# Fuzzy Logic Based Force-Feedback for Obstacle Collision Avoidance of Robot Manipulators

D. Wijayasekara, M. Manic
Department of Computer Science
University of Idaho
Idaho Falls, USA
wija2589@vandals.uidaho.edu, misko@ieee.org

***Abstract*—Robot remote teleoperation enables users to perform complex tasks in hostile or inaccessible environments, without physical presence. However, minimizing collisions with obstacles while maintaining accuracy and speed of task is important. While visual and auditory inputs to the user aid in accurate control, to achieve the required speed and accuracy, tactile and kinesthetic force-feedback information can be used. This paper presents a dynamic real-time fuzzy logic based force-feedback control for obstacle avoidance in a remotely operated robot manipulator. The presented method utilizes absolute position of the robot manipulator to calculate the distance vector to known obstacles. A fuzzy controller utilizes the distance vectors and the velocities of the components in the manipulator to generate force feedback in each axis. Furthermore, the paper presents an interactive graphical user interface that enables users to add or remove obstacles in the environment dynamically. The presented method was implemented on a simple 3-DOF robot manipulator. The presented method was compared to a situation without force feedback. Test results show significantly improved speed and consistency in completing a task when the presented force feedback method is used.**

***Keywords—Force feedback; Remote teleoperation; Robotics; Fuzzy control, Haptics***

## I. Introduction

Robot teleoperation entails interacting and controlling robots from a remote site. The goal of teleoperation is to enable control of a robot in a situation where it is unsafe, difficult or inconvenient for a human to be physically present at the location [1]. However, such control is only necessary when the task of the robot is dynamic and complex such that it is difficult to complete autonomously [1].

Due to the high complexity and the low threshold for deviation in such tasks, minimizing collisions while maintaining high levels of accuracy and speed is difficult. Therefore, providing accurate and useable information to the user about the robot position and orientation as well as the working environment is critical for successful and effective teleoperation.

Visual and auditory inputs to the user are the most widely used methods of information exchange in the field of human computer interaction [2], [3]. However, visual and auditory information might not be sufficient in many cases [4].

Providing information to users via other senses is less widely used because the difficulty in modeling accurate information and the need for specialized devices [2]. However, providing information via the sense of touch, known as haptics, has gained much interest in recent years [3], [5], [6]. To convey haptic information, a haptic device is used which is a bi-directional human interface that provides force sensations to the user while simultaneously communicating with the computer [2], [6]-[8]. Two types of haptic devices exist: tactile and kinesthetic [5], [9]. Tactile devices are based on sense of touch and enable the operator to feel textures and consistency of objects [5]. Kinesthetic devices reflect forces and enable the operator to feel the environment [5].

Thus haptics has been used in a wide area of robot remote teleoperation tasks such as teleoperation of mobile robots [10] operating industrial robotic manipulators [11], remote surgery robots [12], [13], path planning [14] and virtual sculpting [6], [15]. Furthermore, many research have shown the improvement in time and accuracy of task completion by utilizing haptic input to the operator [3], [9], [12], [16].

Several approaches for obstacle and self collision avoidance for robotic manipulators have been explored previously. Force feedback can be used to avoid collisions by providing the user with kinesthetic feedback according to the relative distance to obstacles. This is typically a negative force towards the obstacle and is increased as the manipulator approaches the obstacle. Typically a virtual force field based approach where a force field is modeled surrounding the objects and the manipulator is used [5], [7], [14]. Methods that models accurate real world physics have also been explored for collision avoidance [17]. Mass spring model, models virtual springs surrounding obstacles to avoid collisions while providing kinesthetic feedback [18]. Traditional PD and PID control methods with varying gains have also been explored to provide accurate force feedback to the user for collision avoidance [18]-[21].

This paper presents a fuzzy logic based force feedback generation method for collision avoidance in teleoperated robotic manipulators. The presented method utilizes the distance to obstacles and the speed of the robotic manipulator to generate appropriate force vector using a fuzzy logic system. Furthermore, an interactive Graphical User Interface (GUI) is also presented that enable the user to dynamically manipulate

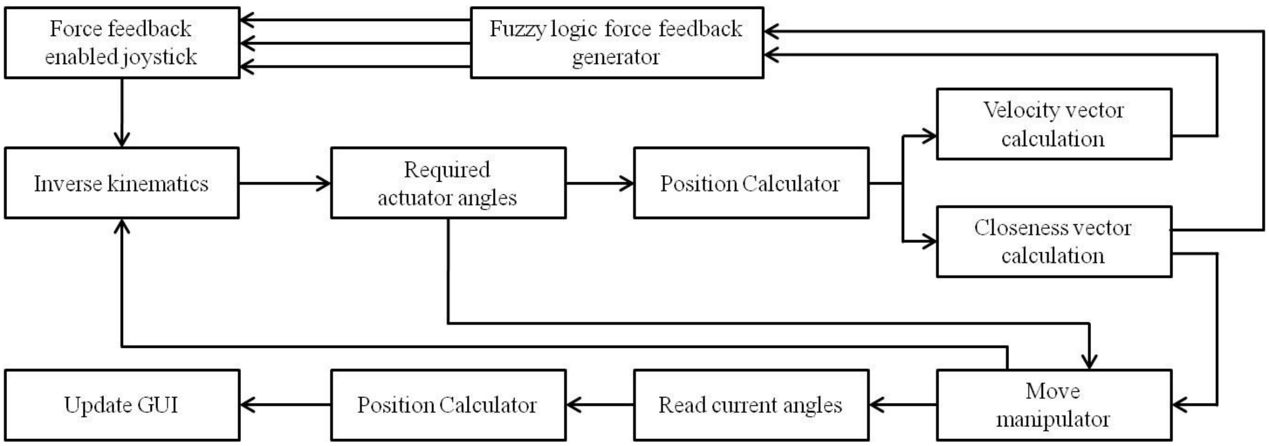



Fig. 1 Overall framework of the presented fuzzy based force feedback method for obstacle collision avoidance

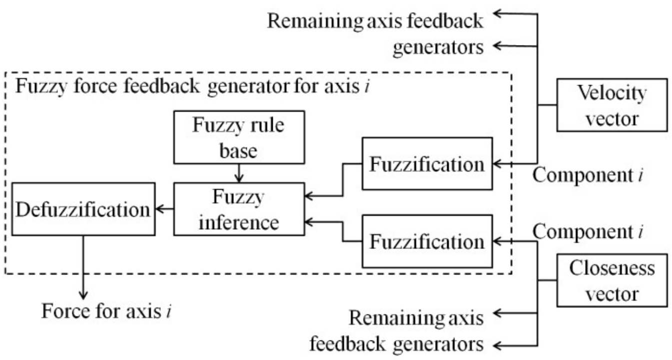



Fig. 2 Fuzzy force feedback generation inference process

obstacles in the environment. The presented method was implemented on a simple 3-Degree of Freedom (DOF) robotic manipulator and tested on a simple task. The experimental results show a significant improvement in the time to complete the task as well as the consistency of the task completion when force feedback is enabled.

This paper is organized as follows; Section II details the presented fuzzy logic based force feedback generation method. Section III presents the hardware and software implementation. Section IV presents the experimental results while section V concludes the paper.

## II. Fuzzy Force-Feedback for Obstacle Avoidance

This section first details the overall architecture of the presented system and then discusses each component in detail.

### *A. Presented system*

The overall framework of the presented method is detailed in Fig. 1. The position and size of the obstacles in the operating area is assumed to be known. The user controls the manipulator using a force feedback enabled joystick device. Once a movement of the joystick is made at time $t$, the required angles of the motors at time $t+1$ for the required movement of the manipulator are calculated. Using these angles the start and end points of each component of the manipulator at time $t+1$ is calculated. This is performed before physically moving the manipulator.

Using the calculated position of the manipulator at time $t+1$, and the position of the obstacles, the closeness vector between the obstacles and each component of the manipulator is calculated. The closeness vector is a vector between the two closest points between the robot manipulator and a given obstacle. Similarly, using the position of the manipulator components at time $t$ and time $t+1$, the velocity vector for each component is also calculated.

The closeness vector with the smallest magnitude and the velocity of that component is selected as the force generation velocity, distance pair. And each of the $x$, $y$ and $z$ components of the selected closeness vector and the velocity are then passed on to the appropriate fuzzy force feedback generation system. The fuzzy system then generates the required forces for each axis for time $t+1$. The fuzzy system and inference process is detailed in sub-section II.B.

The closeness vector generated and the required angles are then used to move the robot manipulator to the required position at time $t+1$. The closeness vector is utilized to prevent collision in extreme cases by disallowing movement if the magnitude of the closeness vector is less than a preset value $\partial d$ .

Simultaneously, the generated force values for each axis are sent to the joystick and thus the user. Furthermore, the current actual angles at time $t+1$ of the motors are measured and the absolute position of the components of the manipulator is calculated. This information is used to update the position of the manipulator in the Graphical User Interface (GUI). The current actual angles are also stored for calculating the required angles of the motors at time $t+2$.

### *B. Fuzzy Logic Based Force Feedback Generation*

The fuzzy logic based force feedback generator utilizes the generated closeness vector at time $t+1$ and the velocity vector between time $t$ and $t+1$ to compute the required force to the fed back to the user.

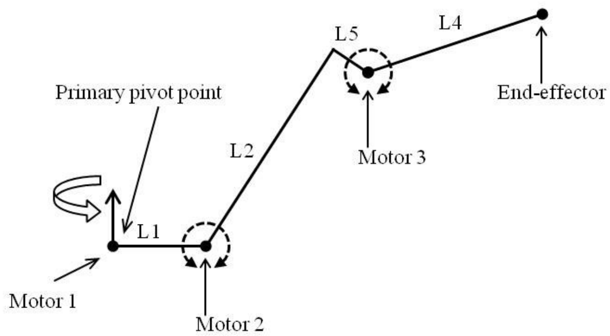



Fig. 3 Schematic of the implemented 3-DOF robotic manipulator

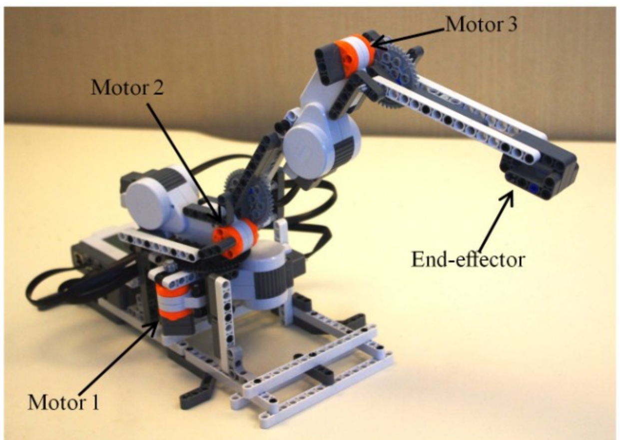



Fig. 4 The implemented 3-DOF robotic manipulator using Lego NXT

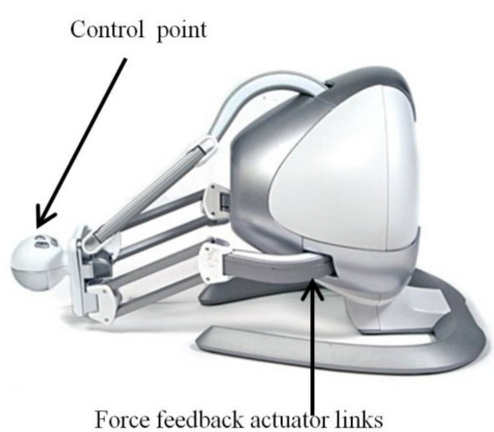
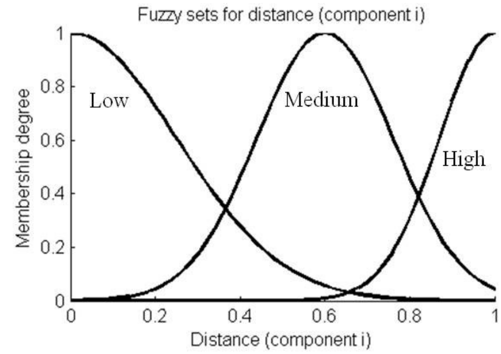
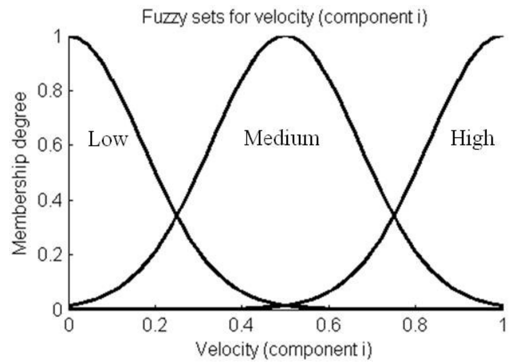



Fig. 5 The Novint Falcon 3-DOF force feedback joystick device

For each axis *x*, *y* and *z*, a separate force feedback generator is used, which generates the force pertaining to that axis. Each force feedback generator takes the axis component of the velocity vector and the axis component of the closeness vector. The axis component of the closeness vector is the distance from the manipulator to the obstacle in that axis. The basic block diagram of the fuzzy inference process is depicted in Fig. 2.




(a)

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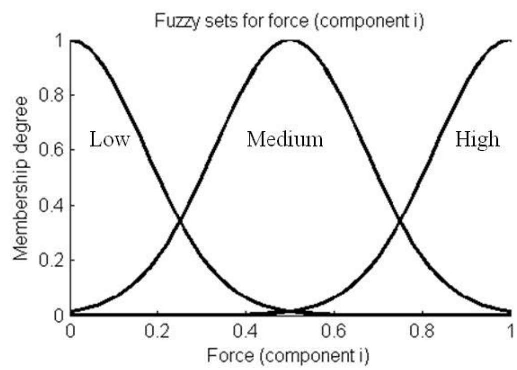



(c)

Fig. 6 The fuzzy sets used for inputs and output for each axis (a) distance, (b) velocity, and (c) force

By utilizing separate controller for each dimension, different forces can be generated for each dimension by means of different rule sets and fuzzification parameters. This enables application and robot specific rules to be implemented without any changes to the overall architecture.

For space considerations the steps of the fuzzy inference process will not be detailed in this paper. Specific implementation used for this paper is detailed in Section III.

## III. IMPLEMENTATION

This section details the specific implementation of the presented method.

TABLE I
FUZZY RULE BASE FOR AXIS *I*

| Distance comp *i* \ Velocity comp *i* | Low | Medium | High |
|---|---|---|---|
| Low | Medium | High | High |
| Medium | Low | Medium | Medium |
| High | Low | Low | Medium |

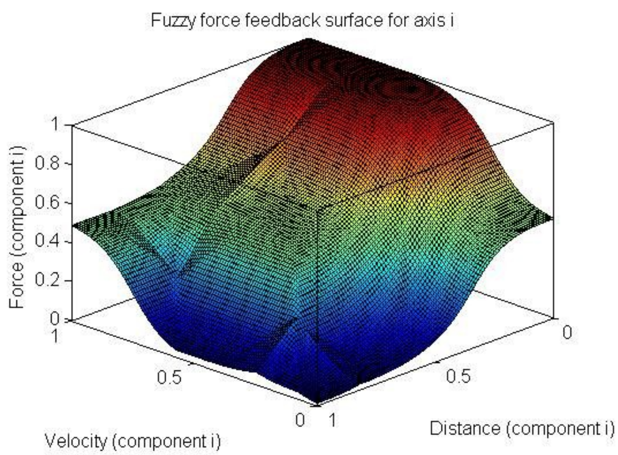



Fig. 7 The output surface of the implemented fuzzy force feedback generator

## A. Robot Manipulator and Forcefeedback Enabled Joystick

For the purpose of this paper, a simple 3-DOF robot manipulator with 3 actuators was implemented using Lego NXT [22].

The schematic of the implemented robot is depicted in Fig. 3. Fig. 4 shows the actual implemented robot. An inverse kinematics method was used to derive the angles of the motor for the desired end-effector position. The actuator angles can be read via the NXT interface for calculating the actual position of the robot after a movement has been made.

As the force feedback enabled joystick device, the Novint Falcon device (Fig. 5) was selected [23], [24]. The Novint Falcon device has 3 degrees of freedom and 3 actuators work in conjunction to provide kinesthetic or tactile feedback to the user.

## B. Fuzzy Logic Based Force Generation

As mentioned in section II, each axis is given a separate force generation system. For the simple system implemented in this paper, the same force feedback generation rules and fuzzy sets were used for each axis.

Gaussian membership functions were used for each of the inputs and the outputs. Fig. 6 shows the input fuzzy sets for the distance (Fig. 6(a)), velocity (Fig. 6(b)), and the output force (Fig. 6.c). Table I shows the utilized rule base. The control surface generated by the rule base and the given fuzzy sets is depicted in Fig. 7.

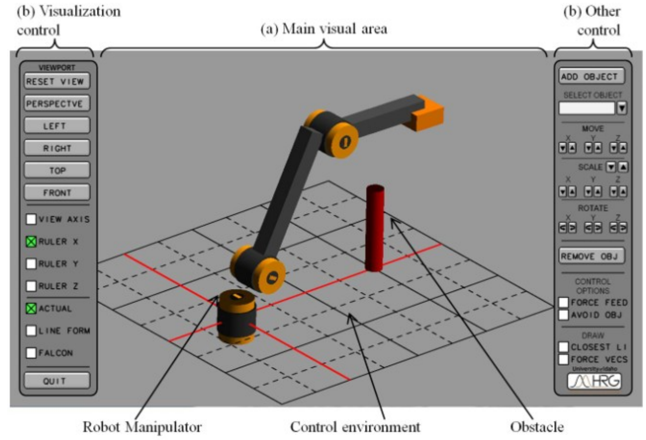
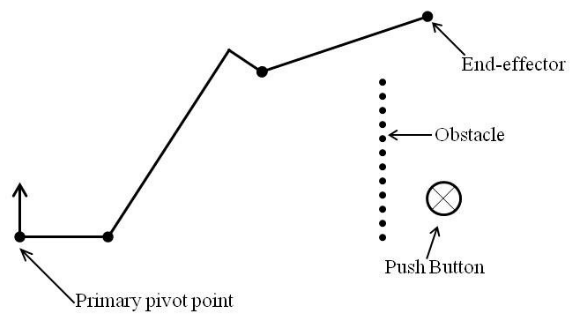
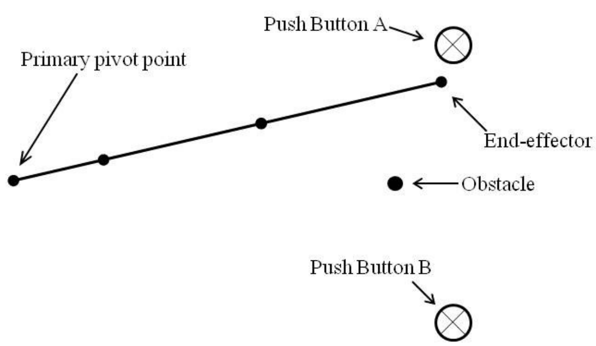



Fig. 8 The implemented Graphical User Interface (GUI)




(a)




(b)

Fig. 9 The experimental setup (a) side view, (b) top view

## C. Graphical User Interface (GUI)

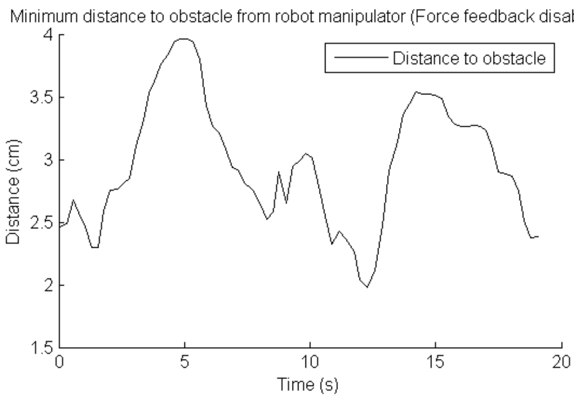
An interactive Graphical User Interface (GUI) was implemented that displays the control environment along with obstacles and the current position of the robot manipulator. The GUI acts a virtual environment that can be used as a visual aid for robot remote teleoperation. The implemented GUI is shown in Fig. 8.

The GUI consists of 3 separate control and visual areas. The main visual area (marked (a) in Fig. 8), displays the current position of the robot manipulator and obstacles in the environment.

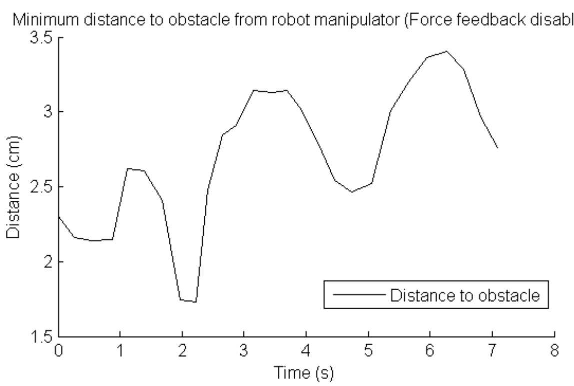
The visualization control panel (marked (b) in Fig. 8) contains visualization controls. These controls enable the user

TABLE II
AVERAGED RESULTS FOR TASK COMPLETION

| Force feedback | Time for completion (Seconds) | | Average distance to obstacle (cm) | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard deviation |
| Enabled | 12.01 | 1.10 | 3.22 | 0.71 |
| Disabled | 22.11 | 3.37 | 3.41 | 2.11 |

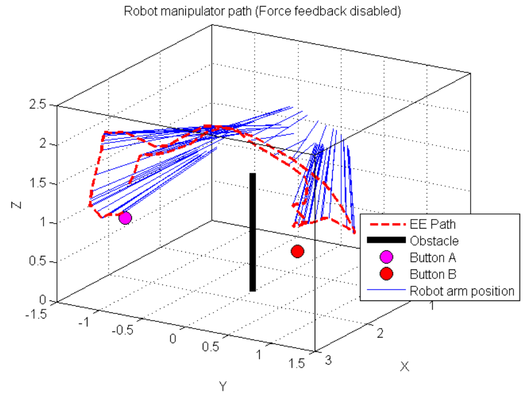


(a)

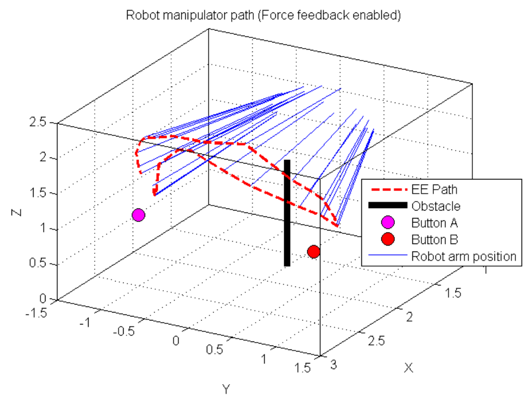


(b)

Fig. 10 Minimum distance to the obstacle from robot manipulator (a) force feedback disabled (b) force feedback enabled



(a)



(b)

Fig. 11 Robot manipulator position with respect to the obstacle (a) force feedback disabled (b) force feedback enabled

to visualize the environment from different points of view as well as using different representations.

Finally the obstacle and force feedback control (marked (c) in Fig. 8) panel enables the user to dynamically add or remove obstacles and manipulate the size position and rotation of the obstacles. Furthermore, this panel also houses controls for enabling and disabling the force feedback.

## IV. EXPERIMENTAL RESULTS

A simple task using the implemented system detailed in section III was setup for evaluating the presented force feedback generation method.

The task shown in Fig. 9, comprised of pressing one button (Button A in Fig. 9) at which time the data recording was commenced. Once this button is pressed the user needs to move the manipulator while avoiding an obstacle to press a second button (Button B in Fig. 9) and move the manipulator back to press the first button, at which time the task will be completed. This task was chosen for its repeatability, ease of manipulation, and low time for completion.

The task was given to 10 different individuals with varying levels of exposure to robot control. Each user was given up to 30 minutes to familiarize themselves in controlling the manipulator. After familiarizing, the task mentioned above was completed 10 times by each user alternating between force feedback enabled and force feedback disabled. The position of each component of the manipulator along with the force generated and the time to completion was recorded. Furthermore, the distance to the obstacle at each time step was also recorded.

The average results of the task for all users in each scenario are presented in Table II. The time to complete the task is lower with the force feedback enabled. Furthermore, the low standard deviation for time and distance to obstacle when force feedback is enabled is representative of the consistency of performance.

Figs 10(a) and 10(b) plot the magnitude of the closeness vector for the fastest completion times with and without force feedback respectively. Similarly, Figs 11(a) and 11(b) plot the location of the robot manipulator for each of the above cases,

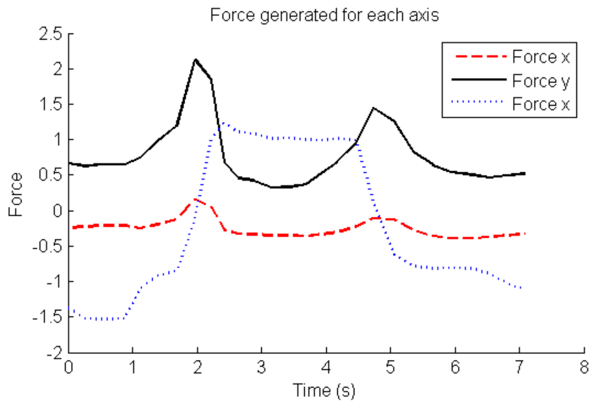



Fig. 12 Generated force feedback for each axis

with respect to the push buttons and the obstacle. It can be observed from these figures that with force feedback enabled the movement of the manipulator is smoother and less prone to abrupt changes. Figure 12 shows the force feedback generated for each axis for the case shown in Fig 11(b).

## V. CONCLUSION

This paper presented a dynamic, real-time fuzzy logic based force feedback control for collision avoidance in remotely operated robot manipulators. The presented method utilizes distance vector from the obstacle to the robot manipulator and the velocity of the manipulator to generate feedback force for each control axis. Furthermore the paper presented an interactive GUI that enables users to dynamically interact with the control environment.

The presented method was implemented on a 3-DOF robot manipulator coupled to a commercially available 3-DOF force feedback enabled joystick. The presented method was tested against a force feedback less control for a simple task. 10 different individuals were given a simple task to perform 5 times with and without the presented force feedback method. The experimental results show that with force feedback enabled the task completion time was significantly improved. Furthermore, with force feedback enabled the consistency in task completion time and manipulator movement was also increased.

Future work entails comparing the presented fuzzy logic based method to traditional force feedback methods. Furthermore, the presented method can be further extended to include other factors such as friction forces and the manipulator position error forces for more accurate control.

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