Literature Survey

Introduction

For spine surgeries, robotics has started playing a huge role in making surgery easier [1]-[7]. Human error can cause a lot of complications in a person after spinal surgery. In [1], vertebral implants are being done and it is a very important part in the surgery plans nowadays. As mentioned above, the error of placing the pedicle screw correctly by a surgeon is about 3-55%. A robot can significantly reduce the error percentage while placing the pedicle screw. With recent developments in spinal surgery, from [2], it is visible that image processing techniques are one of the major inputs into spine surgery robots. The automatic placement of pedicle screws in the spine is being designed. In [3], bone tumor surgery is being the most important subject that is being addressed here. The surgery has a lot of errors due to manual surgical instruments. The advantages of higher precision and minimal invasiveness is achieved by using a robot for the purpose of this surgery. It is less intensive work for the surgeons too. During spine surgery, due to existing forces, there is a possibility that the necessary position and orientation of the robot is not reached and there is a mild error in it [4]. A method is proposed to quantify the deformation of the lumbar spine, based on mechanics of materials. While the pedicle screws are being drilled, there is no feedback [6]. Due to this, the distance of the drilling process is also estimated by the surgeon. A 6 DOF force/torque sensor is used to collect data for the force and torque intraoperatively. The growth of industrial robots is so dynamic that now robots are being made to collaborate with humans than to just help. This change is visible in all the robots that are used to assist the old people while walking,and safe human - robot interaction [8]. Safety, Coexistence and Collaboration are the 3 pillars for the safe interaction of humans and robots. In [8], for the purpose of safety, collision avoidance is being checked. Collision avoidance fails in case the robot cannot see the movement of the human. Ie., the movement of the human / obstacle is faster in that split second. In these cases, the physical collision can be checked and then the collision can be avoided. The venipuncture robot is used to find the venous blood vessels to take blood from the needle and then withdraw the needle. In the case that the doctor needs to do a spinal puncture, the images are taken from a CT to check where the puncture has to be made [11]. A novel idea of creating a minimally invasive spine surgery robot is used here by using image processing of a CT to get the necessary points where the robot will have to do the spinal puncture process. Robots like the Mazor SpineAssist, Mazor Renaissance, ROSA Spine, etc [12] are used for the purpose of spine surgery pedicle screw placement. All robotic systems must avoid dynamic obstacles autonomously, for which, path planning will be required [13]. Path planning is one of the most important methods required while designing a robot system. In this literature review, various methods are going to be looked into which are being performed in the medical surgery robots, mainly, the minimally invasive surgery robots.

Methods

1. Kinematics, Dynamics and Control

DH parameters are used to get the forward kinematics of the surgical robot [2]. The origin of each coordinate is fixed on the joint of each link. The transformation matrix T06 is calculated. Individual transformation matrices between each link are calculated and multiplied. Once the kinematics is calculated, the workspace is going to be calculated with respect to the kinematics. There are 2 kinds of workspaces, which are non-working and working zones. Every link has its own limitations and the robot forward kinematics must be found within the limitations. Inverse Kinematics is used to move the robot in an expected trajectory. The robot pedicle screw placement must be done correctly so that the spinal surgery can be done properly. These kinds of robots are being used in the surgery of hips and knees.

In [5], the spherical coordinates are being used for the purpose of the orientation control. The intersection of the needle guides are being found so that the exact location of the pivot can be determined.

A GUI is being used to perform the task of locating where the needle needs to be placed for the purpose of the surgery [7]. Once located, the mechanical device consists of a 3-DOF cartesian stage with prismatic joints for the initial positioning of the tool. A Planar Double Parallelogram is being used for the purpose of creating independent rotations for the mechanism.

The kinematics of the robot is being found out by using Image Acquisition to find out the relevant 3-D data of the 6-DOF robot [9]. Once achieved, for the forward kinematics, the DH parameters are being found for the robot.

The detailed analysis of the kinematics of a 5-DOF robot is being found out by using DH parameters [11].

A parallel manipulator is being used and the error between the joint locations is being found [16]. The coordinate system is being established after which the kinematics is being found by using DH parameters and transformation matrices. Analysis of the joint-link trains are being done and then for error minimization, the kinematic calibration is done again.

A parallel manipulator is being used here and the kinematics is being found out by using Euler rotation matrices [17]. The GUI is created to move the robot in any given direction. Surgical robotic system for spinal surgery is being developed here.

A master-slave approach is being used in this paper [18]. Here, using transformation matrices, the kinematics of the robot are being established for the phantom desktop of the master and slave robot.

2. Collision Avoidance

The dynamics model of the robot needs to be known properly to find if there is any collision between the obstacles and robot [8]. Differential Kinematics is being used here. The collision is being avoided by finding the residual force that is remaining after the collision. The sensor data is being used to determine the obstacle and robot distances.

The obstacles are being considered to be either spheres, cylinders and cuboids [9]. The collision is being detected between the joints of the robot and that of the robot with the work space. Once, obstacles are detected, improved A* algorithm is being used for avoiding collision in the given path.

Data is being collected from the IR camera sensors and once collected, a data acquisition system is being created for the purpose of understanding the flow of data [10]. Once this is achieved and the noise - signal is found, an empirical model is being found. Key point recognition is used for feature extraction and finally the vertebral displacement is obtained which is mainly caused by respiration.

The error model for the given robot is being found out after which the precision of the position is being determined by performing the position analysis by calculating the different types of error [11].

Model Predictive Controller is being used for predicting where the obstacles are going to be and hence obstacles are being avoided [14]. The performance of the robot is also being checked.

Data Acquisition and Data Analysis can be done to find the obstacles and the necessary path to follow [19].

The given problem takes the geometric constraints into consideration [23]. The movement to the target point is done by avoiding obstacles. This is being embedded in the path planning control algorithm.

3. Path Planning

The robot path is being generated by finding the velocity field for the robot [1]. This is done so that the robot does not fail to find the position in which the pedicle screw must be inserted.

Image Processing is being done using DICOM to find the robot path points [3]. Once this is found, a closed spine path is being found. Here, there needs to be tool calibration. Once, this is done, the robot is moved to the particular location for the drilling to begin.

The model for the lumbar spine is being created to check where the robot is being placed properly and whether there is any margin of error [4]. This is done by checking the various forces like the axial forces on the deformation of the lumbar spine and other torques and are being recorded and with the help of this data, the proportionality constant is being calculated and with this the margin of error is calculated.

The PRM (Probabilistic Road Map) and RRT algorithm is being used to plan the path of the robot [13]. Here, the obstacles are considered to be cylinders and each robot link is also considered to be a cylinder. Collision avoidance is checked.

Image processing is being used for the purpose of finding out the 3-D points using CT images [15]. The model is being created and then the trajectory is being tracked. The error is being reduced by using least square approximation.

Image processing is being done using DICOM [20]. Affine transformations are being used for the reconstruction of the 3-D image and if there is any distortion in the image.

An architecture is created in such a way that the robot will know where to move automatically [21]. This is done by using Fuzzy Logic techniques on the velocities of the joints. This is the step on auto-guided movements for the robot assistant to find free-obstacle paths to a target location.

To solve the path planning problem, optimization techniques and hybrid optimization is being used to avoid obstacles [22].

There are two kinds of motion planner being created [23]. The global motion planner consists of finding a smooth path to perform a given task by using potential fields. The local motion avoids obstacles through the use of an analytical modulation matrix from one point to another.

4. Dexterous Workspace

For finding the dexterous workspace of the robot, initially the transformation matrix is being found to check the maximum movement of the robot in the x, y and z axis [24].

With respect to the given robot, the value changes and with the help of these extreme values, a cuboid is being created with the length, breadth and width being x, y and z respectively,

120 degree arc used to define the dexterous workspace [25]. By sampling the reachable workspace, the dexterous workspace has been found.

The dexterous workspace is being calculated by using image based calculations [26]. Obstacles are also being registered in the given space. The workspace is being created to avoid obstacles also.

Conclusion

In the following literature review, there are various methods that are being used to find the collision avoidance, path planning and workspace of a given robot for minimally invasive surgeries. These techniques can be easily incorporated into minimally invasive spinal surgeries also. The given review, gives a detailed description of every procedure executed.

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