Study of Needle Insertion Parameters of Human Body Tissue for Surgical Operations

Santosh Kumar Patidar

Department Of Industrial Design

National Institute of Technology, Rourkela

Rourkela-769008, Odisha, INDIA

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Study of Needle Insertion Parameters of Human Body Tissue for Surgical Operations

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In

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by

Santosh Kumar Patidar

(Roll: 213ID1367)

Under the Guidance of

Prof. BBVL Deepak

Department Of Industrial Design

National Institute of Technology, Rourkela

Rourkela-769008, Odisha, INDIA

2013-2015

Dedicated

To

My loving parents and my niece

Department of Industrial Design

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ORISSA, INDIA – 769008

CERTIFICATE

This is to certify that the thesis entitled "***Study of Needle Insertion Parameters of Human Body Tissue for Surgical Operations***", being submitted **SANTOSH KUMAR PATIDAR**, Roll No. **213ID1367,** to the National Institute of Technology, Rourkela for the award of the degree of ***Master of Technology*** in Industrial Design, is a bona fide record of research work carried out by her under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.

The thesis, which is based on candidate's own work, has not been submitted elsewhere for the award of a degree.

In my opinion, the thesis is of the standard required for the award of degree of Master of Technology in Industrial Design.

To the best of my knowledge, he bears a good moral character and decent behavior.

Supervisor

Dr. B.B.V.L. DEEPAK,

Assistant Professor, Department of Industrial Design

NATIONAL INSTITUTE OF TECHNOLOGY

Rourkela-769 008 (INDIA)

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Santosh Kumar Patidar
213ID1367
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ABSTRACT

The thesis introduces the study on needle insertion during the laboratory experiment. The percutaneous needle insertion is performed several times in day to day life. Manually placement of needle in the tissue may cause damage inside the body so the thesis presents the existing methodology of needle insertion and researched methodology in our laboratory. It shows the proper way of needle placement and which parameters are necessary to keep in mind when perform the needle insertion. It deals with the proper way of needle insertion, minimise the deflection of needle inside the tissue and gives an idea of reduction in deformation of tissue. The test procedures and experimental setup provide an understanding on the mechanics of needle placement and the design improvement of insertion instruments.

The experimental analysis optimize the results of operative parameters of needle when it insert in the tissue like needle translation motion during the insertion, needle rotational motion during insertion, angle of needle insertion and force acting on the needle when it inserted in the tissue. The optimize results provide a brief knowledge for the surgeons about the needle behaviour during the insertion in soft tissue so surgeons are pre imagined the situations by which they would going through during the operation. The model enhances the quality of insertion by presenting the optimize model for parameters of needle insertion. In most of the insertion operations accuracy and precision is important parameters which must be kept in mind by the surgeons when they performed the insertion of needle inside the tissue so this is study is relevant for them to get the accuracy and precision in work. The aim of this research is to present standard methodology for needle insertion which can be possible by experimental analysis of needle insertion in laboratory.

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Introduction

1.1 Introduction

Many diagnostic medical operations require surgeon to accurately insert a needle through soft tissue on a specific target in the tissue so it is common requirement of any percutaneous insertion that the needle should be placed accurately and it deforms the skin properly. It is known that the effectiveness of the treatment depends on the accuracy by which the needle is placed inside the tissue so the percutaneous needle insertion is drawing great attention of the surgeons in the medical science. Replacing the manual needle insertion operations by robot is also need of time so it is relevant to study various parameters related to needle insertion for developing the model or robot which can perform the insertion operations. We have conducted an experiment to fetch the data require to setup a robotic model related to needle insertion in soft tissue. The manual placement of needle sometime causes damage inside the tissue it may disturb the cancer cells and can be responsible for diseases caused by needle deflection. To curb the problems linked with manual operations and develop an accurate robotic insertion arm manipulator it is necessary to conducted pre experiments on needle insertion to know the needle behaviour.

The effectiveness of the operation depends mainly on the accuracy of the needle insertion. However we faced many problems when it done manually. Surgeon does the operation based on visualization and his personal prediction on the target but if we are conducting experiment on the problem of needle insertion then we are considering this point also that find out the location of the target is also a basic task. Therefore, in order to overcome these problems and to perform percutaneous needle insertion with high accuracy, high efficiency and high precision, a computer-guided system can be used. Computer guided system is used for imaging the inside structure of the body which is very helpful in puncture operations. The technique may be MRI, IR imaging. CTscan etc. When an experiment conducted with imaging then the accuracy and precision enhance and it is basic need of needle insertion operation. The importance of the imaging technique is become vast when we talk about the complete automatic model for needle insertion. The output in the form of images can be used as a feedback to the control circuit and based on that the control circuit takes actions. In the figure 1.1 the manipulator setup with phantom model is shown. This is transcutaneous robot-assisted ablation-device insertion navigation system developed by Yang et al. [1].

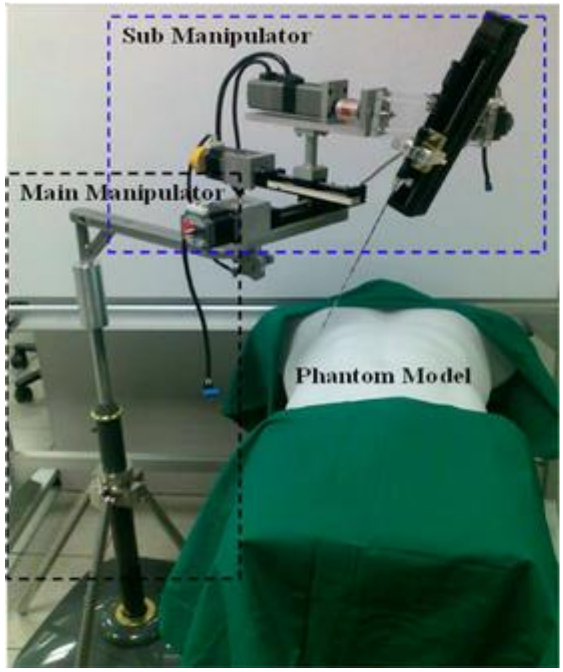

Figure 1.1: Transcutaneous Robot-assisted Ablation-device Insertion Navigation System [1]

1.2 Origin of the work

In the current scenario of growing medical science and updated scientific methods in every field of engineering, medical robotics has its own significant and importance in surgical operations. Today the needle insertion robotics is drawing the great attention of surgeons and scientists because of its accuracy and precision in puncture of the tissue. The manual insertion of needle in deep surgical operation like prostate, lever and cardiac surgeries is a very typical task having a problem of tissue deformation and needle deflection during the insertion. To overcome these problems medical science developed an automated needle insertion robotics device which can perform the surgical operations related to needle insertions with high accuracy and less human interference.

1.3 Problem Statement

In the percutaneous insertion operations visibility of the target, access of the target and the tool settlement on the target are the key issues. In the manual needle placement the accuracy is not guaranteed since it totally depends on the surgeon’s prediction and visualisation. The problems to identify target location, target uncertainty, deflection of needle and deformation of tissue are the biggest problems incorporated with percutaneous needle insertion, So the need of the study is to perform experimental analysis for the various parameters related to the needle insertion in soft tissue during the surgical operations like needle insertion velocity, needle rotation velocity, angle of needle insertion, reaction force on the needle from the tissue, deformation of tissue due to needle and needle displacement in the tissue etc., mainly the deformation is due to the needle diameter and needle tip size. It may also deform due to the tissue related factors such as mechanical properties [2,3]. To set up a pre analysed model of needle insertion is the fundamental task to reduce unwanted injuries and problems occurred due to unsuccessful insertion on needle. The collected data are very useful for design of the insertion robot.

1.4 Objectives

The objective of the study is to develop an experimental model for the needle insertion. We are emphasising on the needle insertion parameter such as velocity and rotation of insertion. The needle insertion robotic device is design to improve the precision and accuracy of the needle puncture in soft tissues during the surgical operations. The experimental study emphasises on the parameters required to design the robotic arm for an accurate needle insertion operations. During the experimental analysis the needle insertion parameters like needle insertion velocity, needle rotational speed during insertion, angle of the needle during insertion, force acting on the needle when it punctures tissue etc. are measured by developed setup and then draw the graphs for obtained data. Basically the experiment is conducted to demonstrate the practicability of needle insertion robotic device.

1.5 Thesis review

This thesis on the study of needle insertion comprises by the following sections.

Chapter 1: Introduces the introduction of the thesis. It covers origin of work, problem statement, objectives and thesis review.

Chapter 2: Introduce literature survey on the needle insertion concept. It comprises by Computer added surgical operations, Design of needle, Method of puncture the tissue, Feedback to the needle, Control mechanism , Deformation of tissue and study of force

Chapter 3: Introduces model development for the experimental analysis. This section comprises by Mechanism involved, Components used, and Interfacing of components and Summary.

Chapter 4: Introduces the experimental analysis for the needle insertion model in laboratory.

Chapter 5: Introduces conclusion of the work

CHAPTER 2
LITERATURE REVIEW

2.1 Literature survey

This literature review introduced the surveys for the origin and current work development of surgical systems for needle insertion. The surgical robots are differentiated on the basis of their surgical procedures. Till the date many studies have been done over the topic of needle insertion in soft tissue some analysed papers are given below. These papers deals with all aspects of the percutaneous insertion such as art of needle insertion, design of needle, different mechanism of the needle and feedback on the needle etc. I have done the literature survey of many papers and based on different concept and methodology the work can classified as below.

1. Computer added surgical operations
2. Design of needle
3. Method of puncture the tissue
4. Feedback to the needle
5. Control mechanism
6. Deformation of tissue and study of force

2.2 Robotics in surgery and computer aided surgery

Robotic devices in purpose of surgery are firstly computer-integrated surgery (CIS) systems, and secondly they are medical robots [4]. In different words, the robots are used for just provide assistance to the surgeon in carry out the different surgical processes. Computer integrated surgeries are most common now days and most compact also. The use of computer in surgical processes improves the precision of the operation and reduces the dependency of operation on human. We can classify the CIS in two categories which are given below.

2.1.1 Surgical CAM/CAD

Preoperative planning basically begins with two-dimensional (2-D) or three-dimensional (3-D) medically obtained images, together with information about the patient. The images obtained in this procedure can be attached with basic information about patient anatomy and mutability to produce a computer based images of the individual patient, obtained images are then used in special surgical planning process. In the operating room this collected information is registered as the actual information of the patient. This information can be obtained by the use of x-ray, ultrasound or MRI etc.

2.1.2 Surgical assistants

Surgery may be an extremely interactive method and plenty of surgical selections are created within the operating room (OR). The goal of surgical artificial intelligence isn't to switch the doctors with a mechanism, however to supply the doctor with a brand new set of terribly versatile tools that reach his or her ability to deal with patients. We typically speak of medical automaton systems as surgical assistants that employment hand and glove with surgeons. A special sub category of those systems are typically used for remote surgery. Currently, there are two main sorts of surgical assistant automaton. Mainly the operating surgeon extenders are operated directly by the operating surgeon and amplify or elongate the surgeon's ability to govern surgical devices used in surgery.

2.3 Design of needle

To consider the design aspect of the needle is also an unavoidable term, till the date many designs have been developed but few found their place in operating room. The prototype for the design of medical robots that is best suited for research centres is also developed. Such prototype provides a base approach to construct the model in order to install accuracy in the system.

Alonso et al. [5] studied "A design framework for surgical robots" and according to them originally, the branch of medical robotics was in the influence of industrial robotics. They said the specific applications of medical science led to research on well suited mechanism and kinematics and materials (i.e. biocompatibility and/or compatibility with medical imaging systems). In turn, the organizational guidelines for medical instruments regulation also change on the basis of research work; the standards then decide which instrument will reach up to the operation room. These days three decades are passed but few prototypes are reached in public.

Lisandro et al. [6] presented "Design and kinematic analysis of 3PSS-1S wrist for needle insertion guidance" In this work they presented kinematic analysis for 3PSS-1S mechanism for needle insertion guidance robot as implementation as a spherical wrist. The introduced 3PSS-1S mechanism is having ability to reduce dimensions and it has low weight. This can allow the spherical movements and provides needed requirements to the serial-parallel arm. The solution obtained by this method then computes with numerical method's result.

Robert et al. [7] studied "Design Considerations for Robotic Needle Steering" Mostly the medical process require needle insertion, but needed accuracy limited due to unwanted and unnecessary obstacles in the path of needle, changing in target position caused by deformation of tissue, and undesired needle bending takes place after insertion. In order to reduce these limitations, Robert and their team developed robotic systems that insert the needle actively in soft tissues. Bending in needle happened due to bevel tip structure, and flexible needle enhance the steering. An experimental model for needle insertion is developed by them that include image data acquisition, force/torque sensing elements, translated needle insertion and control mechanism for needle translation and rotational speeds. They performed experiments on a phantom tissue to determine the insertion velocity effects on needle and angle of insertion of needle. Based on the results they conclude that needle insertion in the tissue does not depend on the needle insertion velocity but it depends on the angle of needle insertion

2.4 Method of puncture the tissue

Tissue puncture is also a point which is studied by many researchers till now. When the accuracy is needed in any surgical process that assist needle insertion procedure, then tissue puncture is a matter of consideration. The aim of the several researchers is to develop a best suitable model which can reduce the chances of tissue deformation during the operations. Some concepts on tissue puncture technology are given below.

Hirokazu Saito et al. [8] represented "Detection of needle punctures to blood vessel by using electric conductivity of blood for automatic blood sampling" Although blood testing and sampling is performed frequently in daily life; an automatic system to take blood samples has not yet been evolved. To develop an automatic needle control blood sampling mechanism, the changing puncture force and electric conductivity of blood is required. An injection needle having electric electrode is set up on the device with a load cell for measuring puncture force. When needle inserted in the blood carrying cells the blood started flow in needle, it caused short circuit between the electrode of needle and electrode of skin surface.

S.H. Teoh et al. [9] studied "Bone material properties and fracture analysis: Needle insertion for spinal surgery" The effectiveness of percutaneous needle insertion in needle based therapy and biopsy is the main point of discussion. However, the position of the needle in the tissue is depends on the material properties of bone and tissue as well as the shape and size of the needle also. They surveyed the literature related to the bone material properties and interaction in bone needle when needle placed inside the bone. The study described the research related to the bone material properties and integration of images the study also discusses the feasibility of available methods.

2.5 Feedback to the needle

For needle insertion studies the force/torque measurement is one of the most important parameter of consideration. When needle inserted in the tissue it get reaction force from the tissue this force is measured by many techniques. Some are listed below.

Sumanth et al. [10] studied "Assessment of Vibrotactile Feedback in a Needle-Insertion Task using a Surgical Robot" The presented study examined the effect of vibrotactile feedback in a needle-insertion process using a surgical robot. Some participants performed the task given, manually by hand and by using a surgical robot, with or without vibrotactile feedback. The significance of the vibrotactile feedback signal is to show the deviation in force detection, with the amplitude of the siganal modulated by the magnitude of force. The task of participants' was to insert a needle on a particular pre marked area and insert it out from the pre marked point from entrance. The guidelines for participants were to hold the needle at the set position that minimized side-loading and prevented complete rotation of the needle in needle driver. The forces exerted on the simulated tissue pad by the needle were recorded. On the basis of result they knew that the vibrotactile display reducing the deviation in force-direction during the insertion task, but it is time consuming. By hand it tools twice time then the task performed by robot. One participant, assist with surgical robot experienced less force with the surgical robot than with the hand. The VT feedback reduced the amplitude of force which was perpendicular to the surface, but this is not for the forces which were along the suturing surface.

Yo Kobayashi et al. [11] presented "Position control of needle tip with force feedback and liver model" they studied that in the thin needle deflection will be more, the needle movement in consideration with deflection is needed. The correction in deflection can be done by (a) taken out force feedback, (b) liver model (c) force feedback and liver model; these three are carried out to control the needle tip position. From the experimentally obtained data it is clear that the process (c) is more effective than other.

M.C. Bernardes et al. [12] repredented "Robot-assisted automatic insertion of steerable needles with closed-loop imaging feedback and intraoperative trajectory re planning" they present a robotic approach for needle steering in percutaneous procedures. The method illustrate concept of duty-cycled rotation for needle to perform needle insertion with adjustable curvature arc, and to compensate system disturbances and uncertainty it uses closed-loop imaging feedback techniques with re planning intraoperative motion strategy. The close loop re planning strategies is suitable for dynamic process since it does not depend on roadmaps. Evidently, simulation done under the presence of movable obstacle conferred advantages in error correction. The aim of such tests is that the needle tip should reach on the target in phantom.

Rebecca Kokes et al. [13] studied for “Towards a tele operated needle driver robot with haptic feedback for RFA of breast tumors under continuous MRI” this study focused on the development of the MRI assisted needle driver system for breast tumours under MRI imaging while being operated from the outside of scanning room with the help of haptic feedback. The needle driver model checked for tumour and RFA.

Berk Gonenc et al. [14] studied “Virtual needle insertion with haptic feedback using a hybrid actuator with DC servomotor and MR-brake with Hall-effect sensor” after research they found that the stable and fast force feedback with high strength is required in haptic applications. They realized that the combination of actuators is required to get desire output so the aim of the study is to develop hybrid actuator with dc servo and magnetorheological (MR). By installing the Hall-Effect sensor in breaks the hysteresis is eliminated. To the best of our knowledge, this is the first such design incorporated into an MR-brake.

2.6 Control mechanism

In the medical science in various types of surgical operations the mechanism of the model pays the role of back bone. Here also in needle insertion robotic family the control mechanism is important to understand and study well. Behind every working model a control mechanism exist whose work is to govern the process on the same way some needle insertion mechanism are stated below.

Rong Wen et al. [15] represented “Hand gesture guided robot-assisted surgery based on a direct augmented reality interface” in the treatment of lever problems the radiofrequency (RF) ablation is best option. However, proper hand-eye coordination is the necessary in accurate needle insertion and the RF needle navigation also affects the insertion. This study proposed a development of hand gesture guided surgical robot system; assist with augmented reality (AR)-based surgical field in percutaneous procedures. Simple hand gesture is used to interact with AR and surgical robot. The proposed study has done on the mannequin model. From the Experimental results it’s clear that the hand gesture guidance effectively guides the surgical robot and the robotic model improve the accuracy of the percutaneous needle insertion.

A. Ayadi et al. [16] studied “An Image-Guided Robot for Needle Insertion in Small Animal Accurate Needle Positioning using Visual Servoing” the testing of new medical therapies generally performed on small animals. They introduced a CT-scan based robotic needle insertion system in order to enhance the medical procedures during treatments. The operator defines the entry point of needle in skin and target in the CT-scan images. The target is then showed in the robot display unit. At the last the needle insertion is performed by visual servoing. This model allows high accuracy and independent from proposed needle model.

Yo Kobayashia et al. [17] studied "Development of an integrated needle insertion system with image guidance and deformation simulation" The purpose their work was to develop an image guided and deformation simulated integrated system for an accurate needle insertion. They designed a needle insertion manipulator for liver deformation which is based on ultrasound guidance. For the experimental study to check the effectiveness of the proposed manipulator they conducted vivo experiment in which they used porcine liver. The result of this experiment demonstrates that the needle is inserted on the target smoothly and perfectly.

M.J. Oldfield et al. [18] studied "Highly resolved strain imaging during needle insertion: Results with a novel biologically inspired device" in any kind of minimally invasive surgery the percutaneous needle insertion is a common thing. However, it's necessary to focus on the interaction between tissue and needle also focuses on the side effects of the migration of the target and needle. Removal of these effects is fondly desirable, but it totally depends on the detailed analysis of the needle–tissue interactions. They introduced an adapted Digital Image Correlation (DIC) technique, which is used to gauge mechanical behaviour on the skin surface.

Daniel Glozman et al. [19] studied "Image-Guided Robotic Flexible Needle Steering" They presented their study on a robotic system for needle steering in flexible soft tissue guided by real-time fluoroscope. It is computer based technique in which a target and obstacle locations are defined. Based on trajectory calculated by computer the needle hits the target.by the use of an inverse kinematics algorithm, the trajectory path for the needle is calculated.

M. Baumanna et al. [20] represented "Prosper: Image and robot-guided prostate brachytherapy" In the Brachytherapy for prostate cancer the cancer cells are destroyed by putting iodine radioactive seeds through hollow needles into the glands. The ultrasound (US) imaging is used to introduce the seeds into the prostate. They introduced the three procedure of imaging: i) by using 3D US; ii) enhancement US data with MRI registration; iii) by using specially designed needle insertion instrument assist with imaging data.

Christos et al. [21] researched "Tracking and Position Control of an MRI-Powered Needle-

Insertion Robot" The MRI technology is the excellent procedure for imaging so it is used in variety of procedures. Nowadays the radiologists are assisted with MRI compatible robots technologies are being developed. Recently, MRI powered robots are also developed. The MRI pulses are used by this type of robot for actuation and imagination and based on obtain data the needle insertion is performed. The MRI scanner generates electromagnetic field, which develops forces to puncture the tissue.

2.7 Deformation of tissue and study of force

The whole research is in light because inability of manual operation to perform the perfect needle insertion. When the needle inserted in the tissue, the tissue get deform. This deformation is not the required parameter related with the insertion of needle. So the analysis of deformation of tissue and force on the needle during puncture are the necessary parameters to know about. Some studies are given below.

Barbara Frank et al. [22] presented "Learning objects deformation models for robot motion planning" In this study they introduced the problem of robot navigation with deformable objects. They represented the recently developed robot having the capacity of acquiring the deformable models. By the physical contact of the robot with tissue, it develops the relation between the force and deformation and also finds out all elastic parameters of the object. Finally obtained deformation model can be used to develop a simulated model. This data allows the observer to know the robot trajectories deformation costs. Finite element simulations methods are time-consuming, so instead of them they used Gaussian process regression.

Yo Kobayashia et al. [23] studied "Use of puncture force measurement to investigate the conditions of blood vessel needle insertion" Central venous catheterization (CVC) illustrate the venous puncture and insertion of catheter for transfusions. They said that the needle insertion parameters like velocity of needle and angle of insertion have not yet to be developed. Previously they have developed a robotic system that will guide the needle puncture path and restore the precision and accuracy. In this study, they proposed control parameters such as insertion angle and velocity to control the needle position in a blood vessel. They had conducted the experiment on porcine jugular vein and collected all values of reaction force.

J. Zhaia et al. [24] represented "A sensor for needle puncture force measurement during interventional radiological procedures" In interventional radiology processes computer-based simulation for training has drawn tremendous attention in recent years since it provide proficiency in order to train patient. The force exerted on the medical instrument during the operations is required to know for development of the simulator. This study also demonstrates the validation of the axial force measurement during needle insertion by force sensor. Finally the values for force measured by sensor are compared with the force values from tester. From the obtain data it is clear that the result from the sensor has high linearity and.

Nantida Nillahoot et al. [25] studied "Development of Veress Needle Insertion Robotic System and Its Experimental Study for Force Acquisition in Soft Tissue" This study presents a Veress needle insertion force sensing system its design and development, and also Veress needle steering robotic system to acquire force data from the insertion in soft tissue . The data from the veress needle insertion is used in robotic surgical operations. The aim of this study is to develop a surgical system that can provide force feedback in surgeries.

Yuta Fukushima et al. [26] studied "Estimation of the cutting force using the dynamic friction coefficient obtained by reaction force during the needle insertion" In this study they introduced a force visualization system which can reduce the human interfaced error in the needle insertion procedures. The aim was to develop a method of finding the cutting and dynamic frictional forces. The force obtained by applying the pressure on a test piece and needle inserted two times in the specimen. Based on force reading the friction force and cutting force are calculated.

Lonnie et al. [27] presented "Force-Based Needle Insertion for Medical Applications" they found the needle insertion is extensive in around all medical procedures. The aim of the study was to develop compact and automated lightweight tools for needle insertion. This can reduce the risk for civilian and military patients. Such instruments could become milestone or the future medical domain research. The purpose of the study was also to develop a needle insertion device based on two force, apart from these also introduced a compliance sensing system will determine point of insertion in the vein.

2.8 Summary

As we observed till the date lot of studies have been done over the concept of needle insertion in the area of medical science. The aim of most of studies is to replace manual model of needle insertion by the automated robotic surgical system to restore the accuracy and precision in the operations. As per the literature review I have done, the needle insertion is the part of the almost all medical procedures for injection of drugs. So it was the goal of the studies that to come with an automated delivery system and reduce the chances of any human error in the operations.

CHAPTER 3
MODEL DEVELOPMENT

Model Development

The model development is the part of the mechanism development for the proposed model for needle insertion. This chapter consist by following parts.

1. Mechanism involved
2. Components used
3. Interfacing of components
4. Summary

3.1 Mechanism Development

The fundamental goal of this study for percutaneous needle insertion is to analyse various parameters effect on the insertion. Angulated needle placement with more DOF has been studied by Su et al. [28].The primary focus of this study is to introduce the needle placement mechanism and integrated hardware and software system. The insertion of the needle in soft tissue required basically two motions, translation and rotational motion. Insertion of needle is government is governing by the translation motion and rotation of the needle is responsible for less deformation of tissue and smooth insertion of the needle. In the figure3.1 shows Fm is the force required for the needle insertion and Tm is the torque.

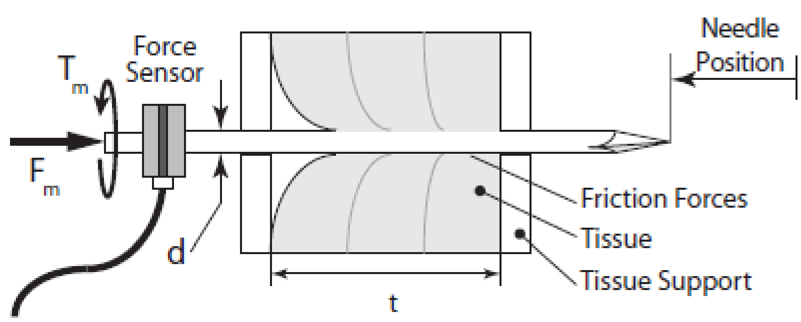

Figure 3.1 Simple concept of needle insertion

For the translation motion I used the servo motor arrangements on the model head. The servo will provide this motion based on the control circuitry. On the other hand the rotational motion is provided by dc motor attached near to the needle head. Apart from the motion mechanism we required some more concepts. All are listed below

i. Force measurement mechanism.
ii. Torque measurement mechanism.
iii. Velocity measurement mechanism.
iv. Angle measurement mechanism.
v. Displacement measurement mechanism.

3.1.1 Force/Torque measurement mechanism

In this model development I am investigating the concept of insertion of the needle inside the tissie or vein. Generally, the surgeon decides where needle should be placed in side the blood vessel based on the force values acting on the needle. Moreover, it is found that the force on the needle is the important data in designing of the surgical needle insertion robot. When needle inserted into the soft tissue, the tissue applied a reaction force on the needle this force we have need to measure. The values of this force give the idea in design of the model. So for the force and torque measurement we required F/T sensor which can measure the force values.

3.1.2 Velocity measurement mechanism

When the needle insertion operation is performed in the soft tissue it is required to measure the translation and rotational velocity. The data obtained in this way are very useful to designing the automated needle insertion system. These data provide the information about the necessary values of the velocity to keep when insertion operation is performed. The linear velocity is measured by the LVDT attached with needle and the rotational velocity is measured by the Hall-Effect sensors.

3.1.3 Angle of insertion measurement

It is found that the deformation of tissue and deflection of the needle inside the tissue is directly affected by the angle of needle. The angle of needle during the insertion is kept in such a way that it should not deform the tissue much. So the angle measurement is also an important data for the insertion study.

3.1.4 Displacement measurement

In most of the study the needle insertion operation is focused on the deformation of tissue. The reduction in tissue deformation and needle deflection is the very useful data for the designing in the surgical system. The displacement of the tissue can be measured by the displacement sensors. A layout of the simple needle is shown in figure 3.2.

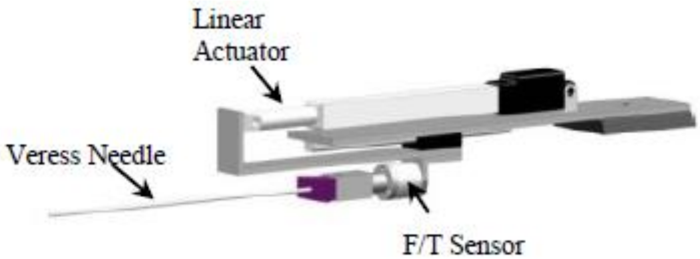

Figure3.2 Basic needle concept [25]

3.2 Component used

The entire model is the based on robotics so the fundamental components are from the sensor family. The used components are listed below

i. Force/Torque sensor
ii. Hall Effect sensor for speed measurement
iii. LVDT for displacement measurement
iv. LCD for display
v. Ultrasonic for distance measurement
vi. Servo and DC motor
vii. Vision sensor for image capturing
viii. Potentiometer

Components are given in the table

S.No	Component	Specification	Application	quantity
1	Force/ torque sensor	Measurement up to 80N, 10 kg/rev.	Measurement of reaction force and torque produced by needle rotation	1
2	Hall Effect sensor	8 - 30 V dc @ 5 mA	Measurement of the speed of rotation in rpm	1
3	LVDT	Measurement the displacement up to 10mm	Measurement of the tissue deformation	1

			during insertion	
4	LCD display	16*4 display unit	Indicate the digital values	4
5	Ultrasonic sensor	HC-SR04	Measure the distance of the tissue from the target	1
6	Servo and DC motors	5 volt motors	Work as an actuator	Servo-2 Dc- 2
7	Potentiometer	5 ohm resistance range	Variable resistor element used to change the voltage values.	2
8	Vision sensor	4G series sensors	Image sensing	1

Table3.1 Components Used

The experimental setup is shown in figure 3.3 which can demonstrate these sensors attached with it. The force and torque sensor attached to the top portion of the needle, since it can measure easily without affecting the needle rotation. When needle inserted into the soft tissue, the value of reaction forces started to display on the LCD screen. These reading are because of the force sensor, it sensing the reaction force continuously and providing the values on display. The interfacing of LCD with force and torque is done in Arduino coding. The LVDT used to measure linear displacement of the tissue when needle inserted. The value of the LVDT is also displayed on the LCD screen. One control circuitry is working continuously behind the model. The servo motor and the dc motor are working as an actuator; all velocity related operations are performed by these two components only. The vision sensor is the part of the imaging; the images of the target can be obtained easily by ultrasound vision sensor. The output of the sensor is attached to the computer on which the images of the target showed. Based on this information surgeon performed the operation. This technique reduces the risk of any human prediction error and also eliminates the chances of affection in cancer cells.

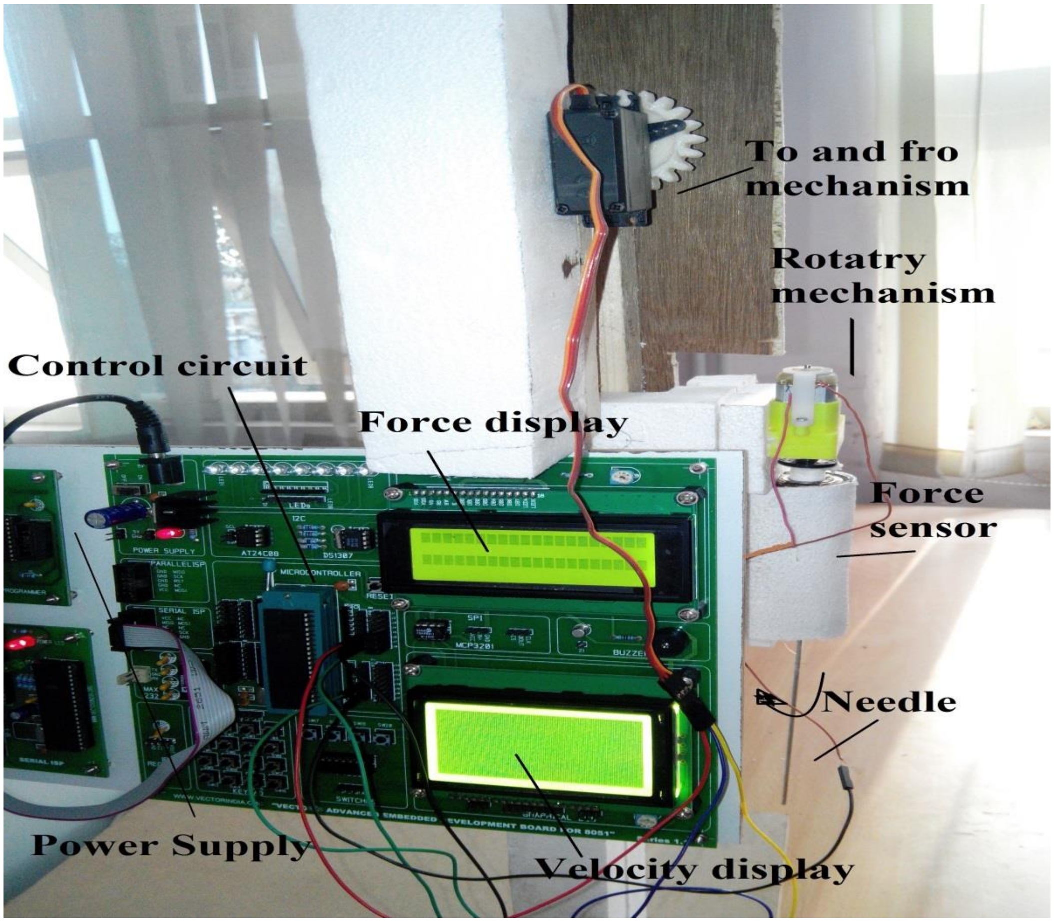

Figure3.3 Architecture overview of the model

3.3 Interfacing of the components

Before develop the entire experimental setup the interfacing of these components have been done and tested in out laboratory. The various interfacing of the components are listed below.

i. Interfacing of the POT with Arduino
ii. Interfacing of the LCD with Arduino
iii. Interfacing of dc motor with Arduino
iv. Interfacing of servo motor with Arduino
v. Interfacing of the ultrasonic with Arduino
vi. Interfacing of the force/ torque sensor with Arduino

vii. Interfacing of vision sensor with Arduino
viii. Interfacing of the hall effect sensor with Arduino
ix. Interfacing of ultrasonic and LCD with Arduino

3.3.1 Interfacing of POT

The potentiometer is the variable resistance device, it consist by a resistive wire having a rotating nob over it. The rotation of nob leads the change in voltage of external connected circuit, since the resistance is changing. The schematic of POT is shown in figure3.4.

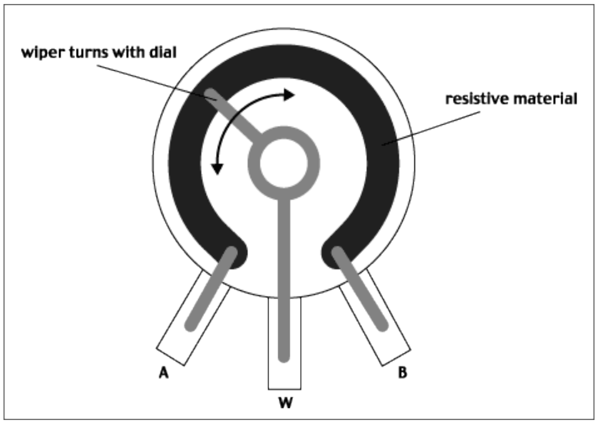

Figure 3.4 Schematic of POT

The interfacing of POT performed in the lab with servomotor. The schematic of POT is shown in below figure3.4. The direction and speed of rotation of the servo motor we controlled by POT in lab and picture of that interaction is shown in figure3.5. When the POT rotates in clock wise the direction, rotation of the motor is also clock wise but the speed of the motor is fully control by the POT. In our experimental model the servo is attached to the needle so the needle motion is controlled by POT.

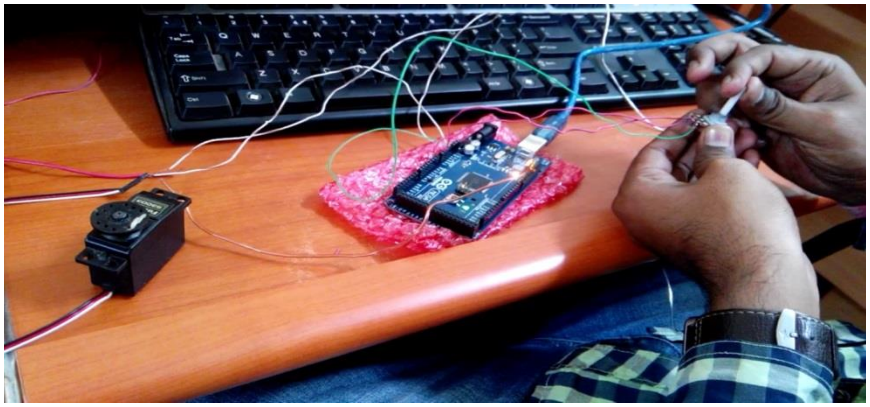

Figure3.5 Interfacing of POT with servo.

3.3.2 Interfacing of the LCD with Arduino

The LCD is the liquid crystal display unit which is used for the display of measurement in digital form. In my experimental setup I used the LCD for displaying the measured values. The interfacing of the LCD is shown in figure 3.6 below.

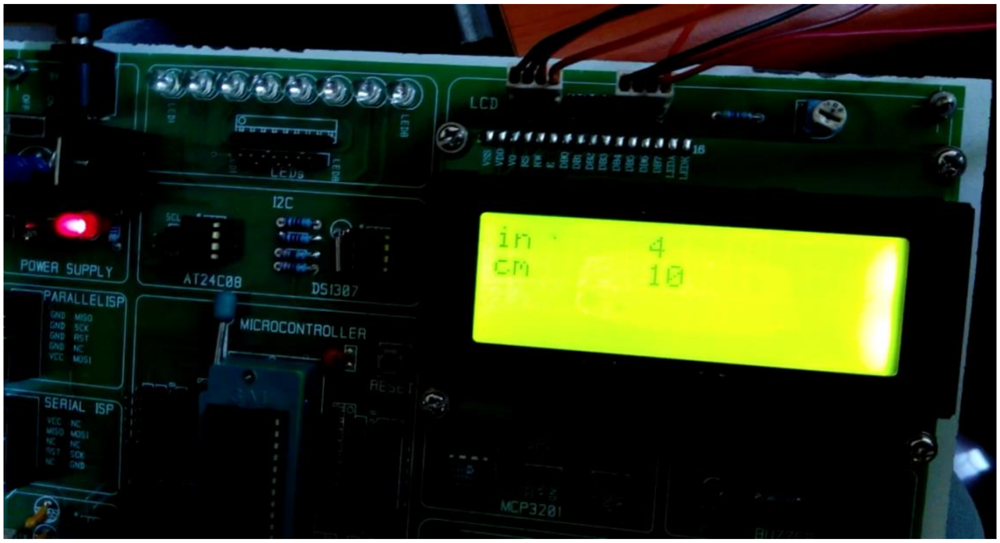

Figure3.6 Interfacing of the LCD.

3.3.3 Interfacing of the DC motor with Arduino

DC motor is used as an actuator in the circuit. In my experimental setup the dc motor is basically using for needle rotation. The dc motor is controlled by the control circuitry based on the value of the readings displayed on the LCD. The rotational rpm is displayed on the screen. DC motor is an electromagnetic actuator which is used for actuation of the process. A schematic of DC motor is shown in below figure3.7

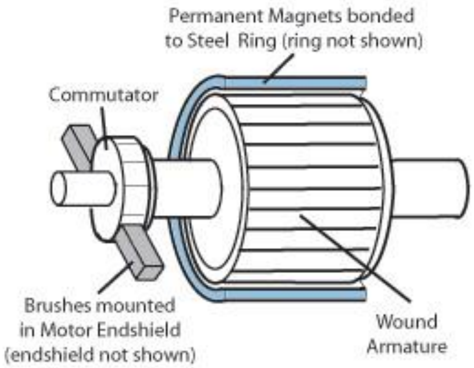

Figure3.7 schematic of dc motor

Interfacing of the DC motor performed in the lab with Arduino is shown is figure 3.8 below.

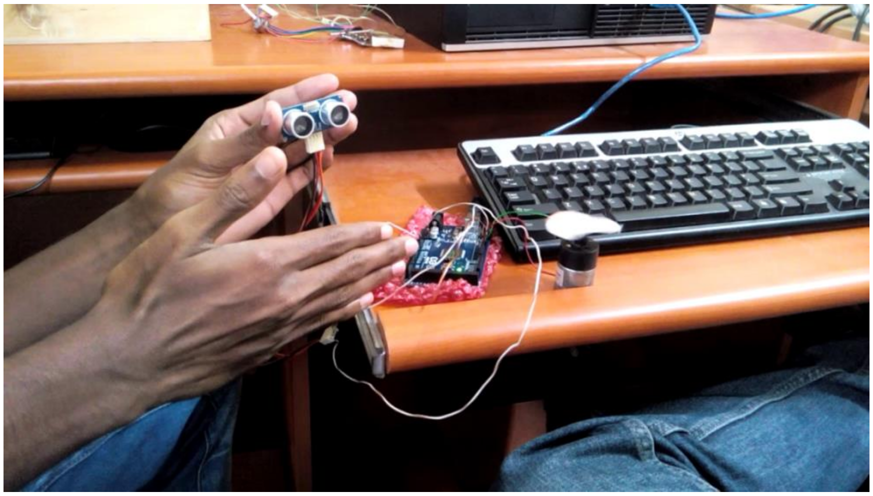

Figure3.8 Interfacing of the DC motor with Ultrasonic

3.3.4 Interfacing of the servo motor with Arduino

The servo motor is an electrical actuator used to actuate the processes. The servo is quite different than the DC motor, in servo motor the rotation is angular while dc rotates continuously. We can control the any angle position at any point of operation. In my experimental setup I used servo motor to develop the translation motion for the needle. The schematic of servo is shown below. The interfacing of servo is shown in figure 3.9.

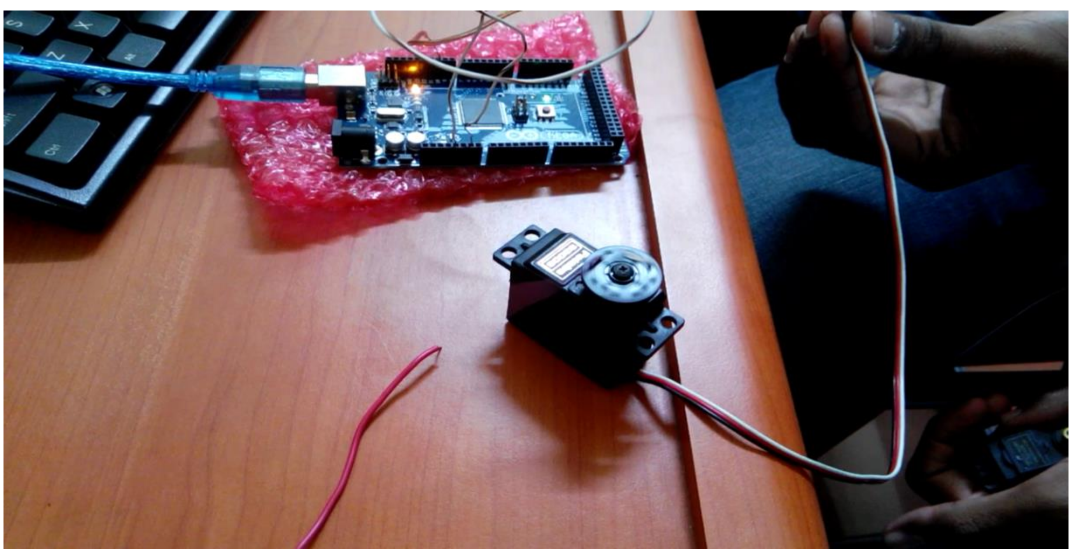

Figure3.9 Interfacing of the servo motor

3.3.5 Interfacing of the ultrasonic with Arduino

The figure 3.10 below is showing the interfacing of ultrasonic sensor with Arduino. The ultrasonic sensor used here is HC-SR04. The ultrasonic sensor having four pins, they are

i. Trigger

ii. Echo

iii. Vcc

iv. Ground

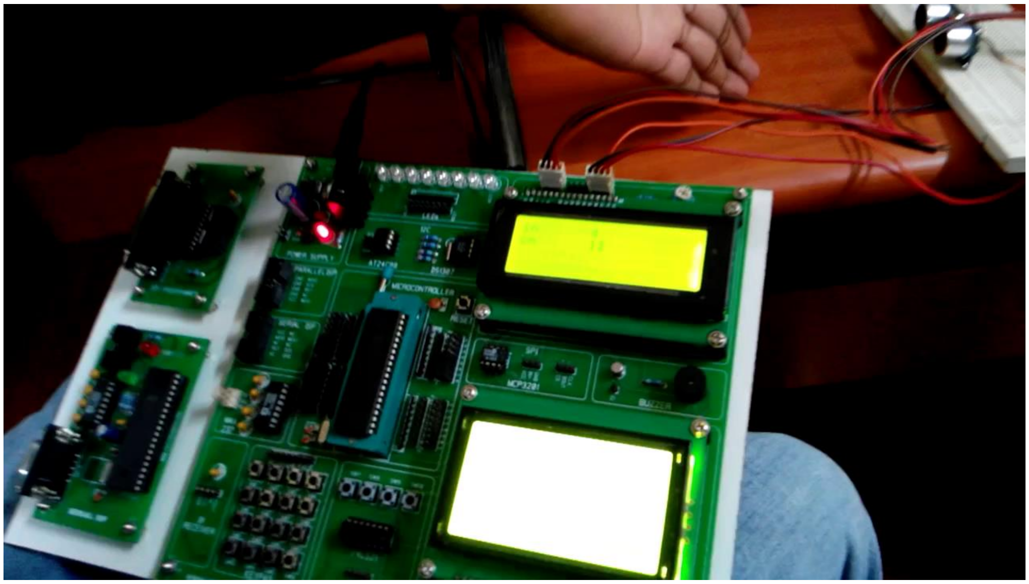

Figure3.10 Interfacing of the ultrasonic sensor with LCD.

Trigger

The PWM pin of Arduino is connected with the trigger pin of the ultrasonic sensor. The trigger pin sends PWM signal to the trigger section. Trigger pin is an output pin. Trigger section receives the PWM signals and start to send the ultrasonic waves. The generated waves hit the target.

Echo

The PWM pin of Arduino pin is also connected with the echo pin. The stroked waves from the target are received by echo pin. The time difference between transmitted and received waves is measured. The difference in time calculated and converted in the distance.

Vcc (power)

It supplies the 5v dc voltage to the ultrasonic sensor. The Vcc pin is connected to the 5v supply of the Arduino controller.

Ground

The ground pin provides zero potential to the ultrasonic sensor. It is connect with the ground pin of the Arduino controller.

3.4 Summary

The mechanism for this experiment is discussed with components used and interfacing of the components. The interfacing of the component used in development of the model is discussed. All components ate interfaced with Arduino. In the section 3.1 the detailed analysis of mechanism development is given. A simple mechanism for the insertion and measurement is developed. Section 3.2 discusses the analysis of components used. For this model we used some sensors, actuators and power supplies. Section 3.3 discussed the interfacing of the components used. It deals with the interfacing of components with Arduino.

CHAPTER 4

EXPERIMENTAL ANALYSIS

Experimental analysis

In our laboratory the experimental setup for needle insertion surgical system is developed, which is a vertical column assisted with rack and pinion mechanism. Our aim is to perform the detailed analysis for the needle insertion in the soft tissue and find out the effect of needle velocity and needle angle over the tissue deformation. It is commonly known that when needle is inserted in the tissue then tissue can deform and needle can deflect, so to eliminate these problems and develop an automated surgical system the detailed analysis is required. In the analysis I focused on the effects of some parameters on the tissue and those parameters are,

a) Needle insertion velocity
b) Needle insertion angle
c) Rotational speed of needle during insertion
d) Deformation of tissue
e) Deflection of needle
f) Reaction force on needle during insertion
g) Needle depth in the tissue

These above mentioned parameters are analysed one by one and observed the effect of all, over the tissue phantom. Once the analysis is finished the graphical analysis is done based on available values of samples. The graphs have been shown in result portion of thesis. The experimental analysis is consisted by following.

i. Experimental setup
ii. Procedure of the experiment
iii. Result
iv. Discussion

4.1 Experimental setup

An experimental setup is designed in the laboratory to perform the analysis of needle insertion in the soft tissue. It is a vertical column assisted with rack and pinion mechanism for the needle translation motion. Apart from this a horizontal bed is designed to keep the tissue phantom over the bed during the insertion procedure. A block diagram of the proposed setup is shown in the figure 4.1. In the figure on a column needle is mounted and the controlling of the needle is done by the controller. One horizontal bed is shown on which tissue phantom can be placed for analysis.

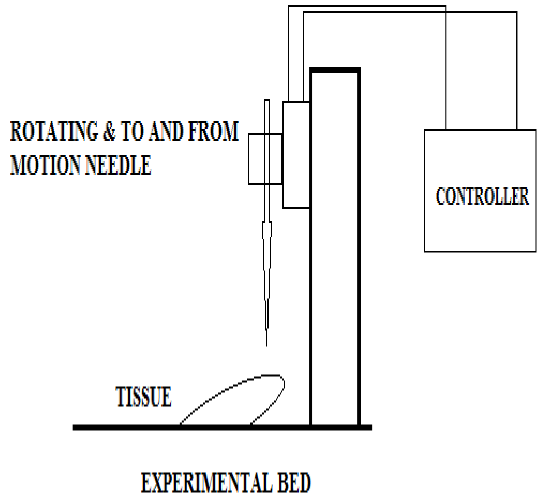

Figure4.1 The experimental set up for the needle insertion operation.

Based on the requirement the experiment can be up performed as an angular rotation of needle in XY, YZ & ZX plane. The needle insertion instrument is totally controlled by control circuit. The needle insertion is guided by the translational motion. The control circuit controls the speed and force of insertion as well as the speed and direction of needle. In my experimental analysis a 6-DOF force/torque sensor is attached to the needle holder in order to measure the forces and torques acting on the needle during insertion.

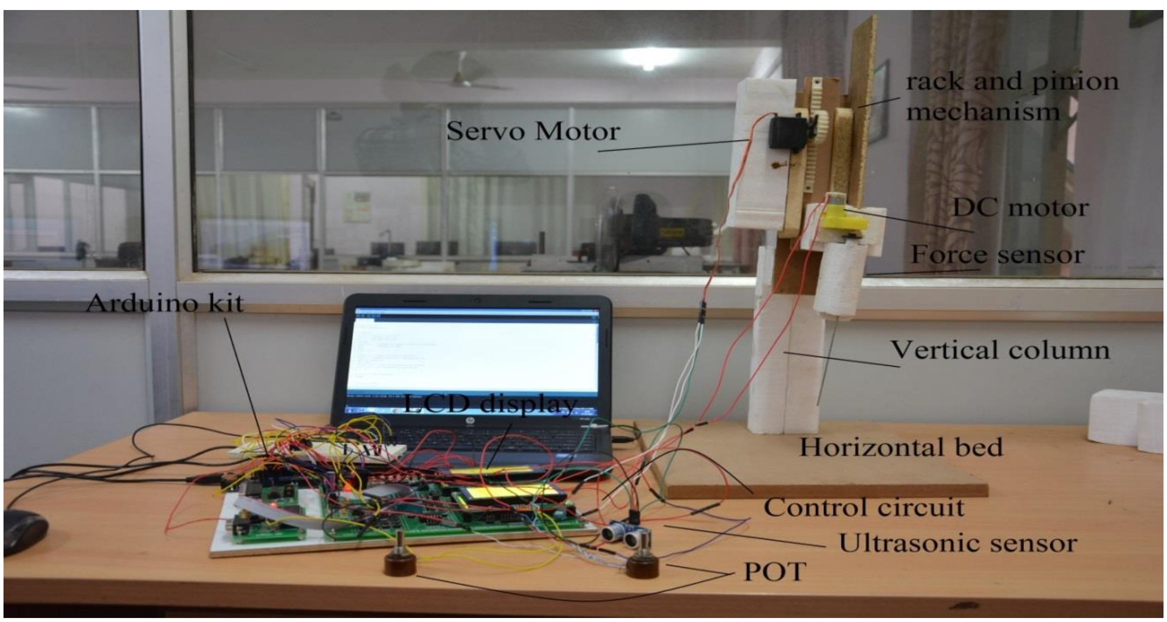

Figure4.2 Experimental setup.

4.2 Procedure and analysis

Experiments are carried out using several tissue layers and artificial veins type structure. It examines the different results by keeping the translation velocity constant and rotational speed as a variable parameter apart from this it also follows the conditions like no rotation of needle, continuous rotation with different speeds. To assure the perfect conditions of veins which should be matched with the inner environment of body, we filled veins with saline solution, and consider the diameter and length of the artificial veins similar to the blood vessel so that veins are subjected to a constant internal pressure identical to that inside the body.

4.2.1 When no rotation of needle

In the first experiment the needle rotation kept constrained and only translation motion actioned for the procedure. A tissue phantom is taken having the same characteristics of the live tissue and is setup on the bed and the needle is allowed to enter in the tissue. In starting the needle kept 10 mm above the specimen and slowly it allow to enter in the tissue. The velocity of the needle translation motion kept constant and starts the insertion operation. As the needle inserts in the tissue, the deformation in the tissue stated and the reading of force and torque are displayed on LCD screen. The deformation of tissue is also measured by displacement sensor and displayed on the screen. All displayed data are taken out, analysed and draw the graph. The velocity of needle insertion now changed and proceeds in above mentioned way. The velocities are 3mm/sec, 5mm/sec, 7mm/sec etc. corresponding displacement and force values are given below in table.

S.No	Velocity of the needle during insertion (mm/sec)	Force measured by the sensor(N)	Displacement of the tissue(mm)
1	1	4.36	2.3
2	2	3.80	5.2
3	3	3.35	8.3
4	4	4.25	10.12
5	5	4.08	14.5
6	6	3.70	18.45
7	7	2.40	24.34
8	8	3.47	28.30
9	9	4.56	36.56

10	10	3.30	40

Table4.1 velocity, force and displacement values

4.2.2 with rotation of needle

It is found that when the needle rotates the deformation of the tissue occurred in less quantity and the reaction force also reduces. The experiment is conducted with rotational speed of the needle changes. The data of force, displacement and speed of rotation are displayed on LCD screen. The graph observed in this way is shown in result section. The concept of rotation is become advantageous, since it reduces the tissue deformation and needle deflection. The table observed is shown below. During the experiment we found that the angle of needle insertion may also be a considerable point for analysis, in this experiment it didn't consider but for the future it can be analysed.

Before going on table analysis, here the dimensions of the tissue are given. The thickness of the artificial tissue was setup 60 mm, keeping in mind that the needle can move deeply for the deflection analysis. The tissue used here having the matching characteristics from the live tissue. We measured the tissue thickness using a scale. The dimensions of the tissue are measure by the scale and then the tissue phantom was setup on the bed stably. The movement of the phantom is constrained for the whole experiment as the reading of the parameters should not be affected. In the figure 4.3 below tissue dimensions are given.

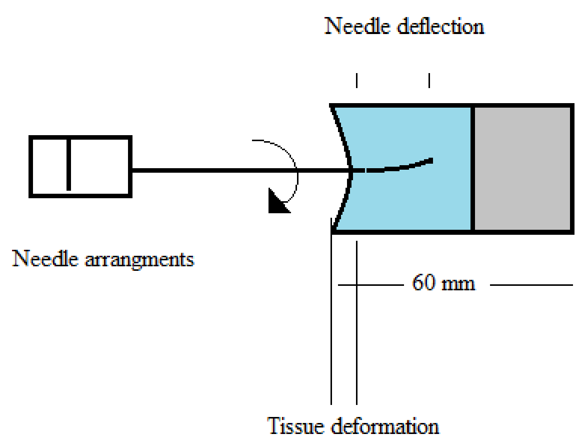

Figure4.3 The dimension of the tissue

S.No	Velocity(mm/sec)	Force (N)	Displacement(mm)	Rotational speed (rpm)
1	1	4.12	9.34	20
2	2	3.43	10.23	25
3	3	3.03	11.34	30
4	4	3.99	12.45	35
5	5	3.88	13.67	40
6	6	3.45	14.34	45
7	7	2.12	15.67	50
8	8	3.34	16.78	55
9	9	4.23	17.23	60
10	10	3.12	18.73	70

Table4.2 velocity, force, displacement and rotational speed

By the observation of the table mentioned above it is cleared that the effect of the needle rotation is advantageous in the needle insertion operations. When the needle rotates during the insertion it reduces the reaction force and also reduces the deformation. It is observed in experimental analysis that the speed should not be high otherwise it can damage the cells during needle deflection. In order to minimise the needle deflection in the soft tissue, the needle should be well sharped and size of the needle is also consider before insertion. The needle dimensions used in this experiment having the diameter is 1.5mm and needle length is 7 cm. The needle dimensions are shown in below figure 4.4.

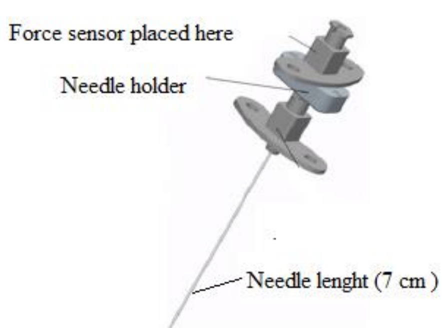

Figure4.4 dimenstions of the needle used and schematic of needle

4.3 Results

The experimented parameters are analysed and on the basis of experimental evidences of insertion, we performed the calculations of the results for the magnitude of the reaction force, displacement of needle in the tissue, velocity of the needle during insertion and rotational speed of the needle. The results for these experiments are shown in figures. The analysis of results has been done for following.

i. Velocity of the needle insertion
ii. Speed of needle rotation
iii. Displacement of needle in tissue
iv. Reaction force obtained from tissue

4.3.1 Velocity of needle insertion

The results for the insertion velocity (v) of needle experiments are shown in Figure 4.5. The graph in Figure represents the relationship between needle velocity (mm/sec) and needle insertion forces (Newton) versus time (s). In the graph, the velocity is taken on X-axis and the reaction force on the Y-axis. The data from the table are plotted in the figure, the highest reaction force is obtained on the surface of the tissue at just insertion of the needle. The highest force point is shown in figure. The force sensor indicated another highest reading when needle touches the base point of the tissue. When needle punctures the tissue, suddenly the force values decreases and then further rises till the deep insertion of the needle. The figure shows sudden decrement in force inside the tissue structure. This force reduces inside the tissue because of softness of tissue inside of it.

The figure 4.5 is shown below. Apart from this relation of velocity and force, the velocity and displacement relation is also exist which is shown in figure 4.7. When the needle inserted in the tissue at different velocity then the insertion of needle in the tissue is measured as the displacement (mm).

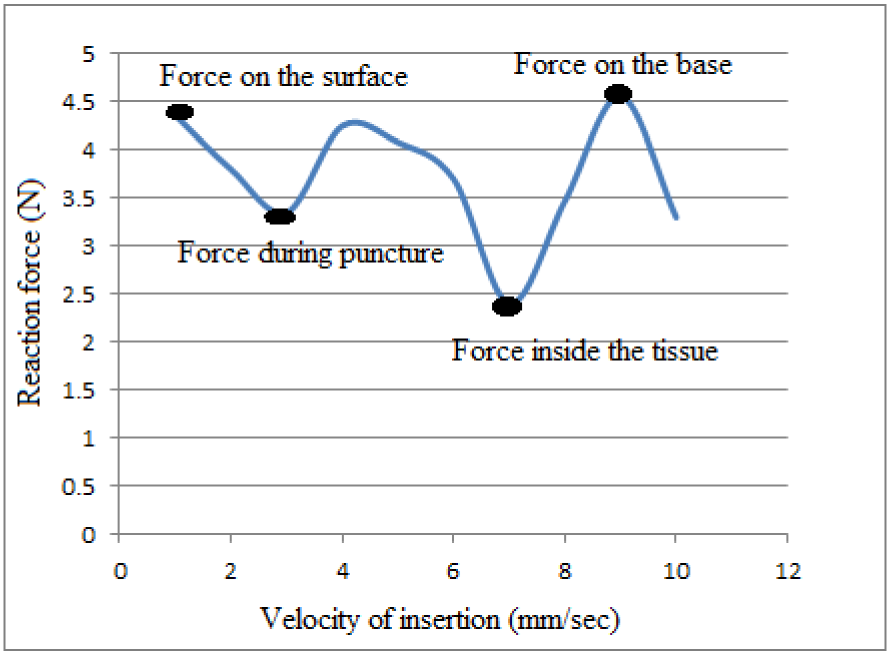

Figure4.5 plot between needle insertion velocity and reaction force on the needle.

4.3.2 Speed of needle insertion

As we discussed earlier the needle rotation is also a considerable point for the analysis point view. The rotation affects the tissue deformation and also the needle deflection. The rotating needle experienced less reaction force compared to without rotation condition of needle. The relation between displacements and rotational speed is shown in figure 4.6. Here from the plotted graph it is clearly shown that the relation between these two parameters are approximately linear, as the rotational speed increased the displacement will also increase. The displacement is not completely dependent on the rotation it depends on needle's insertion velocity also, so the relation between velocity and displacement of needle is also approximately linear. The frictional force due to tissue is also reduced when needle rotates. Here we are not showing the frictional analysis for the experiment. Rotating needle also reduces the chances of deflection of needle in tissue. The deflection of needle caused due to reaction force acting on it. When the reaction force elevated the chances of deflection also elevated but in case of needle rotation the reaction force reduces in considerable amount so the chances of deflection reduces gradually. Finally on the basis of this study it is found that the needle rotation is considerable point for the designing of the surgical needle insertion robot. The graph is shown below in figure4.6.

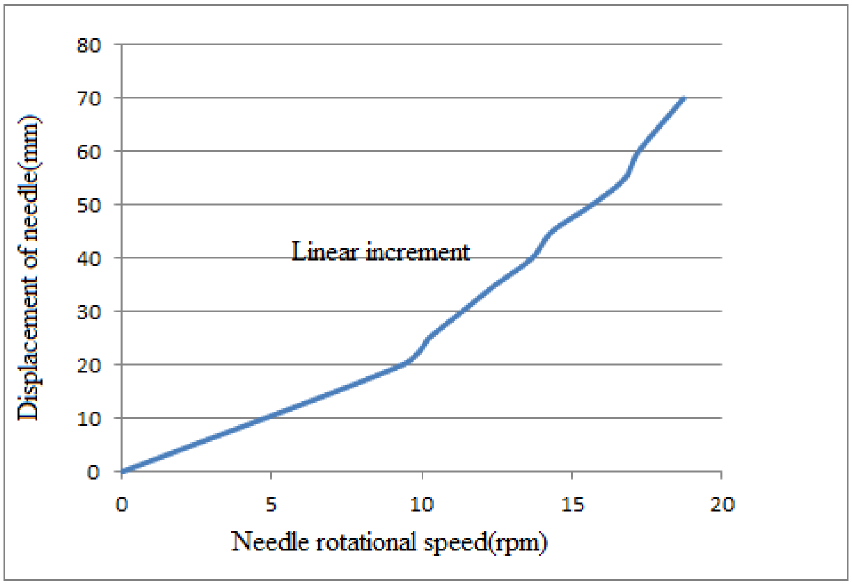

Figure4.6 Relation between rotational speed and displacement of needle

4.3.3 Displacement of needle in tissue

Displacement is directly measurement of the tissue deformation in the tissue as the needle deepens, the deformation occurred so the study of displacement is also needle for the design point of view. The relation between velocity and displacement is shown in below figure4.7.

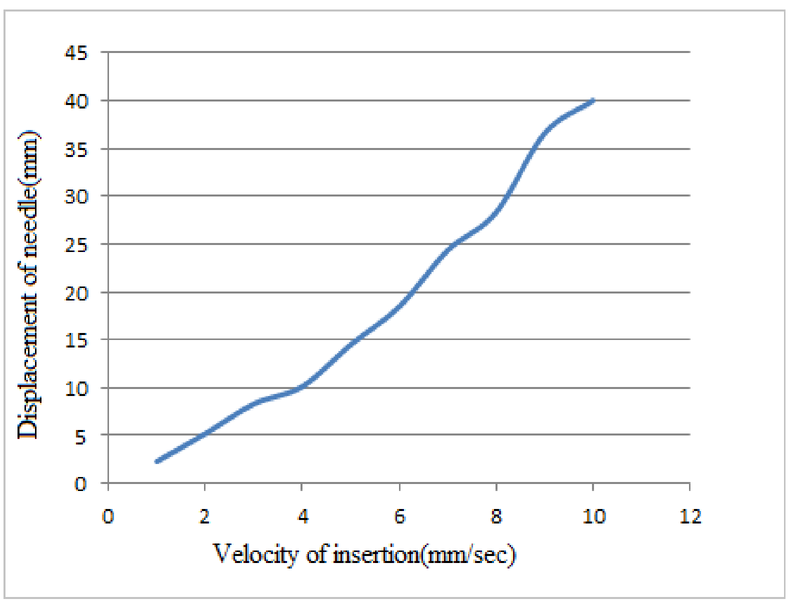

Figure4.7 Relation between velocity and displacement of needle

From the figure it is clearly shown that the displacement of the needle inside the tissue is approximately proportional to the velocity of insertion, as the needle moves forward the displacement increased.

4.3.4 Reaction force obtained from the tissue

In order to design a medical robot for the needle insertion, the experiments on various aspects related to needle insertion is required. The force is the fundamental parameter for consideration while going to design the system. Based on force values we easily know the behaviour of tissue for the needle. To minimise the reaction force we introduced the rotation velocity of needle. Minimum reaction force is the first priority of the experiment since it reduces the needle deflection in tissue. The accuracy increased when reaction force reduced. The relation between force and displacement is shown in below figure4.8.

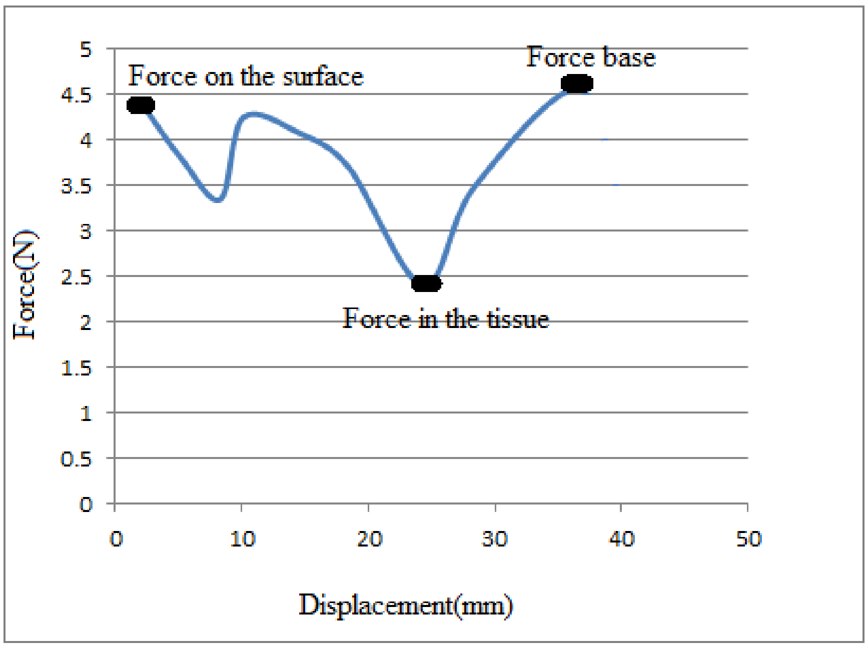

Figure4.8 Relation between displacement and force

In the graph when the displacement of the needle started in the tissue, the reaction force is more because at the surface of the tissue reaction will be more. As the displacement increases the value of reaction force decreases. At the middle portion of the tissue the reaction force minimum and again it started to increase up to the base of needle. At the base the reaction force increased. Finally the obtained data are analysed and develop a optimize model for the needle insertion.

4.4 Discussion

Based on the trend introduced by the results in fig. 2, there are the chances of the force reduction on the soft tissue surface by applying the required insertion velocity. On the tissue surface the force is more because sudden capture of the tissue introduces reaction. Inside the tissue force reduces gradually, since inside structure provides less reaction due to soft cells. The force further increases and it became very high at the base portion of the tissue.

Based on the results shown in fig 2, the relation between rotation of needle and displacement of needle inside can be understood easily. There is a linear relation exists between two, as the rotations increase the displacement also increases. The rotation generates a cutting force, which reduces the reaction force from the tissue. A cutting force has a torque and this torque helps in reduction of the reaction force. Apart from this, the displacement doesn't dependent completely on the rotation it depends on needle's insertion velocity also.

Based on the results shown in fig 2, the relation between needle velocity and displacement is given. The rotational speed vs. displacement and velocity vs. displacement are analogues of each other having same characteristics and these three parameters are mutually dependent to each other. When we introduced no rotation the displacement will occur slowly and with rotation the insertion time will reduce. So the model having rotation velocity of needle is more reliable for designing the surgical robotic system for insertion.

Based on the results shown in fig 2, relation between reaction force and displacement is given.

As the deflection changes its value, the force also changes accordingly. When needle started to insert the force also started to reduce since it has highest value on the surface of tissue. From this graph we can understand the behaviour of needle force as the needle inserted into the tissue. Needle moves from surface to base so in the complete journey of needle the reaction force can be understand and system can be design based on available data.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The reaction force on a needle during insertion into an artificial tissue was independently analysed and measured by a newly designed test setup, and the reaction force based on tissue behaviour is analysed. Apart from this the needle insertion velocity, rotation velocity and displacement of needle in the tissue is also analysed. The non-linearity of the reaction force during the insertion implies that the displacement and rotation of the needle affects the force value. The linearity in the displacement implies that the displacement is directly proportional with velocity and rotational speed of the needle, as the velocity increases the displacement also increased. From the detailed analysed data we can conclude the effects of various parameters over the needle insertion. The important factor among them is reaction force. For the designing of surgical robots the available parameters are very useful. It is pre study before development and design of the model.

5.2 Future work

The force acquisition process is a part of virtual reality force feedback in the robotics surgery system. The main goal of our work is to study the parameters of needle insertion for robotics surgery system which can provide accurate force feedback. The future work includes the development of a simulation for the insertion needle. And for more complicated surgical procedures, the force acquisition experiment can be developed by applying the concept of this work.

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