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Adjustment of the Length Variation With Wire-driven Using the Stand Looper Tension Technique for Surgical Robot Applications

Kicheol Yoon, PhD[1,2,*], Sangyun Lee, MS[1,2,*], and Kwang Gi Kim, PhD[1,2,3]

Abstract

Motivation: The wire-driven method used in the field of surgical robots has the advantage of light weight. However, in the process of pull and push for the operation of forceps, the length of the wire is not match, causing malfunction. To solve this problem, the application of looper-tension technology would be suitable. This paper contributes to adjusting the length of the wire by inserting a stand between the wire-driven joints and adding a looper-tension between the stands to adjust the rotation radius of the roll.
Methods: The method consisting of three rolls and loopers for connection between the stands minimizes errors by adjusting the length of the loop in a balanced state due to the rotation change of the roll during the pull and push of the robot arm. The angle and tension applied to the looper are 25° and 8.6 MPa, respectively.
Results: An output response can be obtained when the reference operating point fluctuates by ± 50% of the input angle and tension, and if the reference operating point fluctuates by ± 30% while the input angle and tension are fixed, the output response occurs oppositely. When a .15 kg object is loaded up/down with 1.5 newton using forceps, the change in length of pull and push coincides.
Conclusion: The advantage is that the error of wire pull, and push operation can be reduced, and accurate operation can be expected. Since the proposed technology is applied between joints, the integration process is not complicated, and the weight is light.

Keywords

biomedical engineering, general surgery, gastric surgery, robotic surgery, simaluation

Introduction

In the surgical field, robots use a wire-driven method enhance precision with an extensive range of motion.[1] Although the wire-driven approach minimizes a robot size and weight, discrepancies may arise when the wire lengths for pulling and pushing motions is not match, affecting power transmission for joint movement.[2,3] To address this challenge, this study proposes a technique of implementing looper strip tension between stands as an alternative to the wire-driven method. Consequently, mathematical analyses and simulations are conducted to examine the potential for error minimization.[4-6] Furthermore, the robot's motion performance is evaluated through animal experiments. As the looper strip tensions connected to each stand can be precisely controlled, it is feasible to minimize changes in pulling and pushing tensions.

[1]Medical Devices R&D Center, Gachon University Gil Medical Center, Incheon, Republic of Korea
[2]Department of Biomedical Engineering, College of Health Science & Medicine, Gachon University, Incheon, Republic of Korea
[3]Department of Health Sciences and Technology, Gachon Advanced Institute for Health Sciences and Technology (GAIHST), Gachon University, Incheon, Republic of Korea

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

Corresponding Author:
Kwang Gi Kim, Department of Biomedical Engineering, College of Medicine, Gachon University, , 701, 38-13 Dojom-ro 3 beon-gil, Namdong-gu, Incheon 21565, Republic of Korea.
Email: kimkg@gachon.ac.kr

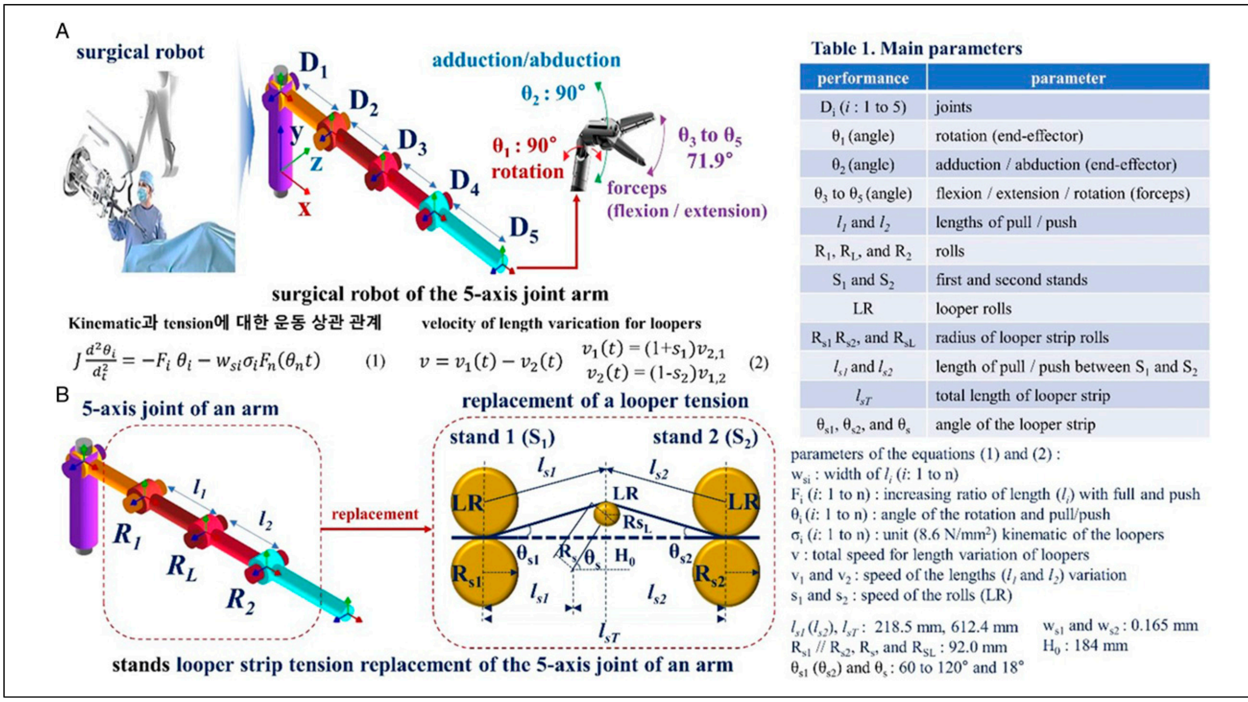

Figure 1. Design process of the stand and looper tension technique in the surgical robot.

Design Methods for Stand Looper Strip Tension in the Arm

The 5-axis freedom robot arm with joints is shown in Figure 1A. From the figure, θ_1 of the 1-axis governs an end-effector rotation, while θ_2 of the 2-axis manages an end-effector left-right rotation. In the 3-axis, θ_3, θ_4, and θ_5 regulate the left and right rotation of the forceps.[7]

The method for minimizing the error in pull and push operations, ensuring accuracy and precision from θ_1 to θ_5, employs looper strip tensions connecting the stands comprising three rolls and the stands, as demonstrated in Figure 1B. The system includes rolls (LR) that initiate rotation in the stand for the forceps' pull, push, and rotation.

If these actions are executed, the lengths of the loopers (l_{s1} and l_{s2}) will change uniformly through kinematic (force) and constant speed (see Figure 1. Eqs.) as the rolls rotate. Consequently, the overall looper strip length (l_T) changes uniformly, minimizing pull and push errors. The uniform change in the looper strip length is facilitated by the middle roll (R_L//R_{SL}), which provides support and rotates concurrently. If the middle roll is absent, it is predicted that pull and push operations will not function uniformly, as the lengths of l_{s1} and l_{s2} increase independently during the pull and push process. Hence, to achieve uniform pull and push operations, the changes in length (tension force and speed) of l_{s1} and l_{s2} between the stands must be identical.

Looper Tension Response Simulation and Results

The time response of tension and roll angle in the stand, corresponding to the uniform change in looper strip tension length during the robot an arm pull and push actions, is illustrated in Figure 2A. As shown in the figure, the angle and tension applied to the looper strip tension are 25° and 8.6 MPa, respectively. At this point, an output response can be obtained when a variation of ± 50% of the reference operating point occurs in comparison to the input values for angle and tension.

As shown in Figure 2B, if the reference operating point varies by ± 30% while the input angle and tension remain constant, the output response occurs inversely. In other words, if the speed difference for the roll of the stand increases, the tension along the length of the looper strip tension increases, and the angle of the looper strip tension decreases.[8]

Design and Performance Test of 5-Axis Joint arm Robot Based on Looper Strip Tension

A robot system that integrates looper strip tension with a 5-axis joint arm is designed, as depicted in Figure 3A. To operate the robot system, a haptic control system is connected to the arm. As demonstrated in Figure 3B, the robot arm moves through the rotational motion of the

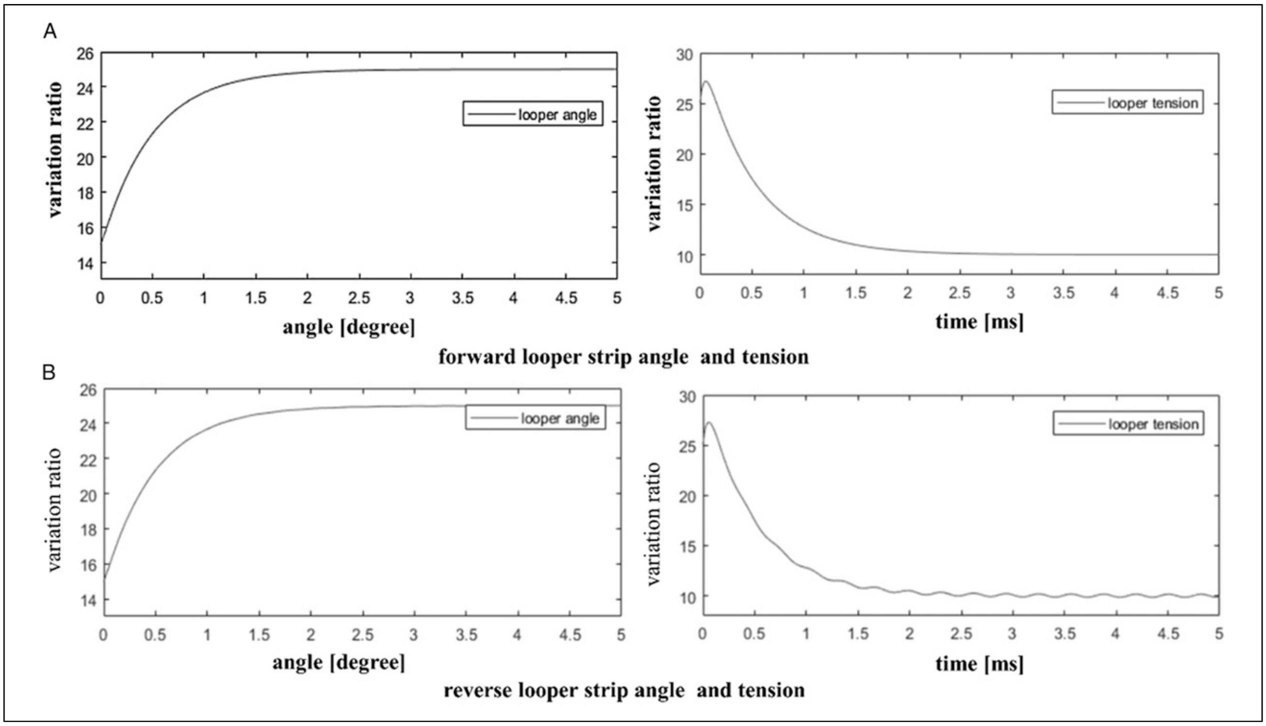

Figure 2. Simulation results for the angle and tension of the forward and reverse direction.

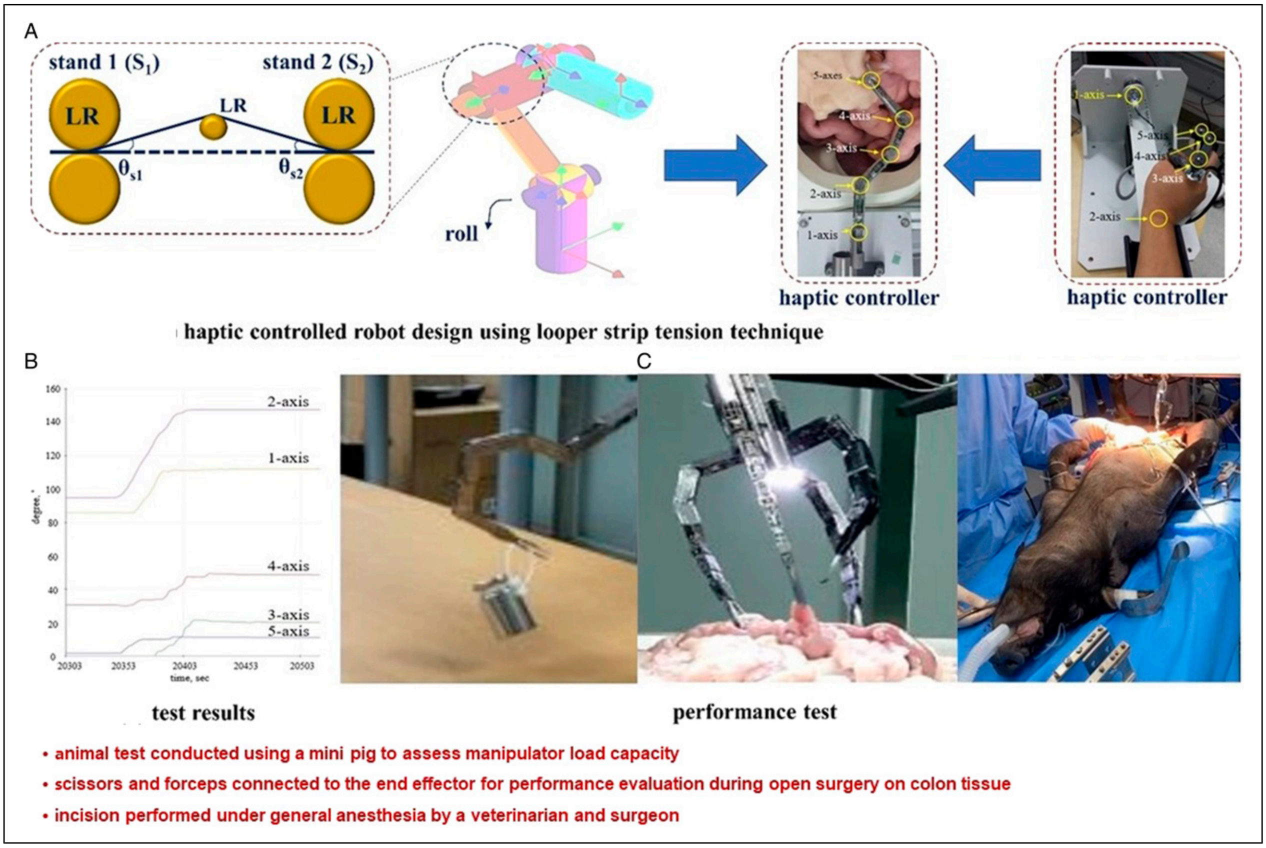

Figure 3. Performance test of the surgical robot with looper strip tension technique.

joints from the 1-axis to the 5-axis. The animal test is used for mini-pig (40 kg) which is descripted for detail test procedure as shown in Figure 3.

When the robot arm moves, the change in length of the pull and push is consistent, as shown in Figure 3C. In the test results of the arm, an object weighing .15 kg can be loaded up/down with a 1.5 Newton force. The robot system integrating looper strip tension with the 5-axis joint arm was able to assess up/down performance through animal experiments. Based on the experimental results, it was concluded that the robot could be effectively utilized for surgical purposes.

Conclusion

This paper contributes to balancing the length by applying the performance of looper strip tension between the joints, as the length of the wire generated during the pull and push process of the forceps in robots used for laparoscopic surgery is inconsistent. The advantage is that the error in wire pull, and push operations can be reduced, leading to more accurate performance. Since the proposed technology is applied between joints, the integration process is uncomplicated and lightweight. As surgical robot motion must be precise, given its relation to life, this technology is expected to be suitable for application in robots used for surgical operations or rehabilitation exercise training.

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Author Contributions

Kicheol Yoon and Sangyun Lee are equally contributed to the this work. Kicheol Yoon and Sangyun Lee are the co first (lead) authors. Kicheol Yoon worked on the concept and design of the study, and Sangyun Lee performed the analysis and interpretation. Kwang Gi Kim performed the simulations and documented the investigation.

Declaration of Conflicting Interests

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ORCID iD

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

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