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PARAMETRIC ESTIMATION OF SURGICAL ROBOTIC ARM USING FUZZY ANALYSIS

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ABSTRACT

In the modern era of innovation and technology, robots-based surgery is emerging as a revolutionized surgical method over conventional open surgical methods. Among various other robotic techniques in bio-medical applications, minimally invasive surgery (MIS) robotic arms are considered a viable choice owning to its small incisions, less rate of infection with better and rapid recovery, less blood loss and reduced post-surgical pain. For MIS robotic arm a flexible seven-degrees of freedom (7-DOF) electric motor mechanism is widely used. It consists of three components including a surgeon console which is used by surgeon to control the robotic arm, a patient cart which contains three to four arms controlled by the surgeon from the console and a vision cart. Among these arms, one is used to hold surgical instruments like scissor and the other one controls the 3-D camera. Vision cart shows the 3-dimensional stereoscopic displays to surgeon on the console. In this work, a parametric estimation based on fuzzy analysis was performed for 7-DOF surgical robots. The effect of movement of joysticks attachment with surgeon console is studied on angle of the robotic arm. The movement of the joystick will change the angle of the robotic arm which will result in the movement of the robotic arm towards and away from the patient. The simulated and the MAMDANI calculated results show a difference of 1.44% which shows the accuracy of the calculations.

Keywords: Robotic Arms, Minimally Invasive Surgery, Fuzzy Analysis

Introduction:

Robots are the machine that performs complex series of action automatically which is programmed by a computer either as an autonomous or tele-operated feature. Robots that take their instruction from the human operator are tele-operated, and the robots which perform their task themselves, without human intervene and control are autonomous [1-3]. Among various types of robots, surgical robots have gained significant importance in the field of biomedical from the last few decades. Surgical robots are very useful because they provide surgeons to do more accurate and quicker operations with minimal error [4-5]. These operations are performed by Minimal invasive surgery (MIS). MIS is a surgical procedure that uses only a small incision in the skin of the patient with instruments such as an endoscope and other surgical instruments [6]. One of the robotic arms for endoscope is passed through the body during the tiny incision with holding small 3D video camera which transfers the 3D image to the surgeon who monitors and control the surgical operation. The tool manipulation arms are passing through the body using separate incisions, holding special surgical instruments to repair remove and eradicate the defects in the patient body. MIS is the substitute for conventional open surgery, and it has many advantages over conventional open surgery such as less blood loss, less risk of infection, fewer and smaller scars, faster patient recovery, reduced post-surgery pain, reduced trauma, fewer transfusions, and shorter hospital stay [7-9].

Traditional medical technology has been improved by introducing robotic techniques in the biomedical field [10-12]. The most important part of any surgical robot is its robotic arms [13-15]. It is simply like a human hand that has a translational (displacement) and rotating (rotation) joint for its movement. The movement of the arm is normally operated by a hydraulic system (pistons), or an electric driver (motor), and pneumatic. These arms usually have 7 degrees of freedom (DOF) which include 3 DOF for shoulder joint including internal and external expansion, internal and external rotation, and front and back flexion. 1 DOF for elbow joint named as flexion, 1 DOF for forearm named supination and pronation and 2 DOF for wrist joint named surround and backbends. The surgical robots are classified in two types including master-slave and camera holder systems.

In the camera holder system, a laparoscope is move and hold by the robot according to surgeon requirements which eliminate the need for any external assistance. It consists of different models such as AESOP, SWARM, and Endo-Assist [16-17]. AESOP (Automated Endoscope System for Optimal Positioning) was developed by Computer Motion, CA, USA and it was the first robot which was approved by FDA in 1994. It consists of one mechanical arm with 6 DOF which were controlled by voice, foot, or hand commands [18-19]. SWARM (Swarup Robotic Manipulator) was first developed by Dr, Suresh Deshpande in 2005, which was controlled by foot pedal or voice. It has 4 DOF with 270° axial rotation around the horizontal axis and 120° rotation around the vertical axis.

In the master-slave system, the surgeon simply sits on the console and controls the actions of the robotic arms of the patient cart [20]. It consists of different models such as ZEUS, Da Vinci, Versius, and SPORT. ZEUS was first developed by Computer Motion, the manufacturer of AESOP to enhance surgeon ability during minimally invasive surgery. It consists of two separate subsystems, a control console, and three robotic arms forming a tele-manipulator system. The right and left arms are used as surgeon's arms, and the middle arm is a voice-controlled arm use for 3D viewing [21-23]. Da Vinci was first developed by Intuitive Surgical, Inc., CA and approved by FDA in 2001. It consists of three components including a surgeon console which is used by a surgeon to control the robotic arm, a patient cart which contains three to four arms controlled by the surgeon from the console, and a vision cart. Among these arms, three arms are used to hold surgical instruments like a scissor and the other one controls the 3-D camera. Vision cart shows the 3-dimensional stereoscopic displays to the surgeon on the console [24-26].

Surgical robots having application in various types of surgeries, which include Cardiac Surgery, Gynecology, Neurosurgery, Orthopedics, Pediatrics, Radiosurgery, Urology, and Gastrointestinal surgery [27-29].

To study the check the experimentalist the righteousness and efficiency of the robotic arm design various simulation tools are used including MATLAB, ANYSY, and TRANSYS for mechanical, structural, magnetic, and parametric estimations of any device [30-32]. Among these techniques, FLC (Fuzzy Logic Controller) is a highly efficient technique that provides very valuable flexibility for reasoning [33, 34]. This is a good way to consider the inaccuracies and uncertainties of any experiment. It is a technique to impose human-like thinking into a controlled experiment.

In this paper, we discuss parametric estimations for the development of a 7 DOF surgical robotic arm which is controlled by an operator using two joysticks. These joysticks use two potentiometers which creates a potential difference between them, which is then used to control the angle of servo motors. Servo motors are used for the movement of the surgical robotic arm.

Fuzzy System Design

For parametric estimation for the development of a 7 DOF surgical robotic arm which is controlled by an operator using two joysticks Input variables have been defined in the fuzzy logic controller to have precise output variable data according to the change in given inputs. The two inputs and one output variables on fuzzy inference editor are joystick1, joystick2, and the angle of servo motor respectively, shown in the Fig.1. It is important, because fuzzy logic provides almost ideal conditions; it has numerous values between 0 and 1.

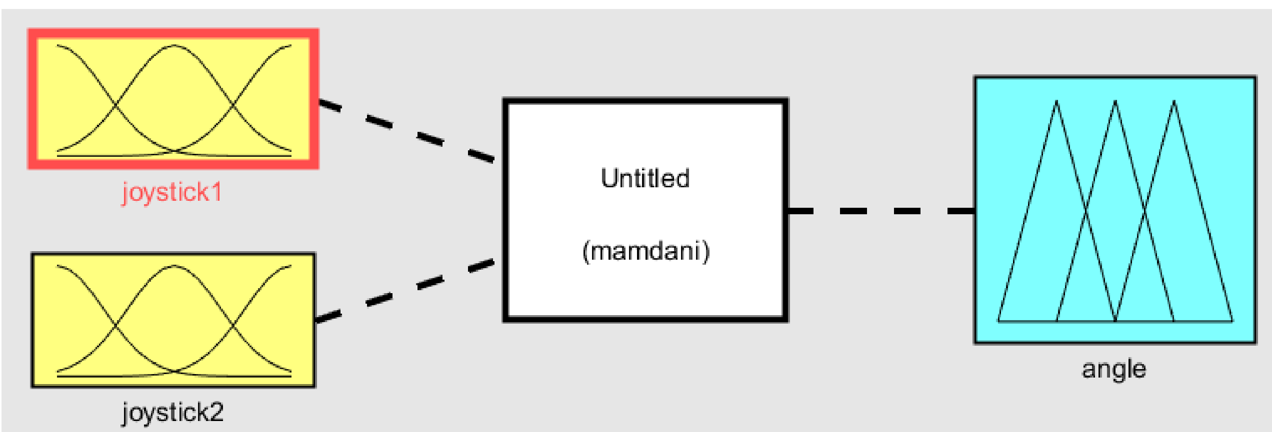

Fig.1. Fuzzy Inference system for the surgical robotic arm

MATLAB membership functions have been used for the input and output variable's graphs. The graph of every two individual entities has been drawn. The graphs for the inputs joystick1, joystick2 and output angle are shown in Figs. 2-4 respectively. The input parameter of both the joysticks was taken in analog voltage values in the range of 0-32500V. The range for output parameter of angle is 0-180^0.

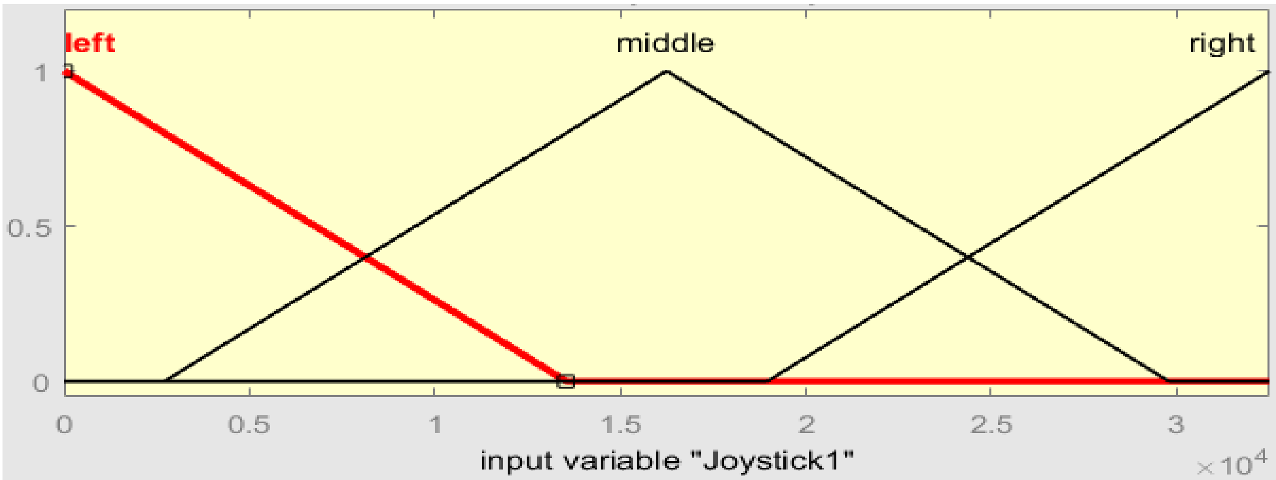

Fig. 2. Membership function graph showing Joystick 1(0-32500V)

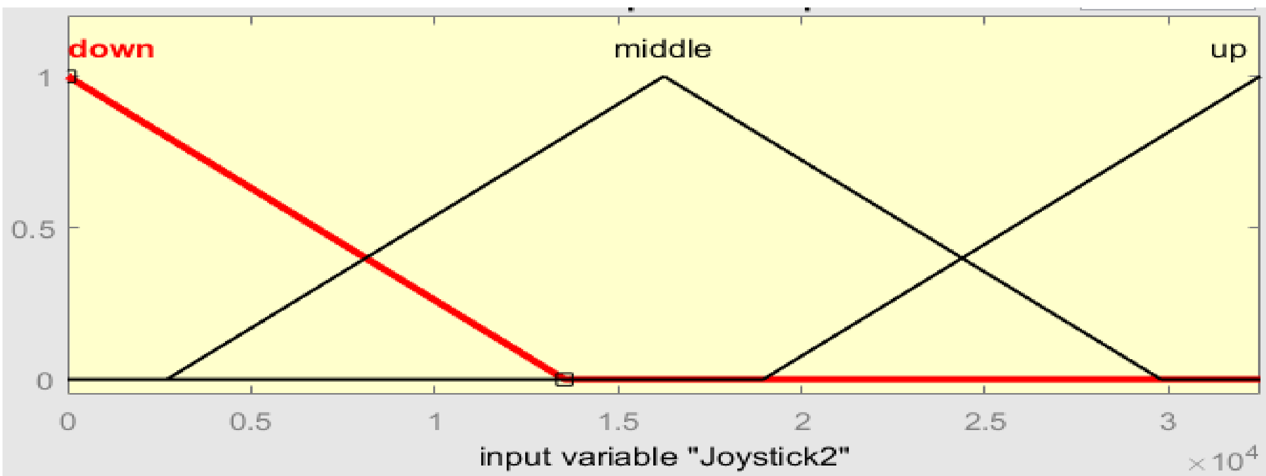

Fig. 3. Membership function graph showing Joystick 2(0-32500V)

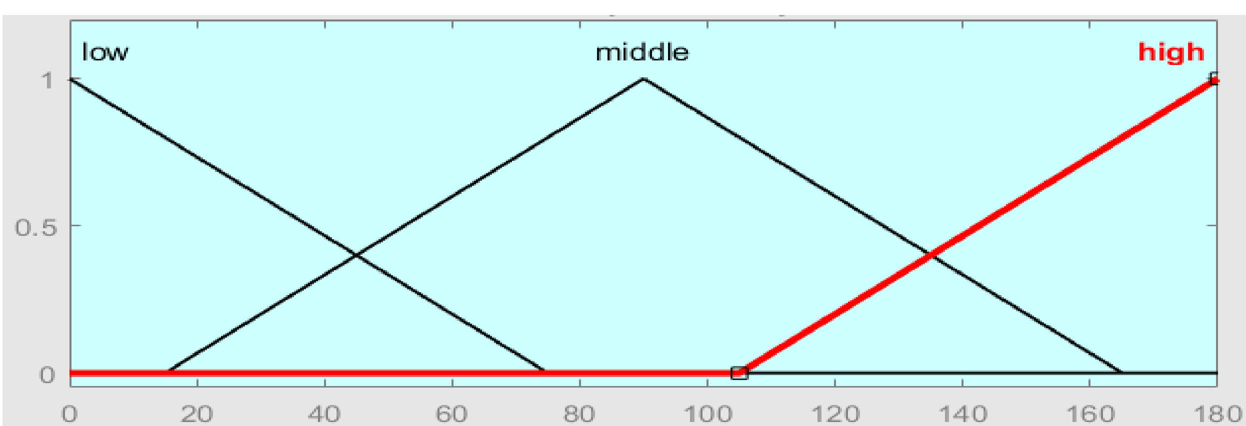

Fig. 4. Membership function graph showing angle (0-180^0)

The membership functions and the ranges assigned to the input and output are shown in Table 1.

Table 1: Membership functions and ranges of inputs and outputs

Input/output	**Membership function**	**Ranges**
Joystick 1	Left	1-1.4 x 10^4 V
	Middle	0.3-3 x 10^4 V
	Right	1.8-3.25 x 10^4 V
Joystick 2	Down	1-1.4 x 10^4 V
	Middle	0.3-3 x 10^4 V
	Up	1.8-3.25 x 10^4 V
Angle	Low	1-75^o
	Middle	15-165^o
	High	110-180^o

Nine rules are defined in the MATLAB rule editor using IF, OR, and THEN logic based on m^n, where m is the number of membership function defined and n is the number of inputs. The defined rules are shown in Table 2. These rules are selected based on their effect on the output.

Table 2: Rules selected for MATLAB fuzzy logic simulations

Joystick1	Joystick2	Angle
Left	Down	Low
Left	Middle	Middle
Left	Up	High
Middle	Down	Middle
Middle	Middle	Low
Middle	Up	Middle
Right	Down	High

Right	Middle	Middle
Right	Up	Low

Based on the rules, 3D graphs are studied. To show up the three values at a time in a graph 'two inputs and one output' we have three-dimensional graph shown in Fig. 5.

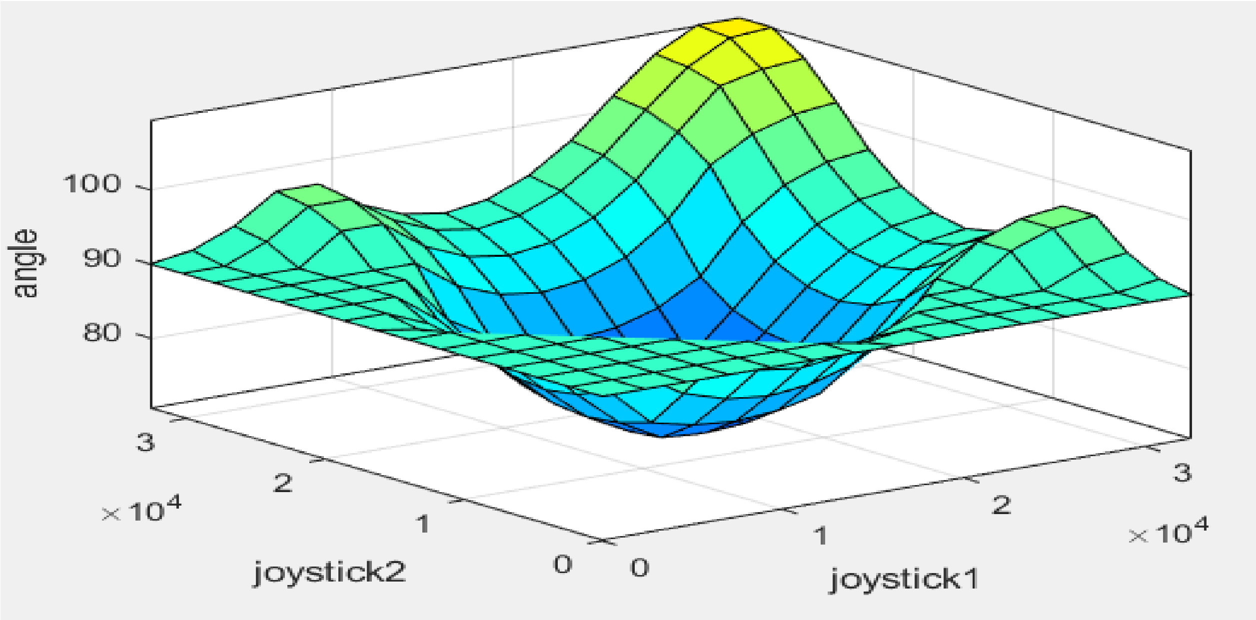

Fig. 5. Three-dimensional graph showing all the three variables

Fig. 5 shows that the angle is zero when both the inputs are at same value, and when the one input is at high and the second input is at low then we have the maximum angle.

Results and Discussion

From the rule viewer screen in fuzzy analysis tool, the crisp value of angle based on selected input values can be seen that is based on the defined rules. For calculations, a crisp value of both inputs including Joystick1 and Joystick2 is selected as shown in Fig. 6**.** Based on these crisp values a comparison is carried out in between the simulated value of output and the calculated value. The calculated value for angle, based on the input crisp value can be seen in Fig. 6.

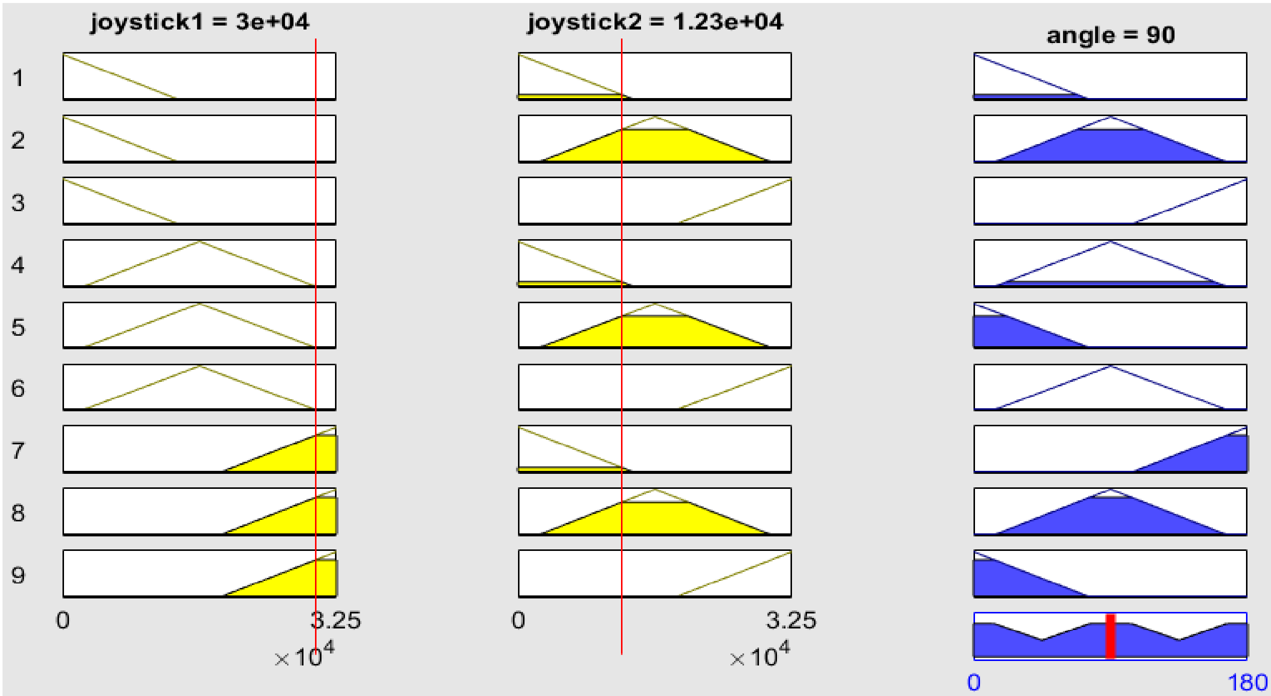

Fig. 6. Rule viewer to show up one output for the corresponding two inputs

Calculation was performed for the crisp value of Joystick1 of $1.23x10^4$ and Joystick2 of $3x10^4$. For these corresponding crisp values, the calculated angle is 90^0. 4 membership functions are selected based on these calculations which are furthermore used to calculate the Mamdani model simulated value. These 4 membership function values are calculated from the selected crisp values. These values depict the highest and the lowest value of the crisp value range. The membership function values are:

$$K_1 = (3.25 - 3 / 3.25)\ x10^4 = 0.076x10^4V$$
$$K_2 = 1 - K_1 = 0.92x10^4V$$
$$K_3 = (3.25 - 1.23 / 3.25)\ x10^4 = 0.621x10^4V$$
$$K_4 = 1 - K_3 = 0.379x10^4V$$

Based on the values of these membership functions, 4 rules are selected out of 9 rules which are considered for this work. The minimum membership function value (Gi) and Singleton value (Vi) is calculated based on Mamdani formula as stated below.

$$\text{Mamdani model} = [\ \Sigma\ (Mi \times Si) / Mi]\ {*}100 \qquad (1)$$

The sum of all the minimum membership function values and singleton values are calculated which are furthermore used to calculate the crisp value of output using Mamdani model.

$\sum Mi = 0.99$
$\sum Mi\ x\ Si = 0.8789$

Mamdani model = [Σ (Mi × Si) / Mi] *100
Mamdani model = 88.77

The Crisp value of the output from rule viewer is 90 and Mamdani model calculated value is 88.7. The error between the simulated value and the calculated value is 1.44% which shows the accuracy of the results. Table 3 Shows the comparison and error value between the simulated and calculated value.

Table 3: Error Calculation between the simulated and calculated values

Simulated Value	MAMDANI Calculated Value	Error
90	88.7	1.44%

Conclusion

In this work, the parameters for the development of surgical robotic arm were studied using fuzzy analysis. The effect of movement of joysticks attachment with surgeon console is studied on angle of the robotic arm. The movement of the joystick will change the angle of the servo motors which will result in the movement of the robotic arm towards and away from the patient. The simulated and the MAMDANI calculated results show a difference of 1.44% which shows the accuracy of the system.

Author's Contribution: G.M., M.K., M.A., conceived the idea and designs the simulation work: F.Q., S.A.A.S., performed the acquisition of data and executed simulated work; G.M., S.A.A.S., performed data analysis or analysis and interpretation of data; G.M., M.A., M.K., wrote the basic draft; M.A., G.M., F.Q., did the language and grammatical edits and critical revision.

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