Can style transfer improve the realism of the simulation of laparoscopic bile duct exploration using ultrasound?

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Introduction

Surgical simulation has demonstrated its potential to improve surgeons' performance through practice [1]. However, surgeons need to be engaged in a challenging way which can only be achieved through realistic practices. There are several types of surgical simulators, including physical simulators, virtual-reality-based simulators, and hybrid simulators [2]. Physical simulators can provide tactile feedback, but are not very realistic-looking and can only provide a limited number of scenarios and anatomies. Virtual-reality presents more diversity of scenarios and pathologies but the tactile feedback is limited. Hybrid simulations aims to combine both methods to provide better training.

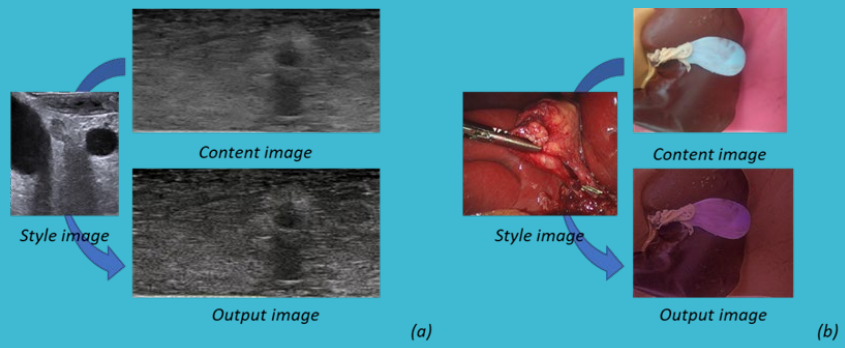
The aim of this research project is to develop a hybrid simulator for laparoscopic bile duct exploration using ultrasound. To our knowledge, there is no satisfying simulator able to teach the challenging steps of this surgery, such as suturing of the bile duct and intra-operative ultrasounds. The simulator needs to feel realistic when the surgeons suture the bile duct and to be ultrasound-visible to allow for radiographic examination. This work focuses on developing a simulator using ultrasound visible materials. Most ultrasound simulators are gel-based resulting in a low-shelf-life, or are made of silicones which have a longer shelf-life but do not look as realistic [3]; however, during a laparoscopy, the surgeon can only observe the surgery through a camera, for this reason, it is possible to enhance the visual realism through images processing of the video.

Method

The utilisation of an image-processing technique, known as style-transfer, is investigated for its potential to improve the realism of a silicone ultrasound simulator. Style transfer is a technique where a CNN is trained to apply the style from a chosen image onto other images [4]. More precisely, style transfer aims to combine a content image (C) and a style image (S), to produce an output image (O) combining the features of the content image and the style of the style image. In the context of surgical simulation, it can apply the style from a picture of surgery on the video frames taken by the endoscopic camera during the simulation, resulting in a more realistic simulation practice.

In this research, a CNN is trained on the COCO database to implement styles from images of surgery onto the simulation. The algorithm is trained to optimise the content loss $L_{content}(C, O) = \frac{1}{2} \sum_{i,j} \left(F_{ij}(C) - F_{ij}(O)\right)^2$ and the style loss $L_{style}(S, O) = \sum_{ij} \left(G_{ij}(S) - G_{ij}(O)\right)^2$ between the input images and the output image, where F_{ij} is the filter from an image recognition CNN at the position (i,j), and G is the Gram matrix of the image.

Result



Results shows that this method can implement the style of real images from surgery onto a silicone-based model to improve its appearance. The algorithm works in real-time to process 480x640 frames using a NVIDIA RTX 3090 graphic card and an Intel® Core™ i9 Ten-Core Processor i9-10900K CPU, allowing its use in a simulation practice. The algorithm not only modifies the colours of the images to make them look more realistic, it also modifies the appearance of small details such as the blood vessels.

One of the limitations of the simulator is that the speed of sound in the silicone is around 1000m/s instead of 1540m/s in the tissues; as a result, the ultrasound images of the simulator are deformed, requiring further image processing to correct the dimensions.

Discussion

The figure shows the potential of using image processing to improve the aspect of medical ultrasound and medical endoscopic images; however, the generalisation of this technique can be limited because of the technology used to perform the ultrasound examination. If the ultrasound probe is connected to a computer, then the image can be processed using the algorithm; but if the image is displayed on a monitor made especially for the ultrasound, then processing the image could prove to be more difficult and challenging because the software of the ultrasound monitor would need to be modified directly. The image processing also requires a computer powerful enough to process the images in real-time.

The surgical practice is a dynamic process and for this reason the algorithm needs to be able to process a video and not just an image. To avoid temporal inconsistencies, the CNN should also be trained to minimise a temporal loss between two following output frames. Previous researches describe style transfer for videos [5].

Previous researches also demonstrate the potential of image processing techniques to enhance surgical simulators [6,7], using style transfer or image-to-image translation.

Conclusion & Future Work

Style transfer has potential to improve the realism of physical simulator for laparoscopic surgeries; however, its generalisation can be complicated by technical limitations. Further work would include an evaluation of the outcome by surgeons.

REFERENCES

[1] D. R. Stather, P. MacEachern, K. Rimmer, C. A. Hergott, and A. Tremblay, "Assessment and learning curve evaluation of endobronchial ultrasound skills following simulation and clinical training," Respirology, vol. 16, no. 4, pp. 698–704, 2011, doi: 10.1111/j.1440-1843.2011.01961.x.

[2] C. Freschi, S. Parrini, N. Dinelli, M. Ferrari, and V. Ferrari, "Hybrid simulation using mixed reality for interventional ultrasound imaging training," Int. J. Comput. Assist. Radiol. Surg., vol. 10, no. 7, pp. 1109–1115, 2015, doi: 10.1007/s11548-014-1113-x.

[3] M. S. Ahmad et al., "Chemical Characteristics, Motivation and Strategies in choice of Materials used as Liver Phantom: A Literature Review," J. Med. Ultrasound, vol. 28, Jan. 2020, doi: 10.4103/JMU.JMU_4_19.

[4] L. Gatys, A. Ecker, and M. Bethge, "A Neural Algorithm of Artistic Style," J. Vis., vol. 16, no. 12, p. 326, 2016, doi: 10.1167/16.12.326.

[5] H. Huang et al., "Real-time neural style transfer for videos," Proc. - 30th IEEE Conf. Comput. Vis. Pattern Recognition, CVPR 2017, vol. 2017-Janua, pp. 7044–7052, 2017, doi: 10.1109/CVPR.2017.745.

[6] I. Luengo, E. Flouty, P. Giataganas, P. Wisanuvej, J. Nehme, and D. Stoyanov, "Surreal: Enhancing Surgical simulation Realism using style transfer," Br. Mach. Vis. Conf. 2018, BMVC 2018, pp. 1–12, 2019.

[7] S. Engelhardt, L. Sharan, M. Karck, R. De Simone, and I. Wolf, "Cross-Domain Conditional Generative Adversarial Networks for Stereoscopic Hyperrealism in Surgical Training," Inform. aktuell, p. 341, 2020, doi: 10.1007/978-3-658-29267-6_75.

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