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A Novel Vibrating Device for the Interventional Surgical Robotic System

Shuxiang Guo[1,2,3*], Jiaqing Wu [1,2], Nan Xiao[1,2*], Chaonan Zhang [1,2], Yan Zhao[1,2] , Guangxuan Li [1,2], Changqi Xu [1,2]
[1] The Institute of Advanced Medical Engineering System, Beijing Institute of Technology, No.5, Zhongguancun South Street, Haidian District, Beijing 100081, China;
[2] Key Laboratory of Convergence Medical Engineering System and Healthcare Technology, the Ministry of Industry and Information Technology, Beijing Institute of Technology, No.5, Zhongguancun South Street, Haidian District, Beijing 100081, China
[3] Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa 760-8521, Japan
E-mails: xiaonan@bit.edu.cn; guoshuxiang@bit.edu.cn;
* Corresponding author

***Abstract* - At this time, centrum cerebrovascular diseases (CCVd) have been a serious threaten to human being's health. Compared with traditional therapeutic method for treating CCVd, the vascular interventional surgery is like to be accepted by patients and clinicians now because it can reduce patients' pain and permit a faster recovery, and it's more like to be used in treating cerebral vascular diseases rather than only in the therapeutic areas of cardiovascular diseases, which needs more accuracy and convenience of the medical equipment. As we know, the blood is very viscous, and there is many friction when the catheter moving in the blood vessel, and many other reasons that impede the catheter move. So we should find some way to avoid this situation. Adding vibration to catheter is a good way for this problem. Therefore, it is essential to realize that it's very meaningful to find out a new method and design a novel device to add vibration to the catheter in the vascular interventional surgery. This paper proposes a new method that guide the catheter with micro vibration, and design a novel device to realize it after studying on vibration of the piezoelectric plate. It is shown that the novel device can conduct the vibration to the catheter well, and it can be the basis of our further research.**

Index Terms – The vascular interventional surgery; Vibration; The piezoelectric plate

I. Introduction

CCVd, which is a very common disease to damage people's health, is a serious threat to human beings, especially the patients older than 50 years old, with a high prevalence rate, high morbidity and high mortality characteristics, even for the most advanced and comprehensive treatment, there are still more than 50% of patients can not take care of themselves. At present, CCVd led nearly 16 million people around the world to death every year, to become the world's largest cause of death[1].

Minimally invasive surgery has acquired revolutionary success in more and more traditional fields, which has become the main theme of the global development of surgery and gradually applied in the field of CCVd. Now,as a mature diagnosis and treatment means of CCVd, the minimally invasive vascular surgery technique is considered to be one of the most practical clinical project at present, with high precision, small trauma, faster recovery and other advantages. It can provide the patients with shorter recovery time and less pains and the surgeons less time consumption, more safety and higher success rate compared to open surgery. Therefore, interventional surgery has been widely used in many clinical surgeries, such as removal of thrombus or foreign body, the treatment of tumors or vascular malformation, and thrombus dissolution.

The minimally invasive vascular surgery is an emerging medical procedure that under the guidance of medical imaging equipment, along the vessel operating the intervention catheter to reach the distant lesion, then implementing the minimally invasive treatment to the lesion position[2]-[6]. Currently, during the process of pushing the catheter, a more common practice is done by hand of the skilled operators directly to insert the catheter in the X-ray images or other gray image monitoring and guidance. As a new technology, it takes lots of the operating skills, for the surgical staff, making the catheter quickly and accurately reach the target position is a very difficult task because of blood's viscosity. The errors or repetitive operations might cause some damage to the patients, when the catheter inserted into the vessel, bring a certain amount of risk to the surgery. [7]-[9] Meanwhile, there is a long time for the surgeons to expose in the x-ray radiation to make a operation, this process would cause damage to the patients and surgeons [10].

To avoid too much radiation for the surgeons (it's inevitable for patients,unfortunately), we need master-slave catheter operating system, which provide more easier and accurate manipulation of the catheter insertion and reduce the harm caused by the X-ray to the surgeons. This system separate the surgeons from the patients and X-rays, after getting the feedback information from the slave side, surgeons operate the main system side to carry out the interventional procedures on the patients with the catheter, while from the various sensors installed on the slave side to get the feedback information in the body especially intravascular[11-15].This help surgeons escape from radiation of X-rays,

The master-slaving catheter system has been widely accepted and applied around the world. The Sensei Robotic System produced by Hansen Medical is the first interventional surgical robot system used in practice. It provides 3D control handle to make surgeons operate easier, and console screen to display the real-time contrast image and the ultrasound image. By 3D visualization module, this product can display three-dimensional image of the heart and the catheter in real time as well as a rough estimation of the tip contact forces on the screen. Meanwhile, this system can realize accuracy position control of catheter[16]. The CorPath 200 System produced by Corindus COMPANY is the first interventional surgical robot system, which applied the passive catheter technology, used in clinical experiment. Through this system, the surgeon out of operaion room control the catheter to insert it into patient's blood vessel by operating operation lever and touching screen, but it need one person replace guide wire and catheter, which will influence the coherence of the operation. Nowadays, the focus in producing the master-slaving catheter system is still the properties of catheter and the control method to improve accuracy of the system[17]. Not many person concern how to reduce the viscous resistance of blood in this system.

For this purpose, we find a new method that adding vibration to the catheter to reduce viscous resistance. In theory, with vibration, blood around the catheter will turn into turbulence, which will form many "vacuum zones " between blood and catheter. In this "vacuum zone", there is no viscous resistance because of no touching between blood and catheter[18]-[19]. So, the whole system will reduce viscous resistance with vibration. In practical, the interventional surgical robot system with vibration has been used to treat other diseases such as CTO (Chronic Total Occlusion)[20]-[22]. The CROSSER CTO Recanalization System produced by Flow Cardia Inc results in vibration of the catheter tip at the rate of 21,000 cycles/secs through their special catheter. This vibration provides mechanical impact and cavitational effects, which aid in the recanalization of the occluded artery. This product testifies vibration will not hurt human's body, and can be used in the interventional surgical robotic system[23].

Studies show that the viscous resistance will influence the safety and efficiency of the surgery and adding vibration to catheter can reduce the viscous resistance in theory without any hurt to person, so we can design a novel device to transmit vibration to catheter efficiently to reduce the viscous resistance in the interventional surgical robotic system. Before using it, we design an experiment to research the vibration's property of the piezoelectric plate in Section II. In Section III, we design an amplify circuit and a device to clamp the piezoelectric plate to transmit vibration to catheter according to the result in Section II. In Section IV, we design an experiment using the device from Section III and reports experimental results. Section V concludes the paper with suggestions for future research.

II. PIEZOELECTRIC PLATE PROPERTY

A. Vibration distribution

To add vibration to catheter more efficient, we should know the property of the piezoelectric plate and how it vibrate at first. We separate the piezoelectric plate into 9 equal rectangles to research the difference from every part's vibration under the same situation. The piezoelectric plate is in Fig.1. To reduce the restraints of the plate and ensure it can vibrate more freely, we design a catching device to clamp the plate when we conduct the experiment. Clamping position is

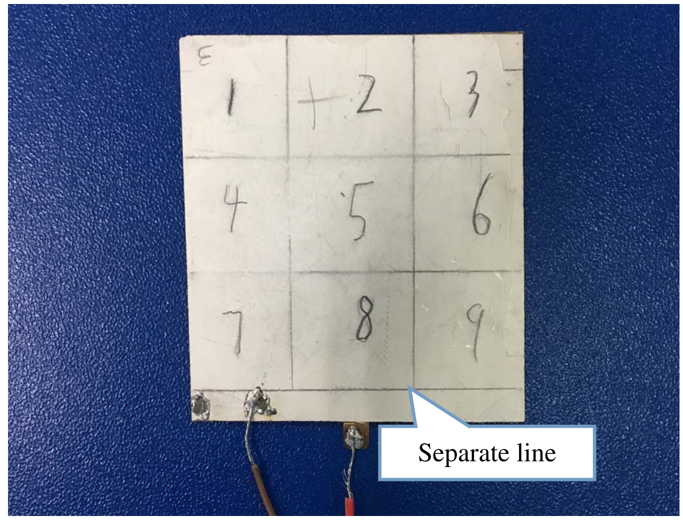


Fig.1 The piezoelectric plate

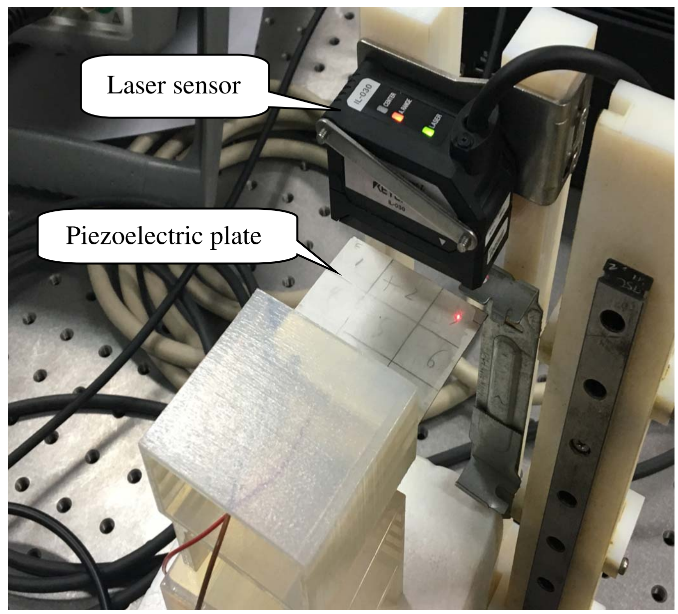


Fig.2 The experiment setup

the separate line shown in Fig.1. The experiment setup is shown in Fig.2. We fasten a laser sensor IL-030 (KEYENCE, JAPAN) and make its detection point at these 9 different areas of the plate to detect the vibration property of the plate, while we change the frequency and voltage of the input signal.Then we can analyze the consequence.

Comparing with different frequency and amplitude of input signal, we choose the sinusoidal signal with a frequency of 10kHz and amplitude of 10V. According to the test result of every area's vibration shown in Fig.3 and Table Ⅰ below (area 1-red thin line, area 2-blue thin line, area 3-yellow, area 4-green, area 5-black, area 6-purple, area7-cyan, area8-red thick line, area 9-blue thick line), we can find the amplitude of every area are all very slight, which are less than 0.02mm, but we analyze the variance of the data. The result is shown in Fig.4, the area in darker color has greater amplitude in variance.

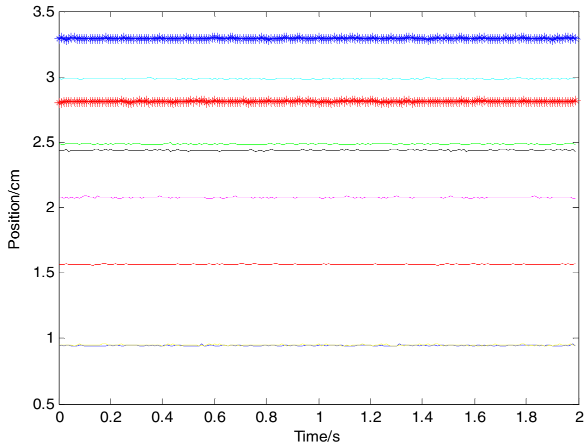


Fig.3 The test result of every area's vibration

TABLE I
THE TEST RESULT OF EVERY AREA'S VIBRATION

Area	Amplitude(*mm*)	Variance($10^{-5}mm^2$)
1	0.017	1.32
2	0.019	1.39
3	0.017	1.36
4	0.017	1.17
5	0.017	1.27
6	0.018	1.20
7	0.016	1.14
8	0.017	1.12
9	0.017	1.08

As shown in Fig.4 below, the variance of every area of the piezoelectric plate is indicated by different color, while light yellow presents the variance range from 1.05-1.15, and yellow presents 1.15-1.25, red presents 1.25-1.35, deep red presents 1.35-1.45 ($10^{-5}mm^2$) .

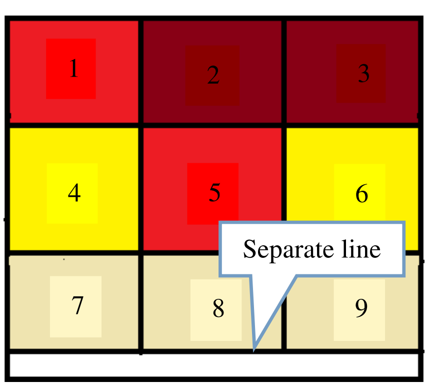


Fig.4 The analyze result of every area's vibration

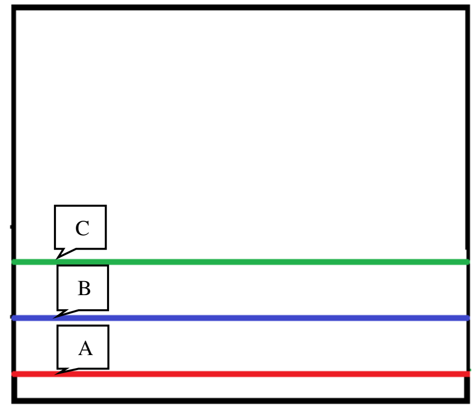


Fig.5 The piezoelectric plate

Then we can find that although the vibration amplitude of every area is almost the same and under 0.02*mm*, but we can differ them through analyzing the variance of every area and find that area 2 is the best. So for convenience, we just consider and use the vibration of area 2 in the rest of this paper.

B. Clamping position

In order to produce better vibration effects, we should research the effects of clamping position of the piezoelectric plate on the plate's vibration and find the best clamping position.

As shown in Fig.5, three different color lines present three different clamping position. The red line is at the same position as the separate line shown in Fig.4, the blue line is at the position that 1/6 of rest part of the plate, and the green line is at the position that 1/3 of rest part of the plate. The result is shown in Fig.6 and in Table II.

As shown in Fig.6, the vibration condition is in accord with the line in Fig.5 in the same color and marked by same letter. We can find that the more part of the piezoelectric plate clamped by our device, the weaker vibration conducted. So we choose separate line at the position shown in Fig.4 when we design the device.

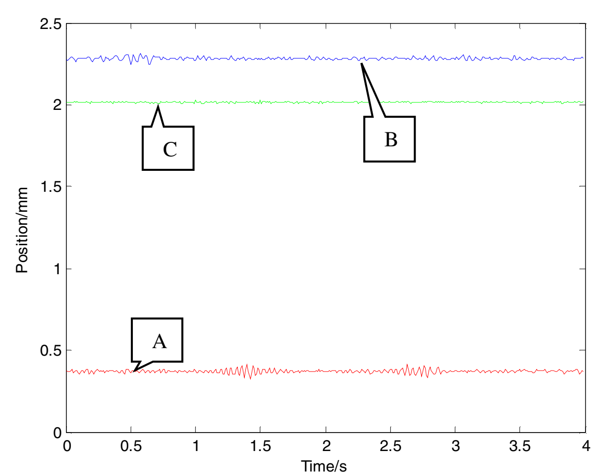


Fig.6 The test result of different clamping position

TABLE II
THE TEST RESULT OF DIFFERENT CLAMPING POSITION

Clamping position	Amplitude(mm)	Variance($10^{-5}mm^2$)
0	0.018	1.42
1/6	0.017	1.33
1/3	0.017	1.27

III. DEVICE DESIGN

According to the result of the research on the piezoelectric plate's properties, we can find that the area with best vibration in the same condition is area 2 shown in the Fig.2, and the best clamping position to ensure better vibration is the separate line shown in the Fig.4. So we can design a novel device to add vibration to the catheter shown in Fig.7 below.

As we can see in Fig.8, the whole system is composed of a steel plate base, a screw slide, a clamping device and a laser sensor. Every part of system is marked in Fig.8.

The clamping device is consist of three parts. Part 1 is the uppermost part of this device which is attached to the laser sensor. Part 2 is a frame that connected to Part 1 and the screw slide, and Part 3 is inside Part 2, and there are two little slide rails between Par 2 and Part 3. And there will be a force sensor in our expectation for force detection experiment in the future. Every part and element of the clamping device is marked in Fig.8.

IV. EXPERIMENTAL RESULTS

Using the device and system designed above, we expect the piezoelectric plate can vibrate as well as it can do in our preliminary experiment, so that we can apply it into the further experiment and the interventional surgical robotic system.

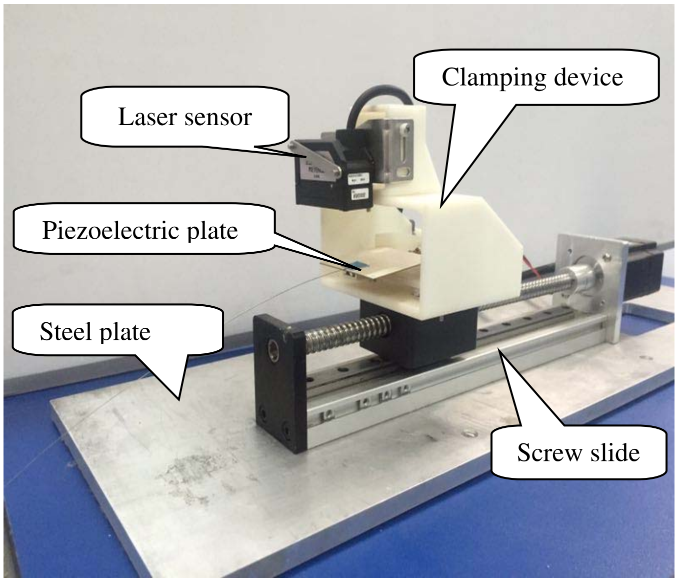
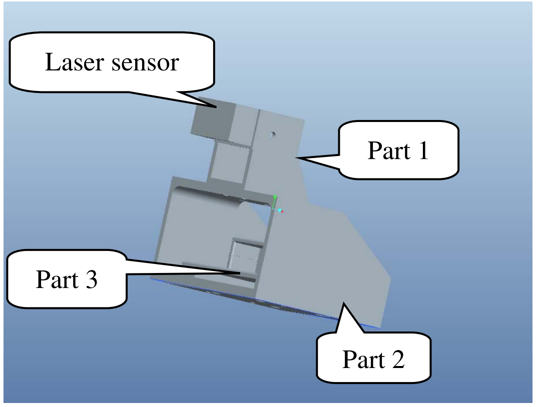
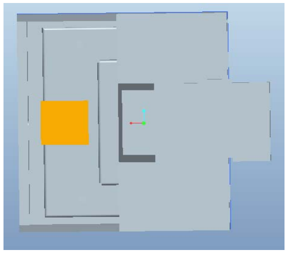


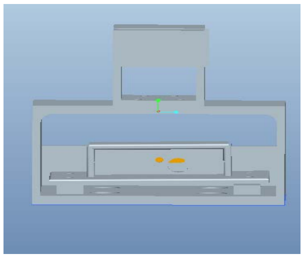
Fig.7 The whole system



(a) The whole clamping device



(b) Top view



(c) Front view

Fig.8 3D graph of the clamping device

In our experiment, the input signal is the the sinusoidal signal with a frequency of 10kHz and amplitude of 10V. The piezoelectric plate is clamped by the device at the separate line, and the laser sensor's detection point is in area 2 of the plate. We begin to sample the data after the screw slide start to move, and then compare the data with preliminary experiment to judge if the device is qualified for our research. The result is shown in Fig.9 and Table III.

As we can see from the data and figure, the vibration of the piezoelectric plate with the device is greater than the one without device.Although there are some influence factors of

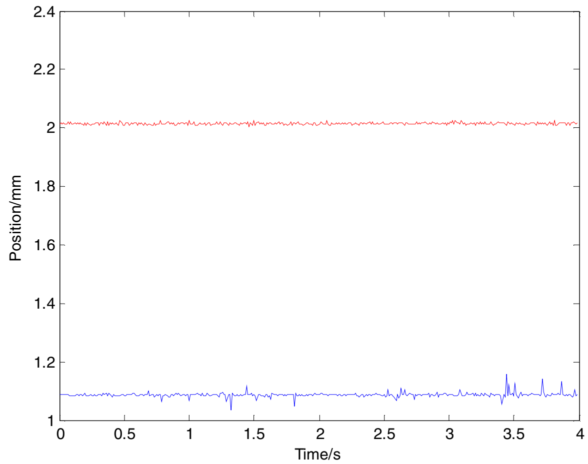


Fig.9 Experiment result

TABLE III
EXPERIMENT RESULTS

Condition	Amplitude(mm)	Variance($10^{-5}\,mm^2$)
Without device	0.018	1.00
With device	0.096	6.63

the system's unstability, but the result still testifies that the novel device is useful and qualified for our research.

As we can see, some experiment datas in the same condition are different in this paper. This is because that the piezoelectric plate's vibration may be influenced by some environment conditions, such as temperature and humidity. So if we need compare the data with other condition's, we will redo experiment to ensure the accuracy.

V. CONCLUSIONS

A new method that adding vibration to catheter to reduce viscous resistance applied in the interventional surgical robotic system and a novel device clamping the piezoelectric plate to realize the function above is proposed in this paper. The purpose of this paper is that transmitting vibration to catheter efficient enough to take the catheter vibrate which can be used in the interventional surgical robotic system to reduce viscous resistance in blood. It is shown that this device can achieve the goal of this research and it is effective according to the experiment's result.

This paper presented a new direction on improving the interventional surgical robotic system that we could continue researching on how to use this device to prove that adding vibration to catheter can reduce the viscous resistance in blood. Hence, we have focused on designing and conducting a new experiment to prove it, and applying it in the system.

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REFERENCES

[1] WHO. Global status report on noncommunicable diseases 2010. World Health Organization, Switzerland, 2011.

[2] Chaonan Zhang, Shuxiang Guo, Baofeng Gao, Feiyu Jia. "The beam theory-based collision force detection of the catheter operating system," in *Proceedings of 2016 IEEE International Conference on Robotics and Automation*, Harbin, China, August 7-10, 2016. pp. 701-706.

[3] J. Dewire, H. Calkins. "State-of-the-art and emerging technologies for atrial fibrillation ablation," *Nature Reviews Cardiology*, vol.7, pp. 129-138. 2010;

[4]Ma X, Guo S, Xiao N, et al. "Development of a Novel Robotic Catheter Manipulating System with Fuzzy PID Control," *International Journal of Intelligent Mechatronics & Robotics*, vol.2, No.2, pp.58-77, 2012.

[5]Rafii-Tari, Hedyeh, C. J. Payne, and G. Z. Yang. "Current and Emerging Robot-Assisted Endovascular Catheterization Technologies: A Review," *Annals of Biomedical Engineering* , vol. 42, pp.697-715,2014.

[6] G. A. Antoniou, C. V. Riga, E. K. Mayer, N. J. Cheshire, C. D. Bicknell, "Clinical applications of robotic technology in vascular and endovascular surgery," *Journal of Vascular Surgery*, vol. 53, No. 2, pp. 493-499, 2011.

[7] Xiao N, Guo J, Guo S, et al. "A robotic catheter system with real-time force feedback and monitor," *Australasian Physical & Engineering Sciences in Medicine*, vol.35, No.3, pp.283-289, 2012.

[8]Willems S, Steven D, Servatius H, Hoffmann BA, Drewitz I, Mullerleile K, Aydin MA, Wegscheider K,Salukhe TV, Meinertz T, Rostock T, "Persistence of Pulmonary Vein Isolation After Robotic Remote-Navigated Ablation for Atrial Fibrillation and its Relation to Clinical Outcome," *Journal of Interventional Cardiac Electrophysiology*, vol. 21, pp. 1079-1084, 2010.

[9]Tercero, Carlos R., et al. "Haptic feedback in endovascular tele-surgery simulation through vasculature phantom morphology changes," in *World Haptics Conference IEEE*, 2013:359-364.

[10]Hasanzadeh, Shahir, and F. Janabi-Sharifi. "Model-Based Force Estimation for Intracardiac Catheters," I*EEE/ASME Transactions on Mechatronics,* vol 21, No.1, pp.1-1, 2015.

[11]Y. Fu, A. Gao, H.Liu, S. Guo, "The master-slave catheterisation system for positioning the steerable catheter," *International Journal of Mechatronics and Automation*, vol. 5, No.1 pp. 1 - 10,2015.

[12]M. Khoshnam and R.V. Patel, "A pseudo-rigid-body 3R model for a steerable ablation catheter," in *Proceedings of 2013 IEEE International Conference on Robotics and Automation*, pp. 4412–4417, 2013.

[13]Burgner, J, et al. "A Telerobotic System for Transnasal Surgery," *IEEE/ASME Transactions on Mechatronics,* vol. 19, No.3, pp.996-1006, 2014.

[14]Hu Z, et al. "Design of a haptic device with grasp and push-pull force feedback for a master-slave surgical robot," I*nternational Journal of Computer Assisted Radiology and Surgery,* vol 11, No.7, pp. 1361-1369, 2016.

[15]Nan Xiao, Shuxiang Guo, Jian Guo, Xufeng, Xiao, Takashi Tamiya, "Development of a Kind of Robotic Catheter Manipulation System," in *Proceedings of IEEE International Conference on Robotics and Biomimetics*, pp. 32-37, 2011.

[16]Xiaonan. Wang, Max Meng, "Perspective of Active Capsule Endoscope: Actuation and Localization," *International Journal of Mechatronics and Automation*, vol.1, No.1, pp. 38-45, 2011.

[17]Y. Wang, S. Guo, B. Gao, "Vascular Elastcity Determined Mass-spring Model for Virtual Reality Simulators," *International Journal of Mechatronics and Automation*, vol.5, No.1, pp.1-10, 2015.

[18]Guo J, Guo S, Shao L, et al. "Design and performance evaluation of a novel robotic catheter system for vascular interventional surgery," *Microsystem Technologies*, vol.22, No.9, pp.1-10, 2016.

[19]A. A. Transeth, K. Y. Pettersen, and P. l. Liljeb¨ack, "A survey on snake robot modeling and locomotion," *Journal of the Robotica*, vol. 27, No. 07, pp. 999–1015, 2009.

[20]Sakes, A, et al. "Treating Total Occlusions: Applying Force for Recanalization," *IEEE Reviews in Biomedical Engineering,* vol.9, pp.1-1, 2016.

[21]Kapralos, I, et al. "Vibrational angioplasty in recanalization of chronic femoropopliteal arterial occlusions: single center experience," *European Journal of Radiology,* vol.83, No.1, pp.155 - 162,2014.

[22]Michalis, L. K., et al. "Vibrational angioplasty in the treatment of chronic femoropopliteal arterial occlusions: preliminary experience," *Journal of Endovascular Therapy,* vol.8, No.6, pp.615, 2015.

[23]J. Guo, S. Guo, T. Tamiya, H. Hirata and H. Ishihara, "Design and Performance Evaluation of a Master Controller for Endovascular Catheterization," *International Journal of Computer Assisted Radiology and Surgery*, vol.11, No.1, pp.1-13, 2015.

[24]Zhang, Wei, et al. "Design and Realization of a Certain Type of Radio Power Amplify Circuit Board Detecting and Teaching Platform," *Advanced Engineering Forum,* vol.6-7, No.1, pp.1042-1045,2012.

[25]W. Peng, N. Xiao, S. Guo and Y. Wang, "A novel force feedback interventional surgery robotic system", in *Proceedings of 2015 IEEE International Conference of Mechatronics and Automation*, pp. 709-714. 2015.

[26]B. Gao, K. Hu, S. Guo, N. Xiao, "Mechanical analysis and haptic simulation of the catheter and vessel model for the MIS VR operation training system", in *Proceedings of 2013 IEEE International Conference on Mechatronics and Automation*, pp. 1372-1377, 2013.