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An Image Information-based Classification Method for Vascular Interventional Surgery Operating Skills

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***Abstract* - The success rate of the vascular interventional surgery (VIS) depends largely on the skill level of the surgeon. Surgeons with different skill levels will have differences in generating movement trajectory inside blood vessels. The operation skills and skill levels of surgeons during VIS can be evaluated through the images that include the movement trajectory of the distal part of the catheter. Thus, it is very meaningful to propose a method to correctly distinguish the operations of experienced surgeons from the operations of inexperienced surgeons. This paper presents a method to differentiate surgical skills of surgeons in vascular interventional surgery. In our study, the movement trajectory of the guidewire in the images based on the two-dimensional vascular models was firstly collected. Then, these images were manually annotated and the Elan software was used to annotate the operation time. In addition, whether the guidewire deformed when it collided with the vascular wall during the operation was obtained indicate the significant differences between the two groups. Corner detection algorithm was used to obtain the motion coordinates of the distal part of the guidewire in each operation. The coordinates of the distal part were drawn on a picture, that is, the distal end trajectory in an operation is generated. The above method was used to obtain all the movement trajectories of experienced and inexperienced operations. Finally, the VGG network was used to classify them and the results were obtained. Finally, the classification accuracy of the proposed method can reach 97.4% from the experimental results, which proved that the proposed method was effective and feasible.**

Index Terms - Vascular interventional surgery, image information, guidewire tip trajectory, VGG network

I. Introduction

According to the survey, in recent years, due to people's unhealthy lifestyle, the incidence of human cardiovascular and cerebrovascular disease is increasing year by year, and the trend of development is younger [1]. In general, the prevalence and mortality of cardiovascular diseases in China are still on the rise. Among them, the mortality rate of cardiovascular diseases still ranks the first, accounting for more than 40% of the deaths caused by diseases among residents, higher than that of tumor and other diseases, especially the mortality rate of cardiovascular diseases in rural areas has been higher than that in urban areas in recent years. The total hospitalization costs for cardiovascular and cerebrovascular diseases are also increasing rapidly [2, 3]. Vascular interventional surgery has been developed for nearly a hundred years. Different from traditional craniotomy or open surgery, vascular interventional surgery involves a surgeon to operate a guidewire or other precision instruments into the human body through the radial vascular in the arm or the artery in the root of the thigh, and deliver the medical instruments to the lesion accurately through the vascular in the body for treatment, as shown in Figure 1.

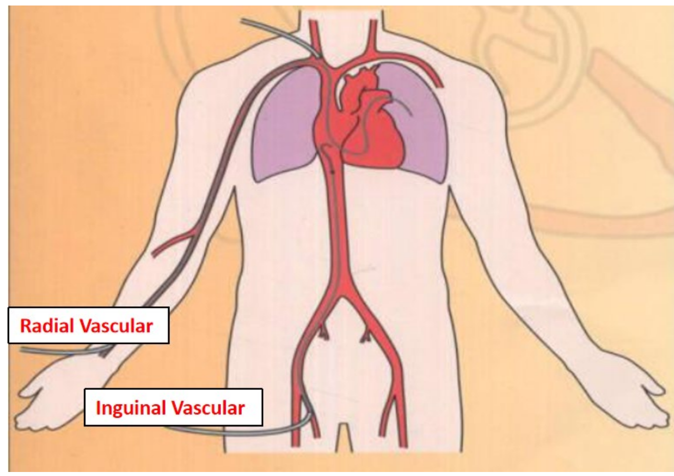

Fig. 1. Puncture map of vascular interventional operation.

Therefore, vascular interventional surgery has some advantages including minimally invasive, quick wound healing and low risk of infection. However, the long exposure to X-rays and heavy lead clothing during the procedure could cause irreversible damage to the surgeons [4, 5]. Based on the above facts, in recent decades, researchers began to pay attention to the development of vascular interventional surgical robots. Representative examples include the CorPath 200 interventional surgical robotic system developed by Corindus Vascular Robotics in the US in 2004 [6]. The Sensei X robotic system developed by Hansen Medical in the US in 2006 [7, 8]. The Amigo robotic system developed by Catheter Robotics Inc in the US in 2012 [9]. The Institute of Automation, Chinese Academy of Sciences designed and completed a set of vascular interventional surgical robot system in 2014 [10]. A set of vascular interventional surgical robot system developed by Shanghai Jiao Tong University in 2018 [11]. A vascular interventional surgical robot system developed by Beijing Institute of Technology [12]-[14]. The above robot systems all adopt master-slave structure. The master site is the surgeon's operation platform, and the slave sit is fixed on the bed in the operating room to complete the command action issued by the master end, so as to liberate the surgeons from the environment full of rays. In addition, the robot has a higher accuracy than the human hand, can be accurate to the millimeter range of operation, which effectively solve the surgeon due to fatigue and other physiological problems. In fact, just as the success of interventional surgery largely depends on the surgeon's years of clinical experience, operating an interventional surgery robot also requires the surgeon's experience and skills. Therefore, in recent years, researchers have begun to study the surgical experience skills of the surgeon, and combine it with the robot system, in the hope that the interventional vascular surgery robot itself can carry the surgeon's experience. The CorPath GRX system developed by Corindus Vascular Robotics, USA, integrates the skills of surgeons to automatically rotate the guidewire tip when the operator retracts the guidewire, thereby changing the direction of the guidewire tip and preparing for the next step [15]. Researchers in Beijing Institute of Technology, designed a robot control method from the end that integrates the operation skills of surgeons by combining with the experience and skills of vascular interventional surgeons [16]-[18].

In addition, because the blood vessels in the human body are complex, weak and different, vascular interventional surgery has very high safety requirements for the operation of both surgeons and vascular interventional surgery robots. A very small mistake may lead to the failure of the operation, which will bring irreparable harm to the patients. Therefore, it is of great significance to accurately distinguish the experienced vascular interventional operation from the novice operation and to give objective evaluation of the operation. Global Rating Scale (GRS) is used internationally to evaluate the surgical operations of surgeons [19]. This method lists the tasks that surgeons need to complete in an operation one by one, and experts score the completion degree of surgeons. Finally, a relatively comprehensive score is summarized and given. However, there are many and complex instruments for vascular interventional surgery, and the scoring criteria of each instrument have not been listed one by one at present, so the workload is heavy. Moreover, this method is very subjective and not convincing. In the study of the Institute of Automation of the Chinese Academy of Sciences, they collected EMG signals during surgeons' operations and generated evaluation criteria based on these signals [20, 21]. In the study of GuoLab of Beijing Institute of Technology, the sequence information of guidewire motion was analyzed to establish an evaluation method for vascular interventional surgery [22]. The methods mentioned above are based on the surgeon's experience and skills to establish evaluation methods. This paper introduces a new method to distinguish surgeons' operative skills in vascular interventional surgery. Firstly, the image information of the guidewire moving on the two-dimensional vascular model was obtained, and the binary image was obtained by OpenCV. Then the corner detection algorithm is used to get the coordinates of the movement of the distal part of the guidewire. The coordinates of the distal part in each operation are drawn in a picture to generate the movement trajectory of the distal part of the guidewire. Finally, two kinds of operation skills are classified by VGG network, and the results are obtained, so as to achieve the purpose of distinguishing the operation of different skill groups.

The remaining of this paper is as follows: the second section is materials and methods, including the introduction of data acquisition platform, experimental setting; the third section is experiments and results, mainly introducing the processing of acquired image information and the results of network classification; the fourth section is discussion and prospect; the last section is conclusion.

II. Materials and Methods

A. Operation Platform

In our study, we used vascular models that were made of industrial wax. The fabrication method of the vascular models has been introduced in our previous work [23]. A camera was used to capture the motion of the guidewire in the vascular model at a frequency of 10 frames per second, and the image size was 480 pixels x 640 pixels. Figure 2 and Figure 3 represent the self-made vascular models and data acquisition platform, respectively.

Fig. 2. Self-made vascular model.

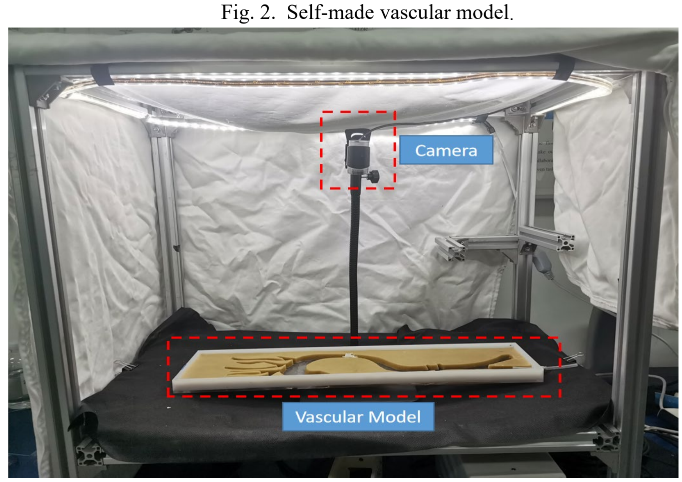

Fig. 3. Data acquisition platform.

TABLE I
THE OPERATING TIME OF THE FOUR OPERATORS (TARGET LOCATION1-7)

Operating Time(s)									
Character of Operation	Target Point / Operator	1	2	3	4	5	6	7	Average
Experience	A	00:02.7	00:07.0	00:14.8	00:06.5	00:05.3	00:04.4	00:10.9	**00:07.4**
	B	00:01.7	00:03.2	00:04.1	00:04.5	00:02.5	00:01.1	00:03.0	**00:02.9**
Inexperience	C	00:06.7	00:23.6	01:04.3	00:39.2	00:13.2	00:14.9	00:41.7	**00:29.1**
	D	00:07.2	00:12.7	00:45.7	00:24.1	00:24.9	00:12.1	00:56.9	**00:26.2**

TABLE II
THE OPERATING TIME OF THE FOUR OPERATORS (TARGET LOCATION 8-14)

Operating Time(s)									
Character of Operation	Target Point / Operator	8	9	10	11	12	13	14	Average
Experience	A	00:12.2	00:03.4	00:08.5	00:10.7	00:11.5	00:13.7	00:08.5	**00:09.8**
	B	00:03.0	00:03.3	00:10.3	00:23.4	00:11.3	00:20.0	00:21.7	**00:13.3**
Inexperience	C	01:04.0	00:07.3	00:16.2	00:34.1	00:15.2	00:31.5	00:41.4	**00:30.0**
	D	01:52.1	00:07.9	00:20.8	00:29.9	00:21.1	00:36.4	00:25.4	**00:36.2**

B. *Experimental Setting*

The initial position and the target position were marked on the vascular model. There were 14 target positions in the four vascular models, as shown in Figure 4. Four operators were asked to operate the guidewire from the initial position to the target position, 4-6 times for each position. We regarded the guidewire distal part from the initial position to the target position as one operation. There were two experienced operators and two inexperienced operators. The camera captured images throughout the process, and finally collected 228,214 images from four blood vessel models by four operators. Among these images, 520 experienced operations and 462 inexperienced operations were extracted.

The camera images were combined into a video, and the Elan video labeling software was used to mark the operation time and whether the guidewire was deformed during the operation due to collision with the vascular wall. The operating time (time for the distal part of the guidewire to reach the target position from the initial position) of the four operators was statistically obtained as shown in Table I and Table II. The operating time of the two skill groups was plotted into a scatter plot, as shown in Figure 5. We can see that

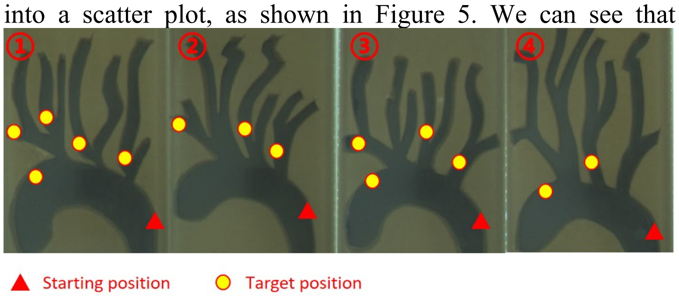

Fig. 4. The initial and target positions on the vascular models.

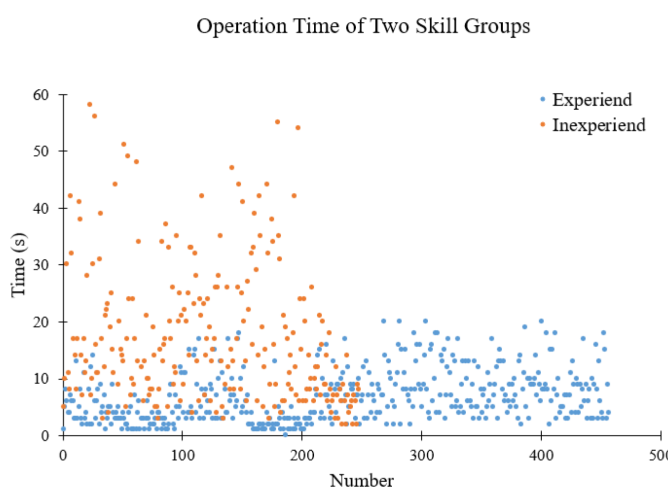

Fig. 5. Operation time of two skill group.

there is a significant difference in the operating time between experienced and inexperienced operators. Moreover, in the labeling process, we found that there was a significant difference in the motion trajectory of the distal end of the guidewire between experienced operation and inexperienced operation.

III. EXPERIMENTS AND RESULTS

A. *Data Preprocessing*

In this experiment, firstly, the collected images were preprocessed according to the method introduced in the second section. By using the OpenCV library in Python, two adjacent images were subtracted to obtain the moving image of the guidewire, and the obtained image information of the guidewire was binarized. The binarization image of the guidewire was shown in Figure 6.

Then, the corner detection algorithm was used to obtain the coordinates of the distal end of the guidewire of the continuous frame image in an operation. Each distal sitting mark in an operation was drawn on a picture to generate the distal movement trajectory. The generated distal-end trajectory was shown in Figure 7 and Figure 8. Among them, Figure 7 shows the distal end motion track of the guidewire operated by experienced operators, and Figure 8 shows the distal end motion track of the guidewire operated by inexperienced operators. Each operation was represented by four trajectories.

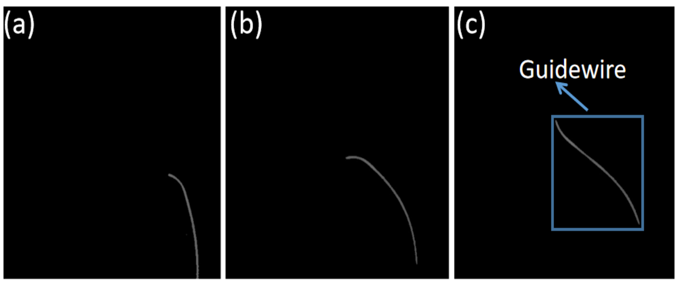

Fig. 6. Binary image of the guidewire.

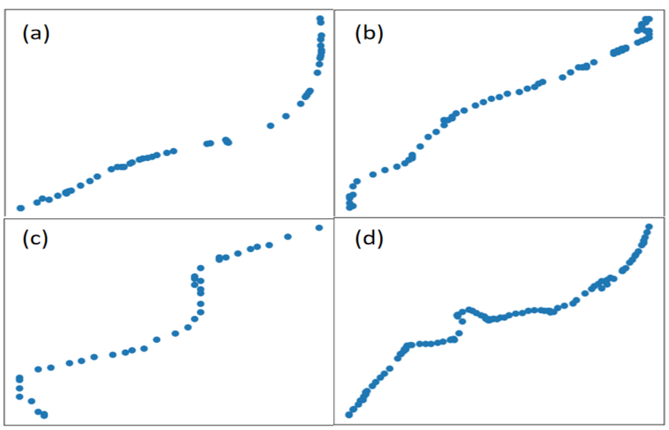

Fig. 7. Trajectory of distal end of guidewire operated by experienced operator.

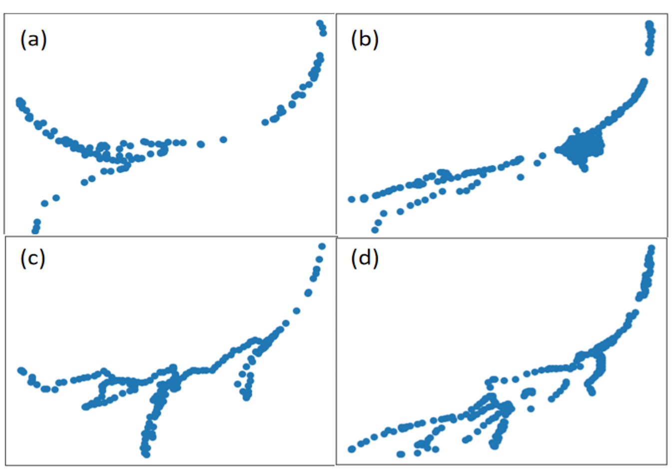

Fig. 8. Trajectory of distal end of guidewire operated by inexperienced operator.

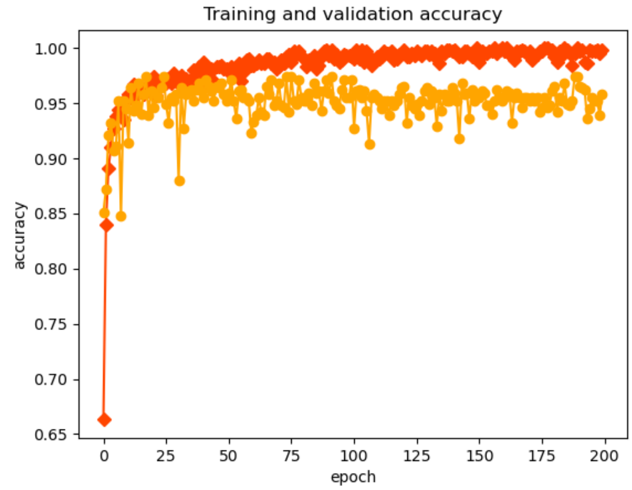

Fig. 9. The accuracy of network classification.

B. *The Classification Results*

In the experiment of this paper, a total of 228,214 images were collected. 520 experienced operations and 462 inexperienced operations were extracted from these images, and a total of 982 operations were obtained. Therefore, 982 motion trajectory images of the distal end of the guidewire were produced and used as the dataset of this experiment. The classification network adopts the mature VGG network, 20% of the dataset was used as the testing set, and the rest was used as the training and validation set of the network. Experienced 200 epochs in the VGG network to obtain the accuracy of the training set and the validation set, as shown in Figure 9.

IV. Discussion

The clinical experience of vascular interventional surgeons is very important for both the clinical treatment of vascular interventional surgery and the research of vascular interventional surgery robot, which will not be explained in detail here.

In the experimental setup of this paper, two experienced operators and two inexperienced operators operated the guidewire respectively to simulate the vascular interventional surgery experiment on the two-dimensional vascular model. A total of 228,214 images were collected. We then combined the captured images into a video and annotated the video using the Elan annotation software. The time between different operations and whether the guidewire deforms due to collision with the vascular wall during the operation were mainly concerned. The labeling results showed that the time taken for the two skill groups to operate the guidewire to reach the same target point was significantly different, and the time taken by the experienced operator was significantly lower than that of the inexperienced operator. In addition, there is also a difference in the factor of collision deformation of the guidewire distal end. However, the vascular model used in the experiment was relatively simple, so the difference was not obvious. In addition, we found in the annotation that when the two skill groups operate the guidewire to reach the target point, the movement trajectory of the distal end of the guidewire was very different, which was very revealing.

According to the method introduced in this paper, corner detection algorithm was used to obtain the coordinates of the distal end of the guidewire for each image in an operation, and these coordinates were drawn on an image. Figure 7 is the guidewire distal end track operated by experienced operators. The characteristic of this kind of trajectory is that it is very continuous. The guidewire reaches the target position from the initial position almost at one time, and will not go wrong. Figure 8 is the distal end track image of the guidewire operated by an inexperienced operator. As we can see, there are often many branches in the trajectory, which means that the guidewire does not enter the target vascular correctly at one time when it encounters the vascular bifurcation, usually accompanied by several false attempts. In addition, as shown in Figure 8 (b), the distal end of the guidewire rotates several times at a vascular bifurcation, which is the operator looking for a suitable angle to enter the target vascular.VGG network was selected and manually classified data were used to train the network.

V. Conclusion

The main purpose of this paper is to distinguish the operation of two skill groups based on the image information of guidewire motion. The corner detection algorithm is used to get the motion trajectory of the distal end of the guidewire, and the trajectory is classified by VGG network. The final classification results were shown in Figure 9. The accuracy of the test set reaches 97.4%.

The study in this paper only stops at classifying the operations of surgeons with different skill groups. In the future study, more indicators in the operation process of vascular interventional surgery will be integrated to establish the evaluation method of vascular interventional surgery. In subsequent studies, the EVE vascular model will be used to collect data for analysis.

Acknowledgment

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