Inverse Reinforcement Learning algorithm for intra-vascular and intra-cardiac catheter's navigation in Minimally Invasive Surgery

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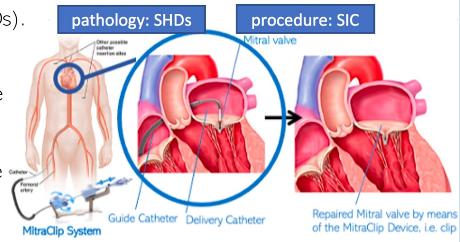
Introduction: Structural Interventional Cardiology (SIC)

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

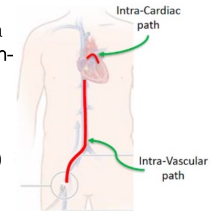
SIC procedures' **drawbacks**: not ergonomic and technically demanding, steep learning curve and problems in the suitable positioning of the catheter [1].

Need to develop a **robust path planner framework** to improve the robustness in obstacle avoidance and risk management in complex environments [2],[3].



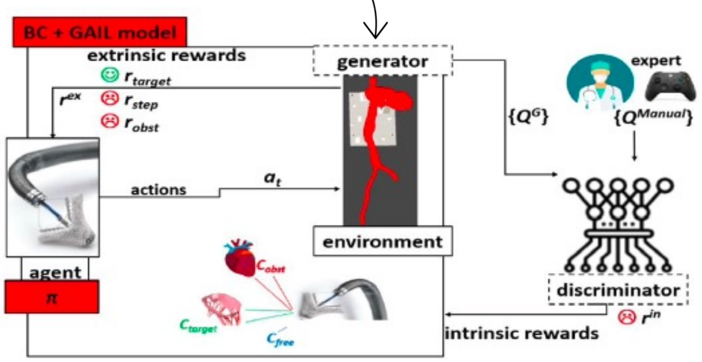
Objectives

Development of a **pre-operative path-planner**, both in the intra-cardiac (IC) phase and intra-vascular (IV) phase.

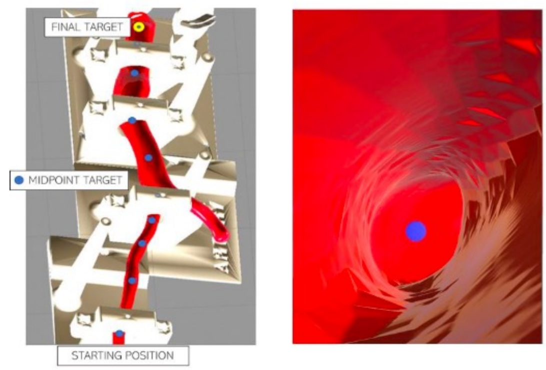


Materials and Methods

Proposed Methodology: Inverse Reinforcement Learning (IRL) based on Behavioural Cloning (BC) + General Adversarial Imitation Learning (GAIL) approach

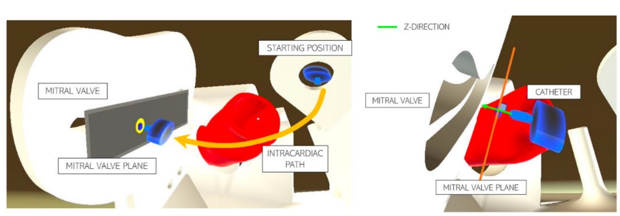


At each time step (t) the discriminator network takes in input the expert (Q^{Manual}) and agent (Q^G) trajectories. Subsequently these two trajectories are compared, generating an **intrinsic reward** (r^{in}) that relies on a **similarity score**, updating the agent's policy **(π).** This loop carries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



Training details IV planner:

- Path from the peripheral access point of the catheter to the access of the heart's chamber.
- Midpoint target's: intermediate target along the length of the vein, needed for the success of the training.



Training details IC planner:

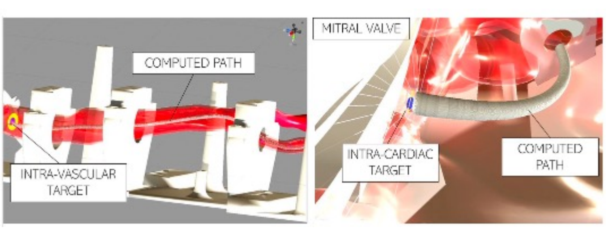
- Path from the heart's access to the final target position upon the mitral valve.
- Importance of the orientation in clinical application for the correct placement of the catheter's clip.
- No intermediate targets were placed in the IC pathway.

Results

Benchmark measures:

- The **success rate** (SR [%]): ratio between the insertions reaching the target and the total number of simulated insertions.
- **Time** [s] required to perform the path.
- **Target position error** (TPE [mm]): Euclidean difference between the needle's final position and the target position.
- **Target orientation error** (TOE [°]): difference between the needle's final orientation and the target one (ONLY IC planner).

	SR	Time	TPE	TOE
IV planner	79	32.12±0.11	1.77±0.88	/
IC planner	88.6	10±1.2	0.63 ±0.36	5.99±3.10



Computed path for the intra-vascular section and the one computed to the target placed upon Mitral Valve in the intra-cardiac phase.

Conclusion and Discussion

The presented work assessed the performance of a **new IRL- based path planner** for steerable needles able to minimize the interaction with vessel's walls during the intra-vascular navigation and avoiding collision with heart's anatomical obstacles during the intra-cardiac phase.

References

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[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.
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