

Introduction: Structural Interventional Cardiology (SIC)

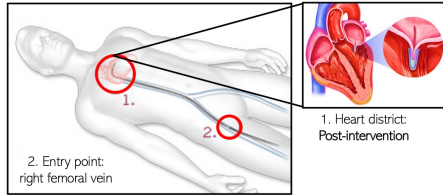


Fig. Transcatheter Mitral Valve Repair via MitraClip system

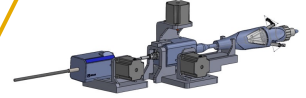
SIC procedures: treatment of Structural Heart Diseases (SHDs).

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.

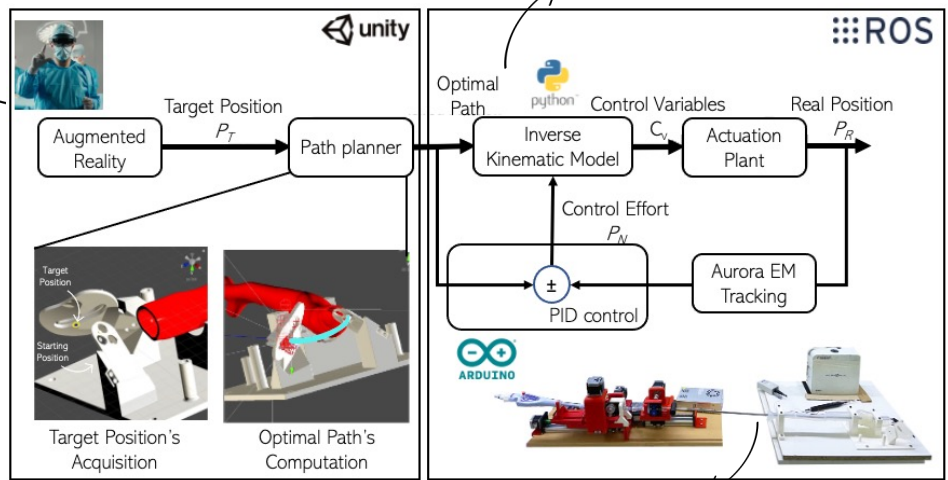


The Inverse Reinforcement Learning (IRL) path planning algorithm finds the **Optimal Path** taking into account constraints given by:

- 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, performs the motions. A Proportional Integrative Derivative (PID) position control implements the correction, using real-time information coming from electromagnetic (EM) sensors.

Results: Path Planning

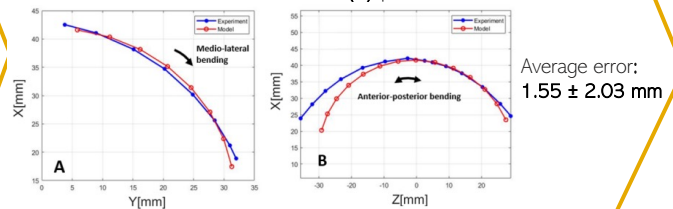
Given the inputs of the Path planner, the following **Benchmark measures** were analyzed:

- 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 |

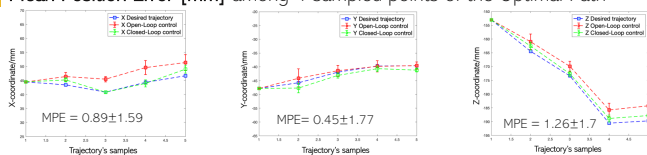
Results: Model validations

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



Results: Autonomous system

Mean Position Error [mm] among 4 sampled points of the Optimal Path



Comparable execution time (ET) with the manual practice (**tens of seconds**).

Improved **Target Position Error (TPE)** averaged for 3 different targets

| 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

- [1] P. Legeza, G. W. Britz, T. Loh, and A. Lumsden, "Current utilization and future directions of robotic-assisted endovascular surgery," *Expert Review of Medical Devices*, vol. 17, no. 9, pp. 919–927, 2020.
- [2] A. Mousa, S. Khoo, and M. Norton, "Robust control of tendon driven continuum robots," in 2018 15th International Workshop on Variable Structure Systems (VSS). IEEE, 2018, pp. 49–54.
- [3] J. Hasan, H. Asma, and K. Saibal, "Mitraclip: a novel percutaneous approach to mitral valve repair," *Journal of Zhejiang University-SCIENCE B (Biomedicine Biotechnology)*, vol. 12, (8):633-637, 2011.
- [4] Koubãa, Anis, ed. *Robot Operating System (ROS)*. Vol. 1. Cham: Springer, 2017.