# SYSTEM INTEGRATION OF A FORCE-REFLECTING MANUAL CONTROLLER WITH ANY SV203 CONTROLLED PLATFORM

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## ABSTRACT

*An inexpensive general-purpose interface is developed which allows the integration of a force-reflecting manual controller with any platform that uses the SV 203 controller. The software also allows for remote operation and access to the remote system through the internet. To demonstrate this teleoperation system and its generality, three subsystems are developed which uses SV203 controller: (1) a one degree-of-freedom force-reflecting manual controller, (2) a modified palm pilot robot kit (slave robot) and (3) a one-degree-of-freedom slider bar platform. In demonstrations, subsystems (2) and (3) were used as remote systems. The software was developed in Visual Basic platform to control the remote slave system. The software has been designed for any task rather than for a specific task.*

## INTRODUCTION

There are many tasks hazardous to human life which can be accomplished remotely using telerobotic manipulators. A telerobotic operation involves interaction between a human operator and a remote robotic system via communication channels. The performance of the communication channel plays an important role in the stability of the telerobotic system [1]. Passivity of the communication channel, having a constant delay, to guarantee the stability is first introduced by Anderson and Spong [2]. The technology has advanced to the stage where telerobots are versatile and effective enough to be used in a wide variety of circumstances. These teleoperators (also known as remote control devices or manual controllers) are in use around the world in many different environments as diverse as the nuclear reactors, police forces, military operations, space applications, and undersea tasks [3]. The system usually consists of two robot manipulators that are connected in such a way as to allow the human operator to control one of the manipulators (the master arm) to generate commands which map to the remote manipulator (the slave arm). This paper will introduce the integration of the one degree-of-freedom manual controller (master arm) with the palm pilot robot platform (PPRK) and 1-DOF slider bar platform (slave arm) resembling teleoperation.

## FORCE-REFLECTING MANUAL CONTROLLERS

A force-reflecting manual controller or joystick for teleoperation is a device where contact forces from a remote manipulator are felt on human operator through physical contact with a control device known as "master", or "hand controller". Force-reflecting manual controllers are classified as into two; serial and parallel structures. The main advantage of serial structure over the parallel structure is it has larger workspace [4]. The main goal of this project is to design a compact, inexpensive and light weight 1-DOF FRMC prototype, for this purpose we will discuss about the prototype which is being developed at Florida International University. Different components used in the prototype development of master robot and slave robot are discussed below.

## RC SERVO

RC servos are cheap, easy to control, come in a convenient form factor and are available in different sizes, speeds and power ratings. RC servo compares its current position, given by a built in potentiometer which is connected to the output shaft, to an input Pulse-Width Modulated (PWM) signal, and then moves until its position matches the input signal. Radio control servo motors are very useful in the small robotic experiments because they are small, compact and inexpensive. The pulse width lasts for approximately 0.6 ms to 2.4 ms, where the servo will reach its minimum and maximum position. At 1.5 ms pulse, the servo is set to the middle (neutral) position. This pulse is repeated every 14 to 20 ms. Servos are usually designed to rotate only up to 90 degrees on either direction. Fig 1shows one of the Futaba servo motor.

Figure 1 Servo motor FP-S148

Futaba type servo motors were not developed for continuous rotation. In order to move the servos continuously the servo has to be modified [5].

## SERVO CONTROLLER

Although direct computer connection to servos provides a simple and inexpensive way to control them, other alternatives are usually more preferable. Servo controller boards, such as Pontech's SV203 board, are often used to control servomotors. Because servo controller boards have been designed just to drive servos, they can usually control more servos than microcontroller boards can. On the other hand, microcontroller boards have been designed for embedded control and they have a wider array of input options for sensors. Pontech's SV203 servo controller board accepts serial data and outputs Pulse Width Modulated (PWM) signals to control RC servos. Fig 2 shows the SV203 servo controller board.

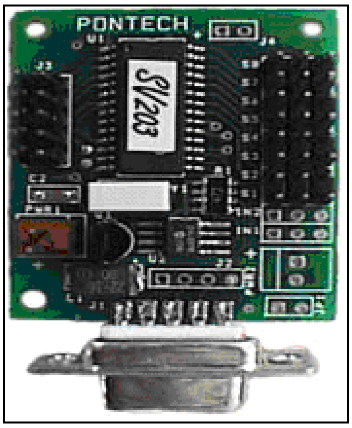


Figure 2 SV203 Controller board

The SV203 board can simultaneously control up to eight servos (8 digital outputs) and has five A/D inputs. Serial communications via a standard RS-232 cable to the COM port of a computer provides a simple user-friendly interface [6]. The Pontech SV203 controls its servos via an 8-bit signal (PWM). An 8-bit signal can take $2^8$ values (from 0 to 255). If we define the 0 signal as $0^o$ and the 255 signal as $180^o$, then the $90^o$ signal will be 128.

## SENSORS

Sensors can be described as devices used to measure physical parameters and the algorithms for interpreting sensor data. Sensors can be grouped into two: internal and external sensors. Internal sensors are used to measure variables within the robot, joint angles, wrist forces, platform velocities, and external sensors to measure variables such as range, vision and voice. Sensor capability in each activity is essential for a robot to work in an unstructured environment, where it has to respond to changes in that environment. A typical sensor consists of a transducer and an electronic circuit [8]. Several types of sensors that are useful for robotic applications are: Potentiometers, position sensors, tachometers, range sensors, proximity sensors, tactile sensors, and vision sensors [9].

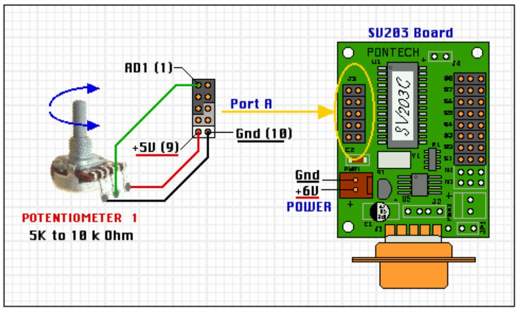


Figure 3 Potentiometer connections on SV203 controller

Potentiometers are used to track the position of the servo through the SV203 servo controller in our project. This potentiometer is attached to the servo motor of the joystick through some linkage which inturn gives the position of the servo whenever there is displacement. Fig 3 shows the connection of a potentiometer to the SV203 controller. This potentiometer works only at 5 volts current and is to be plugged in at one of the A/D inputs of the SV203 controller.

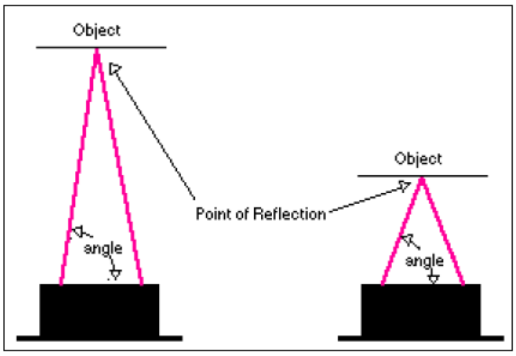


Figure 4 Distance and angle calculation

The main sensor used in our project is the Sharp GP2D12 analog infrared ranger [11]. Sharp IR rangers use triangulation and a small linear CCD array to compute the distance or presence of objects in the field of view (Fig 4), which results in greater reliability and accuracy than many IR sensors that use time-of-flight techniques. Also, these new rangers offer much better immunity to ambient lighting conditions and to the color of the reflected surface than other IR sensors [12]. These sensors have a minimum range of 10 cm (~ 4in) and a maximum range of 80 cm. The beam is very tight, just about 3 cm wide and less than 3 cm in height at 40 cm. Such characteristics make the sensors quite suitable for unidirectional measurements, but not so great for general obstacle detection. Some advantages over ultrasound ranger sensors, traditionally used for obstacle detection, are: IR sensors do not suffer from ghost images;

furthermore, the angle at which they face an obstacle can be as high as $60^{o}$ without affecting distance reading [12]. IR sensors also have much lower power requirement compared to the battery-hungry ultrasound sensors. Finally, price becomes an issue when ultrasound sensors are over five times more expensive than IR sensors [7].

## PLATFORM DESIGN

We have developed five prototype concepts; FRMC concept using ball screw mechanism, FRMC concept with belt transmission system, FRMC concept with gear transmission system, FRMC concept with drive roller and belt system and FRMC concept utilizing direct drive mechanism. Among the developed 1-DOF FRMC concepts we have built direct drive mechanism, which is judged to be more efficient than others This concept of prototype has the following advantages over the other concepts of prototypes which we have considered for designing; high backdriveability, low backlash, low friction, compact, inexpensive, high availability. We have developed both master and slave robot to check the correctness of the system. Fig 5 and fig 6 shows the master robot [9].

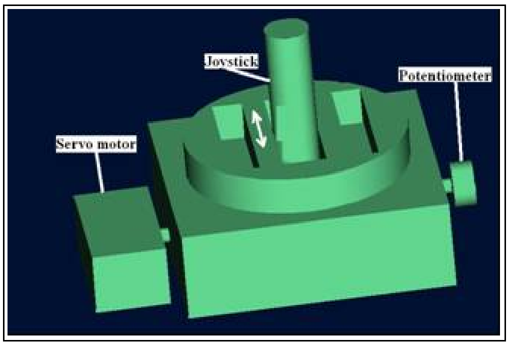


Figure 5 Proposed design of 1-DOF FRMC (master robot)

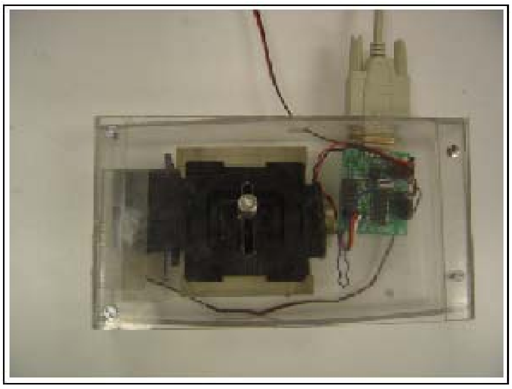

Figure 6 Developed design of 1-DOF FRMC (master robot)

By using this concept of direct drive method in FRMC makes the design more compact and also more efficient as it directly coupled to the joystick. The maintenance of this FRMC is inexpensive and the total cost for building it is also less costly compared to the other methods. By directly coupling the motor shaft to the joystick, we can have acceptably high torque and also smooth operation. Due to the direct linking of joystick to the motor shaft we don't have any intermediate losses. We also don't have any frictional losses or backlashes in this case.

## SOFTWARE DEVELOPMENT

In order to achieve quick and simple control over the hardware of the platform, a Visual Basic program was written to be able to control the platform when it is connected directly to a computer. We have decided to program in Visual Basic to communicate between the SV203 controller and the computer. The main reasons to choose Visual Basic is due to the fact that it is easy to program, is a powerful programming tool, as well as developing GUI interface and control through serial port are easy when compared to the other programming platforms. This program proved extremely useful when testing the servos of the platform, as they allowed simple and fast control over the hardware and they could be modified fairly quickly. The form of the software is shown in the Fig 7.

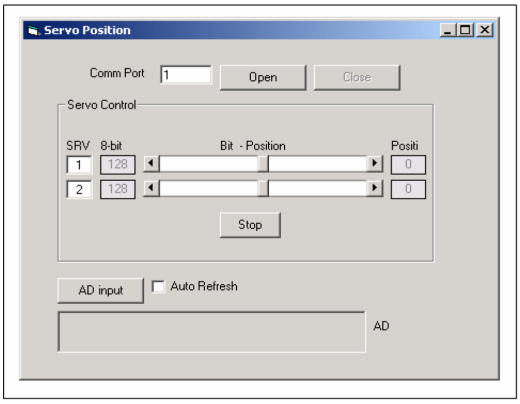


Figure 7 GUI developed to control SV203

The code is able to control upto eight servos through SV203 controller and can also control five A/D ports. We have used a potentiometer to identify the shaft position of the servo motor, which is connected to the A/D port of the SV203.

Now our 1-DOF joystick (master robot), and a car picture (representing a platform) on the PC monitor which is assumed to represent the slave robot and used an airplane icon (on the PC monitor screen) as an obstacle on the platform's motion path. We have developed a graphical user interface in VB to make sure our master robot is working fine.

The GUI opens and closes the COM port, also controls servomotors and the A/D channels that are connected to the SV203 controller. When the 1-DOF joystick is moved in space, the shaft position of the servo is captured by the SV203 controller through the potentiometer attached to it and the platform (slave robot) on the PC monitors moves accordingly. When the platform approaches the obstacle (the plane icon), various color schemes (green, yellow and red) warn the user of an impending collision. And if the user still tries to move the platform in the same direction, the operator feels the force reflection in the opposite direction so that the platform is moved away from the obstacle. After the platform is out of the collision area, force reflection is turned off and the current joystick position is set to the zero or home position.

Later we have updated the program so that the user can choose an icon to represent the slave robot either as a walking robot, car, or dinosaur. Similarly, obstacles can be represented on the screen in the form of a chair, football, doll, penguin, or aeroplane. The program also gives user the option to choose either position control (constant speed) or velocity control (variable speed) mode. The program also gives the user an option to specify a time delay, the amount of time delay, or no time delay. This program is also updated to let the user choose the direction of the slave robot motion (X or Y direction), which makes movements in the plane possible. The updated GUI is as shown in fig 8 below.

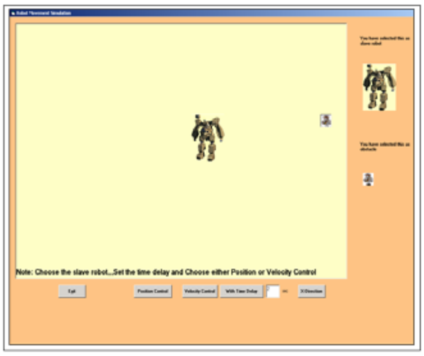

Figure 8 GUI of Visual Basic program

## SLIDER BAR PLATFORM DESIGN

In order to test the 1-DOF FRMC, a platform has to be developed. So initially we have developed a simple 1-DOF sliding bar platform which is built by using a RC servo motor, infrared range sensor, sliding bar, SV203 controller. The system operates at 7 V of power supply. Fig 9 shows the slider bar platform developed to test 1-DOF FRMC.

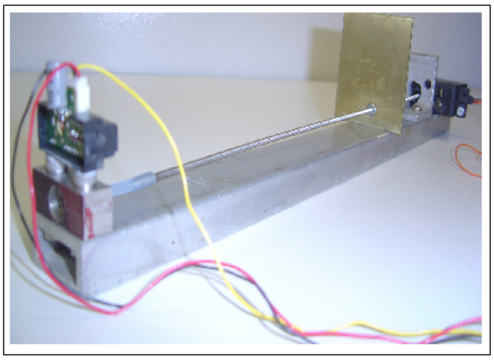

Figure 9 Slider bar platform

When the joystick is moved in forward/backward direction, the potentiometer reads the position of the joystick and will send the signal to the SV203 controller, according to this potentiometer feedback SV203 controller produces the signal to activate the slider servo motor to move it in forward/backward direction accordingly. The sensor on one end of the slider bar monitors the path of the moving part and will send the signal to the SV203 controller. Once the moving part (plate) reaches the boundary of the slider bar then the signal from the infrared sensor is sent to the servo controller which in turn moves the servo motor coupled to the joystick to the other side and will produce force reflection if the user still moves the joystick in the same direction and the servo motor which is driving the slider bar will rotate in reverse direction until it reaches the boundary on the other side.

## PALM PILOT ROBOT KIT (PPRK) PLATFORM DESIGN

A platform named palm pilot robot kit was developed by freshman Grigoriy Reshko and Dr. Matt Mason at Carnegie Mellon University (CMU). We have decided to use this PPRK to test our 1-DOF FRMC. Fig 10 shows the PPRK designed at CMU. The PPRK is a small robot that uses a palm as brain of the kit. The main purpose of designing PPRK was to make mobile robots available to everyone.

Figure 10 PPRK platform

The PPRK empowers a palm pilot to move about and sense the nearby environment. The base uses three omni-wheels that allow driving in any direction with independent control of rotation, meaning it moves holonomically in the plane.

The base also has three optical range sensors to see the nearby environment up to about a meter away [10]. This PPRK uses a Brainstem controller which can be programmed by using Basic, C, C++ or Java. The program to control the PPRK is loaded on to the palm pilot and the brainstem controller receives the signal from the palm and responds accordingly. This brainstem controller operates at 6 V of supply. This kit can also be controlled by the desktop PC instead of palm. The commands are sent to the controller through the RS232 serial port [13]. So we have decided to buy only the required parts and assembled the PPRK platform. Table 1 below shows all the required parts to build a PPRK.

Table 1 parts required to build the PPRK

| Part name | Quantity |
|---|---|
| 4cm diameter omni-directional wheels | 3 |
| Modified RC servo motors | 3 |
| Sharp GP2D12 Infrared Rangefinders | 3 |
| Brainstem Controller | 1 |
| Palm Pilot III | 1 |
| 6 V battery | 1 |
| Clear Cast Acrylic Disk | 2 |
| Male DB9 connector | 1 |

## PALM PILOT ROBOT KIT (PPRK) PLATFORM DESIGN MODIFICATION

The mobile robot PPRK uses the brainstem controller while the 1-DOF FRMC developed uses the SV203 controller. Integrating PPRK with FRMC may cause a problem while programming. So we have decided to modify the PPRK, by replacing the brainstem controller with SV203 controller as it fulfills all the requirements of a brainstem controller.

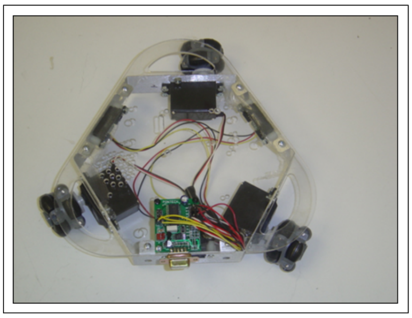

Figure 11 PPRK modified mobile platform

So the modified PPRK will be having SV203 controller instead of brainstem controller, three RC servos, three IR sensors, 6 V of power supply. The SV203 controller receives the signal from the palm and will send commands to the servos accordingly. The power supply to the sensors is taken from the unused servo pins on the SV203 board as the board cannot supply power through the AD power supply to all the three sensors. Fig 11 shows the modified PPRK kit.

## SYSTEM INTEGRATION

Integrating the hardware and software for remote control systems is essential as it also requires integration and operation of its components over the network. Hence, in addition to the traditional hardware and software system design, we address broader system integration. In our system, integration means controlling the platform (PPRK platform modified for our project to represent the remote system) with the 1-DOF FRMC prototype through the software developed. It is important to develop the software in such a way to control the slave robot (modified PPRK) by the master robot (1-DOF FRMC) in real time as well as to incorporate a capability to control other remote systems.

In the present project, the structure of the sensing, planning, control system and the computer architecture has been designed for any task rather than for a specific task. The software interface developed is user-friendly, and this property of the system enables the user to complete the required task more efficiently. The two robots (master and slave) which are connected to two different computers (client and server) are operated by Winsock control (Visual Basic) through internet. In the system developed, the 1-DOF manual controller will get the feedback from the remote slave robot in two different methods; one by force reflection and the other by visual information received from the remote site through video camera attached to the slave robot.

In this visual feedback system, the video camera replaces the sensors of the force feedback system. The system with force feedback is capable of working in the remote site by seeing the simulations or the animated remote site on the screen of the computer to which it is attached while the system with the visual feedback is capable of seeing the real time video of the remote site through video camera attached to the slave robot. Integration of the modified PPRK platform, 1-DOF FRMC and the software makes the system more complex. However, the software developed is capable of controlling any robot built with the SV203 micro controller through internet by the 1-DOF FRMC developed.

## OPERATING THE SYSTEM SOFTWARE

The process of operating the system software is discussed below. There are two computers used in this process and are named as client and server. The 1-DOF manual controller (master robot) is connected to the server side and the modified PPRK or the 1-DOF slider bar (slave robot) is connected to the client side.

First the client side computer should be connected to the server side computer by entering the IP address of the server side computer. Once they are connected, both the computers are able to send and receive the data. The 1-DOF manual controller (master robot) has to be loaded on the server side. Similarly the modified PPRK or 1-DOF FRMC (slave robot) has to be loaded on the client side. As both the systems, master robot and the slave robot use SV203 micro controller, they have to be connected to the computers through RS232 port. Fig 12 shows the basic process of the system developed.

The position of the joystick is tracked by the potentiometer attached to it and that AD reading is sent to the server side computer through SV203 controller and RS232 port. The AD reading from the server side computer is sent to the client side computer through internet. The client side computer sends the AD reading to the SV203 controller through RS232 port, which compares the AD reading with the condition and will move the servo attached to the slave robot accordingly. At the same time the reading of the IR sensor on the remote site is sent to the client side computer through SV203 controller and will in turn send that AD reading to the server side computer through internet. The AD reading of the IR sensor is checked with some conditions and will make the SV203 controller to decide whether to call force reflection on the joystick or not.

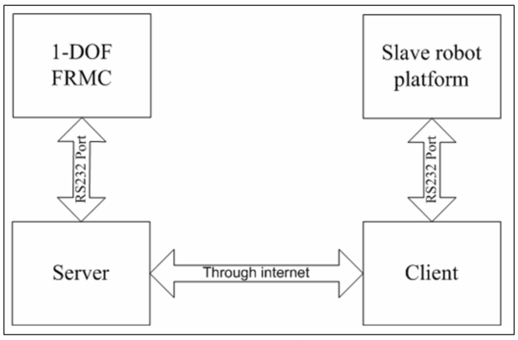

Figure 12 Process of the system developed

As this process is continuing the AD reading of the potentiometer is sent to the server side computer and on the screen of the server side computer the user can see the simulation of the remote site environment and feels as if he is working in the real environment. While operating joystick the platform on the computer screen moves accordingly, and as it approaches any obstacle on its path and if the user still tries to move the joystick in the same direction, various color schemes (red, yellow and green) warn the user of impending collision which also sends the force reflection command on the actual 1-DOF FRMC.

## VISUAL FEEDBACK

In this process, the user operating slave robot will see live video of the environment where the slave robot is operated through the video camera attached to the slave robot. The system settings of this operation are described as follows. First the client side computer should be connected to the server side computer by entering the IP address of the server side computer. Once they are connected, both the computers are able to send and receive the data. The 1-DOF manual controller (master robot) has to be loaded on the server side. Similarly the modified PPRK or 1-DOF FRMC (slave robot) has to be loaded on the client side. As both the systems, master robot and the slave robot use SV203 micro controller, they have to be connected to the computers through RS232 port. A web camera should also be connected to the computer USB port and is kept on the slave robot as shown in the fig 13 below.

The position of the joystick is tracked by the potentiometer attached to it and that AD reading is sent to the server side computer through SV203 controller and RS232 port. The AD reading from the server side computer is sent to the client side computer through internet. The client side computer sends the AD reading to the SV203 controller through RS232 port and will move the servo attached to the slave robot accordingly.

As this process is in progress the user can see the live video of the remote site through the web camera attached to the slave robot at remote site.

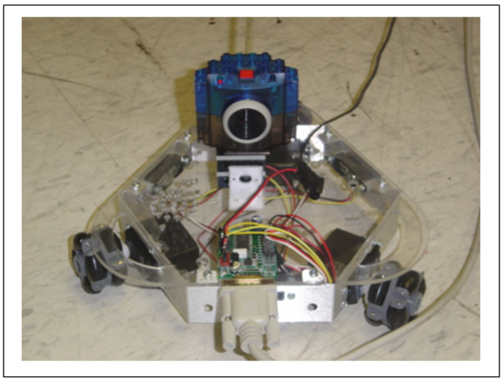

Figure 13 Camera attached to the PPRK

## CONCLUSIONS

In this paper, 1-DOF FRMC prototype is designed and developed to demonstrate the principle of 1-DOF FRMC. All of the important components used in the design of the 1-DOF FRMC have been described. The final assembly of the system has been developed.

1-DOF platform has been constructed to check whether the prototype is working properly or not. For this purpose, a 1-DOF slider bar has been designed and constructed for use as a remote platform. The components used to develop the 1-DOF slider bar have been described in this chapter. As a secondary remote platform, PPRK mobile robot model has been developed and its parts specifications have been listed. PPRK robot has been modified to enable its integration into the 1-DOF FRMC.

The software developed to control the 1-DOF FRMC has been briefly described. Integration of 1-DOF FRMC with the developed platforms, i.e., 1-DOF slider bar and the modified PPRK mobile robot, has been described. The software developed in Visual Basic is generic, which allows the 1-DOF FRMC control any robot built with SV203 micro controller through the internet (teleoperation).

## FUTURE RECOMMENDATIONS

The robot movement is not completely synchronized with the feedback received from the remote webcam in case of visual feedback system. There is a time delay of 2 to 4 seconds observed between the real time video and the video received at manual controller site. This is due to the network problem; this limitation can be solved by using a high-speed network.

Higher degrees of freedom, such as 2-DOF and 3-DOF, manual controllers can be developed. A 2-DOF can be easily developed from the design we currently have presented. By attaching another RC servo at the other end of the mechanism, which is used to measure the shaft position of the servo, we can develop a 2-DOF FRMC.

Moreover, the slave robot movement is restricted to the maximum length of RS232 serial cable and the USB cable (web camera). This restriction can be avoided by using a wireless transmitter and receiver at the remote site, which makes the slave robot to overcome the limited boundary conditions.

Also, virtual reality (VR) environment may be developed. Various components such as the VR unit, microphone and speakers can also be integrated with the software developed, which makes the system more useful and appealing.

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