B. TECH. PROJECT REPORT

On

Dual Loop Motion Control for Mechanical Error Correction in Trajectory-Tracking of 3 PRP Planar Manipulator

BY

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DISCIPLINE OF ELECTRICAL ENGINEERING

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Dual Loop Motion Control for Mechanical Error Correction in Trajectory-Tracking of 3 PRP Planar Manipulator

A PROJECT REPORT

Submitted in partial fulfilment of the

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Of

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ELECTRICAL ENGINEERING

Submitted by:

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CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Dual Loop Motion Control for Mechanical Error Correction in Trajectory-Tracking of 3 PRP Planar Manipulator "** submitted in partial fulfilment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr. Santhakumar Mohan(Associate professor, Mechanical Engineering),** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the students with date

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CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of our knowledge.

Signature of BTP Guides with dates and their designation

Preface

This report on “Dual Loop Motion Control for Mechanical Error Correction in Trajectory-Tracking of 3 PRP Planar Manipulator " is prepared under the guidance of Dr. Santhakumar Mohan.

Through this report, we have tried to give a detailed and comprehensive method for design and institution of smart & affordable vending machine.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added graphs and figures to make it more illustrative.

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It is their help and support, due to which we became able to complete the design and technical report. Without their support this report would not have been possible.

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Abstract

This project deals with control of a planar parallel manipulator having configuration 3 PRP (prismatic-revolute-prismatic) using dual loop motion control scheme. The planar manipulator is fabricated for real time experiment and control scheme is implemented having dual loop. This control scheme consisted two loop ma outer loop and inner loop. Inner loop control the joint space using the inverse kinematics relation using the given task. Outer loop controls the task space error using camera. This control scheme is effective to overcome task space error for the real time operation. Real time experiments are conducted to validate control scheme. This shows effective improvement in comparison to conventional joint space control scheme.

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Dual Loop Motion Control for Mechanical Error Correction in Trajectory-Tracking of 3 PRP Planar Manipulator

CHAPTER 1

Introduction:

Robots are combination of mechanical architecture and electronic circuits and over that there is control schemes to control its motion. Generally they are controlled by evaluating their dynamic model but it is not possible to obtain the exact inertial values of the robotic system. So using model based controller doesn't become a complete solution for the motion tracking problem. On the other hand robot may contains many kind if errors like mechanical errors, geometric errors, backlash errors, sensor noise etc. Hence simple joint space control scheme cannot be able to solve the problem of accurate movement to follow the desired trajectory. Hence we

The available control schemes are proposed to correct the joint space of the manipulator, which takes the joint space of the manipulator [1, 2, 3]. For overcoming the difficulty of inaccurate model of the robot manipulator adaptive control schemes are also proposed [2] or task space control schemes [3]. Some controls depends on model and by evolving the effect of friction, joint clearances etc. The performance can be improved [1, 2]. The adaptive control scheme can predict the effective behaviour and modify the model so as to match to the original dynamic model of the robot [3]. Researchers tried many ways to overcome the effect of misalignments and manufacturing defects by calibration techniques while implementing the control law[4].These calibration schemes are to critical and increases the cost of the process.

To overcome such effects some implementation has been made on flexible manipulator using dual loop motion control scheme [5] also in to correct the effect of configuration errors in the manipulators [6]. To overcome the effect of the configuration errors there are schemes which can use a task space sensor [7].

Each of the techniques described above have their respective advantages and limitations. Therefore, in the paper a dual-loop or cascade control scheme proposed with redundant sensor feedback inputs based on simple inner-loop proportional-integral-derivative (PID) control along with an integral outer-loop control which compensate the mechanical errors exist in the system. The outer-loop uses the task space sensor feedback and corrects the joint space through the help of inverse kinematics. The proposed control scheme is implemented on a 3 PRP manipulator. The manipulator is commanded to track a complex trajectory and a circular trajectory with and without outer-loop control. It is realized that the tracking performance is improved with the dual-loop control.

The remainder of the paper is structured as follows: in Chapter 2 the conceptual design of the manipulator is suggested and the architecture of the proposed control scheme has been presented in this chapter. Chapter 3. Contains the details of the equipment used to fabricate the experimental setup and the complete experimental fabrication is explained here. Chapter 4, discusses about the real time experimentation and implementation of the control scheme of the fabricated prototype. Finally, Chapter 5 presents the conclusion of the project.

CHAPTER 2

CONCEPT OF THE PROPOSED SCHEME

2.1 Conceptual diagram of manipulator

Proposed manipulator has three linear guides all in horizontal direction as shown in figure 1 (as a conceptual design in joint arrangement). These three linear guides are arranged in a U-shaped base. Each leg is having PRP (prismatic-revolute-prismatic) configuration. Total number of legs in this manipulator is three which makes this manipulator having configuration 3 PRP. The three linear movement are represented by r_1, r_2 and r_3. The end effector position is represented by x, y and θ.

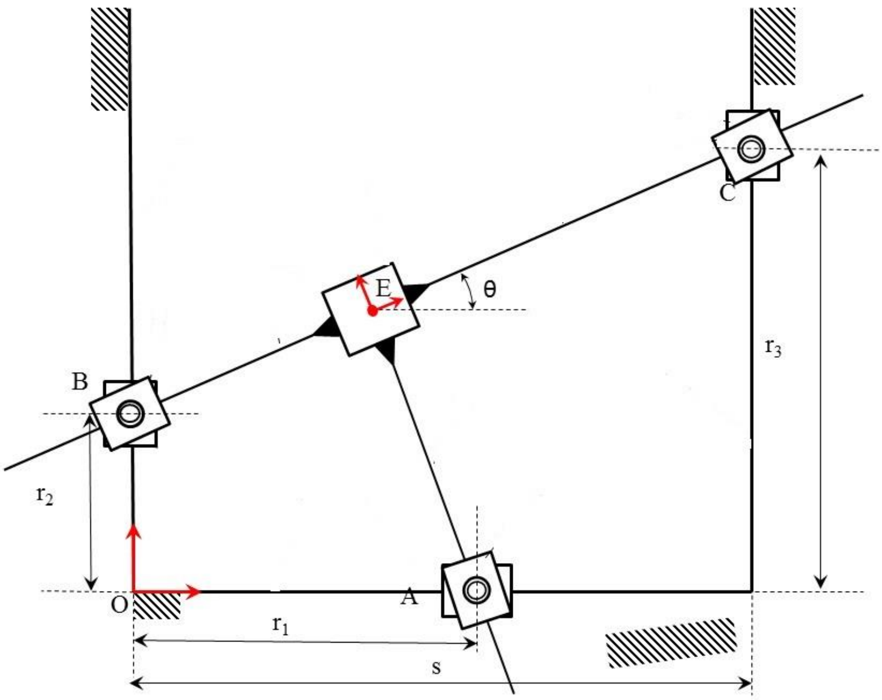


Fig. 1 Conceptual Diagram

The forward kinematics of the manipulator tells where the end effector would be when the joint parameters are known. These can be written as

$$x=\frac{d\left(r_1 d+r_2\left(r_3-r_2\right)\right)}{d^2+\left(r_3-r_2\right)^2}$$
$$y=\frac{d\left(r_2 d-r_1\left(r_3-r_2\right)\right)}{d^2+\left(r_3-r_2\right)^2} \qquad (1)$$
$$\theta=\tan^{-1}\left(\frac{r_3-r_2}{d}\right)$$

The inverse kinematics describes how the joint space can be derived using the task space coordinates of the manipulator

$$r_1=x+y\tan\theta$$
$$r_2=y-x\tan\theta$$
$$r_3=y+\left(d-x\right)\tan\theta \qquad (2)$$

This manipulators motion can be control using these mathematical relation also these equations are going to be used in the control strategy.

2.2 Control Architecture:

Control architecture consist of two control loops one is the inner loop another is the outer loop. The outer loop takes the task space feedback and compares with the actual task space required and find the error in the joint space using inverse kinematics it takes the integral of the error value multiplies it with a gain K_0 add the value to the internal loop error

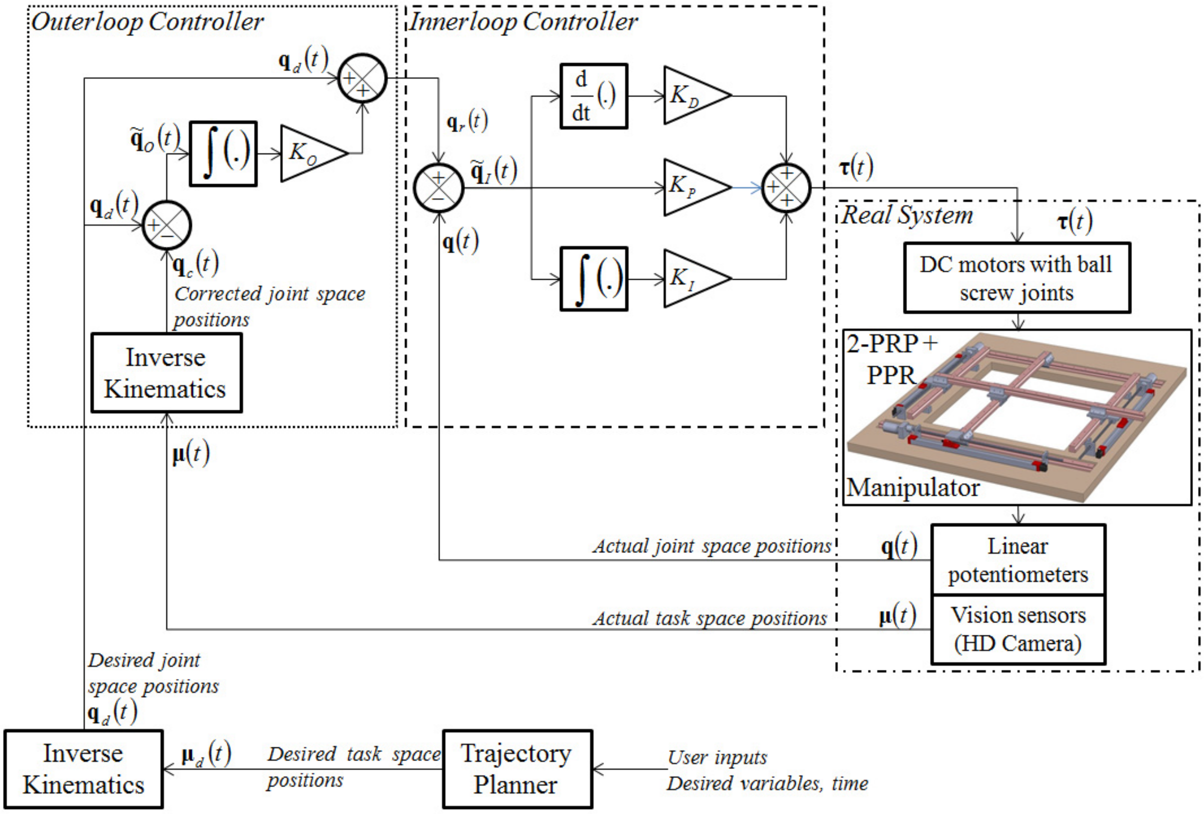


Fig. 2 dual loop control scheme

While the inner uses the outer loop feed and joint space feedback to find the error in the joint Space and compensate the error using PID (Proportional Integral Derivative) control scheme.

In this way the task space error is converted into an equivalent joint space error variable and converges when the task space error tends to zero.

The constants K_P, K_D and K_I are the gains multiplied to the proportional, derivative and integral error value to give input for the torque.

By optimizing the gains you can find out the best possible combination of the gains to get minimum error performance in the trajectory tracking operation

CHAPTER 3

Fabrication of Real Time Prototype

3.1 Fabrication of Experimental Prototype:

The prototype consist of three actuators which are aligned as u-shaped base, an optical table is used as a stationary base to support the setup and maintain the accuracy of the setup. Further the linear motions are obtained using linear guideways and ball screws. The idea is to move the linear actuator using ball screw movement which is powered by DC motors. Further, the fixtures are made using the 3D printed parts which designed in CAD software. These are assembled and 3PRP parallel manipulator is made using further two linear actuators connected to each of the three legs with a rotary joint.

To power the motors there is power supply used which has adjustable voltage supply, our DC motors works at 12V. Hence, provided by the power supply. In between there are motor drivers which moves the motor using control signals obtained from Arduino. This Arduino is getting signals from the MATLAB program in the Computer to conduct the trajectory tracking operation.

A camera is mounted on the top of the setup to read the task space feedback of the manipulators end effector. This camera is read by the MATLAB code which is acting as bridging software in the connecting the joint space and task space in the common program to function as dual loop.

3.2 Equipment’s Table:

The description of the equipment used in the fabrication and in making the electronic circuit for the dual loop control setup are given in Table 1.

Table 1: Description of the equipment used to fabricate the prototype

COMPONENTS	DIAGRAMS	DESCRIPTION
1. DC Motors		12 Volt
2. Honeycomb Breadboard		Optical breadboard (1000X1000 m grid size 25X25 mm
3. Linear Potentiometer		OPKON (5 Kohm)
4. Linear Guide		Width- 15mm, Aluminum
5. Couplers		8X12 mm

6. Ball Screw		Steel (12X12 mm)
7. Motor Drivers		18 V 20 A DC Motor driver
8. Power supply		DC power supply
9. Arduino		UNO R3
10.Camera		Microsoft HD camera
11. Fixtures		Self-made by using 3-D Printing machine

3.3 Experimental Setup:

Experimental setup consist of the complete assembly of the manipulator with camera mounted on the top and circuits to control the motion using the Arduino- MATLAB Interface.

For Image processing some colored part are kept in the setup to detect the coordinates of the end effector.

The optical desks ensure the linearity of the setup and robust alignments. Further to support camera metallic mechanism mounting breadboards are used.

The setup is color sensitive and light sensitive so adequate arrangements of light is require for successfully conducting the experiments.

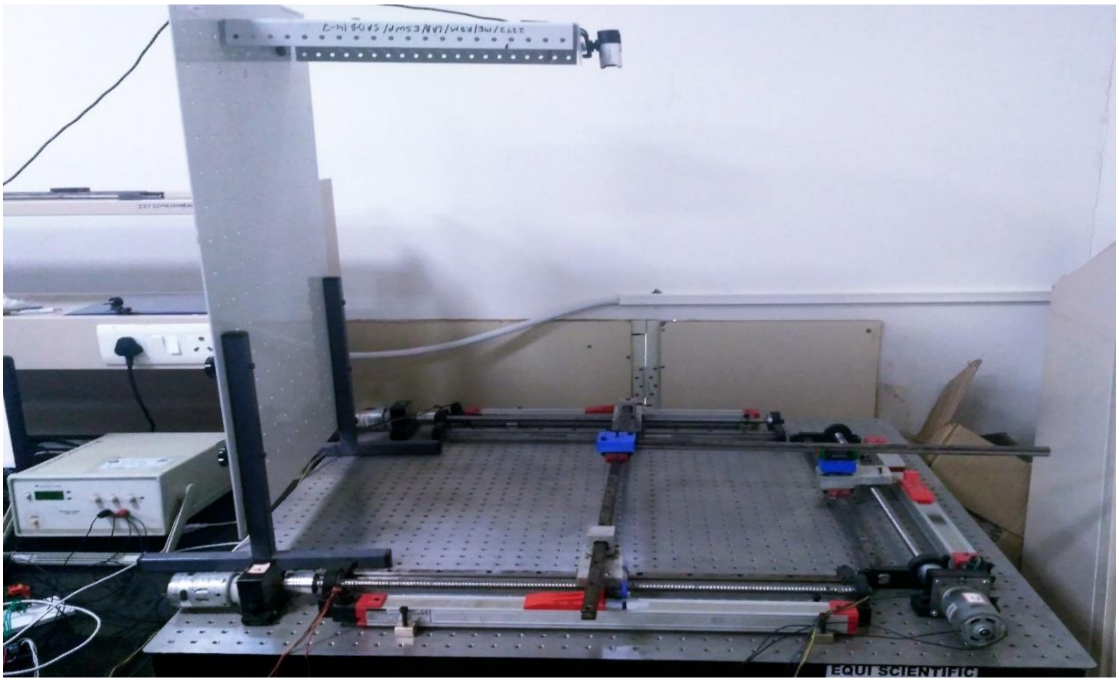


Fig. 3: Experimental Setup

CHAPTER 4

Real Time Experiments

4.1 Experimental setup:

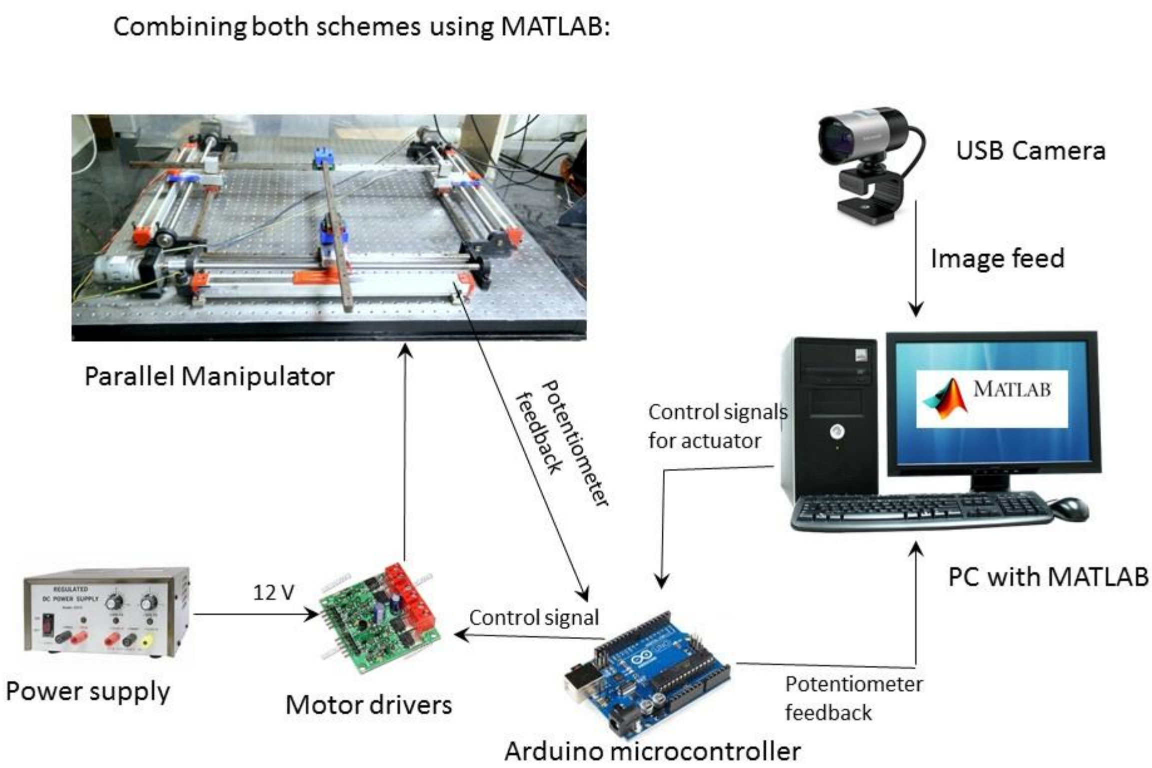


Fig. 4 Experimental arrangement for the trajectory tracking using dual loop setup

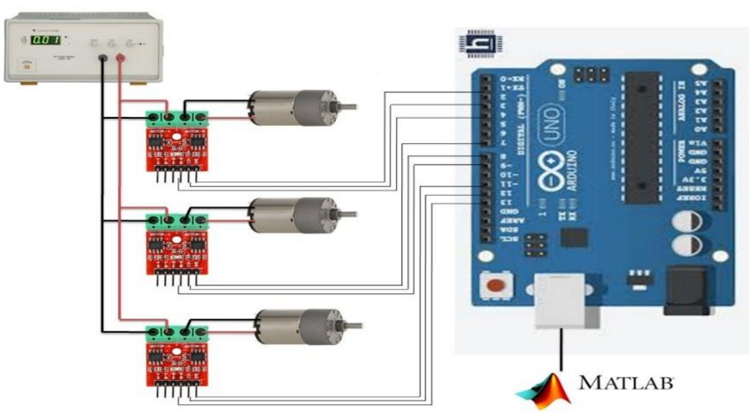
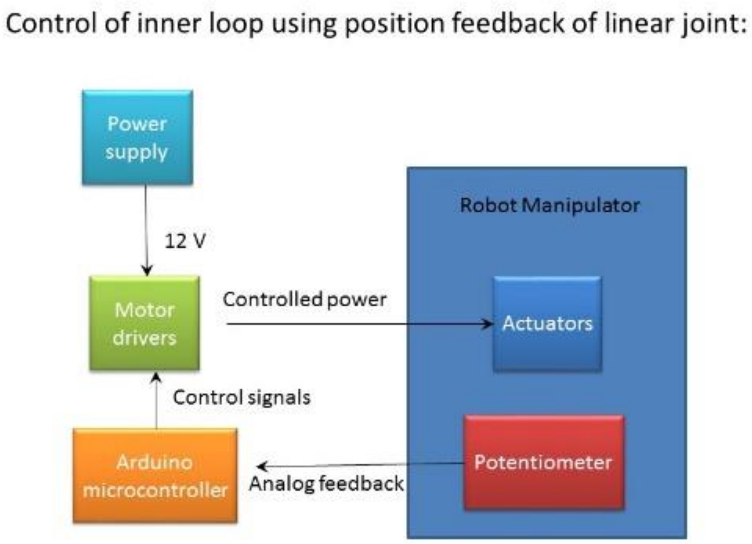


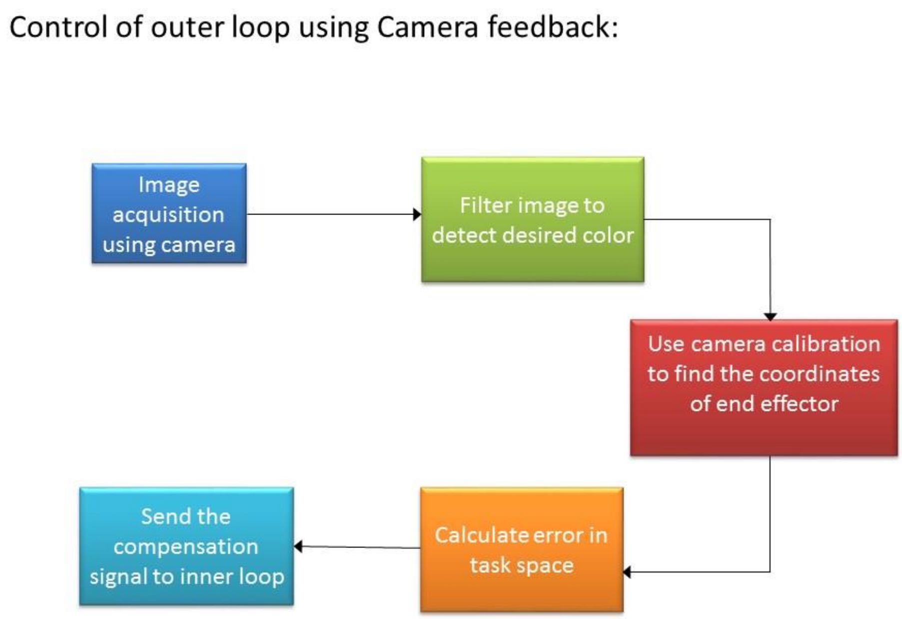
Fig. 5 Experimental arrangement for motor control using Arduino

4.2. Feedback Diagram from Potentiometer:



In inner loop power supply gives 12 V to motor driver. Potentiometers send the analog feedback to Arduino microcontroller and Arduino send those control signals to motor drivers. So according to control signals motor driver gives the controlled power to Actuators.

4.3 Feedback Diagram from Camera:



4.4. Image Processing Photographs:

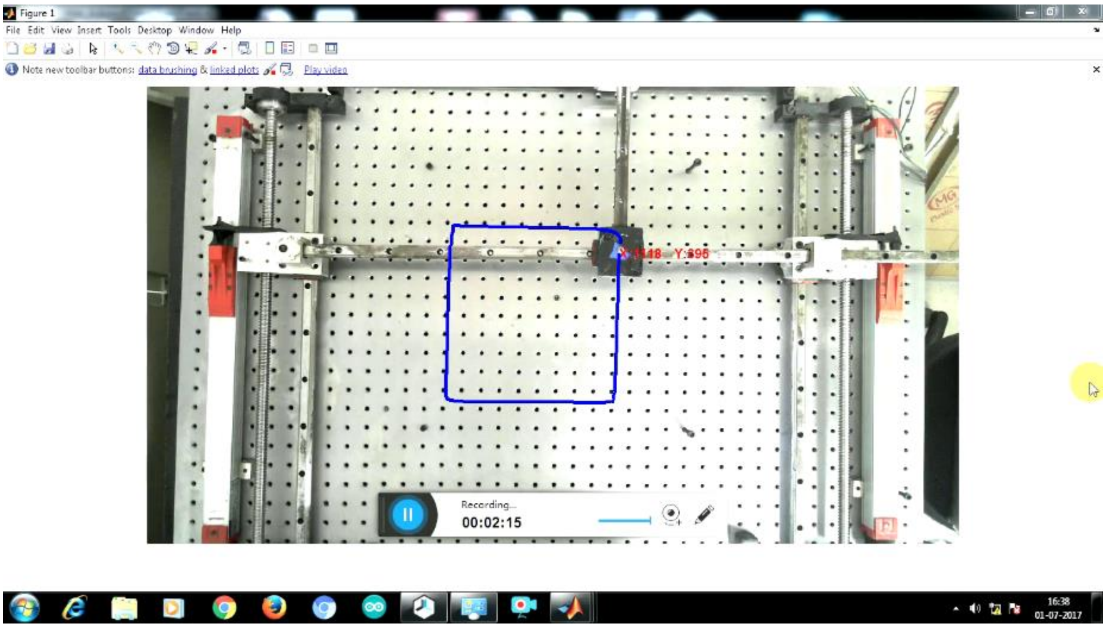


Fig. 6 Manipulator following given trajectory

4.5 Results

The task space results are taken from camera feedback and the joint space feedback is taken from potentiometers. The results are clearly showing the reduction in the task space errors. The trajectory taken was square in shape and traced by the control scheme the results are obtained once by simply using the inner loop having outer loop gain as zero. To see the effect of the inner loop only which is driven using PID controller. While for the validation and improvement done by the outer loop the gain is increased to a value where it gives significant improvement in the results. These results are compared on non-optimal values which means the error can be reduced to further lower values by optimizing the control gains.

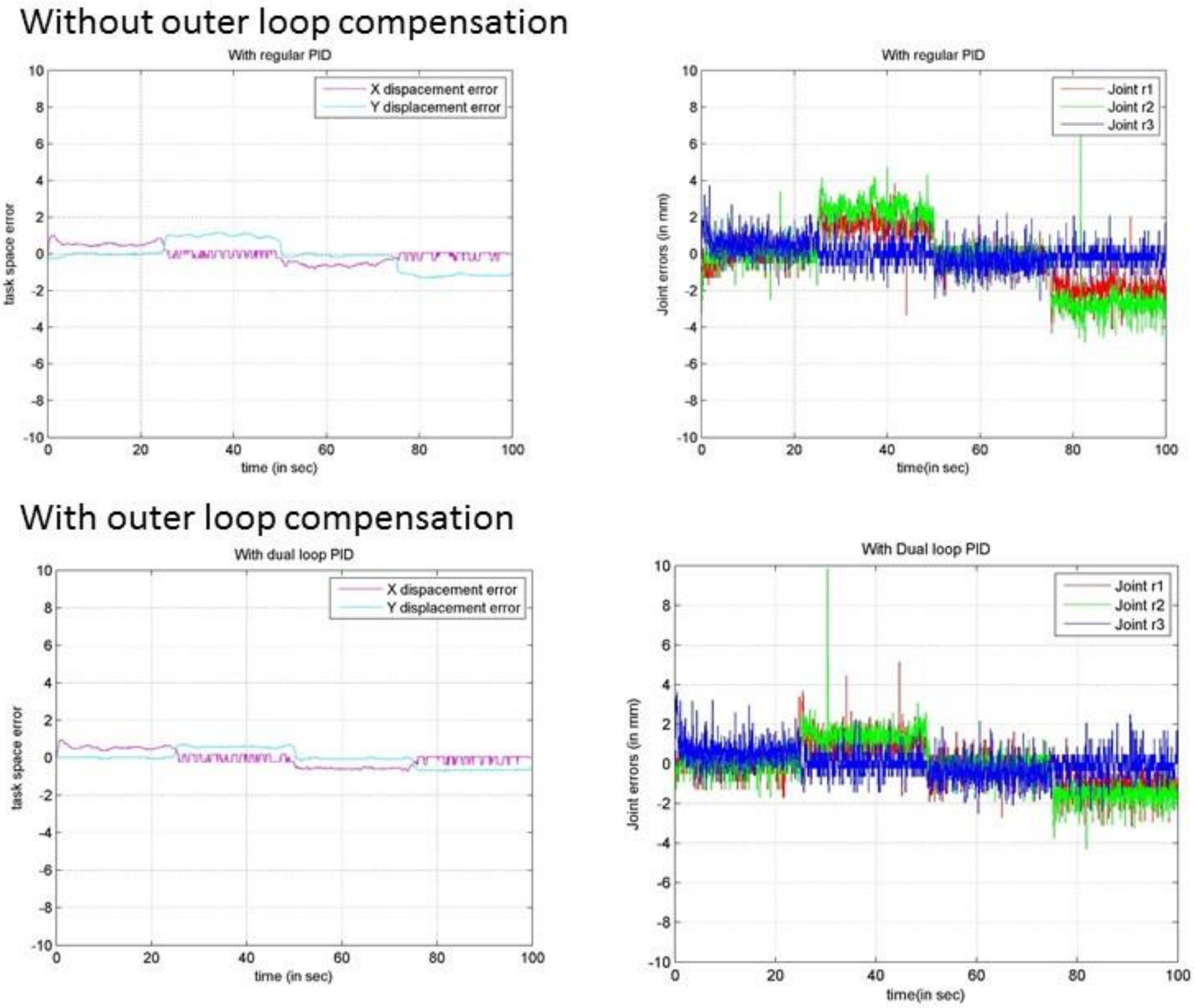


Fig 7 Comparison of regular joint space PID and dual loop PID in compensating the errors

Chapter 5

Conclusion

So the dual loop control schemes is proved to be effective in compensating the errors caused by the mechanical inaccuracies and joint clearances present in the mechanism. It can compensate the task space error using a task space feedback. Here the task space feedback is provided by the camera mounted the top. This makes a bit slower as the program has to do image processing of the image and give the data feed at real time hence the system need to respond within certain interval in order to carry out real time operations. The results shows that the error has significantly reduced in comparison to the regular PID controller.

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