with while investigating the field of robotic surgery and tele-robotics. I wish to specially thank Dr. Beulent Oksan for all the help with the statistical analysis. I would like to thank Mr. Alex Cao, Mr. Anuj Awasthi, Mr. Keshav Chintamani, and Mr. Veeral Patel for all the help they provided over the course of thesis. I appreciate all the advice and support given to me by my thesis committee member, Dr. Trilochan Singh.

1. Background and Significance

1.1 Robotic Surgical Camera

Laparoscopic surgery is a type of surgery that involves the insertion of a laparoscopic camera into the abdominal cavity through the abdominal walls. The surgery is then performed using specialized equipment, which is designed to be maneuverable in this constrained space. When this type of surgery is performed using robots, most often the robot performs the camera handling.

The camera is the only source of reference the surgeon has of his surgical area, especially when even the surgical tools are robotic. Allaf specifies 4 main functions the robotic camera has to perform. They are as follows:

- Maintain the surgical point of interest in the centre of the image
- Provide the required magnification of the area
- Produce and maintain a horizontal image of the point of interest.
- Perform the preceding actions automatically, although they may be modulated by the surgeon

He also emphasizes the importance of maintaining the surgical point of interest [Allaf et al, 1998] at the centre of the image.

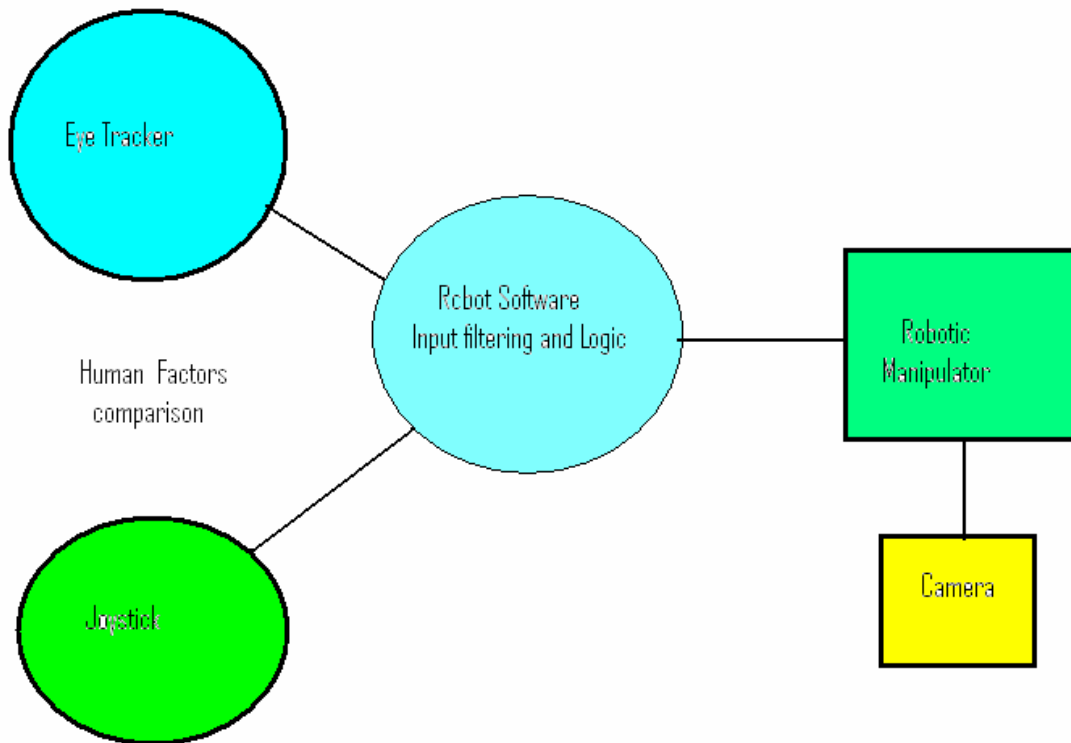


Figure 1 Overall system architecture

1.1.1 Surgical Camera Control Technology

The system developed at the Universitat Politècnica de Catalunya [Casals et al] shows a motion control system capable of moving the camera following the movements of the instruments, thus permitting the surgeon to forget the problem of controlling the camera and allowing him or her to concentrate on the surgical procedure itself. This system is based on a SCARA industrial manipulator modified with a universal joint in the end effector.

An extension of this device permits to free space near the stretcher since the robot does not need to be placed right beside it. The control of the camera is achieved through a computer vision system that tracks special marks on the instruments.



Figure 2 Surgeon performing a laparoscopic surgery with the computer vision guided camera control system similar to the one used Universitat Politècnica de Catalunya

It was noted that the above system had some inherent flaws. The computer vision system continuously tracks the surgical tools and centers upon the area, which it may consider as being relevant, based on the position of the tools. However, the surgeon's area of interest may not always be the position of the tool as seen in a non-robotic laparoscopic surgery. This system would subject the surgeon to some amount of strain as a result of looking at the small portion of the screen displaying his area

The Computer Motion Aesop is a commercial system intended to move the camera according to the commands of the surgeon, first through a pedal and after through a speech recognition system [Allaf et al, 1998]. The surgeon issues a set of voice commands to move the camera to acquire the required scene. It is a 4 DOF (Degree of Freedom) robot attached to the stretcher, and presents an end-effector with

three axes (two passive and one active). The passive ones guarantee the compliance between the camera and the insertion point, and the active one rotates the camera around its longitudinal axis. The voice-controlled robot has its own set of limitations. The job of constantly keeping pace with the movement of the tools can become tedious. Often the surgeon will be working with surgical areas being small compared to the whole available view.



Figure 3 AESOP surgical system

Face mouse [Nishikawa, 2003] is another camera control system used to automatically control the laparoscopic camera. This is an image-based system which tracks the surgeon's facial features real time and uses the facial gestures as an input for the camera control system. This method involved the use of a CCD camera and the control was based on the head movements made by the surgeon. For example, if the surgeon moved his face side to side it was taken as an input for pan/ tilt of the camera.

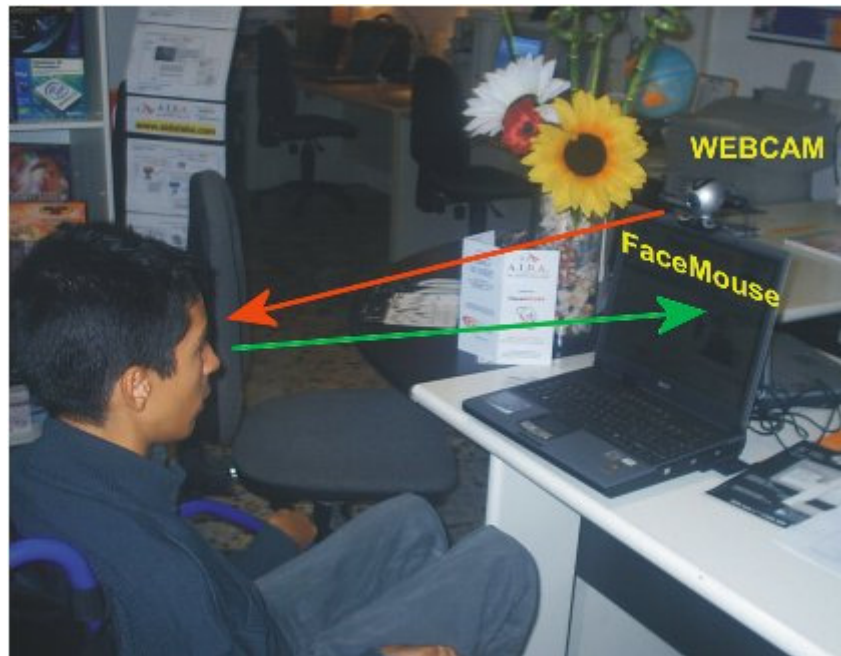


Figure 4 An application of the Face Mouse concept

The face mouse [Nishikawa, 2003] application has all the same issues associated with voice-controlled robot. In fact the constant pitch, yaw and roll movements that the surgeon has to make with his head can cause considerable strain to the neck muscles. Hence the gaze based control system is a suitable alternative for the following reasons:

- The process is completely automated relieving the surgeon of one voluntary input requirement.
- The system will resemble the surgeon manually moving the endoscopic camera but without having to provide the input signal.

1.1.2 Eye Tracker Application

An application involving the ASL 504 eye tracker was developed as an alternative to the abovementioned techniques. Using this approach, the eye tracker system is used to determine the eye's point of gaze and the output coordinates are then streamed to the eye tracker/robot interfacing system. Then a program converts the data in the mouse coordinate system. In this case the intent to click is a prolonged gaze at specific area.

The following are the areas of this research that are beneficial to my thesis:

- Obtaining the horizontal and vertical coordinates with the eye tracker
- The technique of live streaming of the horizontal and vertical coordinates
- Interfacing of eye tracker and computer

A code has been written in VC++ to obtain the X, Y coordinates from the serial output of the eye tracker control system.

1.1.3 Gaze Controlled Robotic Camera System

In today's surgical robotic systems, the surgeon is bombarded with multiple sets of controls. It has become increasingly important for the surgeon to keep track of various aspects that lead to successful surgery. If there is anyway that the burden on the surgeon could be reduced, there is a strong potential for a significant benefit to the whole process. The benefits can come in the form of reduced surgical times and decreased workload on the surgeon. In case where a surgeon does a remote surgery it is very important to keep track of the tools and their exact location to which they are

pointing. In today's surgical systems (e.g. Zeus Surgical systems) the camera is positioned through voice control. My project intends to replace this existing voice controlled system with an automated system relying on the point of gaze of the surgeon on the display. The initial idea of the project is to build a 2-degree of freedom robotic arm with a camera mounted at its end effector. I intend to use an eye tracker to determine the point of gaze of the surgeon viewing the sample 'surgical area' on the display. This data is interfaced with the robotic system through software, which positions the camera in accordance with the point of gaze.

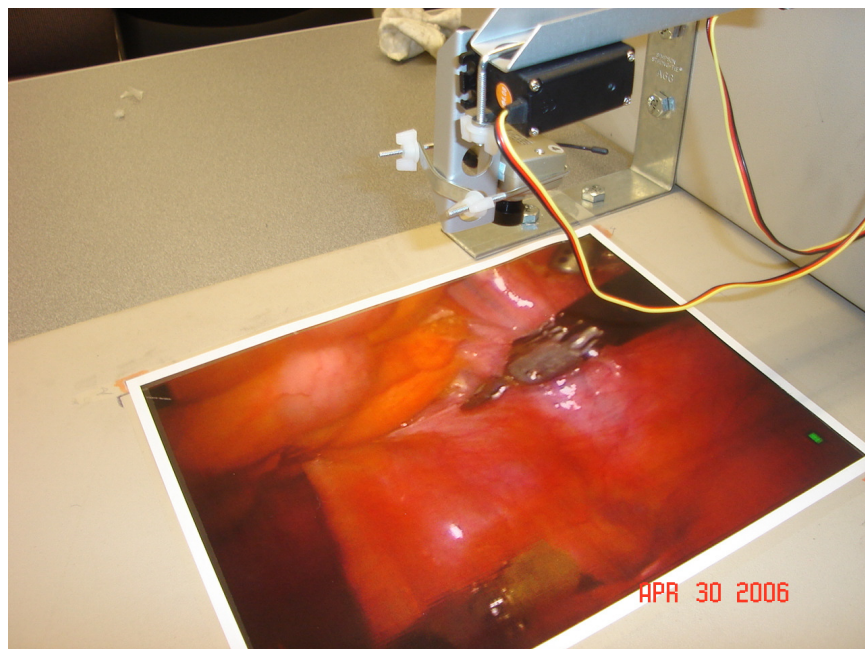


Figure 5 Robotic Camera Setup

An eye tracker is a device for measuring eye positions and eye movements. There are several types of eye trackers based on the tracking technique that it employs. ASL 504 eye tracker as shown in the Figure 6, which I intend to use in my project is based on the pupil and corneal reflection recognition technique. The measurement is

displayed as a cursor or set of cross hairs superimposed on the image from a scene camera or other video source showing the subject's field of view, and may also be recorded digitally on the eye tracker Interface PC, or exported as a real time serial data stream to an external device. For my project I have used the real time serial data stream option.



Figure 6 ASL Eye Tracker system

The ASL 504 comes with the user interface software called E5000. This software can be used to obtain the horizontal and vertical coordinates of the point of gaze of the user. These coordinates can be transmitted real time via a serial port to the interface computer. In addition to this data the device also gives the diameter of the pupil of the user. This data could prove beneficial in future research utilizing eye tracker data as an input for additional surgical tasks like adjustment of digital gain.

2. Methods

2.1 Robotic Camera System

A robotic camera with 2 degrees of freedom was constructed. The 2 degrees of freedom is sufficient for demonstrating the movement of the surgical camera to cover surgical areas of interest (2 – Dimensional). This system was built using the following hardware:

A small wireless 2.4 GHz camera with an inbuilt transmitter was used at the operation site for the surgical view. This camera was fitted to the end effector arm of the robot. The camera had a resolution of 320 X 240 pixels and was good enough for the purposes of comparing input methods in this study. The transmitter transmitted the signals to a local computer subsequently displayed at the remote console thus providing the surgeon sitting with a view of the actual surgery.

A four-channel receiver connected to the video server was used for receiving signals at the server. In this case we would be using a single channel for video receiving, though in the future depending upon the need of multiple views, we can add 3 more cameras using the same set of receiver.

For controlling the motion of the arm of the robot, servo motors were used. The servos acted as the “Muscles “of the robot. The servo motors used should produce sufficient torque for driving the links of the arm and the end effector. For doing this standard HS 422 Servo motors were selected. HS-422 is one of the most durable and reliable servo motors. With its dual iron-iolite bushings, high impact resin gear train and

high performance circuitry, the HS-422 features excellent centering and resolution. The HS 422 produces a stall torque of 3.3. Kg.cm. that is sufficient to move the links in XY plane. The servo has a speed of 0.16 sec/60 o, size of 41 X 20 X 37 mm and weight of 45.5 /1.6 g/oz. The Servo motors are controlled through the controller which provides input signals to the servomotors regarding its orientation. For this project I am using two servos for controlling the link and the end effector.

The links served as the “Bones” of the robot. The links were made of hardened 6061-T6 structural grade aluminum alloys, which is precision-formed before hardening with custom die. In my system I am using two six hole (for the robot arm) and a four hole link (for the end effector arm).

Usbor servo controller connects to the PC USB port using a USB cable and runs up to 32 servos under software control. The Usbor also has 32 channels of 8 bit A/D. The orientation of the arm is in a vertical direction, and the servo is used to control its motion along Y-axis. The other servo is mounted on the end effector arm of the robot and is used to control the motion of the end effector along the X-axis. The controller is supported with auxiliary Software Development Kit in VC++ and coding was done in Visual C++ to control the motion of the robotic arm in X-Y plane.

Pivot Post and fasteners are used for most arm-like constructions. No base is required as the camera is going to be mounted on a flat surface and is going to be stable. Not all arms need grippers. A Gripper Assembly mates easily with two servos, and it is used for interlocking the motors. The gripper can accommodate objects up to about .9” (~23 mm). Link Horn washers and Pivot Post washers were used for fixing

various components of the robotic arm. Clamps allow quick, flexible attachment of servos to this base. Clamps secure servos to links. Bolts and Nuts were also used for fixing various components of the links and motors.

2.1.1 Programming Procedure

The program to control the robotic camera was written in VC++. The ROBIX hardware did not have a MATLAB SDK. The program read the file written by the input programs. These are the MATLAB programs that take input from the eye tracker and the joystick. More on this is explained in the ensuing sections. The value read by the VC++ program refers to a type of movement required from the camera. Hence once this number is read, the program calls on the functions defined in the ROBIX program to modify the encoder values of the servo motors. The function MOVEROBIX is then used to make the corresponding servo movements. The following is snippet of the code:

```
/* C++ to move servos */
int main()
{
    Connect ();
    int encoders[2];
    String old_value="99";
    String present_value;
    Encoders [0] =0;
    Encoders [1] =0;
    while (1){
    ifstream open_file("c:\\MATLAB\\work\\gaze.csv", ios::in);
```



```

if (open_file.is_open()){
getline (open_file,present_value);
if (present_value=="0"){ //when the gaze.txt value is zero we do nothing
cout<<"out of scope";
    }
if (present_value=="1")
    {
if (encoders[0]+125<=250)
if (encoders[1]+280<=560)
    {
    {
Encoders [0] =encoders [0]+125;
Encoders [1] =encoders [1]+280;
    }
    }
moverobix(&encoders[0]);
    }
.....
open_file.close();
}

```

Figure 7 Snippet of the code to control the robot

2.2 Eye Gaze based Input System

The ASL 504 Eye Tracker was used to track the point of gaze of the subject. ASL 504 is designed to measure a subject's eye line of gaze with respect to a stationary surface in the environment. This measurement is displayed as a set of cross hairs as shown in the figure 8 The ASL eye tracker uses corneal and pupil reflection technique to determine the fixation point. The first stage in recognition of the pupil and CR by the eye tracker is performed by edge detection logic. Threshold levels for pupil and CR edge detection are adjusted with the slide switches labeled "Pupil" and "CR" as shown in the Figure 8

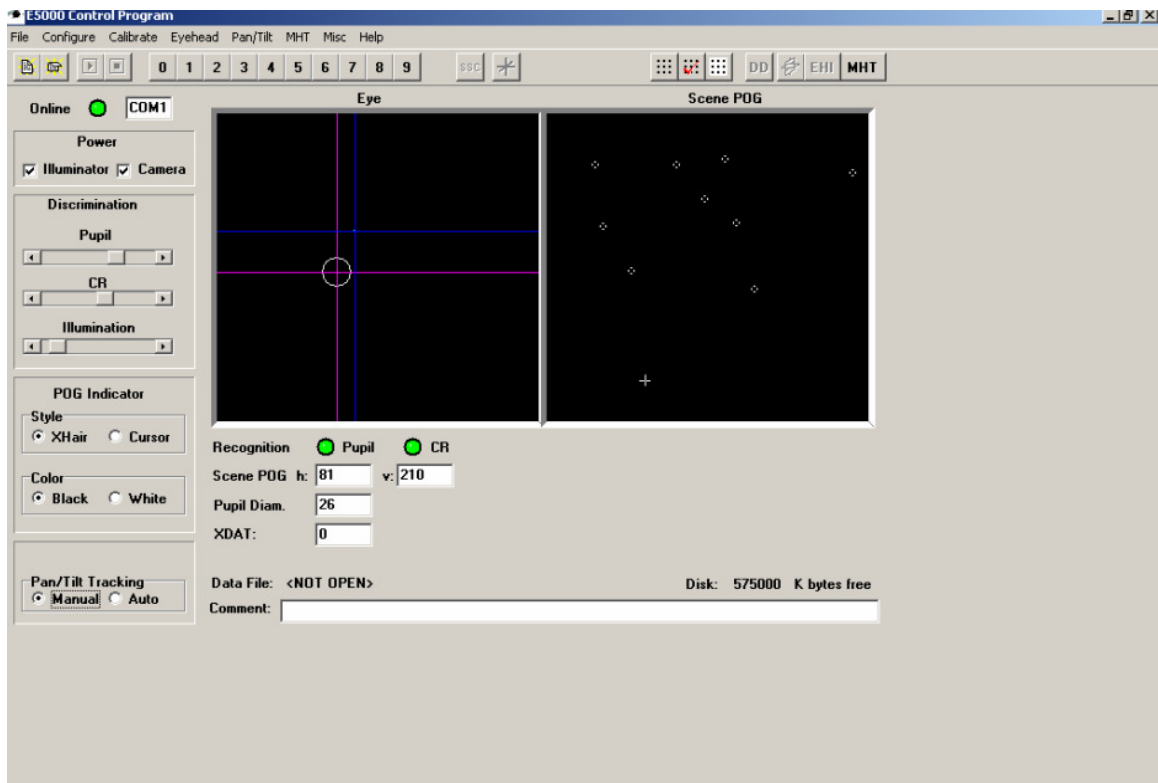


Figure 8 Eye tracker control program – E5WIN

2.2.1 Setup

The Eye Tracker System was comprised of a Control Unit, Pan/Tilt optics eye camera optics module, a video monitor, Two PC's (Interface PC and a Display PC) and cables for connecting control unit to interface PC and Pan/Tilt optics to scene camera. The Proper setup of ASL Eye Tracking System is very important for having best results. There must be no windows or intense sources of light in front of the subject. The other important consideration is that the interface PC and the two video monitors can be a distraction for the subject of the experiment. It is recommended to keep them out of the subject's view.

The raw data measured by the Eye Tracker is the separation between the pupil centre and the corneal reflection (CR). The relation between these raw values and eye line of gaze differs for each subject and for different optical unit and scene camera positions. The purpose of the eye calibration is to provide data that will allow the Eye Tracker processor to account for individual subject differences. The objective is to have the subject look at each of the nine calibration points. Eye Tracker calibration is done by setting nine target points that are at known positions on the scene monitor. These target points are entered into memory with eye tracker's "set target points" function. Once we set these target points we have to save these target points. The subject is required to look at the set of nine points and these locations are calibrated with respect to the eye gaze fixation points.

The crosshairs imposed on the corneal and pupil reflection are lost due to inability of the system to constantly perform edge detection on the reflected image. This resulted in flickering and hence the eye gaze fixation data was lost during certain instants. This problem was overcome by running the eye tracker at the maximum frequency of 60Hz. Hence it does not make a significant impact on the overall eye tracking performance as eye gaze samples within such a short time frame can be assumed to lie within the same zone.

2.2.2 Extraction of Eye Gaze from Eye Tracker

The eye tracker system comes with software called the E5000 control software. However this software cannot be used to extract the X-Y coordinates that is required. Hence a program was written in MATLAB to extract this data.

Once the data is retrieved it was processed to be useful in controlling the robot. A program has been written in MATLAB to discern between the surgeon's points of gaze on the reference screen. This can be achieved by dividing the screen into zones based on pixel position and determining to which zone the acquired point of gaze belongs.

Because the eye tracker's position on the screen varies continuously, hence to keep track of the position of the image of the eye pupil is an arduous task. To accomplish this, a method similar to 'K means algorithm' based method of control is proposed. According to this, the entire screen is divided into several zones based on the X-Y coordinates. However the degree of belongingness (Degree of membership) of the point of gaze with each zone can be considered crisp rather than fuzzy. Hence if the

point of gaze lies within a zone, the point of gaze can be assumed to be returning standard coordinate values of the centre of zone 1. These returned values are transmitted and based upon the values of the centers of the zone the end effector is moved.

2.2.3 Programming Procedure

A code was written in MATLAB to extract the raw point of gaze values and process them. The method of determining the belongingness to the preset zones was coded into MATLAB. Thus the program determined the zone and wrote a value denoting each zone into a text file. The VC++ program mentioned in section 1.2.1 to move the camera uses this value. Figure 10 explains the method involved as a block diagram. The following is a part of this program:

```
% program to locate the zone in which the point of gaze falls
```

```
.....
```

```
% Connect to Serial Out port
```

```
Port =2;
```

```
streamingMode = 0;
```

```
cameraUpdateRate = 60;
```

```
baudRate = 57600;
```

```
s.Connect (port, baudRate, streamingMode, cameraUpdateRate, types)
```

```
c=0;
```

```
For i=1:4000
```

```
    msg = s.GetDataRecord;
```

```
    a=cell2mat (msg(4,1));
```

```
    b=cell2mat (msg(5,1));
```

```
    c = 0;
```

```
    If ((a >= 1) & (a <= 86))
```

```
        If ((b >= 1) & (b <= 80))
```

```
            c = 1;
```

```
        End;
```

```
    End;
```

```
.....
```

```
CSVwrite ('gaze.csv',c)
```

```
End;
```

Figure 9 Snippet of Matlab code to extract eye gaze coordinates

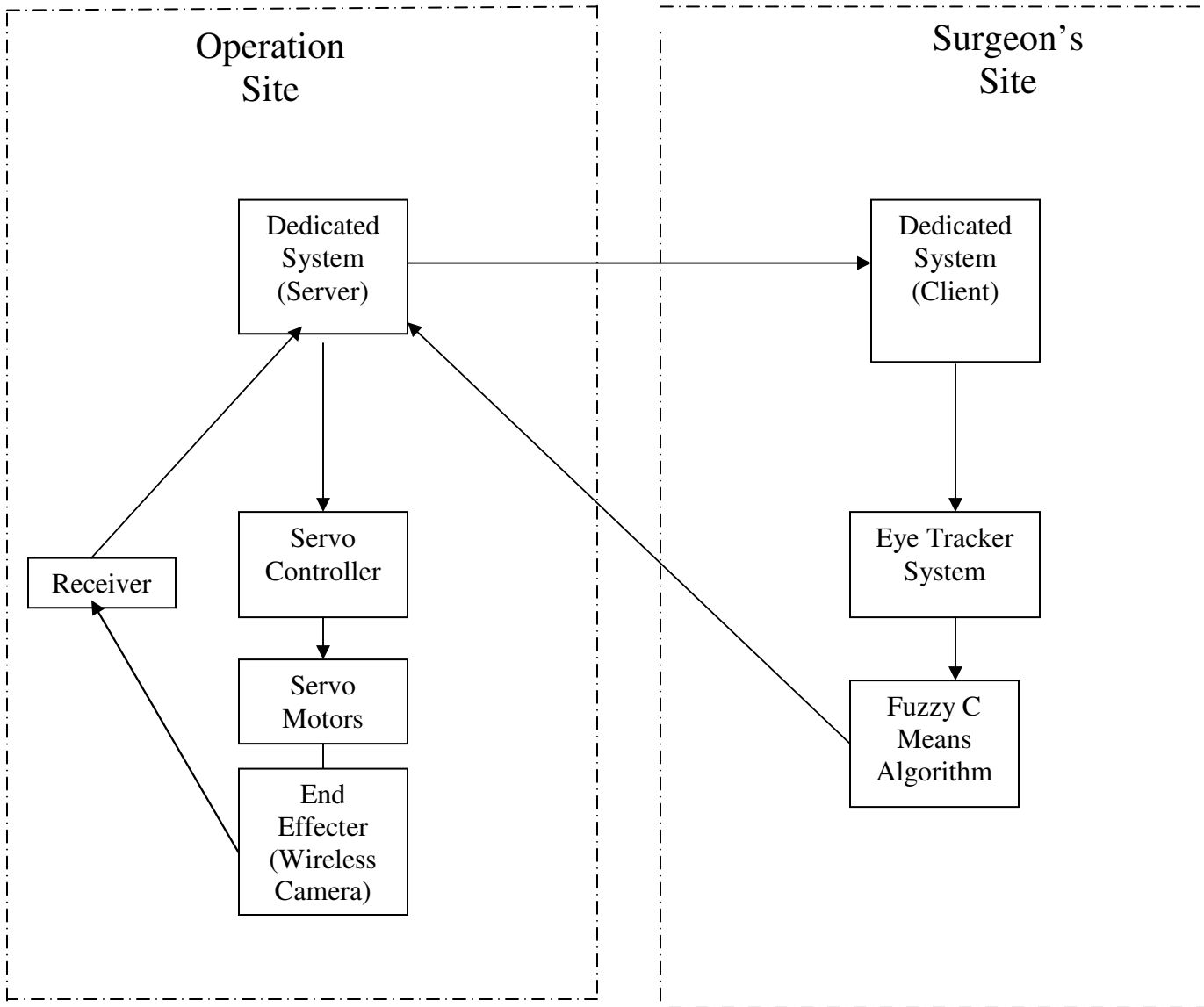


Figure 10 Block Diagram Representing Eye Gaze input control for Robotic Camera

2.3 Joy stick based Input system

2.3.1 Introduction

To better understand the operator performance with the eye gaze based system Joysticks based input was implemented on the same hardware. A joystick is a common input device which in most cases is used as a velocity control device, especially in computer gaming. However in this case it is used for displacement control. Hence the coordinates of the eye gaze will essentially be replaced by the two axes of the joysticks, one joystick for vertical axis and one for horizontal axis. The joysticks used in this study off course have various other input options like a third axis and several buttons. The joysticks were digital joysticks and use universal serial bus (USB) for communication with the host computer.

The figure 11 below illustrates the framework of this input system. The exact same algorithm used to control the robotic camera in the gaze based system is used here as well. A program was written to extract the joystick output and this raw data was processed. The data processing yielded the same kind of numerical values relating to the type of movement needed from the robotic camera. More detailed explanation of the implementation is described later in this chapter.

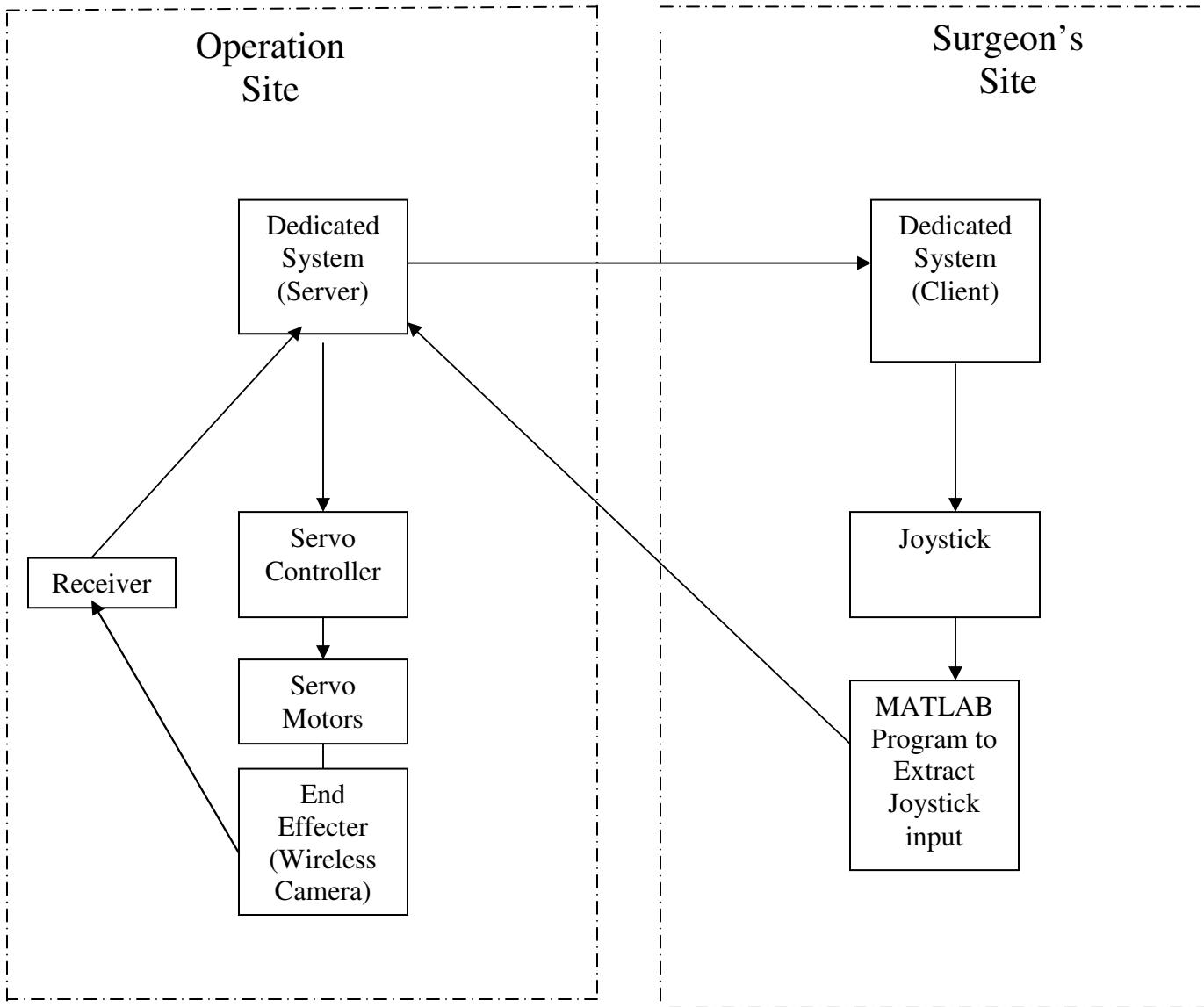


Figure 11 Block Diagram Representing joystick control for Robotic Camera

2.3.2 Joystick Integration

A Dynamic link library developed by the CARES team at Wayne State University was used to retrieve the input to the Joystick. This library could be easily interfaced with MATLAB which is the choice programming software for most of this research.

2.3.5 Setup



Figure 11 Joystick

A single Logitech was used to control the camera. 2 Degrees of freedom out of the many available was used for input. Input to the X axis resulted in pan movement of the camera and the input to the Y axis resulted in tilting of the camera. The program was written in MATLAB to extract the input from the joystick and generate a corresponding number. This number was written to a file. The program to read this file is

the same one used to read the file from the eye tracker program. The algorithm for this program is previously explained in section 1.2.

2.3.6 Programming Procedure

A similar approach to the algorithm used in the eye tracker program is used in this program. The input from the joystick is extracted for X and Y axes. This is in the form of values ranging from 1 to -1. Based on these values the program writes a corresponding value to a text file. The camera control program uses this value to make the corresponding camera movement.

2.4 Overall System Configuration

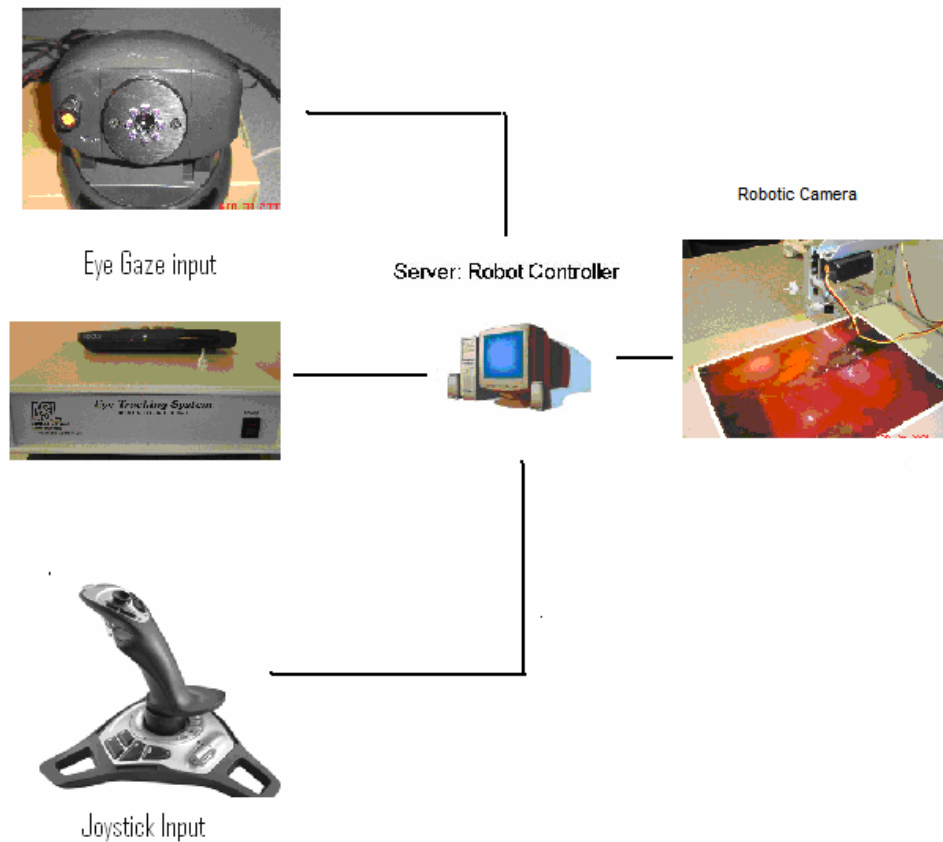


Figure 12 Hardware model of the robotic surgical camera

2.5 Data Collection

Robot data collection is another important feature that is necessary in test beds. The MATLAB program was integrated with functions to write system data to a text file. The path and name of the output file can be user defined and collects pertinent system data including:

- Robot encoder data.
- Input values based on user input from eye tracker
- Input values based on user input from joystick
- Task time noted with a stop watch

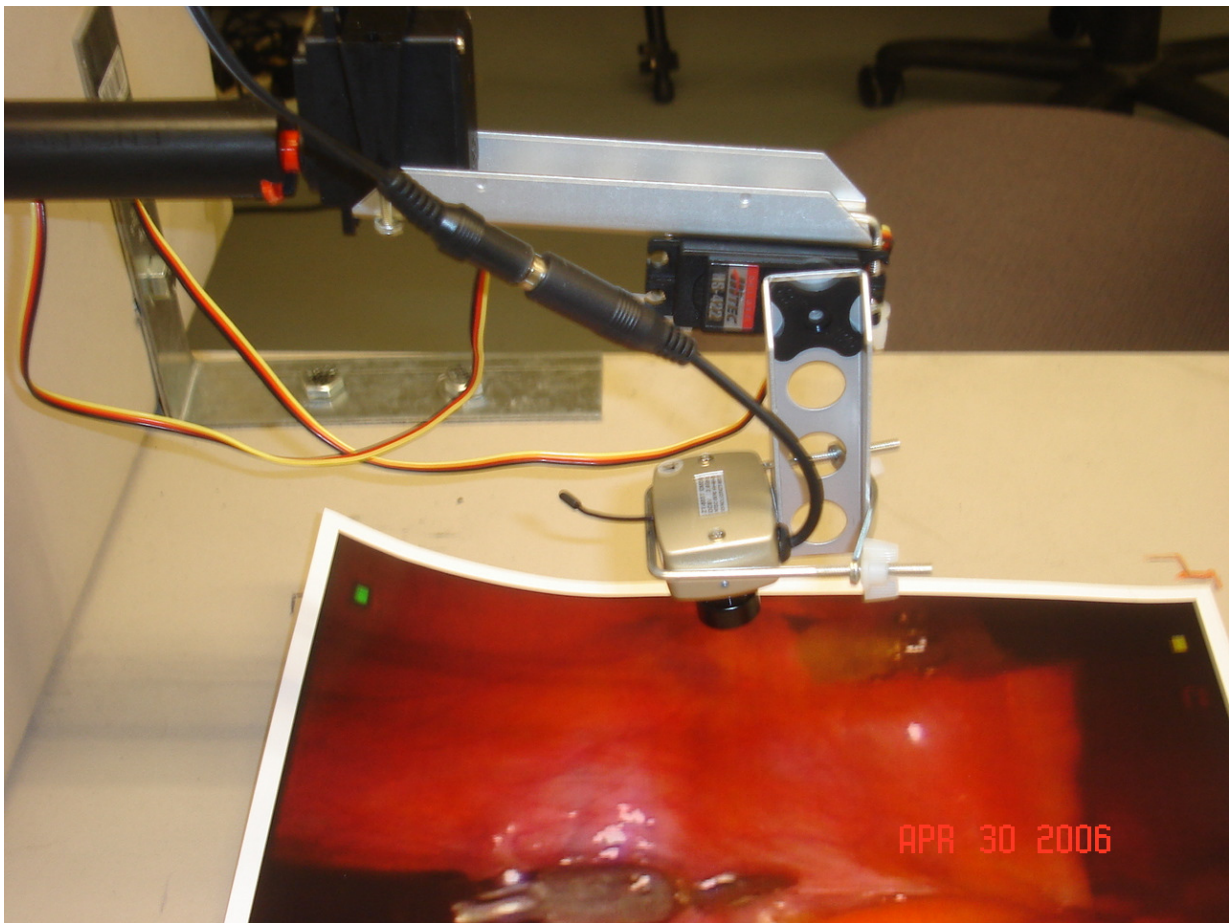


Figure 13 Surgical site

2.6 Surgical Site and Robot Display

The surgical site shown in figure 13, which has the robotic surgical camera, transmits the video feed wirelessly to the video display unit (figure 14). The video display is a 15" computer monitor. The view could also be streamed on the internet and viewed on another computer. A screen shot of the video is shown below.

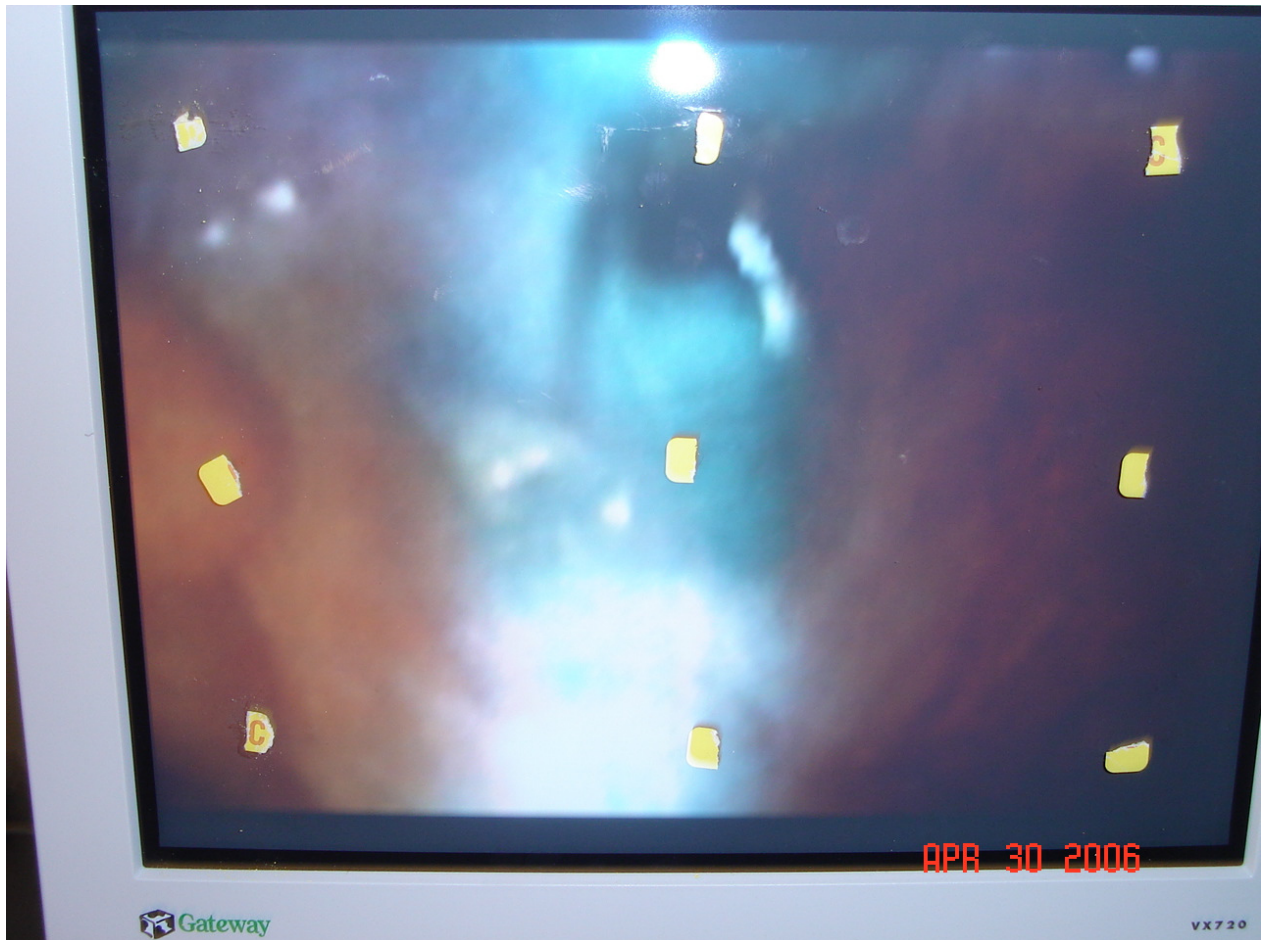


Figure 14 Surgeons view of the surgical site

2.7 Summary

The robotic surgical camera system has been completely integrated with all the described components. The system possesses a fully functional interface that allows ease of testing with subjects and expansion capabilities. The features that are available on the system are:

- Fully integrated robotic surgical camera systems with input devices and raw video feedback systems.
- Fully functional joystick functions.
- Remote control of the robot (server)
- The robotic surgical camera system allows simplified testing of new robot technologies through user studies.

2.9 Robot-Surgeon Interaction Evaluation

2.9.1 Introduction

The current method for controlling the robotic surgical camera is mainly through explicit inputs like voice activated systems. Here we have studied the performance of a similar system, namely joystick based input. Another study was conducted to evaluate the performance of the operator when using the eye gaze based input. Objective and subjective measures were obtained while the subjects performed simple camera manipulating tasks. The operator performed tasks consistent with movements required by the surgeon in the middle of a surgery. It required the operator to move the camera

small distances at a time. A sample surgical area was mapped out with 14 numbers marked on it. To compensate for the additional workload that the surgeon has in the form of manipulating surgical tools, the operator had to read out the number at the center of the video display he/she centered camera upon. Hence in both types of input the operator first positioned the camera and then read out the number. Only if the operator was able to perform the tasks satisfactorily with both types of input, the mental workload was relevant.

To evaluate the workload involved with such schemes, the NASA-Task Load Index (TLX) was used to obtain subjective workload readings. The obtained workload indices will support the assumption that mental workload can be reduced by using alternative input methods. Along with the subjective workload analysis, direct measurement of the time taken and the accuracy was performed. Eye gaze based input is considered to result in lower workloads. In the joystick input the operator is required to target the area of interest, look at that area and manipulate the joystick axes. The eye gaze input does not require the operator to manipulate any input device. Therefore eye gaze system could possibly induce lower levels of workload on the operator. With these measures, the two input schemes are compared.

2.9.2 Methods

2.9.2.1 Workload Assessment

Workload assessment has been the subject of various research over the years. Hart noted that in the evaluation of workload there was no objective standard against

which it could be compared. Attributes that were constituents of the workload calculation formula vary between tasks and between raters. This is due to the fact that workload also depends on the operator's response [Hart et al, 1988] to the task.

Hart also noted that workload [Hart et al, 1988] represented a collection of attributes that may or may not be relevant in controlling assessment and behavior. It was noted that workload calculated for different tasks can be similar due to the way it which was calculated. However these two similar workload ratings will represent two different underlying phenomena based on the conditions of the task. It is also to be noted that there several sources of rating variability. An example of this would an identifiable bias the operator has. Thus Hart concentrated on developing a system which obtained evaluations in such a way that it reduced unwanted between subject sources of variability [Hart et al, 1988].

The fruit of Hart's research was the NASA –Task Load Index [Hart et al, 1988] . This rating scale uses six component scales which are discussed later in this chapter. An average of these six scales weighted by the factor indicated by the rater is intended to give an integrated measure if the overall workload.

2.9.2.2 The NASA-Task Load Index

The NASA-TLX includes six dimensions or scales used to assess mental workload: Time Pressure (TP), Performance (PE), Mental Demand (MD), Physical Demand (PD), Frustration (FR) & Effort (EF) [Hart et al, 1988]. This is obtained on a 12 cm line for each of these six scales. The weights are obtained as a result of the number of times these weights for each scale are selected by the rater. The attached evaluation sheet in the appendix has more information on the evaluation obtaining procedure.

Hypothesis

The hypothesis is that the weighted workload value (WW) is lower for input using eye gaze.

2.9.3 Participants

Ten (8 male, 2 female, age range 20-35 yrs) participants, from the university's faculty and staff, were chosen for the test. Four subjects had previous tele-operation experience with surgical robots and informed consent was obtained from each participant before the test.

The definitions of the dependent variables are provided below. At the end of each series test the participants were queried using the NASA-TLX questionnaire (see

APPENDIX II) [Hart et al, 1988], [Chintamani, 2006]. Each participant performed 6 trials in all, 3 with joystick input and 3 with eye gaze as input.

2.9.4 Experiment Design and Data Treatment

2.9.4.1 Dependent Measures

Time: Time taken to complete the task was counted as the time between the first input and the last input after centering upon the last number.

Subjective Mental Workload: The weights obtained from the NASA-TLX questionnaire by the pair wise comparison and the scales were combined and overall global workload or weighted workload was computed as a function of these weights and scales by the following formula:

$$WWL = \frac{(TP \times WEIGHT + PE \times WEIGHT + MD \times WEIGHT + PD \times WEIGHT + F \times WEIGHT + EF \times WEIGHT)}{15}$$

2.9.5 Data Analysis

SPSS® 14.0 was used to process the data for all 10 participants. In all, 10 X 3 data files were collected. The underlying assumptions were checked and a repeated measures ANOVA was done on the data.

3. Results

3.1 Underlying Assumptions Check

		Tests of Normality					
system		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
trial1	1 Eye Gaze	.098	10	.200(*)	.995	10	1.000
	2 Joystick	.156	10	.200(*)	.920	10	.355
trial2	1 Eye Gaze	.157	10	.200(*)	.963	10	.815
	2 Joystick	.155	10	.200(*)	.975	10	.936
trial3	1 Eye Gaze	.240	10	.107	.946	10	.619
	2 Joystick	.132	10	.200(*)	.971	10	.897

* This is a lower bound of the true significance.
a Lilliefors Significance Correction

Table 1 Test of normality of data

The underlying assumptions of the data were checked. A test of normality showed no significant change ($P = 0.200$) from the null hypothesis that the data was normally distributed.

A test of homogeneity of variances showed that the data conformed to the underlying assumption ($P=0.132$).

3.2 Descriptive Statistics

The mean, maximum, minimum and standard deviation of the data sorted by type of input is given below:

Descriptive Statistics				
	system	Mean	Std. Deviation	N
trial1	1 Eye Gaze	27.5850	1.87610	10
	2 Joystick	33.5630	3.45044	10
	Total	30.5740	4.08792	20
trial2	1 Eye Gaze	23.5190	1.47692	10
	2 Joystick	27.6460	2.94908	10
	Total	25.5825	3.10404	20
trial3	1 Eye Gaze	19.2800	1.19098	10
	2 Joystick	25.1110	1.27944	10
	Total	22.1955	3.22410	20

Table 2 Descriptive statistics of the task times

In terms of ANOVA results for task time, the effect of type of input was significant ($F_{1, 57} = 3.597, p = 0.038$) along with trial number (Trial 1 Vs Trial 2) ($F_{1, 57} = 6.515, p=0.02$) and (Trial 2 Vs Trial 3) ($F_{1, 57} = 7.162, p=0.015$) was also significant.

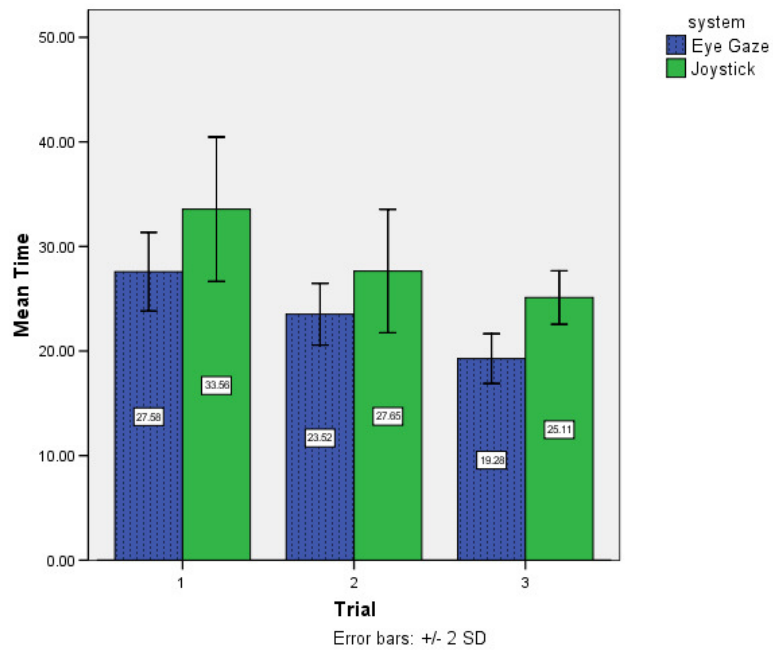


Figure 15 Comparison of time for Eye gaze and Joystick per trial

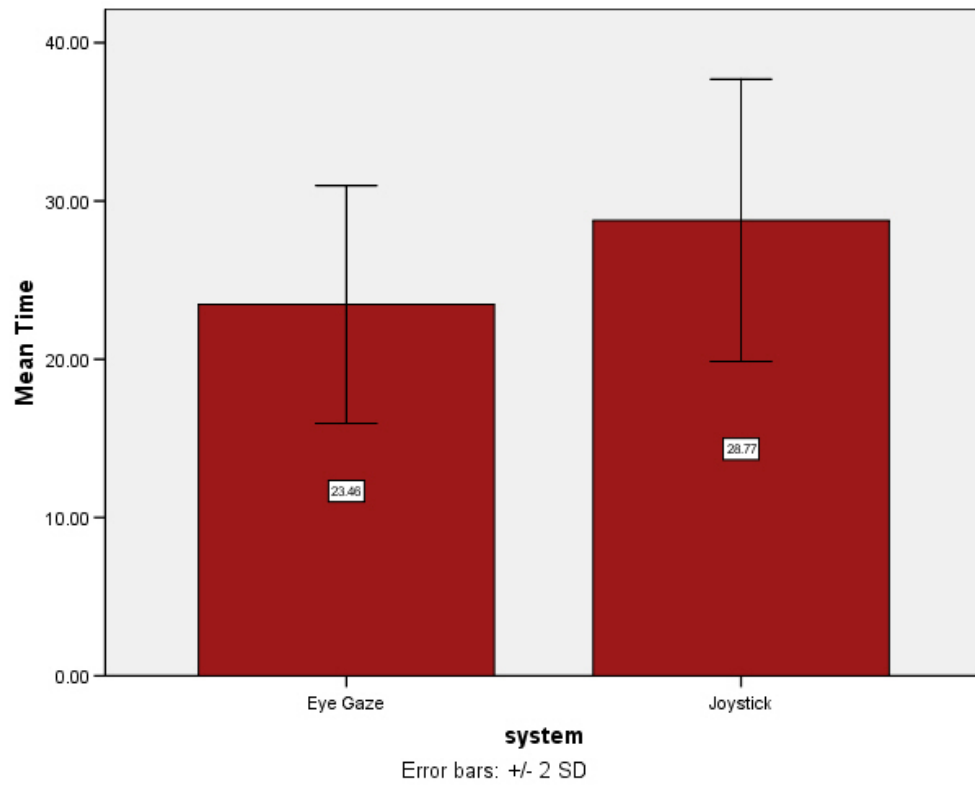


Figure 16 Average times for Joystick and Eye gaze

3.3 Workload

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
System	WeightedWorkload	55125.000	1	55125.000	15.329	.001	.460	15.329	.959
	TimePressure	180.000	1	180.000	.393	.538	.021	.393	.091
	Performance	125.000	1	125.000	1.142	.299	.060	1.142	.173
	MentalDemand	500.000	1	500.000	3.719	.070	.171	3.719	.447
	PhysicalDemand	12005.000	1	12005.000	96.040	.000	.842	96.040	1.000
	Frustration	720.000	1	720.000	5.268	.034	.226	5.268	.584
	Effort	845.000	1	845.000	4.460	.049	.199	4.460	.516

Table 3 MANOVA on the workload data

The MANOVA results showed that there was a significant difference in weighted workload, physical demand, frustration and effort.

Descriptive Statistics

	System	Mean	Std. Deviation	N
WeightedWorkload	1 Eye gaze	796.00	70.585	10
	2 Joystick	901.00	47.011	10
	Total	848.50	79.424	20
TimePressure	1 Eye gaze	40.00	26.667	10
	2 Joystick	34.00	14.298	10
	Total	37.00	21.051	20
Performance	1 Eye gaze	72.00	7.888	10
	2 Joystick	77.00	12.517	10
	Total	74.50	10.501	20
MentalDemand	1 Eye gaze	67.00	11.595	10
	2 Joystick	57.00	11.595	10
	Total	62.00	12.397	20
PhysicalDemand	1 Eye gaze	32.00	13.984	10
	2 Joystick	81.00	7.379	10
	Total	56.50	27.391	20
Frustration	1 Eye gaze	27.00	13.375	10
	2 Joystick	15.00	9.718	10
	Total	21.00	12.937	20
Effort	1 Eye gaze	40.00	12.472	10
	2 Joystick	53.00	14.944	10
	Total	46.50	14.965	20

Table 4 Descriptive statistics of the dimensions of workload

From the descriptive statistics the mean weighted workload was significantly lower for eye gaze input. The Physical demand was also lower for the eye gaze input. The Frustration was higher for eye gaze input. The overall effort for the eye gaze was input was lower than joystick input. The following charts illustrate the above:

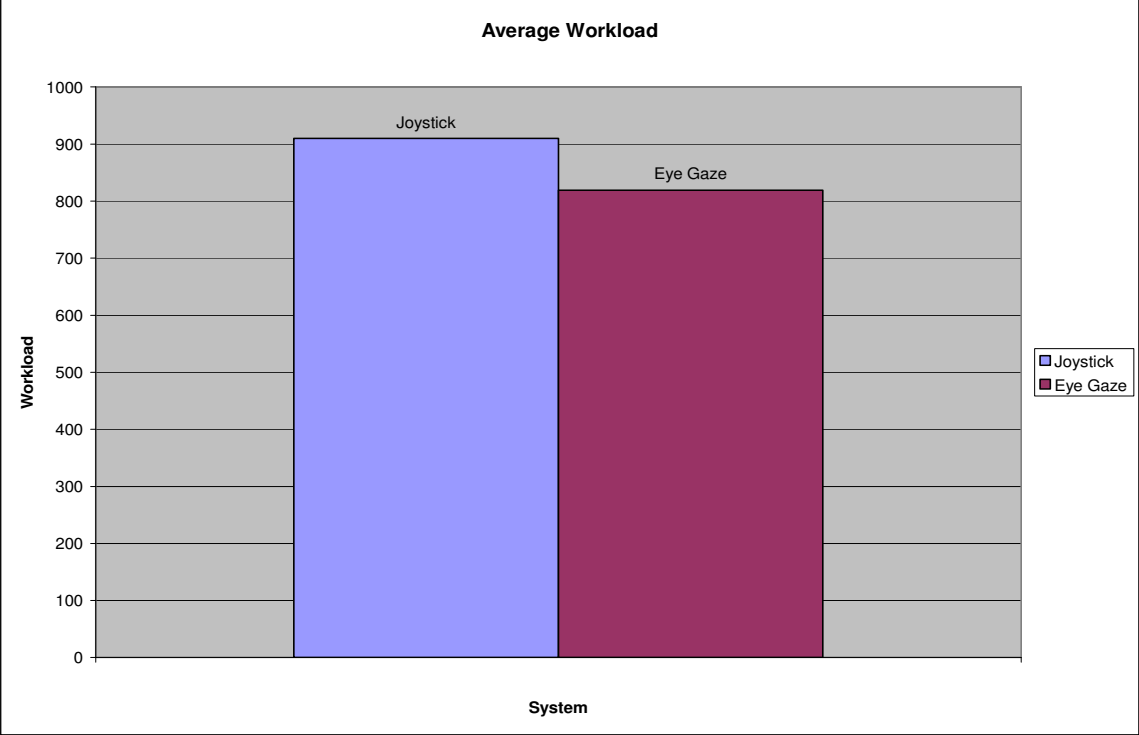


Figure 17 Average Workload for Eye gaze and Joystick inputs

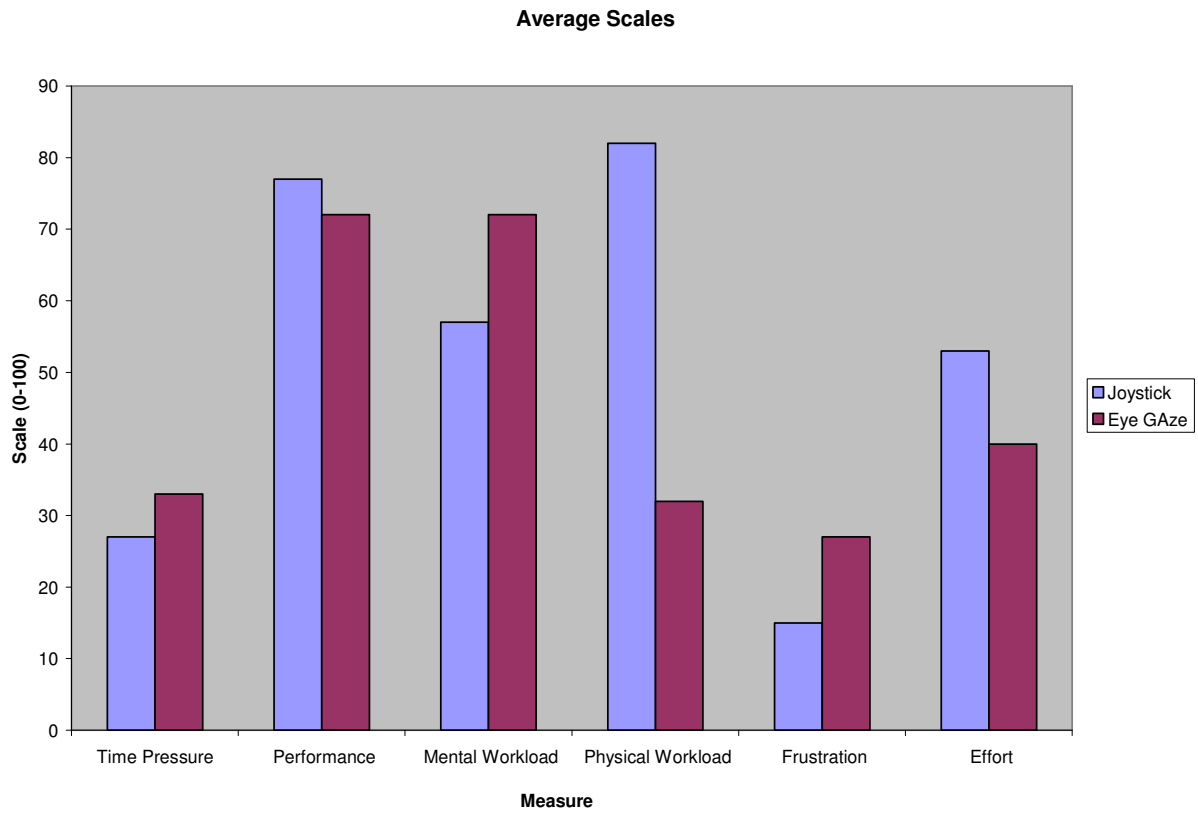


Figure 18 Reported scales for each dimension of the NASA-TLX

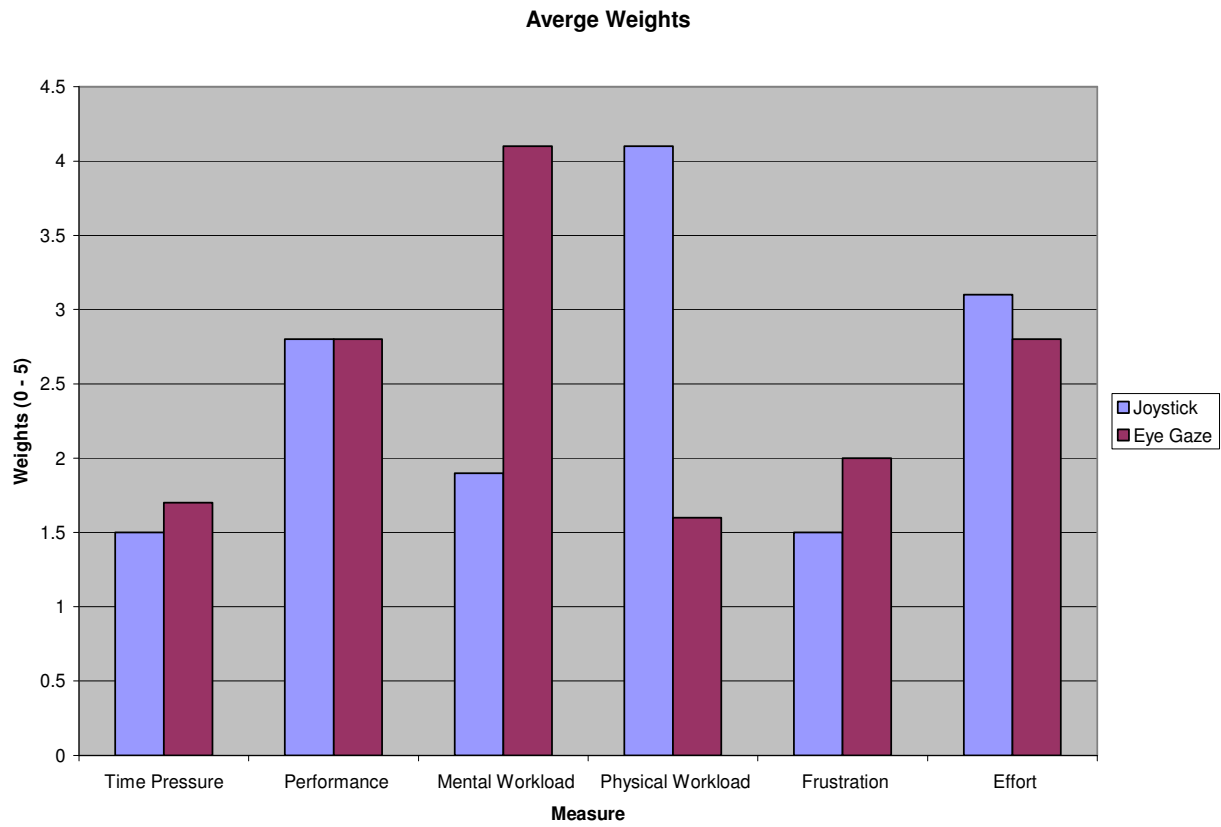


Figure 19 Reported NASA-TLX dimension weights

4. Discussion and Conclusion

4.1 Discussion

The operator workload was lower when using eye gaze input. The time to perform the task was also considerably lowered. Eye gaze system reduced the physical workload, effort and the task time. The decrease in physical demand can be attributed to the elimination of a conventional input system. Reduction in effort could possibly relate to the higher performance to combined physical and mental workload index ratio (1.22 vs. 0.99). Task completion time was significantly lower with the eye gaze system because of the higher frequency of input retrieval by the eye tracker system. The NASA –TLX also showed an increase in the mental workload, time pressure and frustration when using the eye gaze system. The frustration was higher in the eye gaze system due to the system not moving as expected by the participant. This could be attributed to the eye tracker losing pupil or corneal discrimination and eye tracker software lags. This also resulted in higher mental workloads. The reduction in effort can be result of the participant being able to move the camera rapidly and thus finishing the task quicker.

4.2 Conclusion

It is seen that the interaction of the human operator with the robotic camera is unique to the type of input used for control. The operator builds a mental perspective of the input system that controls the robot camera. Using this perspective model, a relation between the input device and camera movement is derived. The operator is placed in a

continuous closed loop cycle with visual cues providing feedback. The reason for lowered workload in eye gaze control could be because of the operator not having to use an additional input device, apart from looking at different parts of the screen which the operator does in the joystick system also. Though the discrete movements made by the camera were the same for both types of inputs, the input method dictated series in which the movements were made. The camera movements were restricted to the transverse and longitudinal axes. For example, to bring the number at the bottom left of the screen to the center, the operator made between 2 to 4 inputs with the joystick. In the case of the eye gaze system, the operator only made one input – look at the corner of the screen. This has a significant impact on the workload experienced by the operator. The workload assessment using the NASA-TLX method was also the first time this system was used on a robotic surgical camera. The results from this study can be used to assess the performance of the NASA-TLX as a workload assessment technique. The overall technology developed here should enable developers to understand and build eye gaze based control into other systems.

5. Future Work

The Computer Assisted Robot Enhanced Systems (CARES) group from the Electrical and Computer Engineering Department at Wayne State University is conducting research to improve the interface between the surgeon and the robot. An eye gaze based control system if implemented with a robotic surgical system like the Zeus () or Da Vinci () can lead to significant improvement in ergonomics of the system. The Da Vinci system has the surgeon seated in a stable position and thus will be easier to implement eye gaze control. A team of researchers with electrical, mechanical and computer science background can bring such a system to life. My work will form a solid base to build on and future researchers can call upon this work to aid the development of such a system.

APPENDIX I: NASA-TLX Mental Workload Assessment

Worksheet

A sample NASA-TLX questionnaire is provided below.

Type of POR:

Subject Name:

Position and payload:

Part I: Weights

Please circle one out of each of the pair that was more significant to you while performing the task.

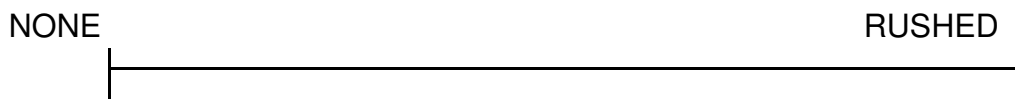
Time Pressure/Physical Demand	Time Pressure/Effort
Performance / Effort	Frustration/Physical Demand
Time Pressure / Performance	Performance/Physical Demand
Effort / Physical Demand	Performance/Mental Demand
Physical Demand/Mental Demand	Time Pressure/Frustration
Performance/Frustration	Effort / Frustration
Effort / Mental Demand	Frustration / Mental Demand
Time Pressure/Mental Demand	

Part II: Scales

Place a mark on each scale that represents the magnitude of each factor in the task you just performed.

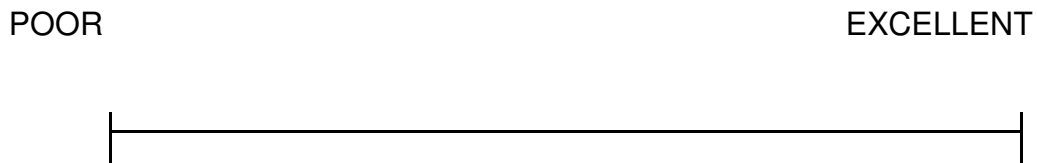
I. Time Pressure

The amount of pressure you felt to finish as quickly as possible.



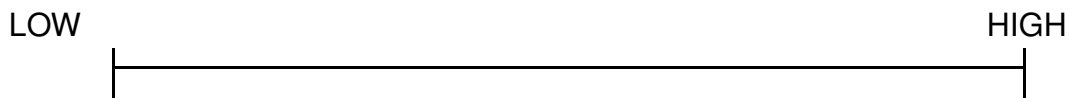
II. Performance

How successful did you think your were in doing what we asked you to do and how satisfied were you with what you accomplished?



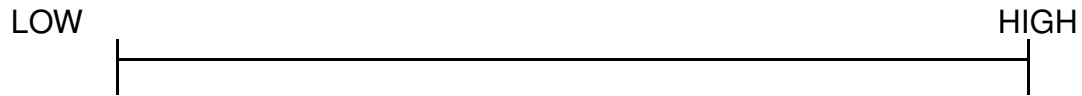
III. Mental Demand

The amount of mental and/or perceptual activity required in translating and rotating the robot and using the joysticks. I.e., thinking, deciding, calculating, remembering, looking, searching, etc.



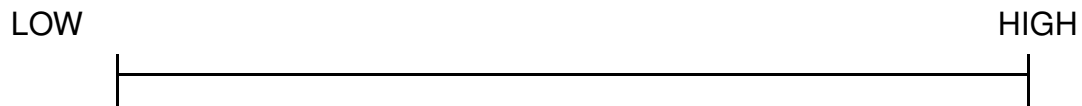
IV. Physical Demand

The amount of physical activity required. For e.g., using joysticks, viewing monitors, etc.



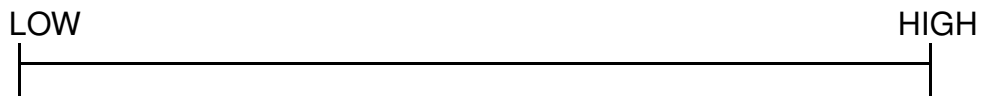
V. Frustration Level

How insecure, irritated, discouraged, or annoyed versus secure, content, complacent, or gratified you felt



VI. Effort

How hard did you have to work (mentally and physically)?



Appendix II: Human factors test sample

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START

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ABSTRACT

DEVELOPMENT OF A GAZE CONTROLLED ROBOTIC SURGICAL CAMERA FOR USE IN ROBOTIC SURGICAL SYSTEMS

by

Anand Sivadasan

December 2006

Advisor: Dr. Darin Ellis

Co-Advisor: Dr Abhilash Pandya

Major: Engineering (Mechanical)

Degree: Master of Science

Robotic surgical Systems can use different types of input systems to control the robotic surgical camera. These include joystick, voice control and computer vision. A new method of camera control is proposed using the surgeon's eye gaze. Two input systems; joystick and eye gaze control are implemented in a robotic surgical camera system. A systems approach is used to develop the robotic system. Subject-based performance studies and a comparison of the mental workload induced on the operator to study the efficacy of the implementations are conducted. The construction of the robotic camera system is detailed with information on the input devices, programming and their integration. The eye gaze system eliminates one voluntary input required from the surgeon. Understanding the interaction of these systems with humans is critical. User performance while operating the system with these two modes of control is evaluated by obtaining tracking and time data during object identification tasks.

Subjective mental workload data was obtained using the NASA-Task Load Index (TLX). Mental workload was found to be lower with eye gaze based control along with task completion time. Performance values did not return very significantly different results.

AUTOBIOGRAPHICAL STATEMENT

Anand Sivadasan

Since the day I first stepped into my father's manufacturing factory, I have never had any doubts as to which field my interests were most focused upon. As I grew up what began as an interest began to influence my way of life and had ended up being instrumental in shaping my education till date. I always envisaged designing and developing new technologies. After I finished schooling with a creditable performance in the 12th grade, I gained admission to the University of Madras (India) for an undergraduate program in Mechanical Engineering. This phase of my life gave me a strong base in mechanical engineering concepts as well as its interaction with electrical and computer systems. I later moved to Detroit, Michigan to pursue a Master's program in Mechanical Engineering. It was here that I met with Dr. Darin Ellis who was involved in many projects with human factors analysis. He introduced me to the Assisted Robot Enhanced Systems (CARES) group, headed by Dr. Abhilash Pandya. Working with these two extremely knowledgeable professors I was able to successfully develop the eye gaze based robotic surgical camera. The wealth of knowledge that I gained during the course of this research will stand me in good stead for all my future endeavors.

