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Positioning Accuracy Test of A Self-Developed 2D C-arm Image Based Robotic Navigation System for Spine Surgery

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Abstract

This manuscript presents positioning accuracy test of a self-development 2D C-arm image based robotic navigation system for assisting the surgeon to implant pedicle screws to the planned locations. The main difference of the system to the ROSA Spine system or Mazor X system is the use of 2D C-arm images instead of 3D C-arm (O-arm) or CT images, which is because 2D C-arm is more popular and available in most hospitals. The surgeon uses a positioning probe to plan drill paths directly on the patient's back, which are projected and shown on the computer-displayed C-arm AP and LA images so that the surgeon can make sure the correction of implantation path. The spatial position and orientation of the implantation path are also input to the robot controller to enable the robot to move automatically the guiding device to align with the planned path. Then the surgeon can easily drill and implant pedicle screw into the pedicle by following the guiding sleeve. The positioning results of phantom experiment indicate that the average distance error of probe tip between planned and guided paths within the pedicle is 1.2 ± 0.3mm and the average direction error between the two paths is $0.4 \pm 0.1^{\circ}$.

1. Introduction

To implant pedicle screws into right positions, the surgeon usually needs to spend time to take a lot of C-arm X-ray images during operation, which also makes a risk for medical persons and the patient to expose in a high-radiation-dose environment. Furthermore, implantation process of spine surgery is highly relying on the surgeon's skill and clinical experiences. This manuscript presents a self-developed 2D C-arm image assisted robotic navigation system for assisting the surgeon to implant pedicle screws to the planned locations (Chang, 2016). The robotic navigation system integrates a NDI Polaris optic tracker, a Universal UR5 robot, and an Advantech all-in-one computer as shown in Figure 1. Instead of using 3D images such as CT (Mazor X) or 3D C-arm (ROSA Spine) which has high X-ray exposure, the developed robotic navigation system uses C-arm AP and LA images for path planning (Lefranc 2016 and Lonjon 2016). After AP and LA images of target spine and X-board (for image projection calibration) held by the robot have been taken, the surgeon uses a positioning probe to plan drill paths directly on the patient's back, which are projected and shown on the computer-displayed C-arm AP and LA images so that the surgeon can make sure the correction of the planned paths. The spatial positions and orientations of the planned paths are also calculated and input to the robot controller to enable the robot to move automatically the guiding device to align with the planned path. Then the surgeon can easily drill and implant pedicle screw into the pedicle by following the guiding sleeve.

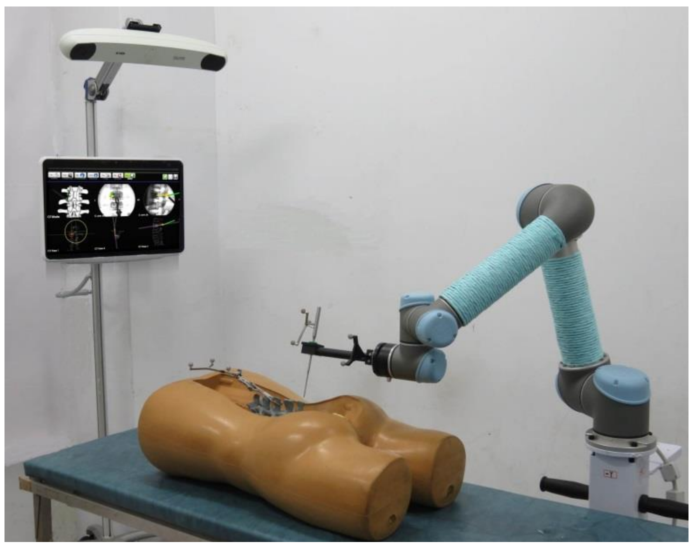

Figure 1: The C-arm image assisted robotic navigation system for spine surgery

2. Experiments and Results

Figure 2 shows the operating room environment for positioning experiment of the self-developed robotic navigation system, where a Ziehm Solo C-arm equipment is used for taking spine sawbone images. The computer displayed C-arm AP and LA images for path planning and navigation are shown in Figure 3. A positioning probe tracked by the optical tracker is placed at the drilling inlet of the pedicle, and its orientation and tip position are detected and projected on the AP and LA images as the planned (target) path. The projections of the tip and another one point of the positioning probe on each of the C-arm AP and LA projections of the positioning probe are chosen to calculate the navigation path (position and orientation) by using C-arm AP and LA bi-plane projection method. After the robot has moved the guiding device to the recorded target path, the path determined by the probe placed into the guiding sleeve is recorded as the guiding path. By repeating the tests for several different pedicles, the experimental results indicate that the average distance error of probe tip between the target path and guiding path is 1.2 $\pm$ 0.3mm and the average direction error between the two paths is 0.4 $\pm$ 0.1^{o}. Moreover, the average distance error of the probe tip between the target path and navigation path that calculated by the bi-plane method is 1.9$\pm$ 0.2mm and the average direction error between the two paths is $0.8 \pm 0.3^{\circ}$ (data was not stable because the projection points were selected manually by the user). The overall positioning errors are less than the desired maximum 2mm distance error and the maximum 2° direction error.

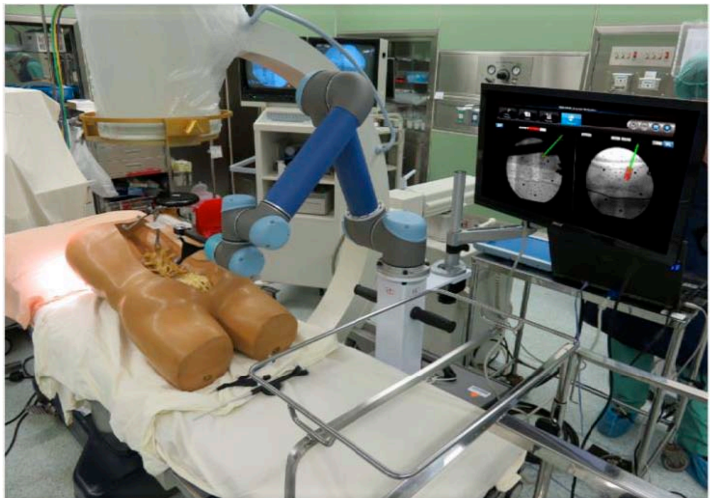

Figure 2: Robotic navigation test at Cathay General Hospital

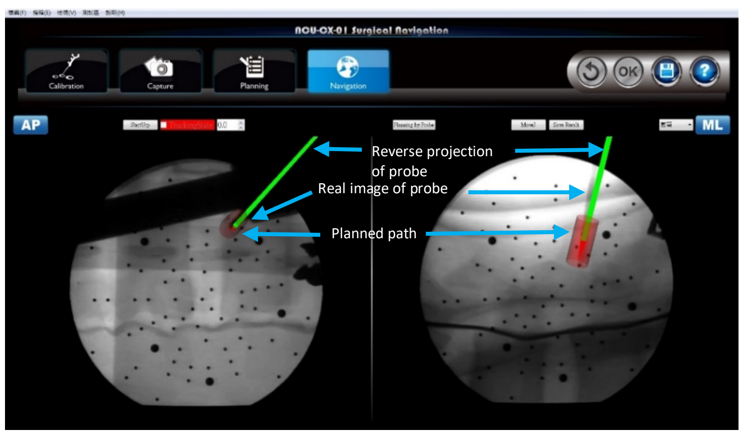

Figure 3: Computer display of Robotic navigation test

3. Conclusion

This study expanded an existing C-arm-image-assisted navigation system with a robot manipulator for minimally invasive spine surgery. Currently, the positioning accuracy of the robotic navigation system using spine phantom seems to be good enough for clinic applications. However, further animal trials are necessary to verify desired functions and validate clinic applicability.

4. Acknowledgement

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