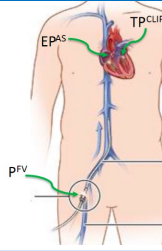


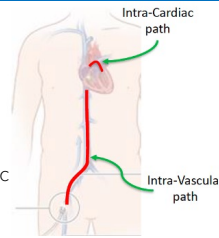
## Introduction: Structural Interventional Cardiology (SIC) [1]

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



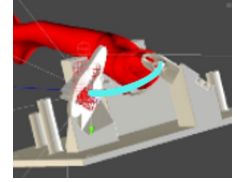
**Input:** Entry Pose of the Femoral Vein (PFV), Entry Pose of the Atrial Septum (EPAS), clip's target pose (TPCLIP)

**Output:** Intra-vascular and intra-cardiac optimal path



## Objectives

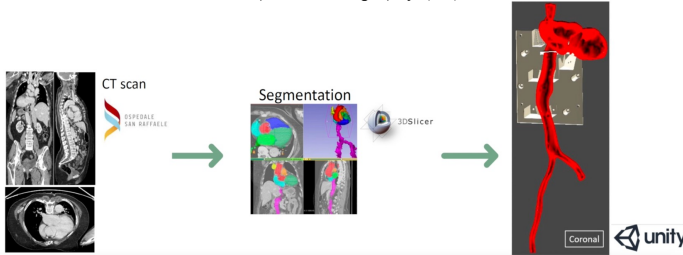
Develop a **pre-operative automatic path planner module** for the ARTERY catheter.



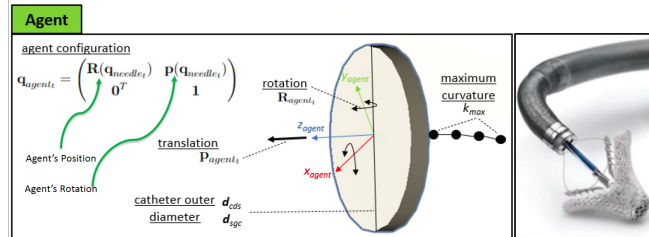
## Materials and Methods

### Creation of the simulation environment:

- The 3D geometry of the anatomical structures of interest was reconstructed from a Computed Tomography (CT) scan.



- The moving agent kinematic constraints are the catheter diameter and the catheter maximum curvature. At t-th time step it can translate ( $q_{agent}$ ) and rotate ( $R_{agent}$ ), from its configuration,  $q_{agent}$  [4]



### 3 methods are considered:

- Manual approach:**  
The manual approach relies only on the expert's ability to drive the agent inside the virtual environment through the use of an X-box joystick

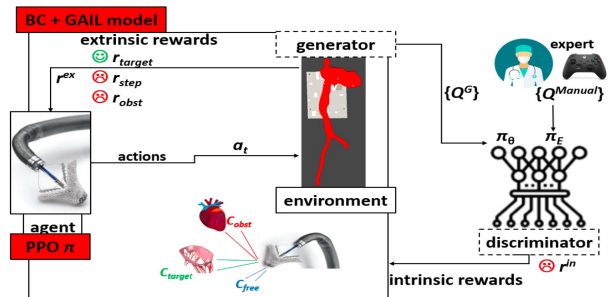


- Iterative Rapidly exploring Random Tree (IRRT) approach:**  
A starting manual trajectory is split in sliding windows. At each iteration, the algorithm searches a path from a specific **temporary starting point** to a **temporary target** one



- Inverse Reinforcement Learning (IRL) based on Behavioral Cloning (BC) + General Adversarial Imitation Learning (GAIL) approach:**

At each time step (t) the discriminator network takes in input the **expert** ( $Q^{Manual}$ ) and **agent** ( $Q^G$ ) trajectories. Subsequently these two trajectories are compared, generating an **intrinsic reward** ( $r^{in}$ ) that relies on a similarity score, updating the agent's **policy** ( $\pi$ ). This loop carries on and it stops when the generator produces a path similar to the one from the expert's demonstrations.



## Results

### Benchmark measures:

- Target Position Error (TPE) and Target Orientation Error (TOE),
- Time and Success Rate (SR).

### Intra-cardiac

Method	time (s)	TPE (mm)	TOE (°)	SR (%)
Manual	8.91±0.48	0.32±0.14	5.17±7.74	100
IRRT	3.51±0.02	0.08±0.00	1.28±0.00	100
BC+GAIL	8.91±0.28	1.79±0.35	5.99±3.10	100

### Intra-vascular

Method	time (s)	TPE (mm)	TOE (°)	SR (%)
Manual	29.93±0.11	0.73±0.51	1.40±4.32	100
IRRT	5.63±0.49	0.33±0.00	0.10±0.00	100
BC+GAIL	32.12±0.11	3.36±1.10	0.77±7.39	100

## Conclusion and Discussion

The presented work assessed the performance of a new IRL-based path planner for steerable needles able to avoid anatomical obstacles while optimizing surgical criteria and trying to respect the catheter's kinematic constraints.

## 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] Unity real-time development platform, 2021. URL <https://unity.com/>.