CLOSED-LOOP CONTROL OF A ROBOTICALLY-ACTUATED DELIVERY SHEATH (RADS) FOR CARDIOVASCULAR APPLICATIONS

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ABSTRACT

Recent technological advancements have significantly improved treatment of cardiovascular diseases. Valve-related diseases such as severe symptomatic aortic stenosis and insufficiency require treatment by open heart aortic valve surgery with cardiopulmonary bypass. This procedure is often considered a high risk for the patients with comorbidities. As an alternative, treatment can be provided by minimally invasive surgery such as transfemoral (TF) and transapical (TA) transcatheter aortic valve implantation (TAVI) [1]. Complications in TAVI-related procedures are often caused by prosthetic valve malpositioning. Complications can result in severe peri-prosthetic aortic regurgitation, valve embolization and occlusion of arteries. Therefore, outcome of the procedure is closely related to valve placement.

The clinician often has limited and non-intuitive control over the tip of the instrument by manipulating its base, which is outside the body. Integration of robotically-controlled instruments has the potential to assist the clinician in accurate valve positioning. Further, compensation for beating heart and respiration motions could be provided by model predictive control and motion profiles based on patient data. In this study, we describe and demonstrate that a robotically-actuated delivery sheath (RADS) can potentially be used to assist the clinician in valve positioning. The RADS consists of a rigid shaft combined with a flexible articulating tip segment. The tip can be controlled in two degrees-of-freedom by using an antagonistically-configured and pulley driven cable mechanism [2]. The RADS is inserted in a water container and its tip motion tracked by two-dimensional ultrasound. The ultrasound image plane is orientated perpendicular to the shaft of the instrument and positioned at the tip. Direct and inverse kinematic models are used to describe the non-linear relation between cable displacements at the base and the corresponding tip position. Both modeling and ultrasound tracking are used in closed-loop control of the instrument tip. We use Kalman filtering to reduce noise in the system. The effect of mechanical hysteresis in the instrument is reduced by a compensation strategy. We experimentally evaluated the integrated system along various paths. Results show a mean tip positioning errors of 0.75 mm and 1.13 mm along the x- and y-axis, respectively.

REFERENCES

[1] D. Himbert, F. Descoutures, N. Al-Attar, B. Iung, G. Ducrocq, D. D′etaint, E. Brochet, D. Messika-Zeitoun, F. Francis, H. Ibrahim, P. Nataf, and A. Vahanian, "Results of transfemoral or transapical aortic valve implantation following a uniform assessment in high-risk patients with aortic stenosis," *Journal of the American College of Cardiology*, vol. 54, no. 4, pp. 303–311, 2009.

[2] G.J. Vrooijink, T.T.M. Ellenbroek, P. Breedveld, J.G. Grandjean, and S. Misra. "A preliminary study on using a robotically-actuated delivery sheath (RADS) for transapical aortic valve implantation." In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, Hong Kong, China, June 2014.