Path Planner Module for a steerable catheter for Structural Interventional Cardiology using Inverse Reinforcement Learning

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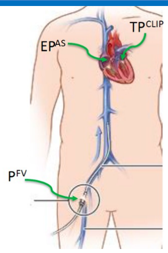
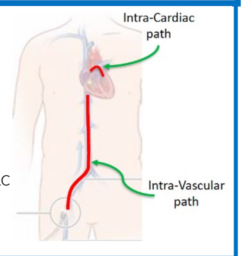
Introduction: Structural Interventional Cardiology (SIC) [1]

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



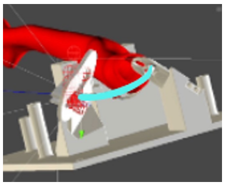
Input: Entry Pose of the Femoral Vein (P^{FV}), Entry Pose of the Atrial Septum (E^{PAS}), clip's target pose (TP^{CLIP})

Output: Intra-vascular and intra-cardiac optimal path



Objectives

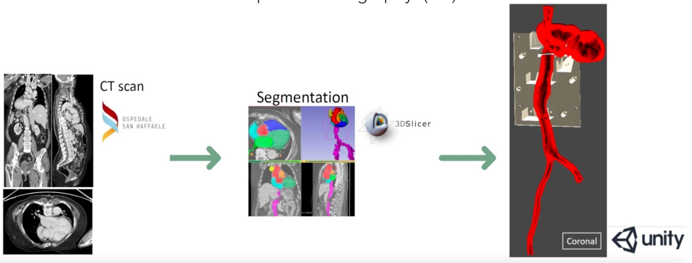
Develop a **pre-operative automatic path planner module** for the ARTERY catheter .



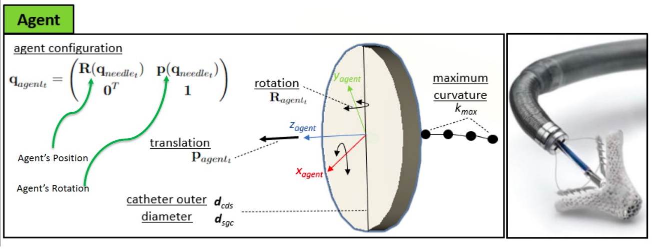
Materials and Methods

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 (p_{agent}) and rotate (R_{agent}), from its configuration, q_{agent} [4]

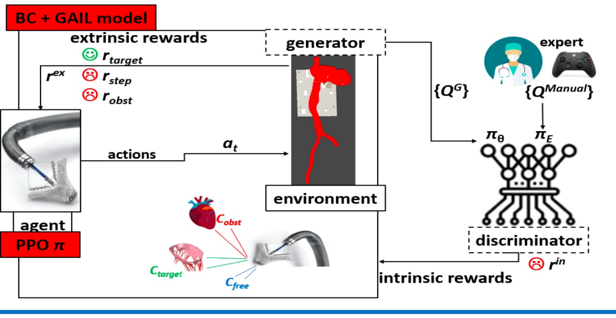


3 methods are considered:

- **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** (π). 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

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Project

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ARTERY AUTONOMOUS ROBOTICS

Collaborations

OSPEDALE SAN RAFFAELE