

Proof-of-Concept Medical Robotic Platform for Endovascular Catheterization

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INTRODUCTION

In endovascular interventions, vessels serve as access routes to deep and remote anatomic regions [1]. Navigation through narrow, fragile, and deformable vessels in endovascular procedures requires considerable skill [2]. Robotic distributed control approaches could improve catheter navigation to bypass anomalies and prevent tissue damage [3]. For particularly narrow vessels, remote actuation through magnetic fields could help in performing complex coordinated motion in three-dimensional (3D) space as magnetic fields are safe and highly controllable [4]. Visualization during endovascular catheterization procedures mainly relies on fluoroscopy, an X-ray based imaging modality that only offers two-dimensional (2D) views of the interventional scene [5]. Conventional approaches are thus characterized by poor situational awareness as constructing a 3D representation from 2D views is mentally demanding. Generating a 3D view via a C-arm is time-consuming and can only be done sporadically to limit patient radiation. Intra-operative 3D vessel representations from non-ionising imaging sources could greatly improve ease of navigation of the medical instruments to target anatomic sites. Another challenge is to provide safe guidance when navigating in fragile vessels from a restricted access point [6]. This could be addressed by path planning to search for a feasible path connecting a start to a goal configuration, while considering the robotic systems constraints and characteristics.

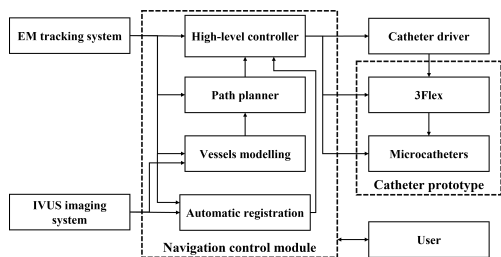


Fig. 1: Overall schematic of proposed medical robotic platform.

In this work, a prototype of a medical robotic platform aimed at endovascular catheterization is developed (Fig. 1). The system integrates several components: a multi-lumen catheter shaft, termed 3Flex, magnetically actuated microcatheter and a navigation control module conceived to help teleoperation and/or autonomous navigation of the 3Flex. This module comprises 3D vessel modelling, automatic registration, path planning, and catheter control. The 3Flex catheter is

designed to carry within it two 6 degrees-of-freedom (DOFs) electromagnetic (EM) tracking sensors, one intravascular ultrasound (IVUS) catheter, and two magnetically-actuated microcatheters envisioned to be controlled by a permanent magnet carrying KUKA robotic arm. However for this prototype, only one microcatheter was used.

MATERIALS AND METHODS

The 3Flex (Fig. 2) is a 3D printed catheter with an outer diameter of 12mm, a length of 500mm, and a 75mm long 2 DOF steerable tip actuated by four integrated pneumatic artificial muscles (PAMs). Its EM tracking sensors are located in two 10mm long sections proximally and distally adjacent to the steerable tip; both are fixed in place in their own lumens and provide position data to the control module. While the design can accommodate a coaxial Fibre Bragg Grating (FBG) for shape reconstruction of the distal segment, it was not implemented here.

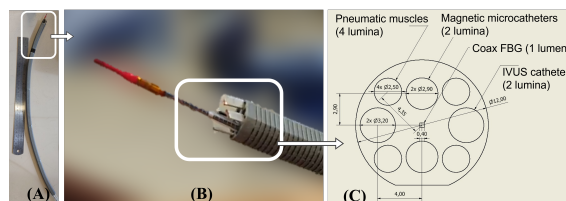


Fig. 2: A) 500mm long 3Flex system (beside a 300mm long ruler); B) view on tip of 75mm active distal section C) cross-sectional view showing embedded functionalities in the 3Flex’s lumina.

Autonomous trajectory planning is designed into the integrated system. Given the preferable anchor region, targets (i.e. two coronary ostia), and start region (patient groin), an optimal path and anchor pose were generated and forwarded to the user. During the trajectory planning, following constraints and system characteristics were incorporated: tip length, bending capability, 3Flex’s outer diameter, magnetic microcatheter length and offset between magnetic microcatheter and 3Flex catheter’s main axis. Real-time IVUS and EM tracking-based vessel modelling technology is integrated in this system. With it, a local representation of the vasculature of the vessel as a 10mm long cylinder-shape at the level of the catheter tip is estimated in real time. This 3D vessel modelling approach provides a 3D representation of the local vasculature for visualization and assists catheter navigation. Navigation assistance is achieved by outputting the 3D vessel model as well as its positioning relative to the 3Flex tip to the control strategy. Furthermore, an online automatic registration approach is implemented based on the intra-operative IVUS and EM tracking data. This registration method requires

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