Path Planning and Control of a Steerable Catheter for Mitral Valve Repair in an Augmented Reality framework

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Introduction: Structural Interventional Cardiology (SIC)

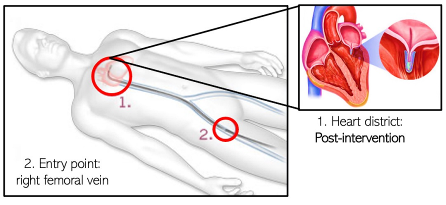


Fig. Transcatheter Mitral Valve Repair via MitraClip system

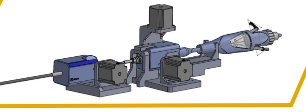
SIC procedures: treatment of Structural Heart Diseases (SHDs).

SIC procedures' **drawbacks**: not ergonomic and technically demanding, steep learning curve, unclear view of the anatomical scene [1].

ARTERY project: introduction of an **autonomous robotic platform** for intra-procedural support, underdevelopment on the commercial MitraClip system [2],[3].

Objectives

Development of an *Autonomous Robotic Platform* exploiting Artificial Intelligence (AI) and Augmented Reality (AR) for **surgeon's assistance.**



Materials and Methods

Proposed methodology:

The operator will define the catheter **Target Position** by simple gesture into the holographic representation.

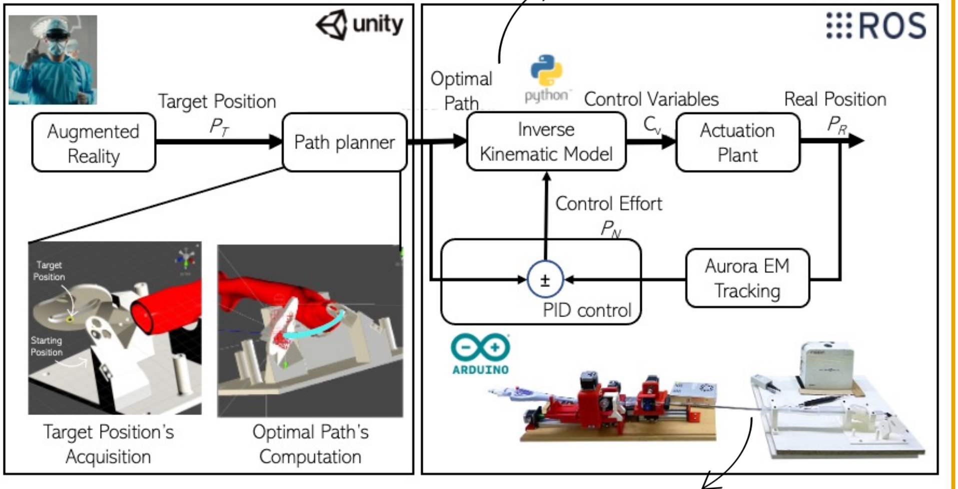
ML-AGENTS 1.0

The Inverse Reinforcement Learning (IRL) path planning algorithm finds the **Optimal Path** taking into account constraints given by:

- anatomical and physical structures;
- Physics of the catheter;
- Starting and Target Position.

The *hardware* integration is performed in the **Robot Operating System** (ROS) framework [4], with a communication frequency of 40 Hz.
The *software* components are developed in Unity environment.

The **Inverse Kinematic Model** of the catheter, based on *Cosserat Rod Theory* (CRT) [2], sequentially translates the points of the path into the **Controls Variables**, i.e. tendons' displacement and linear insertion.



The robotic actuation system, exploiting the Arduino Uno microcontroller, perfoms the motions. A Proportional Integrative Derivative (PID) position control implements the corretion, using real-time information coming from electromagnetic (EM) sensors.

Results: Path Planning

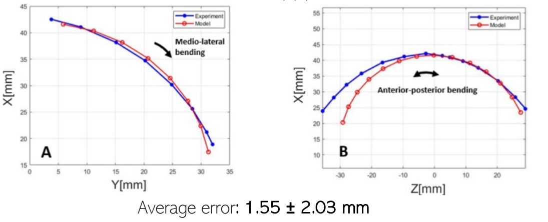
Given the inputs of the Path planner, the following **Benchmark measures** was analyzed:

- Target Position Error (TPE)
- Target Orientation Error (TOE)
- Time (T).

T [s]	TPE [mm]	TOE [°]
8.94±0.18	2.12±0.57	7.41±4.21

Results: Model validations

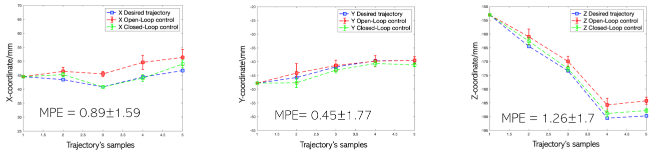
Recorded Trajectory (blue) vs Model prediction (red), Anterio-Posterior **(A)** and Medio-Lateral **(B)** planes.



Average error: **1.55 ± 2.03 mm**

Results: Autonomous system

Mean Position Error [mm] among 4 sampled points of the Optimal Path in the 3 different axes



Comparable execution time (ET) with the manual practice, in the order of tens of seconds.

Improved Accuracy at the Target: **Target Position Error (TPE)** averaged for 3 different targets along mitral valve's plane

Method	TPE x [mm]	TPE y [mm]	TPE z [mm]	ET [sec]
Manual	1.6 ±0.63	3.4±1.88	3.6±2.25	20
Autonomous	0.9±0.54	0.8±0.55	1.5±0.28	15

Conclusion and Discussion

This work presents the preliminary results of a **robotic-assisted system** comprised of an analytical inverse kinematic model based on the CRT that autonomously guide the system to the target.
This device is coupled with an Augmented Reality module and a RL algorithm of path planning.

References

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ARTERY AUTONOMOUS ROBOTICS

Collaborations

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