Simulation of Robotic Arm for Spinal Surgeries Engineered to Replace a Surgeon’s Tasks

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Abstract - A most common abnormality that affects the vertebrae is the disc prolapse. These conditions normally transpire in lumbosacral region and enmesh the spinal nerve at that point. A detoriation to the motor and sensory nerve at that point has an immediate consequence on that particular organ connected with the ascending and descending tract. Disc prolapse in thoracic region leads either to nerve root irritation or cord compression and it needs an immediate surgery to remove the disc lesion which is usually done by discectomy technique, an invasive spine surgery. However, the proposed system is to create a minimally invasive procedure to detach the disc lesion of the spine. The controlled and patient specific pre-operative planning is done by MIMIC using 3D model of the MRI of that patient. The new techniques on robotic arm like segmentation and surgical simulation will provide information about the positioning of the end effectors. Using 3D model design, the robotic arm with 3 degree of freedom is done by the SOLIDWORKS 3D CAD design software. SimMechanics is a MATLAB tool used for simulation of the physical model which gives control to the robotic arm. Furthermore, the simulation result gives the force used to produce torque at the joints and angle of joint due to torque produced. Finally, we show that the simulation in SimMechanics reduces the error occurrence in prototype construction.

Keywords - Disc prolapsed, Minimally invasive surgery, SimMechanics, SOLIDWORKS, MIMICS.

1. Introduction

The vertebral column is the central axis that supports the upper part of the body. It is also known as the spinal column. It helps in providing posture in movement and protects the spinal cord. Due to complex structure of spine, difficulties remain in achieving dexterity and precision of instrument within the confinement of a limited operating space during surgery. In modern era, the control of eye and hand movement during surgeries is one of the main difficulties for surgeons. To overcome the inadequacy and master surgeons’ task, tactile arm based robotic surgical techniques are introduced. This reduces the complications in spine surgery like thrombophlebitis (deep venous thrombosis), infection, persistent pain and transitional syndrome.

The spinal column is composed of a serial combination of bones stacked over each other. All these bones are clenched together by discs that absorb shocks from various stimuli. Any repair of this disc leads to a condition called a prolapsed or slipped disc causing severe pain and discomfort, often leading to severe lower back pain. When the disc which is slipped compresses one of the spinal nerves, then along with pain, numbness will be felt which might gradually decrease by carrying out normal routine activities. Painkillers like paracetamol, anti-inflammatory painkillers, muscle relaxant will help but taking too much of medications will give other side effects.

The only solution to overcome this severity and persistent pain is surgery. Discectomy is the surgical procedure to remove the swollen lumbar disc that exerts pressure on the root of the nerve in the spinal cord and it is done using different techniques based on the patient’s requirement. This procedure happens only at a ratio of 1:10 and is strictly advised for patients with severe nerve compression, locomotive difficulty, muscle weakness, altered bladder functions etc.

In SQ pelvic software which can simulate a tool to plan 3D surgeries, developed and to evaluate various possible pre-operative approaches and potential in orthopedics. In ARCASS adopt viable patient tool that extracts a 3D model of an un-identified patient from 3D medical images in DICOM format.

The Mazar Robotics Renaissance system is a robotic guidance product in the United States used to implant devices during spine surgery. Using the Computed Tomography scan (CT), a prototype of the region to be operated is built. This information is fed into a computerized 3D planning system which helps the surgeon to plan the surgical procedures and infer the test results for the condition and plan preventive measures prior the start of surgery thus resulting in high degree precision and safety. The procedure is carried out by placing the robot aside the patient either by

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attaching it to the patient’s bed or directly anchoring it to the spine of the patient. The size of the robot is about 12 oz beverage can, with a small arm. This arm can rotate and bend to fit on the spine depending on the location and trajectory. This method is only limited to complications like spine fusion surgery, scoliosis correction surgery, vertebroplasty and spine biopsy. It is not applied for prolapsed disc surgery.

In this proposed study a new simulation method for prolapsed disc surgery was designed. Due to complex structure of spinal cord, cutting away the bulge is tedious with the open discectomy surgery. Minimally invasive surgery benefits over open surgery and are particularly evident in spinal surgeries. For minimally invasive surgery we go for modern computer assisted surgical techniques. The patient CT/MRI is collected and patient specific pre-operative planning is done by the software called MIMICS. Thus, the co-ordinates for RCM have been collected. The physical model of the robotic arm with 3 DOF is modelled in 3D CAD software called SOLIDWORKS (2009). This physical model is exported to MATLAB tool SIMMECHANICS to control the model. The force given to the links, torque excited due to force given, and angle of the joints to place the end effector are analyzed. Inverse kinematics is used because the placement of end effector is known, depending on the remote center of motion and the angles of the joints should be calculated.

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Fig. 1: MRI Spine image of disk prolapsed in lumbar region between L4 and L5.

2. Methodology

Pre-Operative Planning

Intervertebral discs (IVD) are fibro-cartilaginous tissue composed of an annulus fibrosus and nucleus pulposus. The annulus fibrosus encloses the nucleus pulposus. Any injury or distinct biomechanical behavior, causes the inner portion of the disk to protrude through the outer ring. This bulges out compressing the spinal nerve passing through. Since, IVD is soft tissue, MR Imaging is prominent diagnostic technique and sometimes myelography is also used in screening [1]. A stack of images obtained in MR scanning techniques of the patient who has complications in spinal cord was modelled for pre-operative planning. A 3D modelling software MIMICS 10.01 by materialize is used for 3D modelling and surgical planning. Any type of 3D data for any physiological disorders can be modelled and used for surgery planning, implant rapid prototyping, and model linking to computer aided design (CAD) [2]. 3D modelling can be done by following steps. Firstly, Stack of MR Images in DICOM format from Patient who has disk prolapsed disorder is collected and imported and the orientation of the images in coronal, sagittal, axial view are chosen. Secondly, masking the Region of Interest (ROI) by thresholding called as segmentation. Grayscale information in the medical images used to create models by masking. The shades of the pixels in an image are related to numbered grey values. The image data can be segmented by grouping similar grey values [3]. To remove the unwanted pixels masked in thresholding region growing segmentation is used. After all other segmentation techniques used to get appropriate masking on ROI, 3D model of the masked region was calculated thirdly [4]. Surgical simulation is done to cut the bulge out of disc which gives the information about dimensions of the cutting point.

Physical model of robotic arm

To formulate this system an essential knowledge on degree of freedom (DOF) helps to link robotic arm. To model this system, it is necessary to be aware of the degrees of freedom (DOF) associated with the arm [5]. By counting the number of controllable joints, DOF is determined. The physiological model of the robotic arm is designed using 3D CAD software SOLIDWORKS shown in Figure 1. SOLIDWORKS serves the basic design tasks by providing different workbenches. In creating this model, a set of tools in workbenches like sketcher, part design, surface design, assembly design is used. The geometric design for robotic arm was designed with reference to [6] is shown in Figure 2.

Fig. 2: Visualization of the robot arm imported from the 3D model into the SolidWorks program.
movements, kinematic constraints and coordinate systems [7]. To get the active model of the robot the following blocks related to CAD model are used. Revolute joint denotes one rotational degree of freedom. The follower body rotates with respect to the base body about a single rotational axis going through collected body’s coordinate system origin. Sensor actuator ports are attached to the joint. Body replaces fixed rigid bodies to which the degrees of freedom are added. Joint actuator actuates a joint primitive with generalized force, torque or linear, angular position, velocity, and acceleration motion signals [8]. Joint sensor measures linear, angular position, velocity, acceleration, computed force, torque of the joint primitive. Body sensor measures the motion of the body coordinate system to which the sensor is connected. This also measures any combination of translational position, velocity and angular acceleration. Scopes are connected to the joint sensors and body sensor [9]. Blocks connected according to the physical model and control model of the robotic arm is simulated.

3. Results and discussion

3D modelling and surgical simulation

The MRI dataset which shows IVD, vertebral column where the spinal cord passing through in sagittal view from the patient who has disk prolapse in lumbar region is used for modelling. In Figure 3, the disk between L4 and L5 is prolapsed and that bulge out entraps the nerves in spinal cord which cause severe leg pain and back pain [10].

In segmentation the vertebrae and IVD has different grayscale values, so both the parts are segmented in different threshold level [11]. Figure 3(a). Shows the vertebrae along with spinal cord are threshold and at the ROI it is not threshold which denotes that there is a bulge out of disc. In Figure 3(a), IVD’s are threshold where the disk between L4 and L5 denotes that it is disturbing the nerves in spinal cord and in Figure 3(c). Only the ROI was segmented. After segmentation 3D modelling of the segmented regions is calculated.

Figure 4 (a-b) shows the respective 3D models of the thresholded regions in Figure 3(a),3(b),3(c).

Surgical planning is done to cut the prolapsed part of the disk. To get the bulge out section the 3D models of vertebrae and IVD’s are fused to together. Then the section to be cut is identified and using the cut with polyline tool [12]. The properties of cutting plane on the model of ROI in sagittal view show the dimensions like thickness, depth of the cut section in Figure 5.

Simulation of Robotic Arm in SIMMECHANICS

The model shown in Figure 6. is simulated to get the active model of the robotic arm. The axis of action to joint blocks are assigned as (0 0 1). This allows the mechanical system to work in an isometric view [13]. The mass and inertia of the referred body which links the joint are specified [14,15]. The joint actuators are connected to joints and give the actuation to joints by force and the joint sensors are used to measures the torque produced due to the force [16],[17]. The scope in connection with the joint sensors plots the torque in X axis and angle of turns in Y axis of all the three joints shown in Figure 6. The scope connected to the body sensor acts as end effector showing the position with combination of velocity and acceleration of the body coordinate system due to motion shown in Figure 7 A-C. Also Figure 8 shows the scope in connection with the body sensor. The performance of arm during simulation in isometric view is shown in Figure 9. The end effector trajectory with respect to movement of arm which shows graph of Time Vs position X(m), Y(m), Z(m).
Thus, this simulation result of the mechanical system reduces the occurrence of error in robotic arm prototype building [18],[19].

Fig. 6: Program scheme-Dynamic model of robotic arm.

Fig. 7: (a) Torque produced during movement of joint 1 (b) Torque produced during movement of joint 2 (c) Torque produced during movement of joint 3

Fig. 8: Isometric view during simulation.

Fig. 9: Trajectory of end effector.
4. Conclusion
In this work we have outlined the process of 3D modelling, segmentation, surgical simulation of set MRI Images using software called MIMICS. This enables to get the patient specific model for pre-operative planning before surgery. To give the physical appearance of the model of 3DOF robotic arm the software called SOLIDWORKS is used. This is user friendly software where we can de design our own model without any flexibility in our required design. The use of SimMechanics as a tool to model the mechanics of robotic arm allows the possibility to simulate the model. Simulation results of robotic arm will reduce the possibility of error occurrence in prototype construction. Future work will be extended to hardware development of robotic arm using arduino programming. Accelerometer to provide feedback data on the robotic arm angles at each joint, DC motor to control angular orientation of the arm, servo motors to control the rotation of the arm about the base, and force sensor to give tactile information will be used in prototype building. Finally, the hardware module and software module are interfaced to test the performance of the robotic arm.

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