

A Method to Reduce Tension Differences in Pull/Push Manipulation for a Robot in Fluorescence Emission-Guided Surgical Microscopy

Surgical Innovation
2024, Vol. 31(4) 443–446
© The Author(s) 2024
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/15533506241240863
journals.sagepub.com/home/sri



Sangyun Lee, PhD^{1,2,*}, Kicheol Yoon, PhD^{2,3,*}, Won-Suk Lee, MD, PhD⁴ , and Kwang Gi Kim, PhD^{2,5,6} 

Abstract

Motivation: A fluorescence emission-guided microscope used to monitor the outcome of cancer removal surgery is highly effective when employing a manipulator to motorize and switch the observation direction. It is necessary to minimize the alignment of looper tension between the stands for pull/push to change the direction of the manipulator and reduce the error rate caused by tension differences. This paper presents a method to minimize the error rate of looper tension between the stands.

Methods: The looper is inserted between the stands of the manipulator to minimize the difference in tension and make the stress on the pull and push of the looper constant. The constant stress allows the manipulator to move stably in left/right, up/down, and left/right movements, which will be effective for full-camera observation and close-up shots of the end effector.

Results: Reducing the tolerance for differences in the manipulator's looper tension (angle and tension) is crucial. When the input value of the looper tension angle is 50°, the output should closely match 50°. Consequently, the measured response has a tolerance of $\pm 49.98\%$, resulting in an error rate of .02% (1/50th level).

Conclusion: A method is proposed to minimize the error rate of the manipulator's looper tension in a robot-based fluorescence emission-guided microscope used to observe the status of cancer surgery. As a result, a stable manipulator with a minimal error rate can achieve a 3.986x magnification for close-up observation by switching between high and low orientations.

Keywords

biomedical engineering, gastric surgery, general surgery, neurosurgery, robotic surgery, surgical oncology, vascular surgery

Introduction

Tumors have numerous distributed blood vessels, and the colors of tumors and blood vessels are similar, making them difficult to observe with the naked eye.¹ Therefore, by injecting a fluorescent contrast agent into the body, the state of tumor removal and lymph nodes can be observed through a surgical fluorescence microscope. However, because the microscope is bulky and heavy, it is difficult to manually move the microscope (left/right-up/down) to the location of the lesion. Therefore, development has been underway to align with the lesion's location using the robot's manipulator.^{2–5} However, within the manipulator, differences in stress between pulling and pushing occur due to variations in joint power and motor weight. These differences can lead to significant errors during the manipulation process, occasionally compromising movement accuracy.^{6,7} This paper presents

¹Department of Radiological Science, Dongnam Health University, Gyeonggi-do, Republic of Korea

²Medical Devices R&D Center, Gachon University Gil Medical Center, Incheon, Republic of Korea

³College of Medicine, Gil Medical Center, Gachon University, Gyeonggi-do, Republic of Korea

⁴Department of Surgery, Gachon University Gil Medical Center, Incheon, Republic of Korea

⁵Department of Biomedical Engineering, Gachon University, Incheon, Republic of Korea

⁶Department of Health Sciences and Technology, Gachon Advanced Institute for Health Sciences and Technology (GAIHST), Gachon University, Incheon, Republic of Korea

* Sangyun Lee and Kicheol Yoon are equally contributed to the work. Sangyun Lee and Kicheol Yoon are the co-first (lead) authors

Corresponding Authors:

Kwang Gi Kim, Department of Biomedical Engineering, College of Medicine, Gil Medical Center, Gachon University, 1342 Seongnamdaero, Sujeong-gu, Seongnam-si 13120 Republic of Korea.

Email: kimkg@gachon.ac.kr

Won-Suk Lee, Department of Surgery, Gachon University Gil Medical Center, Incheon 21565, Republic of Korea.

Email: lws@gilhospital.com

a manipulator control method aimed at minimizing errors.

5-Axis Manipulator Design with Looper-tension Performance Inserted Between Stands

The robot manipulator with joint of 5-axis freedom is shown in Figure 1(a). From the figure, θ_1 of the 1-axis controls the rotation of the end-effector, and θ_2 of the 2-axis controls the left-right rotation of the end-effector. In 3-axis, θ_3 , θ_4 , and θ_5 control left and right radial movement and 360° rotation of the end-effector connected to the camera and LED. The method for minimizing the error in the pull and push operation of the manipulator and end-effector for accurate and precise operation from θ_1 to θ_5 is to connect the stands composed of three rolls and the stand as shown in Figure 1(b).

When pull, push, and rotation are performed, the lengths of the loopers (l_{s1} and l_{s2}) will change uniformly due to kinematic forces and constant speed (as seen in Figure 1, Eqs.), while the rolls rotate.⁸ As a result, the

overall length of the looper (l_T) changes uniformly, minimizing errors in pull and push operations. The reason the length of the looper changes uniformly is that when there is a difference in the length of the looper, the intermediate roll (R_L/R_{SL}) rotates slightly to control the speed, length, and tension of the pull and push of the loopers (l_{s1} and l_{s2}). Without an intermediate roll, one of the lengths of l_{s1} and l_{s2} increases during the pull and push process, leading to an imbalance in the pull and push operations and causing the manipulator to move diagonally.

Looper-tension Response Simulation Between Stands and Results

The time response of the tension and angle of the roll moving in the stand due to changes in the looper length during the pull and push of the manipulator is depicted in Figure 2(a). As seen in the figure, the angle and tension applied to the looper are 25.1° and 8.62 MPa, respectively. During this time, an output response can be obtained when there is a variation of $\pm 49.98\%$ from

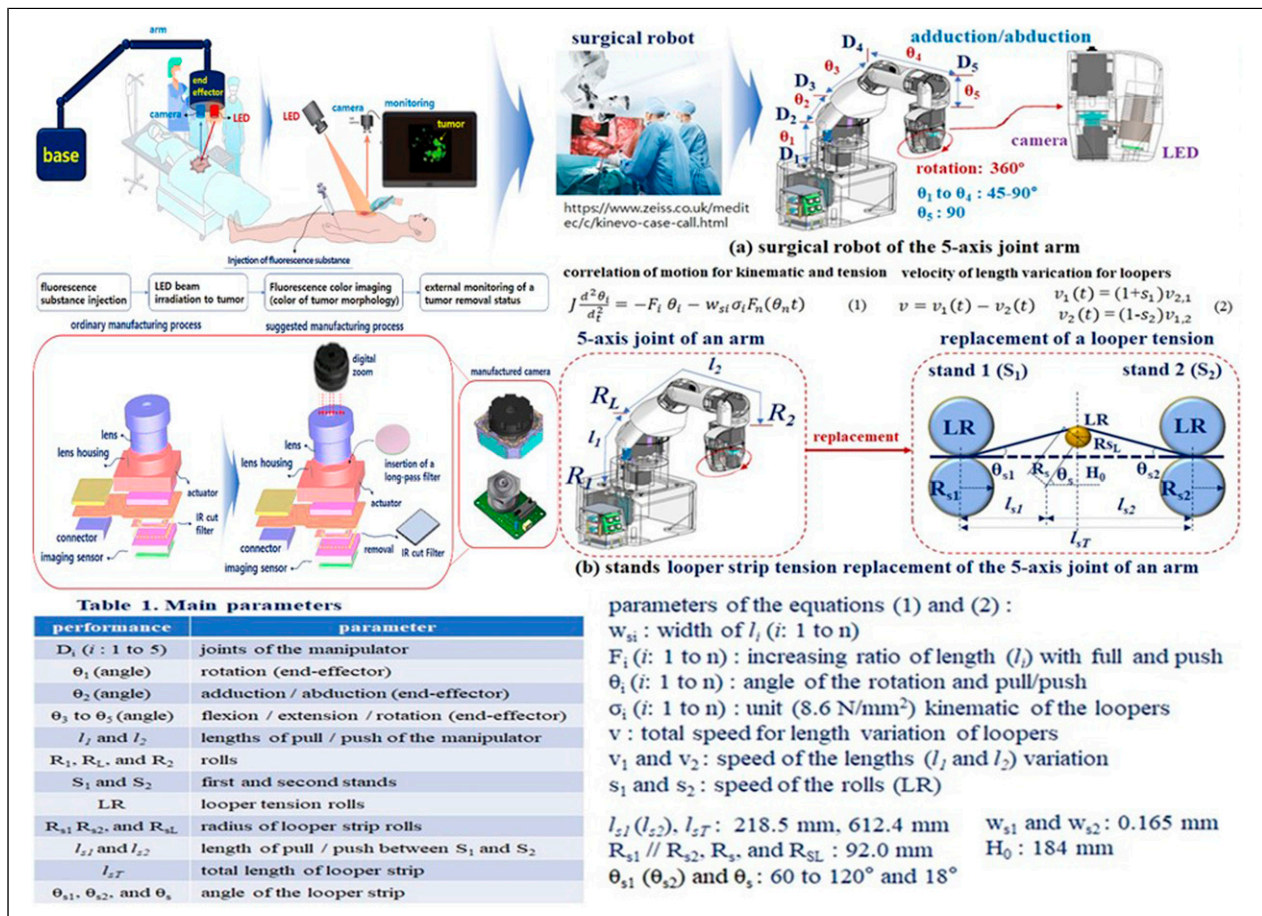


Figure 1. Structure and mechanism analysis of a surgical microscope robot with stand and looper-tension performance inserted.

the reference operating point compared to the input values for the angle and tension. When the input value of the looper tension angle is 50° , the output should closely match 50° . Consequently, the measured response has a tolerance of $\pm 49.98\%$, resulting in an error rate of $.02\%$ (1/50th level).

As depicted in Figure 2, when the standard operating point fluctuates by $\pm 29.99\%$ while the input angle and tension remain fixed, the output response occurs in the opposite manner. In other words, an increase in the speed difference for the roll of the stand leads to an increase in tension for the length of the looper and

a decrease in the angle of the looper, resulting in a dual-sided phenomenon.

Design and Performance Test of 5-Axis Joint Manipulator Using Looper-tension Control Method Between Stands

A robot that combines looper-tension with a 5-axis joint manipulator is designed, as shown in Figure 3(a). The waveform in Figure 3(a) can be moved in the x, y, and z axes (250 mm) by uniformly adjusting the looper-tension between the stands. By connecting a camera

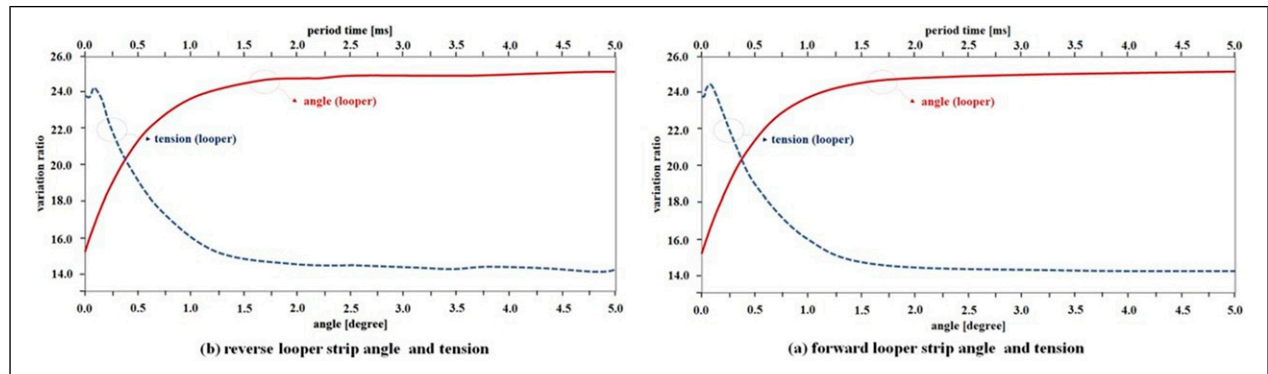


Figure 2. Simulation results for the angle and tension of the forward and reverse direction between the stands.

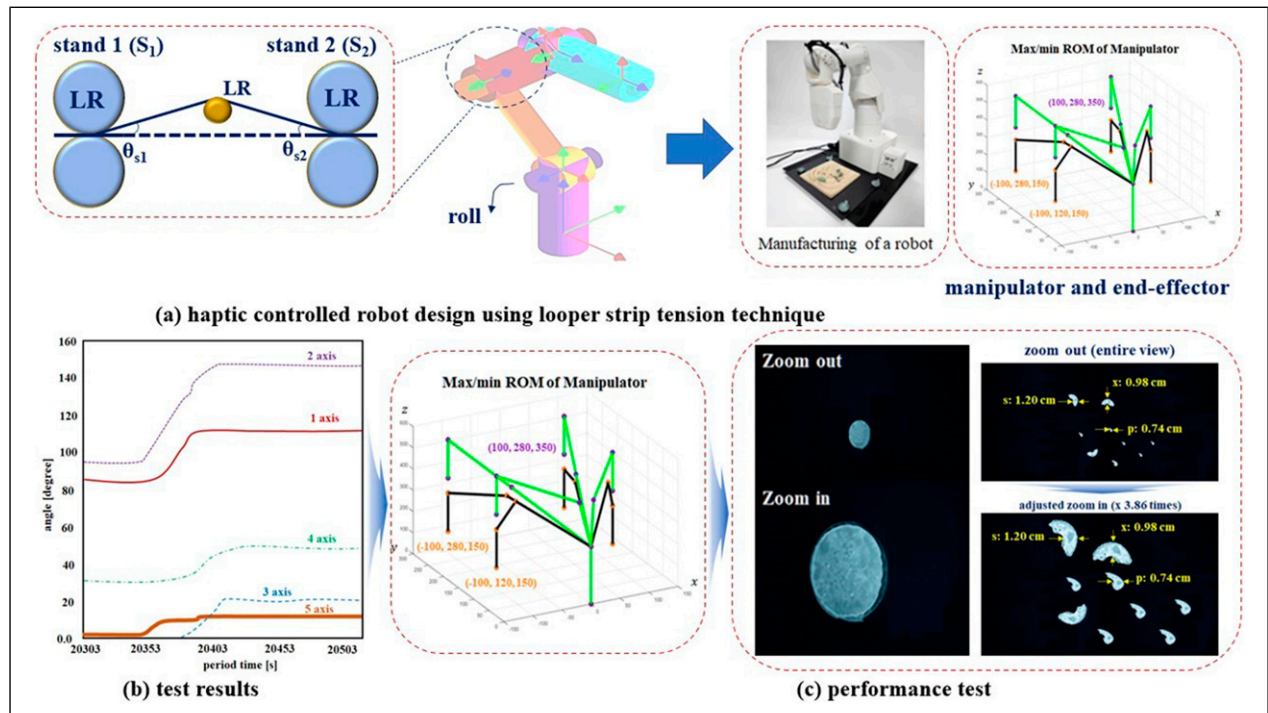


Figure 3. Simulation and imaging results of the designed robot.

with zoom-in/out functionality to the end-effector, close-up and overall shooting is possible. Figure 3(b) represents the angle of the movement radius of the 5-axis joint, while Figure 3(c) shows fluorescence emission (phantom light is generated from it), and performance testing is conducted. In this setup, the camera's zoom-in capability goes up to $\times 3.86$ magnification, with resolutions of 1920×1080 (in) and 9600×3240 (out).

Conclusion

The motor used to move the manipulator left, right, up, and down frequently experiences an overload, so a mill tension function is implemented to minimize the motor's load. Mill tension may increase due to the added weight each time the manipulator moves. Therefore, because the manipulator does not move in the correct direction, the lesion cannot be observed at the desired location. This technology is expected to be suitable for future use in surgical robots and fluorescence emission-guided monitoring robots.

Author's Contributions

Sangyun Lee worked the study concept and design, and Ki-Cheol Yoon worked the analysis and interpretation. Kwang Gi Kim worked for study supervision, and Won Suk Lee worked the providing of clinical informations. Sangyun Lee and Kicheol Yoon are equally contributed to the work. Sangyun Lee and Kicheol Yoon are the co-first (lead) authors. Kwang Gi Kim and Won-Suk Lee are co-corresponding authors. This was contributed by Dongnam Health University, Republic of Korea, Gachon University, and Gachon Univeristy Gil Medical Cneter.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article:

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2021R1A5A2030333) and this work was supported by the Gachon University Gil Medical Center (Grant number: FRD2022-17). Also, the research work was supported by the GRRC program of the Gyeonggi province (No. GRRC-Gachon 2023(B01)).

ORCID iDs

Won-Suk Lee  <https://orcid.org/0000-0003-3580-4319>

Kwang Gi Kim  <https://orcid.org/0000-0001-9714-6038>

References

1. Lin J, Lin LS, Chen DR, Lin KJ, Wang YF, Chang YJ. Indocyanine green fluorescence method for sentinel lymph node biopsy in breast cancer. *Asian Journal of Surgery*. 2020;43(12):1149-1153. doi:10.1016/j.asjsur.2020.02.003.
2. Jin S, Lee SK, Lee J, Han S. Kinematic model and real-time path generator for a wire-driven surgical robot arm with articulated joint structure. *Appl Sci*. 2019;9(19):4114.
3. Maaroo OW, Saeed SZ, Dede MIC. Partial gravity compensation of a surgical robot. *Int. J. of Advanced Robotic Systems*. 2021;18(3):4.
4. Yoon KC, Cho S. M., Kim KG. Coupling effect suppressed compact surgical robot with 7-axis multi-joint using wire-driven method. *Mathematics*. 2022;10(10):1698.
5. Shafiei B, Ekramian M, Shojaei K. Robust tension control of strip for 5-stand tandem cold mills. *J Engineering*. 2014;13: 1-13.
6. Choi IS, Rossiter JA, Fleming PJ. Looper and tension control in hot rolling mills: a survey. *J Process Control*. 2007;17(6): 509-521.
7. Knechtelsdorfer U, Steinboeck A, Schausberger F, Kugi A. A novel mass flow controller for tandem hot rolling mills. *J Process Control*. 2021;104:168-177.
8. Cho S, Chung T, Lee J. S., Yoon KC, Kim KG. For end effector of surgical robot 5 Axis master system development. In 2019 4th International Conference on Intelligent Information Technology (ICIIT 2019) Da Nang, 2019; D0023, Vietnam February 20-23.