Engineering and Materials Science Faculty
German University in Cairo

Wireless non-contact manipulation of biological cells

Bachelor Thesis

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This is to certify that:

(i) the thesis comprises only my original work toward the Bachelor Degree

(ii) due acknowlegement has been made in the text to all other material used

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25 May, 2015

Acknowledgments

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Abstract

This paper describes the non contact wireless manipulation of biological cells using two types of Robots "Parallel mechanisms". First is The Delta Robot which consists of end-effector, base and links. the Delta Robot mechanism depend on that the base should be fixed and the endeffector moves respect to that base allowing unique movements in (x, y, z) coordinates.Secondly is the pantograph which consists of a mechanical linkage connected in a manner based on parallelograms so that the movement of one pen connected to the panto-graph produces an identical movement in a second pen also connected the panto-graph. it moves in (x, y) plane coordinates.Explaining furthermore the operation and manipulation of truly micron sized, bio-compatible ferromagnetic micro-transporters controlled by external magnetic fields that can exert forces of pico-newton scale.Manipulation of such micro and nano particles is of general interest to robotic and biomedical researchers for application as protein crystal harvesting , micro-assembling , and drug targeting.Many technologies have been introduced to accomplish the task of micro-manipulating such as magnetic tweezers,wireless mobile-micro devices,micro fluidic devices , and micro-grippers.In the past few years a number of studies have been done on The utilization of wireless magnetically controlled nano and micro-robots for manipulation of cells because of the comparable sizes of micro-agents and the manipulated particles,the adaptability to variable environments and other application such as noninvasive surgery,and drug targeted delivery. the advantage of using such low intensity magnetic fields is because it is harmless to living organisms and can penetrate most biological tissue.the Delta robot And the panto-graph mechanism are connected to electromagnetic systems that create a magnetic field around particles to move in a certain direction.

Contents

Chapter 1

Introduction

1.1 BackGround about Robots

In 1921 The word robot was first mentioned by the Czech playwright Karel Capek in his satirical play R.U.R. (Rossums's Universal Robot), where he pictured robots as machines which resembled people but operated endlessly [1].
The structure of a robot is mostly mechanical "links and motors" and electronic components such as "sensors". The robot structure various depending on the job it will perform. A typically industrial robot is the serial robot which is built up by an open kinematic chain. This chain can be described as links connected to each other with re-volute joints driven by motors. This structure is also seen in the Automotive industries.
Parallel structures as the Delta-robot have a number of advantages when they are compared to serial Robots. They provide generally higher rigidity and smaller mobile mass than their competitors the serial Robots. Thus they can move heavier payloads because of their light mass compared to a serial Robots. The system structure of a Delta-robot also makes it more rigid perpendicular to the end-effector (For example; resistive against vibration perpendicular to the end-effector). The major disadvantage of the parallel robots is their limited range "workspace" of motion compared to a serial robot, but with a system structure as the Delta-robot this limitation has partially been resolved because it has a large workspace.
Mechanisms that allow a rigid body "the end-effector" to move with respect to a fixed base play a important role in alot of applications. A rigid body in space can manipulate in different ways, Rotational or translational motion. These are called its degrees of freedom (DOF). The position and the orientation of the end-effector (called its pose) can be described by its generalized coordinates. As soon as it is possible to control several DOF of the end-effector via a mechanical system, this system can be called robot[2,3]. A generalized parallel manipulator is a closed-loop robot represents an integrated mechatronics system. A parallel Robot allows its' output link to remain at a fixed orientation with respect to the input link. The use of three such parallel robot links restrains completely the orientation of the mobile platform which remains only with three purely translational

DOF. The input links of the three parallelograms are instrumented on rotating bearings via revolute joints.
The revolute joints of the rotating levers are actuated in two different ways; the linear actuators and Rotational (DC or AC) motors. This mechanism is used to transmit rotary motion from the base to an end-effector mounted on the moving plate.
The use of base-mounted actuators and low-mass links allows the mobile platform to achieve large accelerations in in industrial applications and experimental environments . However, there are some applications that cannot manage these high speeds and accelerations due to the weakness of the parts involved in the process.
The ordinary Jacobian matrix provides a transformation from the velocity of the end-effector in Cartesian space to the actuated joint velocities. When a manipulator is at a singular position, the Jacobian matrix is singular too[4,5]. In the case of the parallel manipulators, it is convenient to work with a two-part Jacobian, the inverse and the forward Jacobians. The advantage is that a two-part Jacobian allows the identification as well as classification of different types of singularities.
Following closely the technique presented by Stamper[6], the forward and inverse Jacobian matrices for the Delta robot are computed[7,8]. The classification scheme outlined by Gosselin and Angles, then allows us to categorize the singularities of the Delta robot into three types.

The First type is realized when different parts of the forward kinematics problem converge, resulting in additional DOF at the end-effector.

The Second type corresponds to the situation where different parts of the inverse kinematics equation converge . This type of singularity results in a loss of movement and occurs at the limit of the boundary of the Robot workspace.

if these two different realizations happen at the same time, it can be classified as the third type of singularity[9]. Additionally, there also exist architectural singularities, e.g. when the dimensions of the moving and fixed platforms can be compared.
Therefore, special care should be taken in the design of these manipulators to avoid these kinds of singularities. there is a solution that we can reduce a certain number of legs from the full kinematic chain and carry out the Jacobian Analysis for the reduced loop; this can be termed as the intermediate Jacobians.

1.2 Robot designing

In order to design a surgical or medical Robots for minimally invasive interventions, First we need to know the exact Workspace that the Robot will manipulate into, doing its function. described in Chapter five.
So in order to specify the workspace an experiment was done by 30 surgeon performing

surgeries on models using a surgical tool attached to this surgical tool some sensors which could measure the surgical tool position, orientation of the surgical tool in the space, forces and torques applied on the surgical tool by the surgeon hands, and the forces and torques applied on the surgical tool by the corresponding tissue, after collecting this data and analyzing it, the results were astonishing 95% of the time, the surgical tools were located within a conical range of motion with a vertex angle of 60 degrees. This type of workspace is known as "dexterous workspace (DWS)" afterwards these measurement was taken on a human patient. realizing that in order to reach the full extent of the abdomen, the surgical tool needed to move 90 degrees in the superior/inferior direction (head to foot) Delta robots are commonly used for grasping and packaging in factories because they can be quite fast and accurate. The greatest advantage of delta robots is speed. Typically, when a robot arm has to move not only a payload, but also all servos in each joint, the only moving part of the delta robot is its frame, which is usually made of lightweight composite materials "carbon fiber".

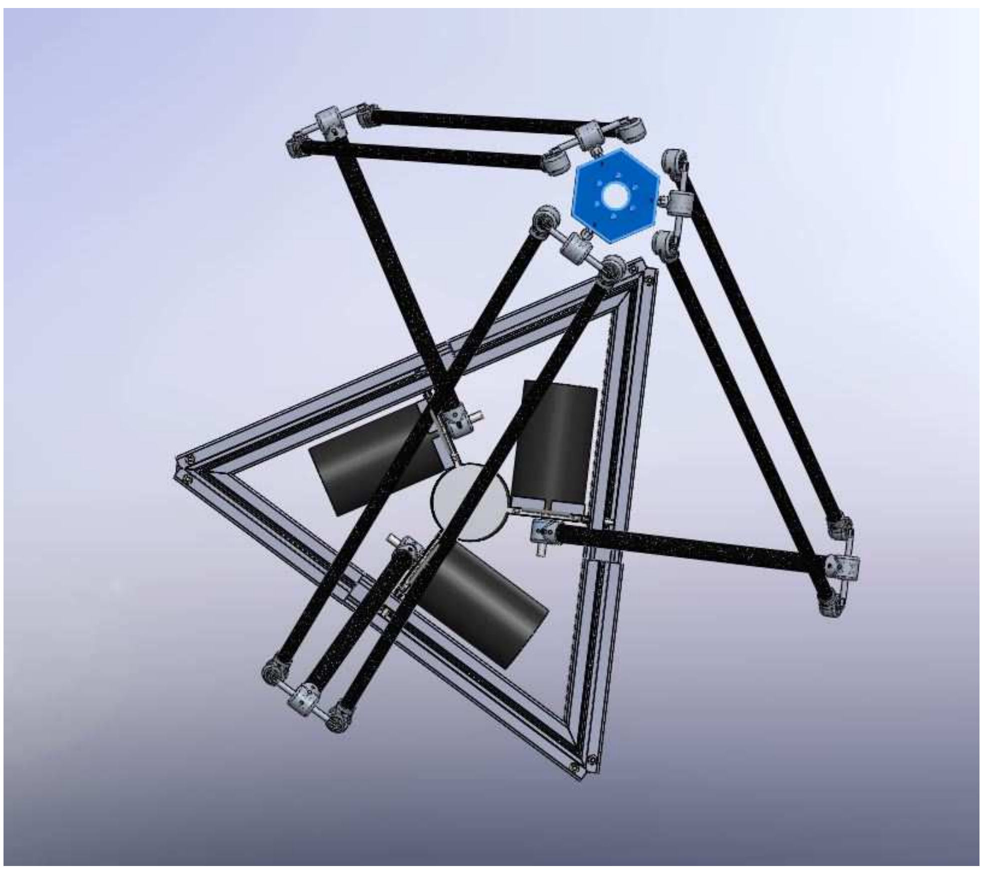

Figure 1.1: Delta Robot design at steward platform orientation

1.3 BackGround about wireless manipulation

Remote manipulation of wireless tablet endoscopes might improve diagnostically the accuracy and facilitated therapy.The first study that was conducted in a volunteer human; tested a new magnetic maneuverable wireless tablets. A wireless tablet endoscope was modified to include neodymium-iron-boron magnets. The tablet's magnetic switch was replaced with a thermal one and turned on by placing it in hot water. A hand-held external magnet was used to manipulate this tablet in the esophagus and stomach.One image was removed from the colon-based tablet, and the available space was used to house the magnets. The tablet was initiated by placing it in a microg of hot water. The tablet was swallowed and observed in the esophagus and stomach by using a gastroscope. tablet's images were viewed on a real-time viewer.

1.4 General Diagram

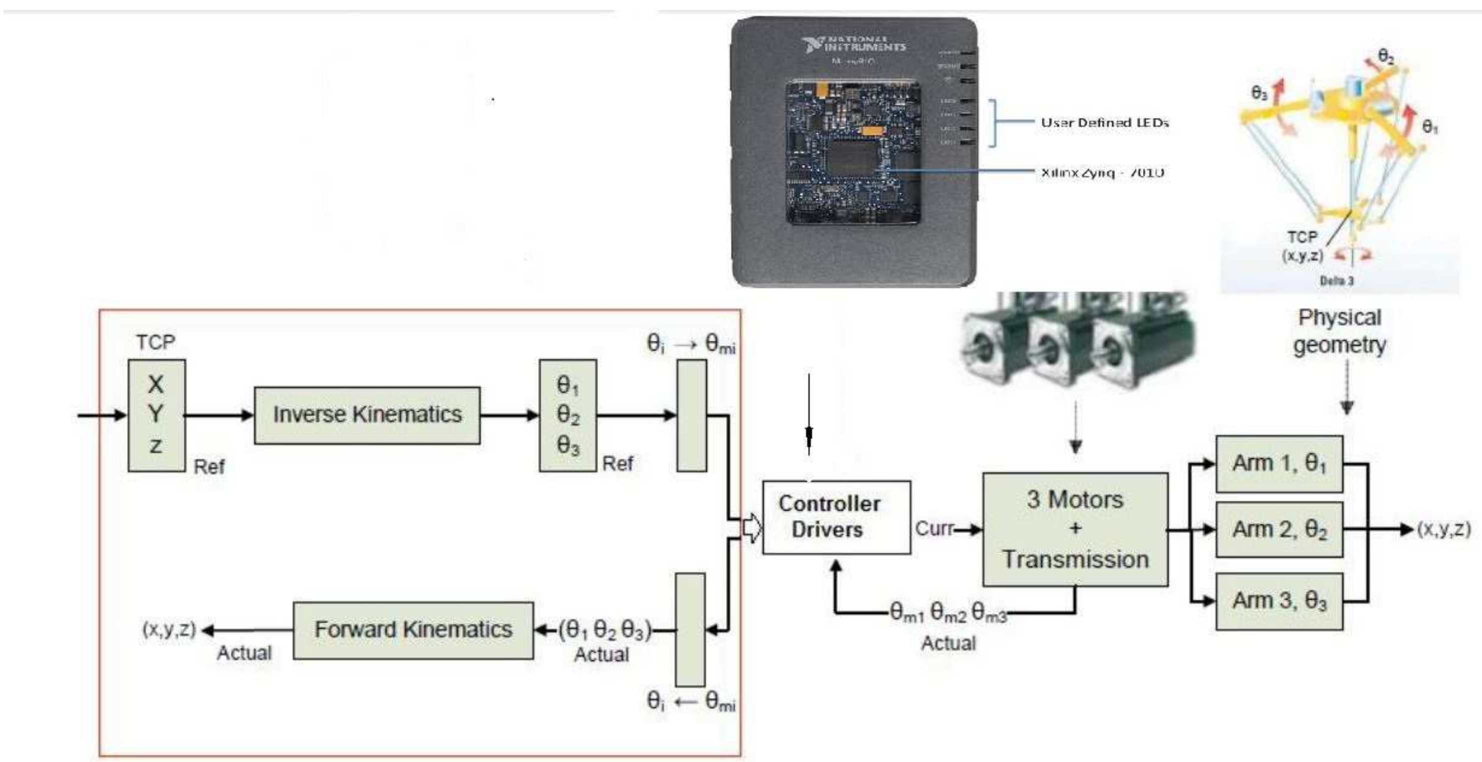

Figure 1.2: General Diagram of the whole System

Chapter 6

EXPERIMENTAL RESULTS

Constructive dimensions	**Values of the constructive** dimensions
f	90 mm
e	50 mm
r_f	250 mm
r_e	450 mm

Table 6.1: Constructive dimensions and restrictions of the parallel structure Delta-robot (rf = upper arm, re = lower arm, f = base and e = end-effector

6.1 Inverse Kinematics Experiment

The moving platform control point P traces an XY circle of center $0, 0, 400^T$ mm and radius 200 mm.
At the same time, the Z displacement goes through 2 complete sine wave motions centered on $Z = 500$ mm with a 1 mm amplitude. This IPK trajectory, at the end of motion, is pictured along with the simulated Delta Parallel Robot, in the MATLAB graphics below.

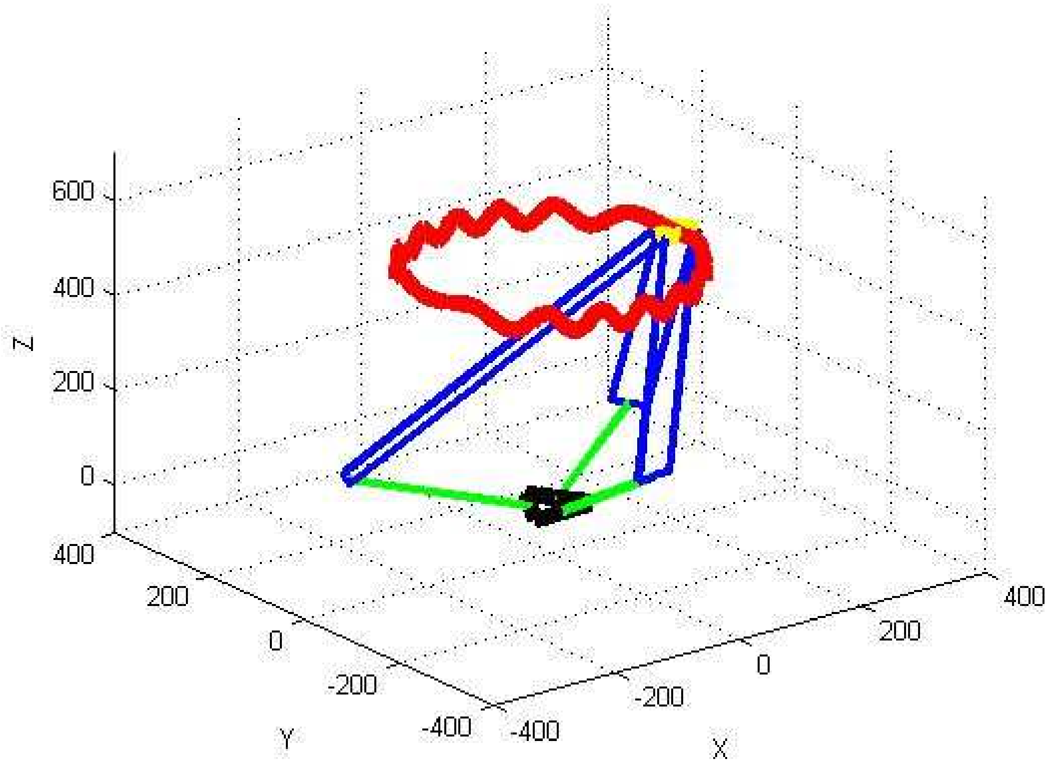

Figure 6.1: XY Circular Trajectory with Z sine wave.

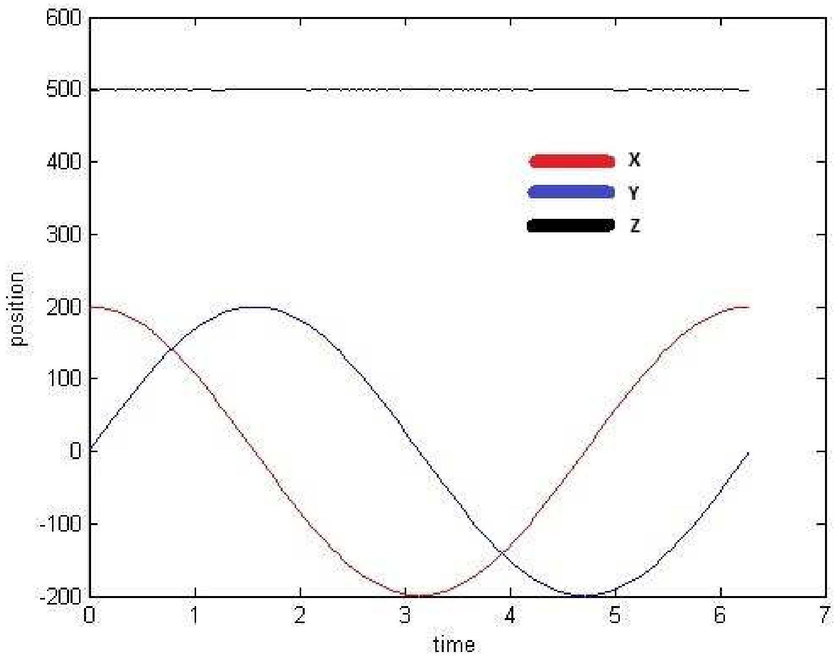

Figure 6.2: Commanded Positions.

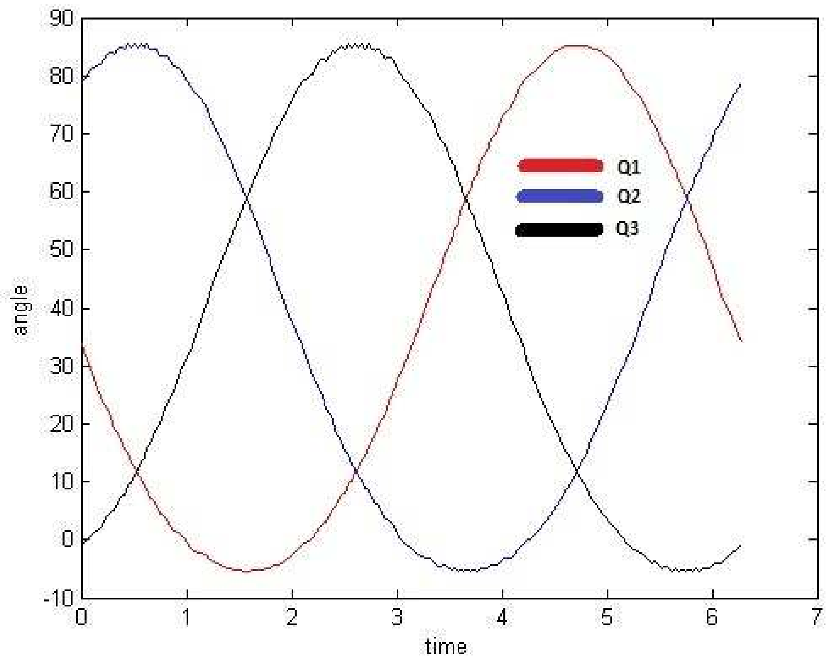

Figure 6.3: Calculated Angles Q1 is the angle of the 1st motor's shaft, Q2 is the angle of the 2nd motor's shaft and Q3 is the angle of the 3rd motor's shaft.

6.2 Workspace Experiment

After appling the workspace algorithm with limits of angles are:

$\theta_1 = -45°, ..., 90°$
$\theta_2 = -45°, ..., 90°$
$\theta_3 = -45°, ..., 90°$

Here's the Matlab results

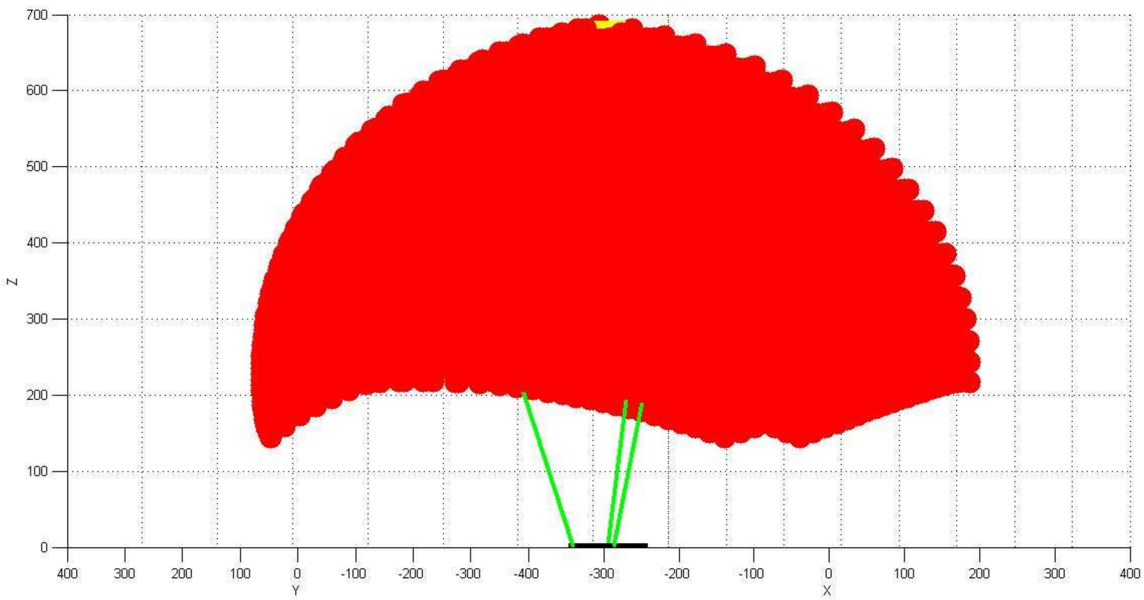

Figure 6.4: Workspace of the Delta-robot in XYZ plane.

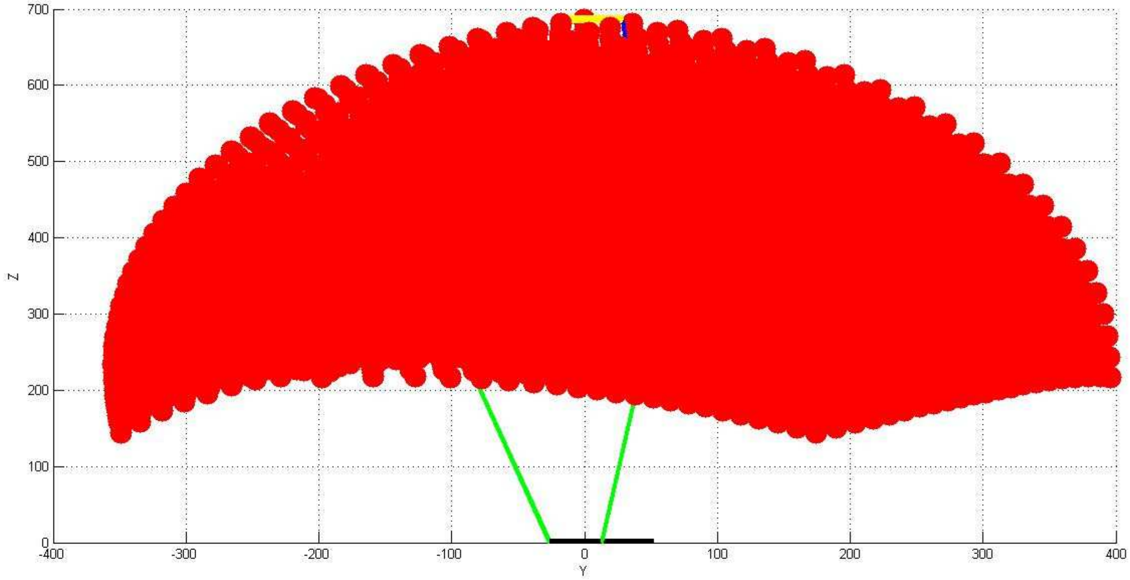

Figure 6.5: Workspace of the Delta-robot in XZ plane.

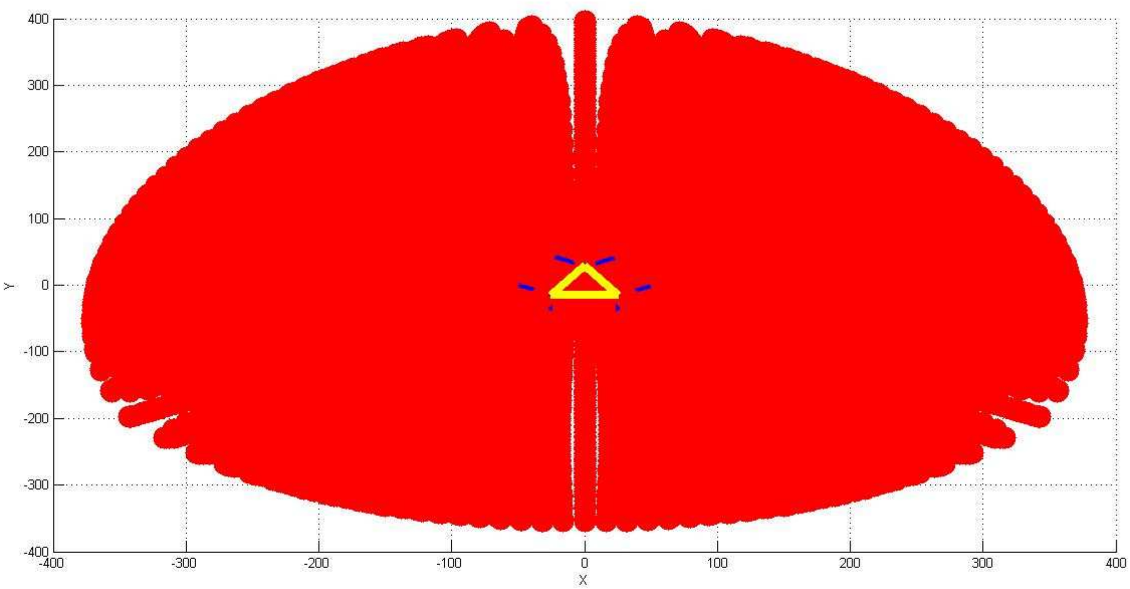

Figure 6.6: Workspace of the Delta-robot in XY plane.

6.3 Force Analysis Experiment

Then I used the Jacobian Matrix we figure out to calculate the force applied on the end-effector at every point it reaches using the equation:

$Torque = J^T \times Force$

Here's the Matlab results

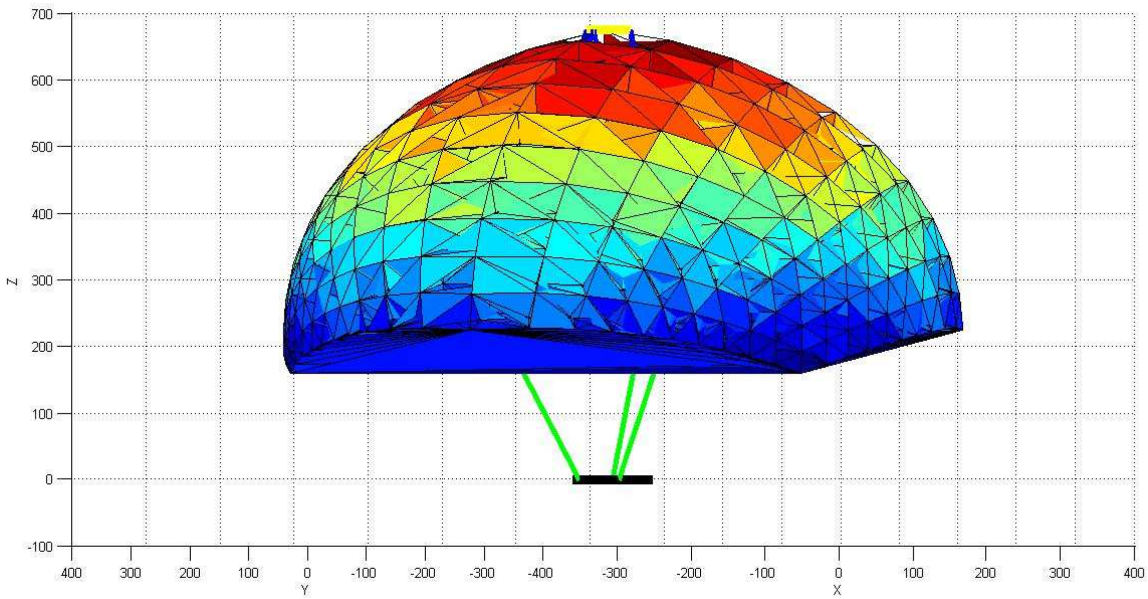

Figure 6.7: Workspace with Force Analysis using the color bar in XYZ plane.

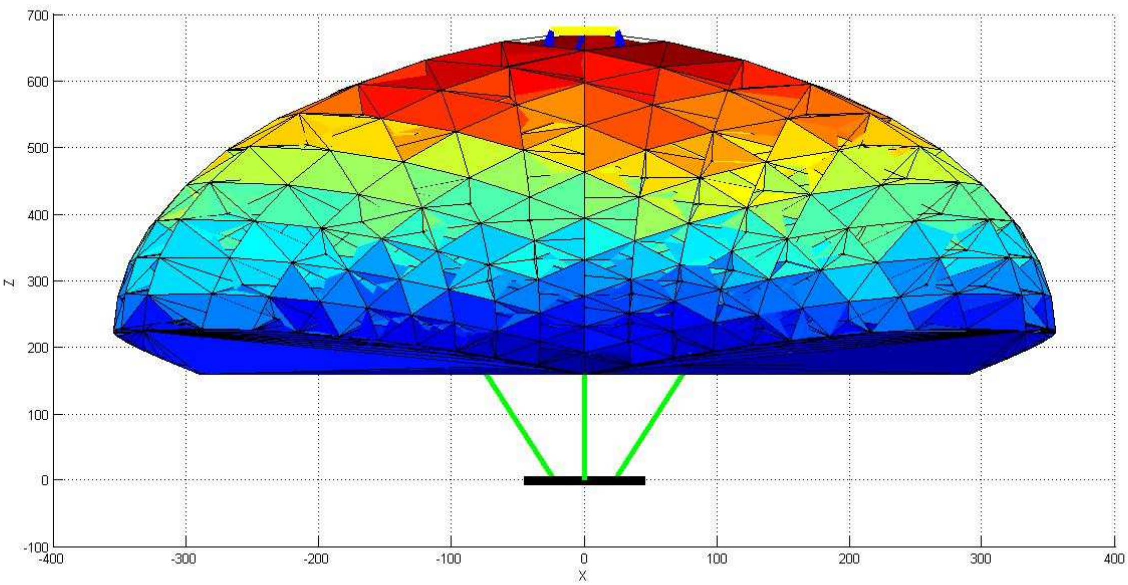

Figure 6.8: Workspace with Force Analysis using the color bar in XZ plane.

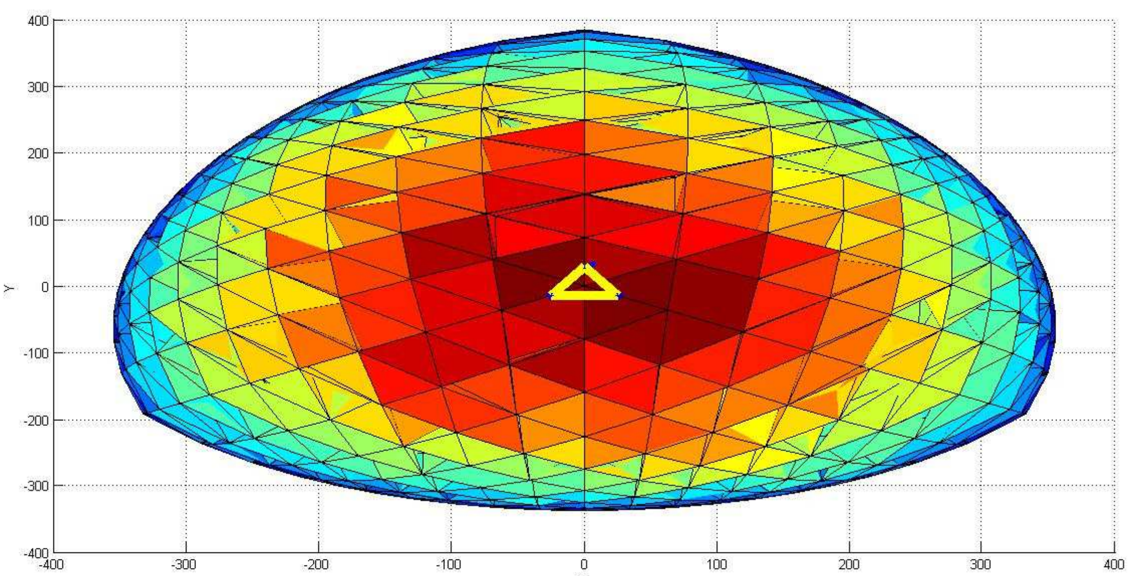

Figure 6.9: Workspace with Force Analysis using the color bar in XY plane.

Chapter 7

Experiments using 2D delta robot

7.1 how bi-lateral system works

Since a transparent closed loop bilateral control system depends on both the position and force control, the following data presents experimental results of a complete scaled bilateral control experiment, Position and velocity of the microparticle are determined using a calibrated microscopic system, whereas the interaction forces at the master-robot and slave-microrobot are calculated using force observers. The force observer at the master-robot is designed based on the input torque and the measured angular veocities in the joint space, whereas the force observer at the slave-microrobot is designed based on the input current to the electromagnetic coils and the velocity of the mircoparticles. The estimated forces in the magnetic system are sent to the 2D delta robot system using an RS-232 protocol, where they are scaled up, and the Force error is calculated to be compensated by the motor as a reverse torque.

7.2 simulation

In order to simulate the forces acting on the end effector for the pantograph mechaism needed to understand the regions where the forces are homogoneus, The task-space forces of the end-effector of the pantograph mechanism are calculated using the Jacobian matrix and the maximum torques provided at the joint-space within different configurations as shown in the figure:

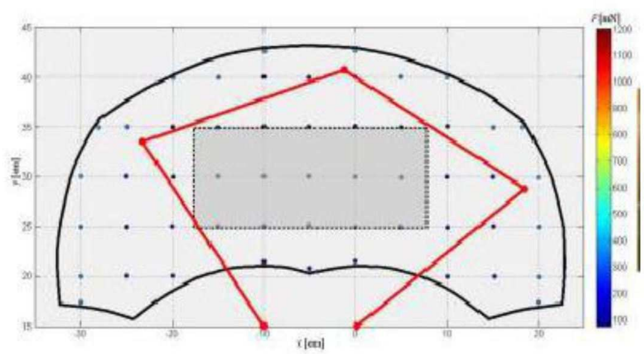

Figure 7.1: Workspace with Force Analysis using the color bar in XY plane.

The forces within the task-space of the 2D delta Robot mechanims are almost homogenous within the workspace (dashed white rectangle) which allows us to operate within the homogoneus and controllable region. As for the magnetic System,here is the model of the Magnetic system using a finite element (FE) model. This FE model is developed using Comsol Multiphysics (COMSOL, Inc., Burlington, U.S.A). The simulation result shown reveals uniform magnetic flux lines in the middle of the workspace when the top and left coils are activated with current values of 1A. This enables us to calculate a magnetic force-current map(Actuation Matrix previously introduced) for the region of interest (ROI) of our electromagnetic system rather than computing the magnetic force at each location of the workspace. First, a square grid of representative points is defined within the ROI of the system. The magnetic field components are calculated at these representative points. The numerical gradients of the magnetic fields are determined and a least square regression is used to provide a magnetic force-current map within the representative points of the ROI:

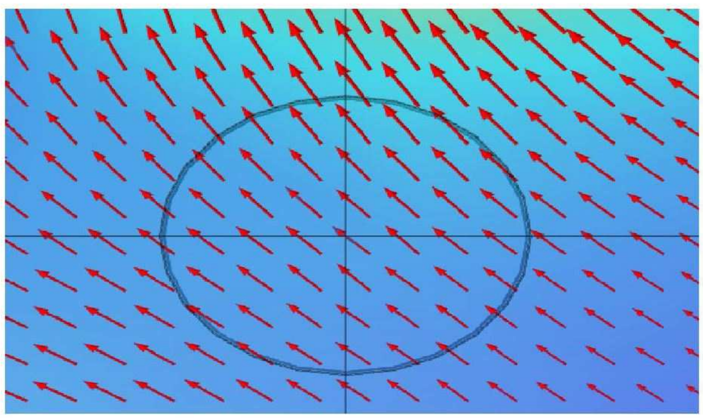

Figure 7.2: magnetic force current map

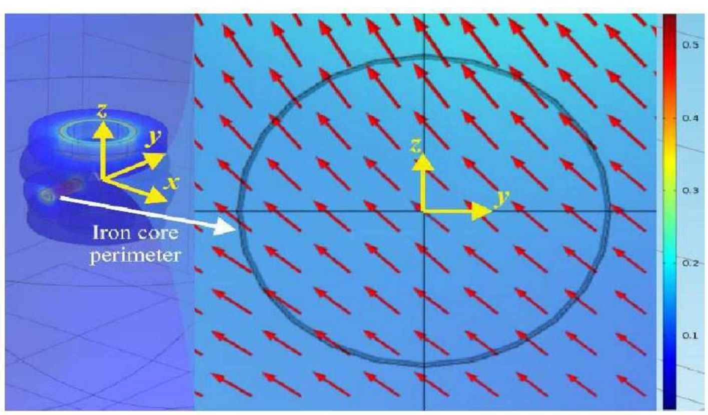

Figure 7.3: showing coordinates and perimeter

7.3 Choosing the control input

in order to stabilize the dynamics of the system for the micro particle we have to use the following control input:

$$Q = k_p e + k_i e(\frac{1}{T_s}) + (K_d \dot{e}) \tag{7.1}$$

Where, K_p = Proportional Gain
e = reference point - actual point
K_i = Integral Gain
T_s = Sampling Time
K_d = derivative gain
$\dot{e}$ = error differential

Furthermore, we used a slow rate to avoid the abnormal increase of the current and possible loss of tracking, and encoder resolution threshold term to account for the inaccuracies of the feature tracking software.First trial to preform position control was as follow:

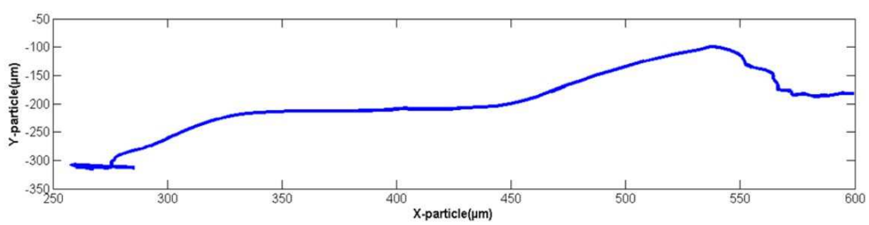

Figure 7.4: movement of the particle

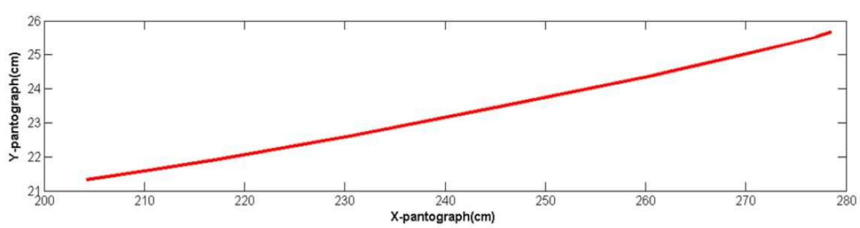

Figure 7.5: showing the motion of the 2D delta-Robot "pantograph"

After adjusting the controller and working with a faster camera the obtained results were as follow:

As shown by the figure, the performance is much better in terms of steady state error and reference tracking, further trajectory is much smoother.

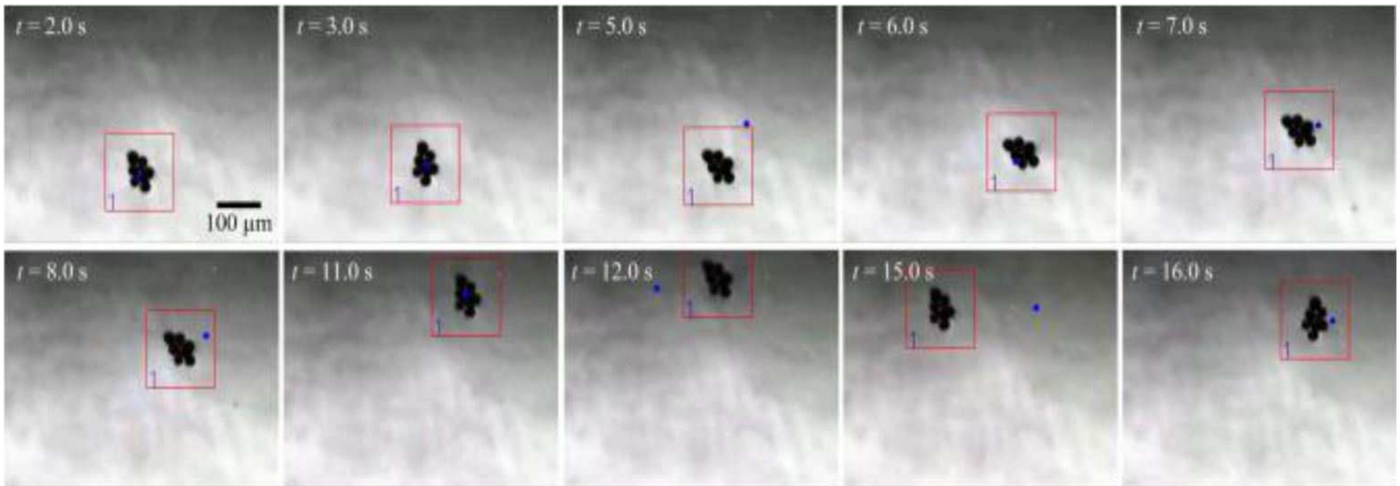

Figure 7.6: particle motion over time

Concerning the experimental results, another closed trajectory position control experiment was repeated, however; position, control and force estimation where achieved at both the master and slave slide, for the position control the following closed contour:

another experiment:

In order to validate the concept concerning position control , more experiments and trajectories were tried and plotted:

Drawing S-Shape

some manipulation and Drawing Z shape

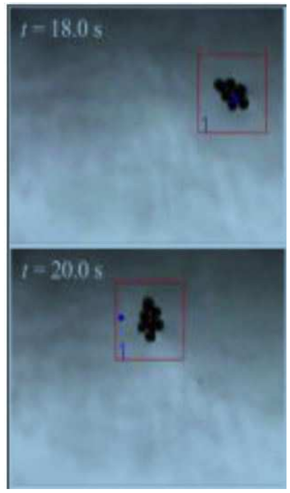

Figure 7.7: particle motion over time

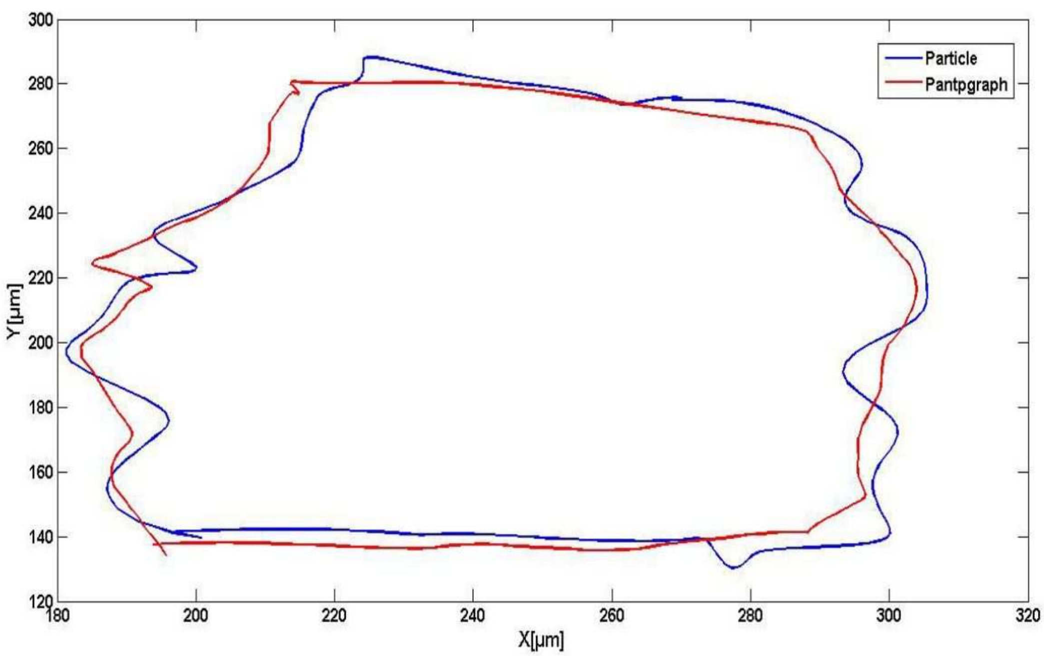

Figure 7.8: Points simulation of closed contour

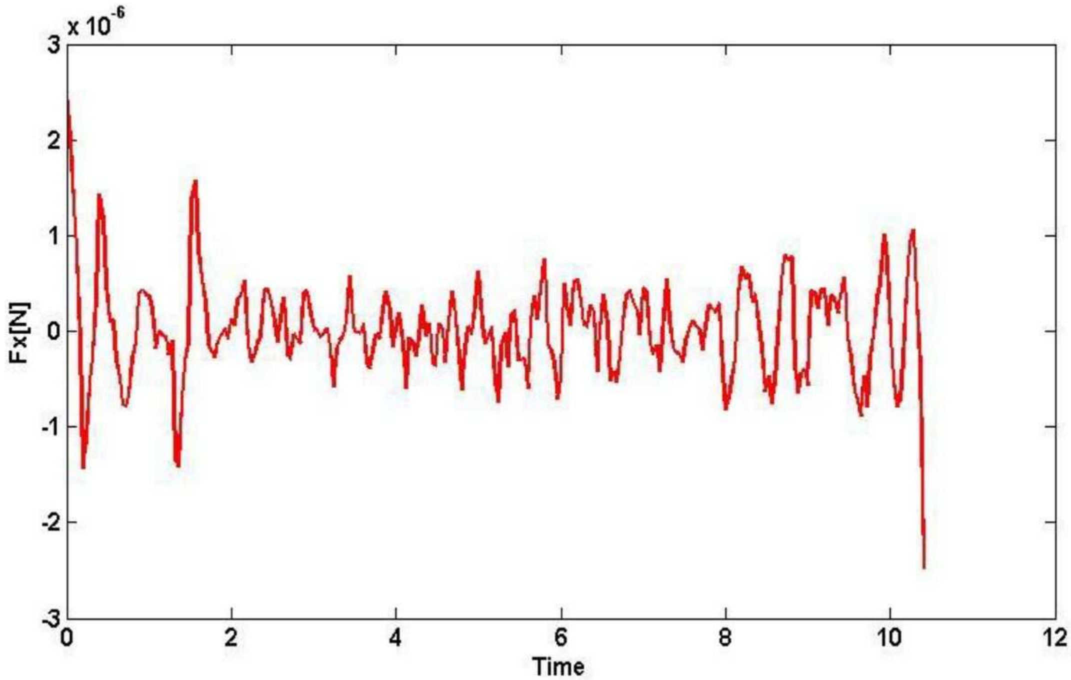

Figure 7.9: Forces disturbance for particles in x- direction

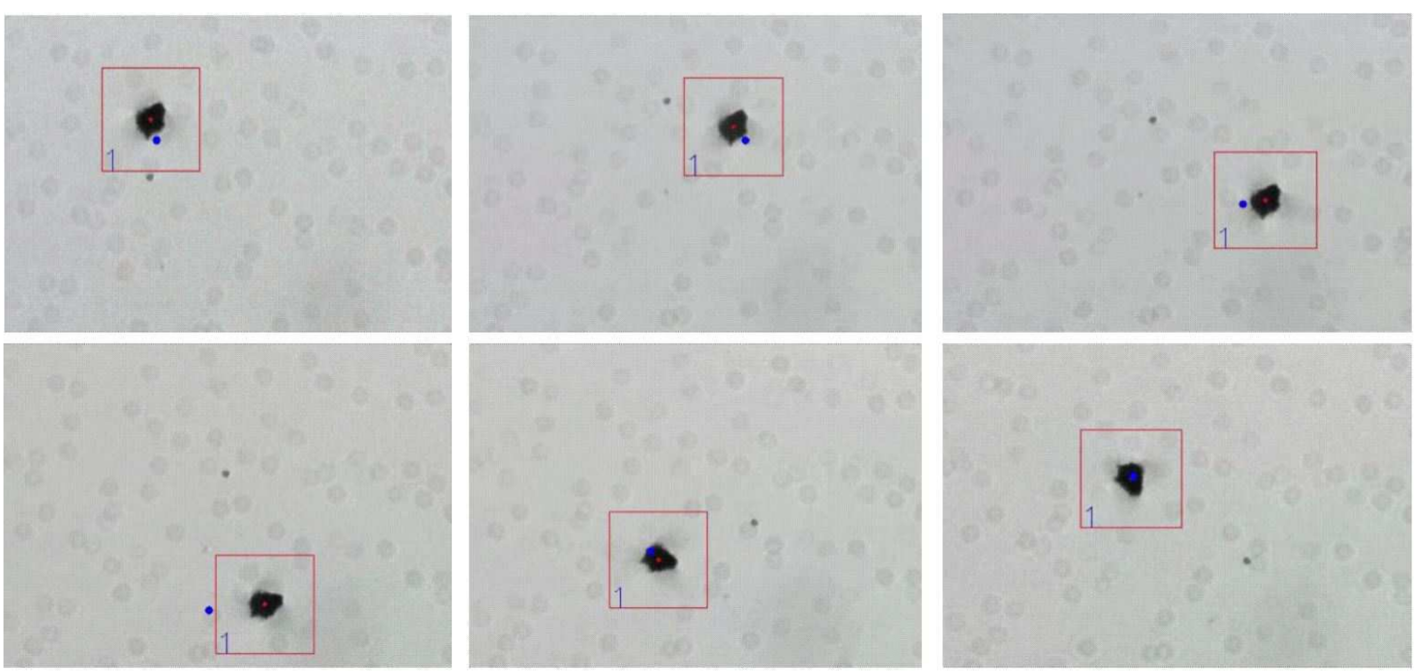

Figure 7.10: manipulating micro-particle wirelessly

S shape:

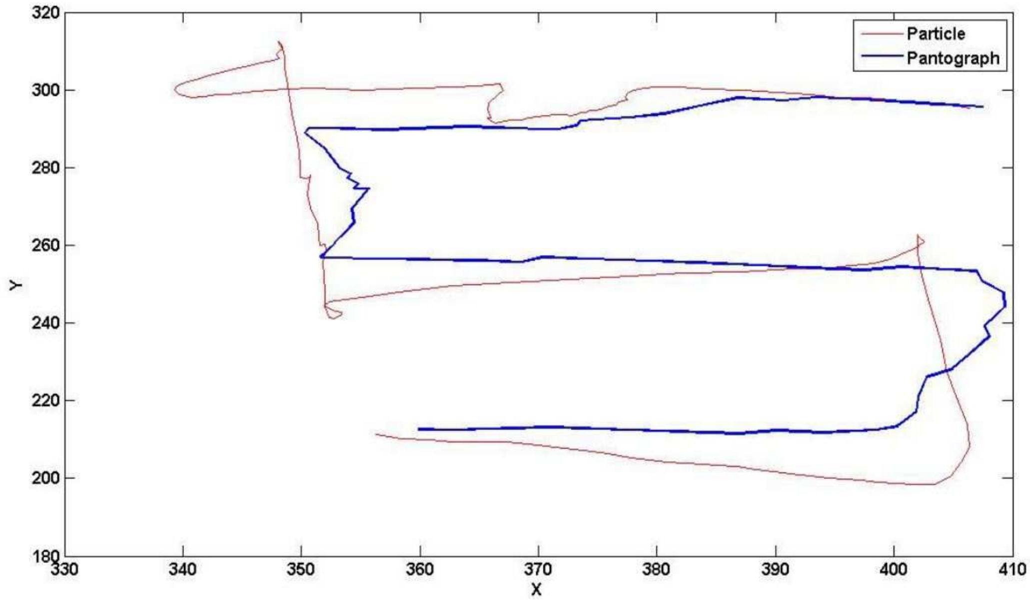

Figure 7.11: S-Shape depicted by particle and 2D Delta Robot

Z shaped:

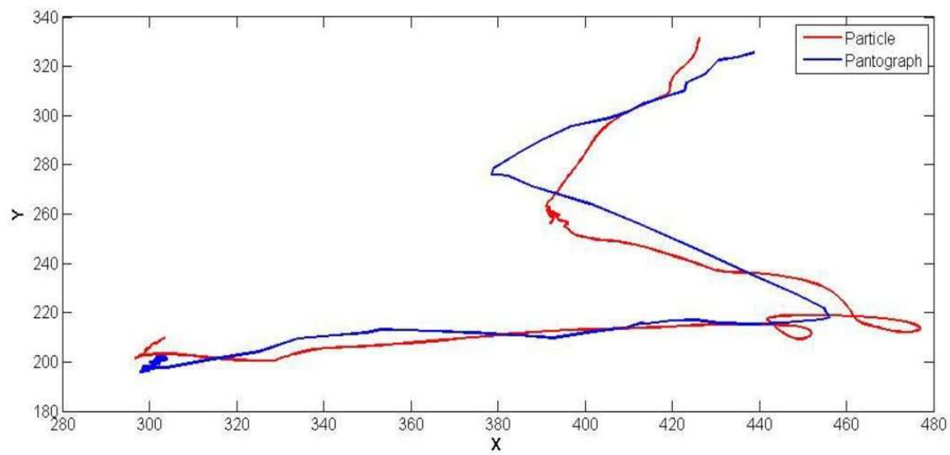

Figure 7.12: Z-Shape depicted by particle and 2D Delta Robot

Chapter 8

Conclusion

in this article the Manipulation of such micro and nano particles has been done and explained by graphs and it can be used further for application as protein crystal harvesting , micro-assembling , and drug targeting.Many technologies have been introduced to accomplish the task of micro-manipulating such as magnetic tweezers,wireless mobile-micro devices,micro fluidic devices , and micro-grippers. the advantage of using such low intensity magnetic fields is because it is harmless to living organisms and can penetrate most biological tissue.the Delta robot mechanism is connected to electromagnetic systems that create a magnetic field around particles to move in a certain direction. which has been proven to be working efficiently above. particles where manipulated with wireless magnetic field without direct contact.

Chapter 9

Future Work

we can add pistons instead of the carbon fiber links in order to increase the DOF and design a rotating base of the Delta robot to increase the workspace and allow complex movements in order to use the robot in noninvasive surgeries and accurate movment.

also we can orient the delta robot as a steward platform orientation and do a gravity compensation control in order to use it as a 3 axis joystick to do a bi-lateral control for micro-particles and to preform a less invasive surgeries if possible.

another developing idea is to give the command to the delta Robot by wireless signal to move. in order for this to be possible we need a wireless controller we already have it is the myRio and to do some adjustment to the exterior design in order to help the delta robot to be a moving robot.