

Autonomous Blood Suction for Minimally Invasive Surgeries

Matthew Foster, Charles DeLorey, and Dominic Jones

School of Mechanical Engineering, School of Electrical and Electronic Engineering, University of Leeds

INTRODUCTION

Robot-assisted minimally invasive surgery (RAMIS) offers advantages over traditional methods, including greater precision, reduced scarring, and faster recovery. The next shift in surgical practice will likely involve increased robotic autonomy to support surgeons and reduce cognitive load [5], [2], [10]. RAMIS surgical procedures often use three arms, with only two actively controlled by the surgeon; the third often holds an auxiliary tool (retractor, suction, etc.). Four-arm setups allow for dual-operator procedures, depending on surgical requirements [12], [11]. These extra arms present opportunities for autonomous task execution.

Blood suction is a repetitive yet vital task that can disrupt workflow and increase cognitive demand when performed manually [1], [13]. Bleeding obscures the surgical field, requiring the surgeon to pause, suction the blood, and ligate the source. Autonomous blood detection and suctioning can streamline this process. Prior work has explored haemostasis and blood detection [4], [8], as well as planning suction paths [9]. Reinforcement learning has also been applied to automate suctioning [6], though optimal trajectory evaluation remains underexplored. We present and analyse four strategies for clearing blood pools to identify the most effective approach.

MATERIALS AND METHODS

A. Simulation Framework

In this work, we utilised CRESSim [7]—a Unity-based surgical simulation platform specifically designed for minimally invasive procedures. CRESSim provides realistic soft body dynamics and particle-based fluid simulation, as well as ROS support for the da Vinci Research Kit [3], making it well-suited for modelling surgical blood flow and suction interactions.

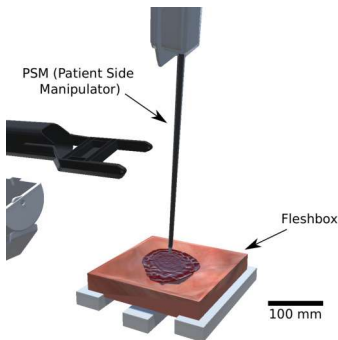


Fig. 1: Blood suction experimental setup in Unity.

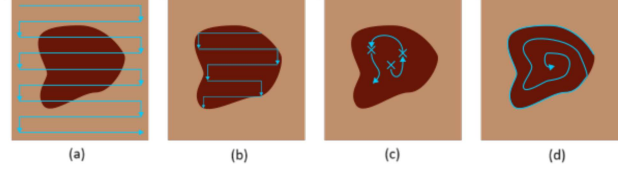


Fig. 2: Suction trajectories: (a) Global Zigzag, (b) Adaptive Zigzag, (c) Centroid Follower, and (d) Inward Spiral.

B. Vision System and Depth Estimation

A stereo camera setup was implemented in Unity using two virtual cameras at a fixed baseline, each publishing RGB images to separate ROS2 topics (Fig. 1). Blood detection used HSV thresholding via OpenCV to generate a binary mask highlighting the largest blood pool. Key metrics—size, centroid, and perimeter—were extracted using OpenCV’s blob detector.

C. Control Algorithms

Previous work in autonomous blood suction uses pre-trained models or simple linear trajectories to clear blood, focusing more centrally on the assistive aspect of the robot. In this work we examine trajectories for covering areas of blood to demonstrate which are more effective for the particular scenario. Four control strategies were implemented, for their relative simplicity in the XY plane as well as making use of relatively straightforward computer vision methods like colour-based image segmentation. The strategies were **Global Zigzag (Baseline)**: A raster path covering the entire surgical field, **Adaptive Zigzag**: Focuses on the bounding box around blood, **Centroid Follower**: Tracks and moves to the blood centroid, and **Inward Spiral**: Follows the outer contour of the blob, which shrinks as blood is suctioned away. The strategies are illustrated in Fig. 2.

D. Experimental Evaluation

A volume of ~100 ml (8000 particles of blood, each with 1 mm radius) was dropped into the "Fleshbox", a 200 mm by 200 mm box for evaluating algorithm performance, and allowed to pool for 5 s, then a suctioning strategy was engaged. Blood removal efficiency for each algorithm was quantified using pixel-based volume estimates published via ROS2. The controllers servoed the suction end effector in X and Y, while maintaining a constant Z position. The blood remaining in the Fleshbox was recorded during the suction task. Each strategy had one run, with the results reported below.

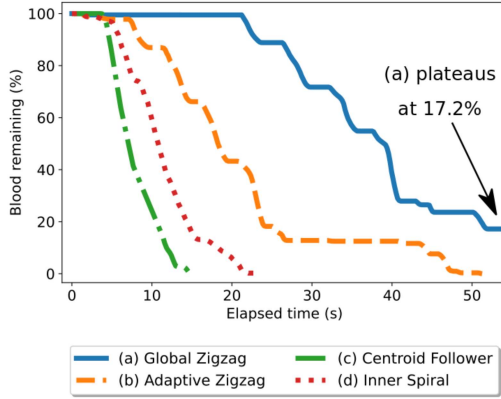


Fig. 3: Percentage blood remaining during suction over time for the four strategies assessed.

I. RESULTS

The blood-remaining-over-time results reveal distinct performance trends across suction strategies. The Global Zigzag provided steady but slow clearance by covering the entire surface, lacking efficiency due to its disregard for blood location (Fig. 3 a). Adaptive Zigzag improved on this by limiting coverage to the blood region, achieving faster and more targeted suction (Fig. 3 b). The Centroid Follower initially reduced blood volume quickly by targeting the largest pool, but would stall as the blood dispersed, highlighting its dependence on dominant blobs (Fig. 3 c). The Inward Spiral proved most effective overall, adapting well to blood shape and concentrating on the evolving centre in a shorter time (Fig. 3 d). While Adaptive Zigzag ended with 0% blood remaining, however in half the time the Inward Spiral strategy achieved 0.025% remaining. Due to surface variation and fixed Z-height, the Inward Spiral offered the best balance of early and sustained performance. Global Zigzag had 17.2% remaining, and Centroid Follower had 0.6% remaining, showing promise in more complex suctioning strategies.

CONCLUSIONS AND DISCUSSION

This work presents four blood suction strategies in a robotic suction simulation platform with a simulated da Vinci surgical robot arm. The Inward Spiral method emerged as the most effective, efficiently tracking the outer boundary of the blood pool and adapting well as the pool shape evolved. Furthermore, the Centroid Follower and Inward Spiral strategies are the most promising for handling multiple or splitting pools, which will be necessary for a more clinically relevant system. Compared to recent research works, our work contributes trajectory evaluation metrics to the task of automated blood suction.

Future work will focus on refining the depth query system to enable Z positioning, allowing full 3D actuation across varied geometries. Transferring this work to a real robot introduces several challenges, notably achieving accurate spatial calibration between sim and real, and detecting blood in varied lighting and tissue

scenarios. Stereo depth estimation is less reliable in real-world surgical scenes due to reflective surfaces, fluid motion, and occlusion. Exploring closed-loop suction trajectories may enable minimising effects such as occlusion of the surgeon's view, or contact with the surgeon's instrument(s). Additionally, applying the suction strategies to more anatomically representative scenes would better integrate our work into the state-of-the-art.

REFERENCES

- [1] J. A. Barragan, J. Yang, D. Yu, and J. P. Wachs, "A neurotechnological aid for semi-autonomous suction in robotic-assisted surgery," *Scientific Reports*, vol. 12, no. 1, p. 4504, Mar 2022. [Online]. Available: <https://doi.org/10.1038/s41598-022-08063-w>
- [2] T. Haidegger, S. Speidel, D. Stoyanov, and R. M. Satava, "Robot-assisted minimally invasive surgery—surgical robotics in the data age," *Proceedings of the IEEE*, vol. 110, no. 7, pp. 835–846, 2022.
- [3] P. Kazanzides, Z. Chen, A. Deguet, G. S. Fischer, R. H. Taylor, and S. P. DiMaio, "An open-source research kit for the da vinci® surgical system," in *2014 IEEE international conference on robotics and automation (ICRA)*. IEEE, 2014, pp. 6434–6439.
- [4] A. J. Miao, S. Lin, J. Lu, F. Richter, B. Ostrander, E. K. Funk, R. K. Orosco, and M. C. Yip, "Hemostat: The first blood segmentation dataset for automation of hemostasis management," in *2024 International Symposium on Medical Robotics (ISMR)*, 2024, pp. 1–7.
- [5] R. Nagyné Elek and T. Haidegger, "Non-technical skill assessment and mental load evaluation in robot-assisted minimally invasive surgery," *Sensors*, vol. 21, no. 8, 2021. [Online]. Available: <https://www.mdpi.com/1424-8220/21/8/2666>
- [6] Y. Ou and M. Tavakoli, "Learning autonomous surgical irrigation and suction with the da vinci research kit using reinforcement learning," 2024. [Online]. Available: <https://arxiv.org/abs/2411.14622>
- [7] Y. Ou, S. Zargarzadeh, P. Sedighi, and M. Tavakoli, "A realistic surgical simulator for non-rigid and contact-rich manipulation in surgeries with the da vinci research kit," in *2024 21st International Conference on Ubiquitous Robots (UR)*, 2024, pp. 64–70.
- [8] D. Richter, A. M. Fard, J. Straub, W. Wei, Q. Zhang, and R. K. Wang, "Relative retinal flow velocity detection using optical coherence tomography angiography imaging," *Biomed. Opt. Express*, vol. 11, no. 11, pp. 6710–6720, Nov 2020. [Online]. Available: <https://opg.optica.org/boe/abstract.cfm?URI=boe-11-11-6710>
- [9] F. Richter, S. Shen, F. Liu, J. Huang, E. K. Funk, R. K. Orosco, and M. C. Yip, "Autonomous robotic suction to clear the surgical field for hemostasis using image-based blood flow detection," *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 1383–1390, 2021.
- [10] S. Schmidgall, J. D. Opfermann, J. W. Kim, and A. Krieger, "Will your next surgeon be a robot? autonomy and ai in robotic surgery," *Science Robotics*, vol. 10, no. 104, p. eadt0187, 2025.
- [11] A. Valverde, N. Goasguen, and O. Oberlin, "Fundamentals of robotic surgery or of robotic-assisted telemanipulated laparoscopy," *Journal of Visceral Surgery*, vol. 151, no. 3, pp. 213–221, 2014. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1878788614000356>
- [12] G. W. Yim, K. J. Eoh, Y. S. Chung, S. W. Kim, S. Kim, E. J. Nam, J. Y. Lee, and Y. T. Kim, "Perioperative outcomes of 3-arm versus 4-arm robotic radical hysterectomy in patients with cervical cancer," *Journal of Minimally Invasive Gynecology*, vol. 25, no. 5, pp. 823–831, 2018.
- [13] S. Zargarzadeh, M. Mirzaei, Y. Ou, and M. Tavakoli, "From decision to action in surgical autonomy: Multi-modal large language models for robot-assisted blood suction," *IEEE Robotics and Automation Letters*, vol. 10, no. 3, pp. 2598–2605, 2025.