Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 7, Issue 24, pages 7-12, 2021

A Novel Image Processing Algorithm for Determining the Optimal Base Point of the Screw for Spinal Surgery

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Abstract –In the preparation phase for a spinal surgery doctors usually use CT and MRI images. Using these images they estimate the size, direction, and placement depth of the screw used for the surgery. As a result, surgical errors can occur. Therefore, an algorithm for reducing surgical errors is needed for supporting the doctors in finding the optimal location for the surgery. The method developed in our earlier work could determine the contour line and the highest point of the vertebra (called the base point) where the screw should initially be placed. In this paper, using the Bresenham line drawing method, we will propose a more accurate algorithm for determining the optimal base point, the direction and the extent of movement of the screw for the spinal surgery.

Keyword spine surgery, CT, medical robot medical imaging, surgery support, medical informatics s

I. Introduction

A prerequisite for successful spine surgery is that the doctor can position the screw used for the surgery in the patient's vertebrae. The doctor can perform the surgery on the basis of experience and with the help of CT / MR imaging performed before the operation [1,2,3]. The doctor is unable to see through the spine, so the surgical experience to date will help determine the size and position of the formerly made screw. As we mentioned in our previous article [4], computer image processing can help in this area as well [5]. Our algorithm which can support the doctor, was able to determine the outline of the vertebra and its surgical area even in its earlier state. The algorithm had to be developed further in favor of the preparation of the surgery. In this article we will show how the developed algorithm can determine the size of the surgical area of the vertebra and the steps of the operation

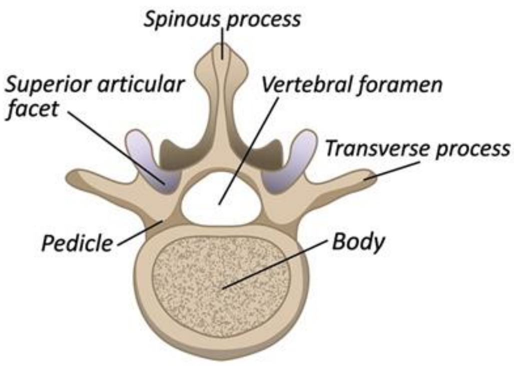
A. Surgery Introduction

We briefly describe the surgical procedure that is supposed to be supported by IT. The human spine may need surgery in many cases., however, only one procedure is described in this article.

The basic function of the spine is to protect the spinal cord and nerves from injury which ensures the stability of the spine. On the one hand, the structure of the spine serves a protective function and on the other hand allows the vertebral vertebrae to move in a coordinated manner relative to each other. If these functions are impaired for any reason (as a result of an accident or aging), the spine becomes unstable. To improve the stability of the spine, spinal surgery is performed [6,7,8]

The goal of spinal stabilization surgery is to eliminate the instability of the spinal section by inserting a metal stabilizing device (screw) into the pediculus, and to eliminate any physical source of nerve compression and pain. To prepare for surgery, the surgeon takes x-rays of the surgical area. Then he plans the surgery in theory and then performs it based on his own experience. However, due to the human factor, certain surgical defects can occur.

Figure 1. Spine anatomy [9]



Like in the case of any other screws, it is necessary to pre-drill the screw used during spinal surgery. This is where the human factor comes in. The surgeon is unable to see through a vertebra and drill exactly into the center of the pediculus. The pediculus is 5-7 mm thick and is not visible to the naked eye as it is covered from above, from where the doctor sees it during surgery (Figure 1). Medical errors result from the above. Sometimes the hole drilled for the screw is drilled by the doctor in the wrong place, which can result in the screw not performing its proper function or, in the worst case, causing permanent damage to the patient. The result of the surgery is seen after another CT scan. If the recording does not show the expected result due to the former error, the patient must be operated on again.

II. Preparing for Surgery

In the preparatory phase the physicians study the patient diagnostic images [10,11]. These images contain slices of the patient. Surgical vertebrae are analyzed by doctors using these images [12]. Based on their previous experience they determine the size of the screws used for surgery (Figure 2), the screw angle, the depth of the drill and where to penetrate the vertebra.

Figure 2. Example of screws what use in spine surgery [13]

As the doctor is unable to see through the patient during the operation, errors occur. Humans are not made based on a template, so the bones are not exactly the same. Hence, it takes a lot of experience to prepare the surgery. The doctor should keep the following points in mind before performing the surgery:

- Records of the operative vertebrae should be studied.
- Determine the size of the hole to be drilled and the screw to be inserted based on the images.
- Determine the entry point relative to the pediculi site.
- The input angle must be determined.
- The drilling depth must be determined.

The main aim of our research is to support these processes by the computer [14,15,16]. Before the surgery a CT images needs to be made of the patient. These images could be analyzed by the computer and the results could be then sent forward to a robot designed for this task. Next we are going to show how the present form of the algorithm can assist the doctors.

III. The Proposed Algorithm

A CT scan of the patient is performed before surgery. Thanks to digital advances, these recordings are stored on a computer. The standard for digital medical images is DICOM. This standard specifies how often the patient should be imaged, which means that a slice thickness can be set before imaging, which determines the size of a spinal column to be imaged. The standard also determines where this image is located within the patient [17]. The DICOM coordinate system (Figure 3.) starts at the top of the human head and is able to tell the exact position of the slice within the human body in a 3dimensional coordinate system. Each slice taken during recording contains the corresponding X Y and Z coordinates.

Figure 3. DICOM coordinate system[17]

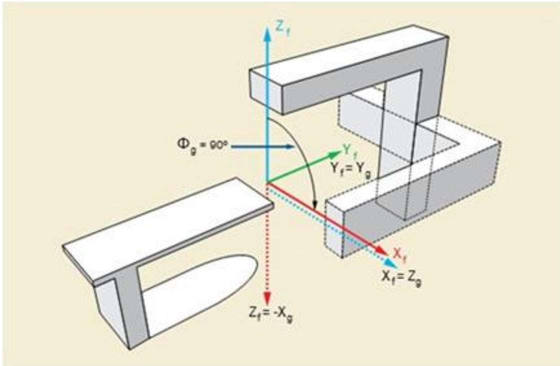


Figure 4 shows a pre-surgical slice of the images that allows the doctor to plan the surgery. Based on this, the physician must select the drill and screw of the appropriate size. Moreover, this recording is available to determine the input angle as well.

Figure 4. A slice of DICOM series before surgery

The algorithm presented in this article has been developed to help the surgeon. In the current state of the algorithm, it can only make suggestion for a selected slice for the physician.

A. Previous Issues

In our previous article [4] we described how the scanned image was able to determine the outline of the operative vertebra and the point where the screw should be placed (Figure 5). Subsequently, the data set out in the previous list had to be determined. A yellow rectangle shows the surgical area. The edge of the pediculus is highlighted with red. The algorithm is supposed to determine the size and middle point of the area in red.

B. Shortly About our Earlier Algorithm.

The first step in developing the algorithm was bringing the images into a format that could be processed with it. We chose the OpenEvilDicom [18] framework for processing and C # as the programming language.

EvilDicom is an open source framework developed for the C # language. It allows DICOM series to be easily scanned into a PictureBox and converted from there to other formats. Examples are Jpeg and PNG. These image formats can easily be processed pixel by pixel in C # There are several OpenSource frameworks for image processing. EMguCV framework is a version of OepnCV for .Net environment [19]. The DICOM Series are from PAMOK, Győr, Hungary, and these series were made by Siemens CT machines[4].

Figure 5. Two circels shows the defined surgical area

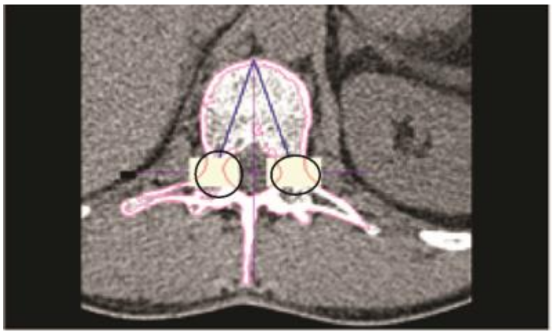


Figure 6 and Figure 7 shows the process of the previous state of our algorithm. Its shows how can detect the pediculi in CT scan of vertebrae.

Figure 6. Flowchart of Pediculli decetion

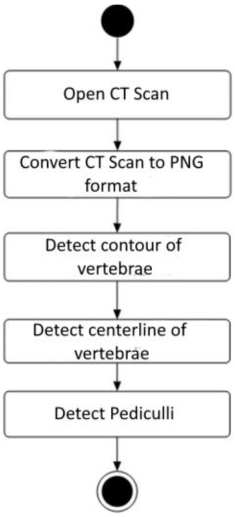
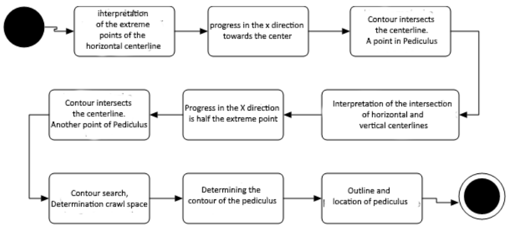


Figure 7. Flowchart of Pediculli detection process



C. *Determination of the Smallest Diametert*

The algorithm was developed from the state shown in Figure 5. Since the size of the screw depends on the size of the pediculi, we had to determine it. The two yellow areas in the figure show where the screw should be placed during surgery, so it was in this area that the pixels that make up each pediculus had to be searched for.

Since it is a requirement that the screw should not protrude from the vertebrae, we had to determine the smallest diameter. During the search we stored the points forming the pediculi, interpreted to the right and left, so we got two sets of points, each point having an x and a y coordinate. The image can be understood as a two-dimensional coordinate system, and we use the Euclidean distance between two points $x=(x_1, x_2)$ and $y = (y_1, y_2)$

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

Where d is the distance sought, x_1 and y_1 are one point on the set of points on one side of the pediculus, x_2 and y_2 are one point on the other side of the pediculus. Of the distances thus obtained, the smallest had to be found. These distances are in pixels and will need to be converted to millimeters as standard medical screws are given in millimeters [20,21].

Figure 8. The two lines represents the minimum distance in pediculus

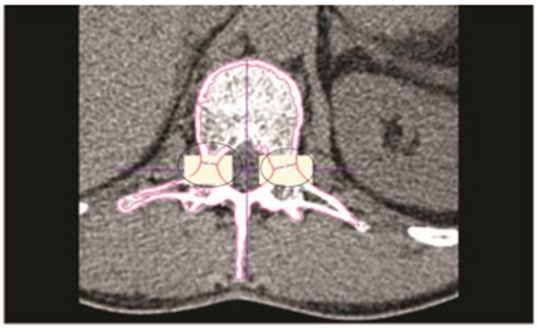
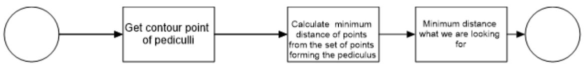


Figure 8 shows the smallest diameter of the two pediculi. In relation to this, it is necessary to determine the direction in which the screw can be positioned, causing the least damage. The direction will be optimal if the screw passes exactly perpendicular to the center of the specified diameter. You can also use coordinate geometry to search for this, since the two points that make up the smallest diameter define a section for which the two extreme points are known. With this in mind, the bolt must pass through the center of the section. The center of the segment is determined by the x and y coordinates of the known points, so a point on the line we are looking for is certainly known.

Figure 9. Flowchart of minimum distance



The equation of a line can be written using two points that fit the line. The center of the section was completely known, which is conceptualized as one of the points in our searched equation. The circled points are shown in Figure 10, where for clarity the points are shown in white.

Figure 10. The midpoint of the lines witch should the drill crossed

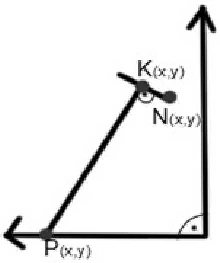
The equation of a line, if we know the two points of the line and its normal vector can be written according to coordinate geometry:

$$(N_x*P_x)+(N_y*P_y)= (N_x*K_x)+(N_y*K_y) \qquad (2)$$

Where in this case:

- $N = (N_x, N_y)$ represents the normal vector, which can be understood as one of the extreme points of the pediculus,
- P is the point where you want to start the drill, K represents the midpoint of the pediculus $P = (P_x, P_y)$ is the point where you want to start the drill, $K = (K_x, K_y)$ represents the midpoint of the pediculus.

Figure 11. The point for equation

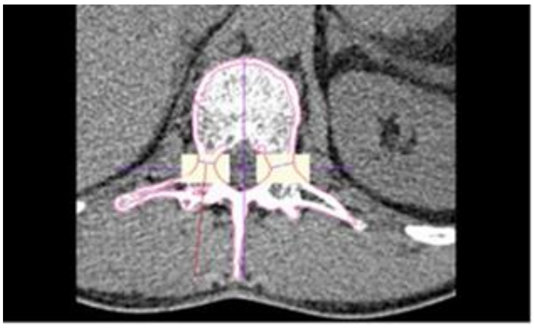


We can assume for P that we know one of its coordinates. This point has multiple roles, on the one hand, to define the straight line, and on the other hand, it will be the so-called starting point, where the drill bit should be moved relative to the center of the vertebra. The centerline of the vertebra was given, as we have already determined this, and the centerline of the vertebra can also be set to the origin of the drill. However, we know the coordinates of this point, so this will be our starting point.

$$P_x = \frac{(N_y*K_y)+(N_x*K_x)-(N_y*P_y)}{N_x} \qquad (3)$$

Figure 11 shows that as a result of the determination of point A, the passage of the drill that exactly penetrates the pediculus was determined. The line shows the way where the drill should go.

Figure 12. The line to pediculus represents the optimal way of drill



D. Defining the Input Angle.

It is now known where the drill should be started. Figure 13 shows that the drill should be started at an angle rather than perpendicularly. The angle searched can also be determined by coordinate geometry.

Figure 13. The angle witch shold given to the drill

The two vectors are known, so they have to determine their angle, and find their position relative to the centerline. The two known vectors start from a common point equal to the drill's starting point. The angle sought is determined by the following equation, given three points which based on coordinate geometry:

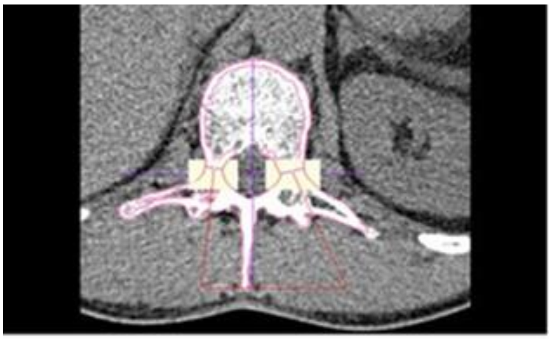
$$cos\alpha = \frac{(x_2-x_1)*(x_3-x_1)+(y_2-y_1)*(y_3-y_1)}{\sqrt{(x_2-x_1)^2*(y_2-y_1)^2}*\sqrt{(x_3-x_1)^2*(y_3-y_1)^2}} \qquad (4)$$

The resulting angle allows us to adjust the drill to the correct angle of the drill. However, it is still necessary to determine the movement relative to the center. For this we need two points which are given:

- one is the starting point of the already defined centerline, the centerline at the top of the vertebra,
- the other point is the point we used to calculate the direction and angle that we were looking for.

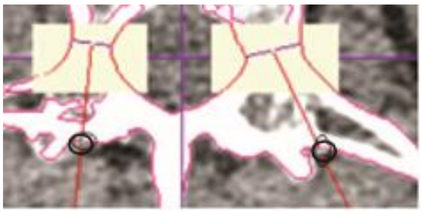
Positioning does not require movement in the y direction, so we only needed to calculate the difference between the x coordinate of the starting point and the x coordinate of the point at the top of the centerline. As the values are represented in pixel and these are difficult to process in reality, it was necessary to determine this movement in millimeters. The resulting image is shown in Figure 14.

Figure 14. The red line shows the optimal path of the drill during surgery. The movement to left and right from the centerline, and the angle for drilling.



We have consulted with doctors about where to begin drilling during surgery. Experience has shown that the drill is started at the beginning of the vertebral body. This point is intersected by a straight line drawn between the origin of the drill and the midline of the pediculus. The point we were looking for is shown in Figure 15.

Figure 15. The two point which is circled what we looking for



As we described in our previous article [4], we invented a unique RGB code for the outline to identify it. The x and y coordinates of these points are not unknown. we could calculate the intersection if we know all the coordinates of the direction. However, in the developmental environment we are working, the algorithm for calculating 2-point line points is not published, so we had to find a way to solve this problem. we have chosen the Bresenham algorithm. The use of Bresenham algorithm was necessary because the line drawing function used in Visual Studio does not determine all the coordinates of a line drawn between two points. However, to calculate the point of intersection of the contour and the line, it was necessary to know the coordinates of the points forming the line.

The essence of the Bresenham line drawing algorithm [22,23,24,25] is to calculate the path from one to the other by knowing the x and y coordinates of the start and end points. By storing this path, all the coordinates of the drawn line were already known, with which we were able to determine the point of intersection of the vertebra. We could also determine the length of the starting point and the point of intersection, so it was possible to determine where to turn the drill. It is unnecessary to turn on the drill at the starting point as it would give you extra time and this time would not be useful, since the surgery time would increase.

CONCLUSION

The developed algorithm can determine the following in its current state for the preparation of an operation:

- Initial coordinates relative to the image in pixels. This must be converted later in millimeters.
- Determine the centerline of the vertebra, which can be used as a reference for moving the drill head, and how many millimeters the drill head must be moved to the right or to the left in order to achieve the starting point
- From this point, the algorithm can determine the required angular rotation to drill through the centerline of the pediculus.
- It can tell how many millimeters the drill has to be moved until it reaches the beginning of the vertebral body.
- It is able to determine the size of the pediculus in millimeters.

As a further development, it is necessary for the physician to be able to make corrections. Although the algorithm calculates optimum values, the doctor may want to modify these data to increase the success of the surgery. Further study of the type and size of surgical screws is necessary so that the algorithm will be able to offer a screw that is guaranteed to be relevant for the surgery and does not cause injury to the patient. In its current state, the algorithm is able to provide parameters on a two-dimensional image. The images of the vertebra show a slice of the vertebra. The algorithm must be able to select from these slices the one that forms the middle.

ACKNOWLEDGMENT

The publishing of this paper was supported by GINOP-2.3.4.-15-2016-00003.

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