Development of a Novel Robotic Catheter Manipulating System with Fuzzy PID Control

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ABSTRACT

Manual operation of steerable catheter is inaccurate in minimally invasive surgery, requiring dexterity for efficient manipulation of the catheter, and it exposes the surgeons to intense radiation. The authors' objectives are to develop a robotic catheter manipulating system that replaces the surgeons with high accuracy. Increasing demands for flexibility and fast reactions in a control method, fuzzy control (FC) can play an important role because the experience of experts can be combined in the fuzzy control rules to be implemented in the systems. They present a practical application of a fuzzy PID control to this developed system during the remote operations and compare with the traditional PID (Proportional-Integral-Derivative Controllers) control experimentally. The feasibility and effectiveness of the control method are demonstrated. The synchronous manipulation performance with the fuzzy PID control is much better than using the conventional PID control method during the remote operations.

Keywords: Fuzzy Proportional-Integral-Derivative Controllers (PID) Control, Manipulation Performance, Minimally Invasive Surgery (MIS), Remote Operation, Robotic Catheter Manipulating System (RCMS)

INTRODUCTION

Endovascular intervention is expected to become increasingly popular in medical practice, both for diagnosis and for surgery. However, as a new technology, it requires a lot of skills in operation. In addition, the operation is carried out inside the body, it is impossible to monitor it directly. Much more skills and experience are required for doctors to insert the catheter.

In the operation, for example the catheter is inserted through patients' blood vessel. Any mistakes would hurt patients and cause damages. An experienced neurosurgery doctor can achieve a precision about 2mm in the surgery. However, the contact force between the blood vessel and the catheter cannot be sensed. During the operation an X-ray camera is used, and long time operation will cause damage to the patient. Although doctors wear protecting suits, it is very difficult to protect doctors' hands and faces from the radiation of the X-ray. There are dangers of mingling or breaking the blood vessels. To overcome these challenges, we need better technique and mechanisms to help and train doctors. Robotic system takes many advantages of higher precision, can be controlled remotely etc. However, compared with hands of human being, none of a robotic system could satisfy all of the requirements of an endovascular intervention. Not only because the machine is not as flexible as hands of human being but also lacks of touch. In any case, robotic catheter manipulating system could provide assistant to surgeons during the operation, but it has a long way to go to replace human being.

A lot of products and researches are reported in this area. One of the popular products is a robotic catheter placement system called Sensei Robotic Catheter System supplied by Hansen Medical (Amin, Grossman, & Wang, 2005; Pappone, Vicedomini, & Manguso, 2006; Srimath, Kesavadas, & Li, 2010). The Sensei system provides the physician with more stability and more force in catheter placement with the Artisan sheath compared to manual techniques, allows for more precise manipulation with less radiation exposure to the doctor, and is commensurate with higher procedural complications to the patient. Because of the sheath's multiple degrees of freedom, force detection at the distal tip is very hard. Catheter Robotics Inc. has developed a remote catheter system called Amigo (Knight, Ayers, & Cohen, 2008). This system has a robotic sheath to steer catheter which is controlled at a nearby work station, in a manner similar to the Sensei system. The first human trail of this system was in

April 2010 in Leicester UK, where it was used to ablate atrial flutter. Magnatecs Inc. produced their Catheter Guidance Control and Imaging (CGCI) system (Nguyen, Merino, & Gang, 2010). This system has 4 large magnets placed around the table, with customised catheters containing magnets in the tip. The catheter is moved by the magnetic fields and is controlled at a nearby work station The Stereotaxis Inc. developed a magnetic navigation system: the Stereotaxis Niobe (Ernst & Ouyang, 2005). The system facilitates precise vector based navigation of magnetically enabled guide wires for percutaneous coronary intervention Catheter manipulator Controller Figure 1 and Figure 2: Remote Catheter Navigation System (RCNS) by using two permanent magnets located on opposite sides of the patient table to produce a controllable magnetic field. Yogesh Thakur et al. (2009) developed a kind of remote catheter navigation system. This system allowed the user to operate a catheter manipulator with a real catheter. So surgeon's operative skills could be applied in this case. The disadvantage of this system is lack of mechanical feedback. Fukuda et al. (Arai, Fujimura, Fukuda, & Negoro, 2002) at Nagoya University proposed a custom linear stepping mechanism, which simulates the surgeon's hand movement. Regarding these products and researches, most concerns are still the safety. Force information of the catheter during the operation is very important to ensure the safety of the surgery. However, measurement of the force on catheters is very hard to solve in these systems. A potential problem with a remote catheter control system is the lack of mechanical feedback that one would receive from manually controlling a catheter (Fu, Gao, Liu, & Guo, 2010; Ikeda, Arai, Fukuda, Kim, Negoro, Irie, & Takahashi, 2005; Koa, Kanagaratna, Wallace et al., 2007; Nainggolan, 2008; Peirs, Clijnen, Reynaerts, Brussel et al., 2004; Saliba, Reddy, Wazni et al., 2008; Wang, Zhang, & Liu, 2010).

In this study, a new prototype robotic catheter manipulating system has been designed and constructed based on the requirements for the endovascular surgery. Compared with robots

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