P-00081

Teleoperative Pedicle Screw Insertion Guiding System for Spinal Fixation Operations

Daral Maesincee
Department of Biomedical Engineering,
Faculty of Engineering
Mahidol University
Nakhon Pathom, Thailand
daral.mae@student.mahidol.edu

Thitamorn Panyawong-ngam
Department of Biomedical Engineering,
Faculty of Engineering
Mahidol University
Nakhon Pathom, Thailand
thitamorn.pan@student.mahidol.edu

Dileep Sivaraman
Department of Biomedical Engineering,
Faculty of Engineering
Mahidol University
Nakhon Pathom, Thailand
dileep.siv@student.mahidol.edu

Panuwat Oiamwong
Department of Biomedical Engineering,
Faculty of Engineering
Mahidol University
Nakhon Pathom, Thailand
panuwat.oim@student.mahidol.edu

Jackrit Suthakorn
Department of Biomedical Engineering,
Faculty of Engineering
Mahidol University
Nakhon Pathom, Thailand
jackrit.sut@mahidol.ac.th

***Abstract*—With the ultimate goal to establish a mock-up system for teleguided pedicle screw insertion with greater precision and accuracy, this paper aims to utilize a haptic device to control an operating robot to reduce the operating time and increase safety for both the surgeons and the patients. Through this method, this study attempts to measure the torques that are involved during the process to evaluate the possibility of using this system in a real clinical setting.**

Keywords—Teleoperation, Pedicle Screw Insertion, Spinal Fixation, Robot-Assisted Surgery, Collaborative Robots

I. Introduction

Pedicle screw fixation is a procedure that provides immediate stability and rigid immobilization to the spine without sacrificing additional motion segments, generally required by other procedures, through the concept of anchorage with longitudinal components and transversal connector for conditions such as microdiscectomies and general spinal instabilities [1]. Although there have been constant advancements to the procedure, the ineffective and inefficient guiding process still results in prolonged operation duration that leads to radiation overexposure on the surgeons with varied precision and accuracy, potentially leading to various medical complications that can have a significant impact on both the patient's long-term recoveries and overall wellbeing. Therefore, this study aims to utilize a haptic device to control an operating robot through coordinate processing, communication and task execution to alleviate this issue.

II. Background

Pedicle Screw Insertion Procedure

Spinal fixation is an orthopedic surgical procedure that not only provides stability to, but also restores anatomic alignment of the spine for various conditions such as microdiscectomies, scoliosis, and other spinal instabilities [2]. In particular, pedicle screw insertion is a popular technique that is usually implemented for spinal fixation purposes due to its ability to provide rigid stabilization to the spine as the screws traverse all three columns of the vertebrae, providing the strongest attachment point to the spine [3], which is usually conducted through:

- *Entry Site Selection and Localization* – with the C-Arm X-Ray Scanner as an imaging tool, the junction between the superior articular process and the middle of the transverse process is targeted and visualized by creating a straight rostro-caudal line along the lateral border of the superior articular facet and a transverse line through the center of the transverse process.
- *Entry Site Preparation* – a stab skin incision is made through both the fascia and the muscle to make a blunt dissection until the transverse process is examined before bone drilling and the insertion of the Kirschner wire (K-wire) to provide anchorage for skeletal traction.
- *Pedicle Probe Insertion* – once the cortical bone is penetrated with a pedicle probe, the correct superior-inferior and medial-lateral directions are maintained in order to properly prepare for the insertion of a pedicle screw.
- *Pedicle Screw Insertion* – with the same trajectory as the pedicle probe, each screw is inserted and connected to one another with a metal rod, in which their placements are confirmed using the C-Arm X-Ray Scanner.

Although it is a well-established method, the lengthy operative time due to the ineffective and inefficient guiding process still impacts both the surgeons and the patients due to X-ray overexposure and possible medical complications such as dural tears and neurological deficits, respectively. Therefore, there is a crucial need for a new method that provides a precise, accurate, and safe guiding option for the procedure.

III. Methodology

A. Phantom Construction

In order to measure the torques that are involved during the guiding process, a phantom was constructed to mimic the actual procedure. The spine model of L4 and L5 "vertebrae" made from polylactic acid (PLA) plastic was three-dimensionally printed and joined together with a "spinal disc" of 9.5 millimeter thickness made from a sponge to make a "spine". On the other hand, the "skin", consisting of the dermis and epidermis layers, were constructed through the utilization of candle gel wax and SOFTCASTFX stretchy casting silicone of 2 to 3 millimeter thickness, respectively, then molded onto the spine.

B. *Haptic Device-Robot Communication*

The establishment of a haptic device-robot communication was done through the connection between the Novint Falcon Haptic Device – a robotic three-dimensional haptic controller – and the ABB YuMi® Collaborative Robot – a human-friendly dual arm robot specifically designed for precise and repetitive tasks – through three main steps:

- *Coordinate Processing* – through the use of the programming language *C++* and the software development kit *CHAI3D*, the coordinate values were extracted and obtained from the Falcon position controller.
- *Communication* – the obtained data were processed to translate these values from the Falcon to the ABB YuMi via local wide area network (WAN).
- *Task Execution* – through the programming software *ABB RobotStudio®*, the values retrieved by the ABB YuMi resulted in arm movements according to the given coordinates.

C. *Torque Measurements*

Using the built-in force detection tool on the ABB YuMi to measure and record the torques at each of the seven joints of its arm at 100 Hz, the values were obtained from the robot's initial position (uncontacted) all the way through each layer of the fabricated phantom, as well as a force sensor for comparison. The values were plotted against time.

IV. Results

A. *Torque Measurement from Force Sensor*

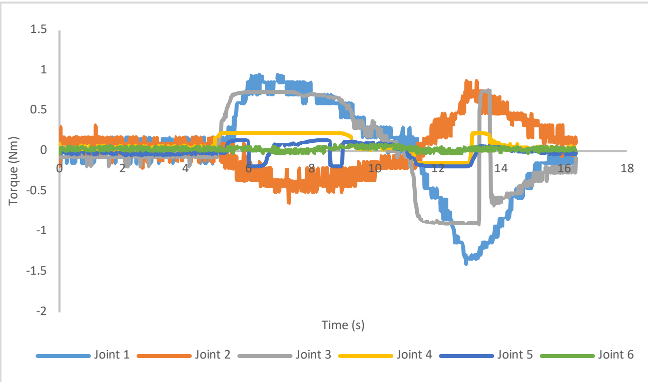

Fig. 1. Torque measurement from force sensor

B. *Torque Measurement on Fabricated Phantom*

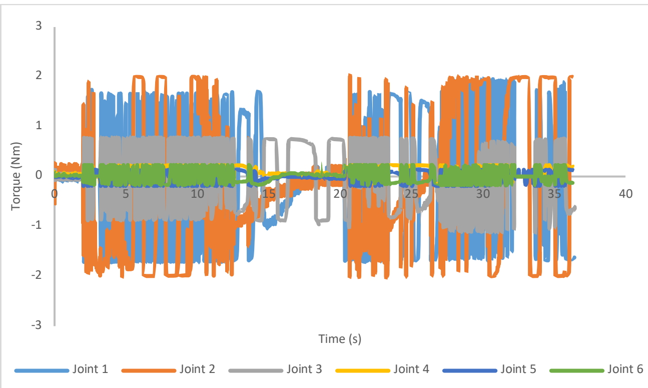

Fig. 2. Torque measurement on fabricated phantom

Figures 1 and 2 display torque values of each of the ABB YuMi joints during each experiment with a force sensor and the fabricated phantom, respectively.

V. Discussion and Conclusion

Through this study, the successful connection between the haptic device (*Novint Falcon Haptic Device*) and the operating robot (*ABB YuMi® Collaborative Robot*) in this mock-up has proven that this teleoperative system could further be adjusted and implemented in the real setting in the future, evident by the test on the fabricated phantom. As shown in Figures 1 and 2, the torques from each of the seven joints on the ABB YuMi arm were successfully extracted and analyzed. This study was divided into two main experiments: i) torque measurement from a force sensor and ii) torque measurement on fabricated phantom. While the former was specifically done to confirm that the ABB joints could really measure and interpret the torque values, the latter was done to mimic the real situation and verify that the system could also be used in real humans.

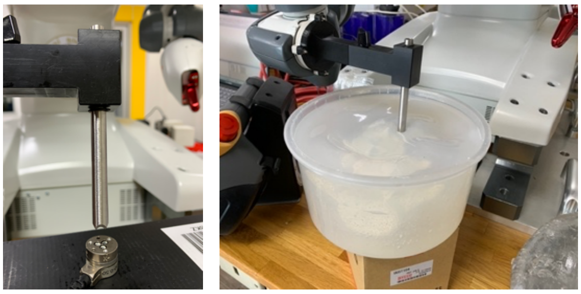

Fig. 3. Torque measurements through two experimental setups

Although the obtained values displayed some inaccuracies due to the generated noise and slight differences between the phantom and the actual body, they were able to estimate the torques that are involved during the guiding process of pedicle screw insertion, which could be compared to the real values – published through past literatures – exerted by actual surgeons in the future in order to determine whether or not this system would be applicable in a real clinical setting.

Ultimately, even though more research and evidence are required, it was expected that this teleoperative pedicle screw insertion guiding system for spinal fixation operations can provide a foundation for future research in this field.

Acknowledgment

This study was conducted under the supervision of the Center for Biomedical and Robotics Technology (BART LAB), Faculty of Engineering, Mahidol University.

References

[1] Delfino H, Galbusera F, Wilke H. Section 11, Chapter 9: Pedicle Screw Fixation and Design : Wheeless' Textbook of Orthopaedics [Internet]. International Society for the Study of the Lumbar Spine. [cited 22 July 2022]. Available from: https://www.wheelessonline.com.

[2] Slone R, MacMillan M, Montgomery W. Spinal fixation. Part 1. Principles, basic hardware, and fixation techniques for the cervical spine. RadioGraphics. 1993;13(2):341-356.

[3] Awasthi D, Thomas N. Pedicle Screw Placement [Internet]. Louisiana State University Health Sciences Center New Orleans. [cited 22 July 2022]. Available from: https://www.medschool.lsuhsc.edu/neurosurgery/nervecenter/tlscrew.html.

[4] Neurosurgery Research & Education Foundation. Lumbar Pedicle Screw Placement [Internet]. 2018 [cited 22 July 2022]. Available from: https://www.youtube.com/watch?v=E6jUl0PRA_A&ab_channel=NREF.