Ecole Centrale de Lyon - INSA de Lyon - Université Claude Bernard Lyon 1

Ampère

Unité Mixte de Recherche du CNRS - UMR 5005

Génie Electrique, Electromagnétisme, Automatique,
Microbiologie environnementale et Applications

PhD title:
RACES : Robot Assisted Catheterization in Endovascular Surgery

Laboratory:
Ampère, UMR CNRS 5005 - http://www.ampere-lab.fr/

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Main objective:
RACES project focuses on the development and control of a surgical robot to provide assistance to surgeon during mini invasive endovascular surgery.

Context :

Cardiovascular diseases are the first cause of death in the world according to the World Health Organization. Among vascular pathologies, abdominal aortic and thoracic aortic aneurysms are the most common during vascular surgery [Nichols et al, 2012].
Endovascular surgery is increasingly used for the treatment of aortic aneurysms. This technique has demonstrated a significant benefit in terms of decreased postoperative complications and average length of stay in comparison with conventional surgery. It consists of using a guidewire and a catheter inside the aorta in order to drop an endoprothesis (EDP) to stop the aneurysm development and to restore blood flow as in a healthy aorta.
This minimally invasive technique is preferred over the conventional technique which consists of an open surgery more traumatic for the patient. However, it requires an important know-how. In fact, surgeons navigate within the vascular network to reach the pathological area. This navigation is in 3D while surgeons have only access to 2D X ray images during the procedure to define the tool position. Moreover this imaging modality involves risks for the surgeon (exposure to X-rays) but also for the patient through the use of contrast agents that can lead to kidney failure for patients at risk (which are numerous in this type of surgery). Moreover, there is a risk of perforation of the aorta. The most complex step of this operation is therefore the navigation within the patient's body. Indeed, surgeons must mentally merge 2D images taken in the operating room with a preoperative 3D scanner of the patient. The RACES project aims at helping surgeons in this navigation task.
There already exists robotic solutions such as Magellan robot, developed by Hansen Medical [HansenMedical]. It consists of a robotic arm that moves a guidewire and a robotic catheter using a remote interface. The main drawbacks of this system are the absence of haptic feedback and navigation assistance. Many researchers have been interested in the development of a robotic catheter. Technologies used are magnetic such as with the Niobe system developed by Stereotaxis [Stereotaxis] [Carlo et al, 2006], based on pull wire [*Jaeger et al, 2017*], using Smart Material Actuators [Couture and Szewczyk, 2017], or using hydraulic actuators [Bailly and Amirat, 2005]. However all these solutions are used only to operate catheters. Indeed, guide wires, which are smaller (1 mm or less in diameter) than catheters (3 mm or more in diameter), are currently not actuated. Moreover, before introducing a catheter, it is necessary to introduce at first a guide wire on which will slide a catheter. Surgeons also find it difficult to correctly position the guide wire. They are therefore waiting for a solution for driving automatically the guide wire and the catheter, so that they can concentrate on the diagnostic part and then on the choice and installation of the EDP.

Keywords:
Control, Mechatronics, Medical Robotics, Haptics

PhD objectives, scientific locks:

Robotic medical team of AMPERE laboratory focuses on the development of high fidelity medical simulators in order to offer realistic hands-on trainings to surgeons. These simulators offer advanced haptic feedback and assessment [Herzig at al, 2017] [Senac et al, 2017]. Members of the robotic team have skills in developing and controlling haptic interfaces, and in mechatronic system control.
The PhD student will be in charge of the robot design to provide navigation assistance during endovascular procedures. A first prototype has already been developed in the laboratory. The latter, driven by a haptic interface, moves a guide wire by reproducing the operator's gesture (displacement in the direction of the guide wire and rotation of the guide around its main axis). The principle has thus already be validated. However, the haptic interface reproduces the contacts in a binary manner, assuming that the guide does not warp and it is not able to ensure an automatic procedure. The second prototype must therefore be able to move the guide wire in the aorta automatically until the desired area. Therefore, the first part of the PhD will consist in implementing an adequate trajectory generator which will take into account the kinematic parameters and the degrees of freedom of the robot. An electromagnetic sensor will be used to get the position and orientation of the guide wire. The displacement should take into account not only the possible contacts with a normal or calcified aorta but also the variable influence of the blood flow according to the position of the guide in the aorta. These informations will rely on 3D anatomical models developed by our partner (LaMCoS, UMR CNRS 5259, INSA-Lyon, University of Lyon).
Once this feature has been validated, a second feature will consist of moving a catheter along this guide and orienting it in the desired direction. For this and to avoid developing a robotic catheter, a pull wire catheter (Medtronics) commonly used in the operating room will be motorized to orientate the catheter in the desired direction and allow the wire guide located within to advance in the desired ostium. It will be necessary to identify all the geometric and kinematic parameters of the catheter in order to be able to control it correctly.
For safety reasons, surgeons must be able to take back the control of these tools at any time by controlling the robot remotely via a haptic interface. This interface should be developed during the thesis to offer surgeons a way to recover their usual haptic perceptions. At first, the haptic interface may be a commercial interface (like the Geomagic Touch) but a specific interface will have to be designed.

Research program and scientific approach

- Bibliographic synthesis of commercial solutions and ongoing research on this type of robot, and on surgical robots more generally. In parallel, the PhD student will have to get used to the prototypes and electrical haptic interfaces (like the Geomagic Touch) available in the laboratory. Modeling and control of mechatronic systems will also be essential.
- Trajectory generation to determine the correct trajectory according to the degrees of freedom and the kinematic constraints of the robot.
- Development and implementation of control strategies for the haptic interface to control the robot.
- In vitro validation, and possibility to carry out in vivo tests on animals.

Background required

Applicant should own a master degree in mechanical engineering or in electrical engineering with good knowledge in automatic control. Expertise in the development of mechatronic systems and/or in the development of control laws will be highly appreciated. Experience on handling prototypes/robots will be appreciated. The project will be gathered by several researchers (assistant professor, research engineer, master students, medical doctors) but the applicant needs to be autonomous to achieve the study.

References

[Bailly and Amirat, 2005] Y. Bailly and Y. Amirat, ‘Modeling and Control of a Hybrid Continuum Active Catheter for Aortic Aneurysm Treatment’, in Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on, 2005, pp. 924–29 <http://dx.doi.org/10.1109/ROBOT.2005.1570235>

[Carlo et al, 2006] Carlo P, Gabriele V, Francesco M, Filippo G, Patrizio M, Simone G and Nicoleta S, Simone S, Alessandra M, Giuseppe A, Laura L, Andreina S, Vincenzo S, “Robotic magnetic navigation for atrial fibrillation ablation’’, Journal of the American College of Cardiology, Vol.47, pp: 1390-1400, 2006

[Couture and Szewczyk, 2017] Couture T, Szewczyk J. Design and Experimental Validation of an Active Catheter for Endovascular Navigation. ASME. J. Med. Devices. 2017;12(1):011003-011003-12. doi:10.1115/1.4038334.
[Hansen Medical] http://hansenmedical.com/us/en/vascular/magellan-robotic-system/product-overview
[Herzig et al, 2017] N. Herzig, R. Moreau, T. Redarce, F. Abry, X. Brun. Nonlinear position and stiffness Backstepping controller for a two Degrees of Freedom pneumatic robot. Elsevier Control Engineering Practice, 73:26-39, 2018, https://doi.org/10.1016/j.conengprac.2017.12.007
[Jaeger et al, 2017] H. A. Jaeger et al, "Automated Catheter Navigation With Electromagnetic Image Guidance," in IEEE Transactions on Biomedical Engineering, vol. 64, no. 8, pp. 1972-1979, Aug. 2017.doi: 10.1109/TBME.2016.2623383
[Nichols et al, 2012] Nichols M, Townsend N, Luengo-Fernandez R, Leal J, Gray A, Scarborough P, Rayner M (2012). European Cardiovascular Disease Statistics 2012. European Heart Network, Brussels, European Society of Cardiology, Sophia Antipolis
[Senac et al, 2017] Sénac T., Lelevé A., Moreau R. Control laws for pneumatic cylinder in order to emulate the loss of Resistance principle. In International Federation of Automatic Control (IFAC 2017), July 9-14, 2017
[Stereotaxis] http://www.stereotaxis.com/products/niobe/