Proceedings of the 2022 Design of Medical Devices Conference
DMD2022
April 11-14, 2022, Minneapolis, MN, USA

DMD2022-1020

COMPUTER VISION ENABLED SMART TRAY FOR CENTRAL VENOUS CATHETERIZATION TRAINING

Dailen Brown
The Pennsylvania State University
University Park, PA

Hang-Ling Wu
The Pennsylvania State University
University Park, PA

Yohaan Satpathy
The Pennsylvania State University
University Park, PA

Jessica M. Gonzalez-Vargas
The Pennsylvania State University
University Park, PA

Haroula Tzamaras
The Pennsylvania State University
University Park, PA

Scarlett Miller
The Pennsylvania State University
University Park, PA

Jason Moore
The Pennsylvania State University
University Park, PA

ABSTRACT

A Computer Vision enabled Smart Tray (CVST) was designed for use in medical training for Central Venous Catheterization (CVC). The effects of background color on the ability of the computer vision algorithm to distinguish between tools and the tray was investigated. In addition, the computer vision algorithm was evaluated for accuracy in tool detection. Results indicate that a white monochromatic background is the most useful for segregating background from medical tools, and the algorithm was successfully able to detect 5 different CVC tools both individually and as a group in various arrangements, even when tools overlapped or touched. When the system was in error, it was nearly always due to one tool which has a color similar to that of the background. The CVST shows promise as a CVC training tool and demonstrates that computer vision can be used to accurately detect medical tools.

Keywords: Medical Training, Computer Vision, Catheterization

1. INTRODUCTION

Central Venous Catheterization (CVC) is a common medical procedure in which a catheter is placed into a central vein of the body to provide access to the heart for the purpose of administering medication and taking measurements. The procedure is often plagued with complications that affect patient health [1]. The procedure involves 15 major steps. Medical residents are typically trained and evaluated by experts in these skills before they are permitted to perform the procedure on patients [2]. This evaluation usually consists of a binary checklist of steps performed correctly [3]. The sequence of steps in CVC is important, and deviation from the correct order can result in complications or failure to complete the procedure. Due to the high rate of complications, training methods often utilize manikin simulators to allow residents to practice without endangering patients, but these methods always require expert oversight which costs valuable time. The need for expert oversight could be eliminated through the development of an automated feedback system. A smart tray concept was previously developed using sensorization to track CVC tools [4], but another way to create such a system is through the use of computer vision to evaluate the correctness of step order and tool usage.

Computer Vision (CV) is a method of image-based analysis in which an algorithm is able to detect changes in pixels from frame to frame and make conclusions about the images presented. The goal of CV is to replicate or improve upon the ability of human vision using computational systems [5]. CV has seen significant growth due to the advent of Artificial Intelligence (AI), Deep Learning, and Neural Networks, and has applications across many industries [6]. CV systems have been successfully used to automate the classification of diseases, medical image segmentation, cancer detection, and more [7]. Though machine learning and AI methodologies are often used to create incredibly complex and robust CV systems, there are also many simpler methods that can be utilized effectively including color-based image recognition, template matching, and blob analysis.

The purpose of this study is to develop a simple CV algorithm to track the usage of important CVC tools during resident training and to evaluate the accuracy of this algorithm in detecting these tools. The design of the training system and CV algorithm is described and the experimental results are presented and discussed.

2. MATERIALS AND METHODS

Sample images of the tools involved were taken and processed in MathWorks (Natick, MA) MATLAB to build an algorithm capable of tracking the usage of these tools. An example of one of these sample images with the CVC tools labeled is shown in Figure 1.

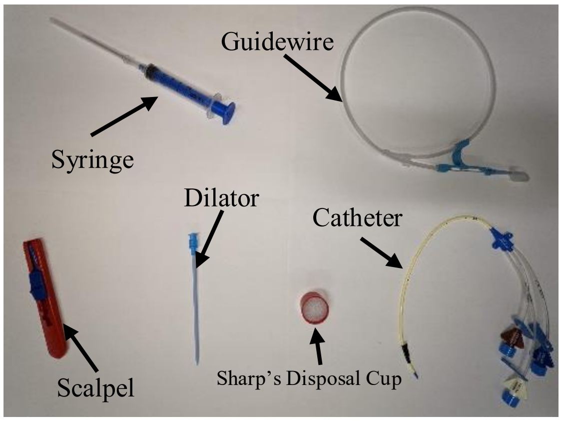

FIGURE 1: SAMPLE IMAGE OF CVC TOOLS USED TO CREATE MATLAB ALGORITHM

The system, denoted as the Computer Vision enabled Smart Tray (CVST), uses a Logitech (Lausanne, Switzerland) C270 HD Webcam and is shown in Figure 2. CVST incorporates a tray with a monochromatic background and a mounted overhead camera. Medical residents lay out the tools of the procedure on the tray and the algorithm detects when each tool is placed or removed from the tray.

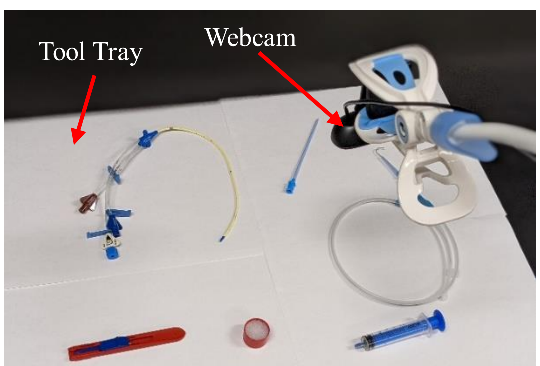

FIGURE 2: THE COMPUTER VISION ENABLED SMART TRAY SYSTEM

The algorithm inputs an image of the tray and compares the known RGB color values of the background with the color values of each pixel to determine sections of the image where the pixels deviate from the background above a certain threshold. The thresholds used were determined by calculating the average color of the background by manually selecting pixels and comparing these values. The algorithm then takes each deviated section and predicts which tool is in that section by evaluating both the size of the section and the color values that it contains.

Two experiments were conducted using the CVST system. In the Experiment 1, 5 background colors were tested to determine how contrasting colors affect the ability to accurately distinguish the tools from the background. This was done by using surfaces of red, green, blue, white, and black as the tray background, and adjusting thresholds manually in attempt to obtain the best possible results.

In Experiment 2, a Tru-Vu (Arlington Heights, IL) SRMH display with a plain white background was used as a backlight to lessen the impact of shadows, which caused notable errors in the algorithm when not backlit. The experimental setup with the backlighting display is shown in Figure 3. Experiment 2 consisted of 2 parts. First, the tray was emptied, and each of the 5 tools was placed and removed 10 times to determine the accuracy of the system in detecting each tool correctly. During this test, the position and orientation of the tool was randomly changed in order to test the robustness of the system. Second, all 5 tools were placed on the tray together and each of the tools were randomly rearranged or removed 10 times to assess system accuracy when multiple tools are involved. It is important to note that the catheter was excluded from this experiment due to the small size of the screen.

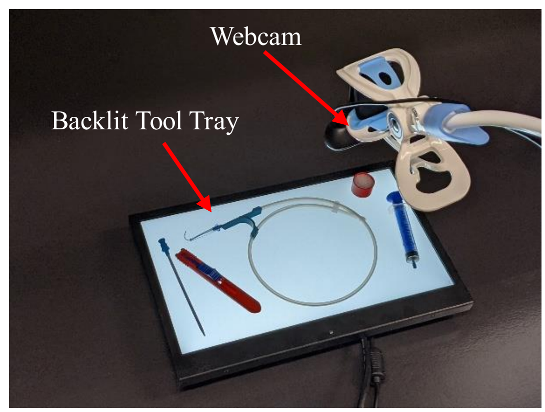

FIGURE 3: THE COMPUTER VISION ENABLED SMART TRAY SYSTEM WITH A BACKLIGHT DISPLAY

3. RESULTS AND DISCUSSION

Figure 4 shows the percent area of the image that was detected as tools on the tray for 5 different background colors in Experiment 1. Based on a manual pixel count performed in Adobe (San Jose, CA) Photoshop, less than 7% of the image will be tools and the remainder will be background. Only the white background resulted in a detection of less than 7% of the image area as tools, with the green background resulting in 7.9% and all other colors resulting in greater than 10% tool area. Figure 5 shows an example of the results of changing the background color of the tray as black and white images representing either background or tool. In this figure, each plot displays pixels as white if they were detected as background area, and as black if detected as a tool.

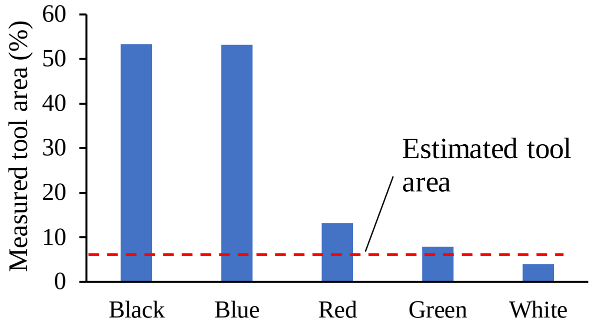

FIGURE 4: PERCENT OF IMAGE DETECTED AS TOOLS FOR 5 BACKGROUND COLORS

As seen in Figure 5, the background color that produced the least error in distinguishing objects from the background was white. The red and green backgrounds allowed the system to more easily detect the thin tubing of the catheter and guidewire, but caused more objects to be confused as part of the background, while the blue and black backgrounds caused the system to confuse more background area as tools. The white background suffered from similar issues caused by shadowing, but the thresholds were able to be adjusted to clearly segregate the background and tool. Adjustments to the thresholds for other background colors proved more difficult and often resulted in overestimation or underestimation of what areas of the image consisted of tools. As a result, CVST will utilize a white background.

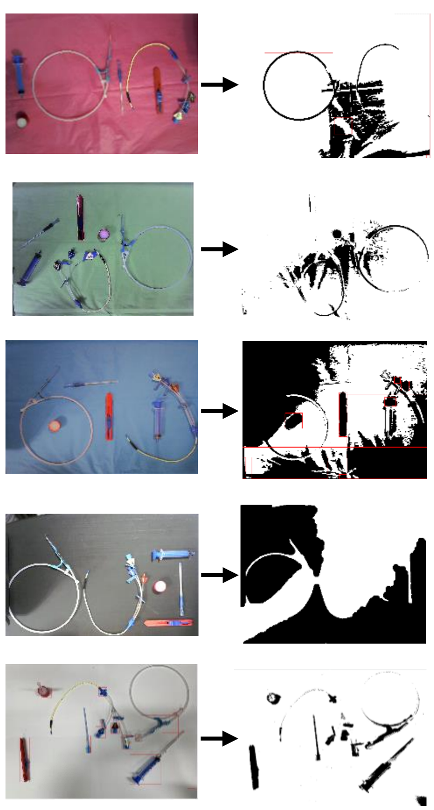

FIGURE 5: THE EFFECTS OF BACKGROUND COLOR ON TOOL DETECTION

In Experiment 2 utilizing backlit tray, the system was able to correctly detect the placement of the syringe, guidewire, and sharp's disposal cup 100% of the time. The scalpel and the dilator were correctly detected 70% of the time and 90% of the time respectively. It was observed that the scalpel was only incorrectly detected when placed in an unnatural way, balancing on its edge, or when placed very close to the edge of the tray. The removal of each tool was only in error when the system didn't detect the placement of the tool previously. In addition, when all of the tools were placed on the tray together, the system accurately detected the syringe, guidewire, and scalpel 100% of the time, while the dilator was correctly detected 90% of the time. The sharp's disposal cup, however, was only detected 60% of the time. This was likely caused by the high amount of white on the disposal cup, which may have caused the cup edges to be confused as a part of another tool close by. This could explain why the system was able to detect the cup with perfect accuracy when placed alone, while unable to do so when placed with other tools. In multiple cases, the system was able to detect the other 4 tools correctly even when they overlapped or touched.

This CV algorithm was able to track the location of CVC medical tools with satisfying accuracy. Through the use of more complex and robust algorithms, the CVST can be effective for CVC training, and its design could be used to create training systems for other medical procedures or tool tracking systems.

4. CONCLUSION

A computer vision system, used to detect medical catheterization tools, known as the Computer Vision enabled Smart Tray (CVST), was developed and tested to determine accuracy. It was found that, of 5 colors tested, a white monochromatic background was most suitable for differentiating tools from the background, and that when using a backlit tray, the system was able to detect the placement and removal of 3 individual tools to 100% accuracy, and the other 2 to 70% and 90% accuracy. The backlit system was also found to accurately detect the arrangement of 4 of the 5 tools even when overlapped, but 40% of the time was unable to detect the sharp's disposal cup, likely due to the high amount of white color on the tool.

Future work will improve the CV algorithm to consider tool overlap, increase the tray area, and apply CV to the advanced testing surface (ATS) [8] which allows for tool interaction with simulated tissue. This complete system will allow for effective automated training of user tool interaction in CVC.

ACKNOWLEDGEMENTS

Research reported in this publication was supported by the National Heart, Lung, and Blood Institute of the National Institutes of Health under Award Number R01HL127316. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. Coauthors Dr. Moore and Miller own equity in Medulate, which may have a future interest in this project. Company ownership has been reviewed by the University's Individual Conflict of Interest Committee and is currently being managed by the University.

REFERENCES

[1] McGee, D. C., and Gould, M. K., 2003, "Preventing Complications of Central Venous Catheterization," N. Engl. J. Med., **348**(12), pp. 1123–1133.

[2] Dong, Y., Suri, H. S., Cook, D. A., Kashani, K. B., Mullon, J. J., Enders, F. T., Rubin, O., Ziv, A., and Dunn, W. F., 2010, "Simulation-Based Objective Assessment Discerns Clinical Proficiency in Central Line Placement: A Construct Validation," Chest, **137**(5), pp. 1050–1056.

[3] Chen, H.-E., Yovanoff, M. A., Pepley, D. F., Sonntag, C. C., Resident Physician, M., Mirkin, K. A., Han, D. C., Professor of Surgery, M., Moore, J. Z., Professor Mechanical Engineering, A., Miller, S. R., and Professor, A., "Can Haptic Simulators Distinguish Expert Performance? A Case Study in Central Venous Catheterization in Surgical Education."

[4] Tzamaras, H. M., Brown, D., Gonzalez-Vargas, J. M., Moore, J., and Miller, S. R., 2021, "Sensorization of Medical Trays for Tray-Based Surgical Procedure Simulation," *Proceedings of the 2021 Design of Medical Devices Conference, DMD 2021*.

[5] Huang, T. S., 1997, "Computer Vision: Evolution and Promise," Report.

[6] Verschae, R., and Ruiz-del-Solar, J., 2015, "Object Detection: Current and Future Directions," Front. Robot. AI, **0**(NOV), p. 29.

[7] Esteva, A., Chou, K., Yeung, S., Naik, N., Madani, A., Mottaghi, A., Liu, Y., Topol, E., Dean, J., and Socher, R., 2021, "Deep Learning-Enabled Medical Computer Vision," npj Digit. Med. 2021 41, **4**(1), pp. 1–9.

[8] Brown, D., Tzamaras, H., Gonzalez-Vargas, J. M., Miller, S., and Moore, J., 2021, "Advanced Surface System for Central Venous Catheter Insertion Training," *Proceedings of the 2021 Design of Medical Devices Conference, DMD 2021*, American Society of Mechanical Engineers.