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I. Introduction

- Magnetically Actuated Soft Continuum Robots (MSCRs) offer enhanced flexibility and miniaturisation potential for endoluminal interventions compared to standard continuum manipulators.
- MSCRs can be programmed with length-wise magnetisation profiles, that impart a specific shape onto the robot under actuation.
- Fibre reinforcements can be embedded within the MSCR to grant higher torsional resistance and prevent out-of-plane behaviour.
- MSCRs have virtually infinite DoF, introducing challenges for modelling, control and actuation.

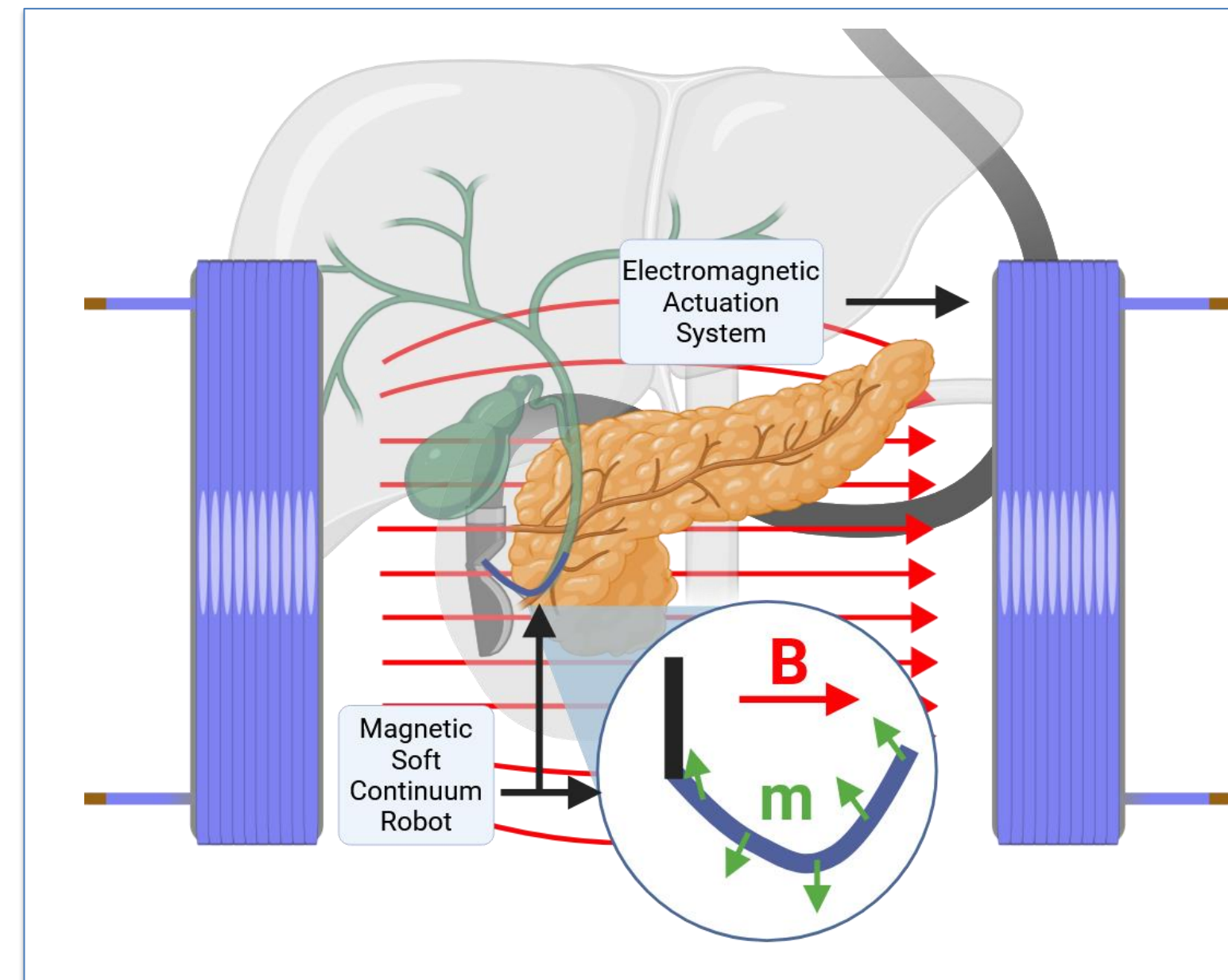


Figure 1: A magnetically controlled soft-continuum robot employed in an endoluminal operation. The robot is externally manipulated by an applied magnetic field (red arrow).

II. Problem Definition

Given an MSCR especially designed for a given feature found in anatomy, navigating a soft phantom requires:

- Modeling:** MSCRs feature hyper-elastic behaviour, infinite DoF and uncertain material properties due to manufacturing.
- Actuation:** Magnetic actuation allows a limited number of DoF to manipulate the MSCR.
- Discretisation:** Rigid links (Fig. 2) can be used to approximate an MSCR in motion, greatly reducing the complexity of the model, at the expense of some accuracy.
- Control:** Through Visual Servoing, the system should be able to reject intrinsic errors (incorrect modeling) and extrinsic errors (disturbances, variations in the scenario).

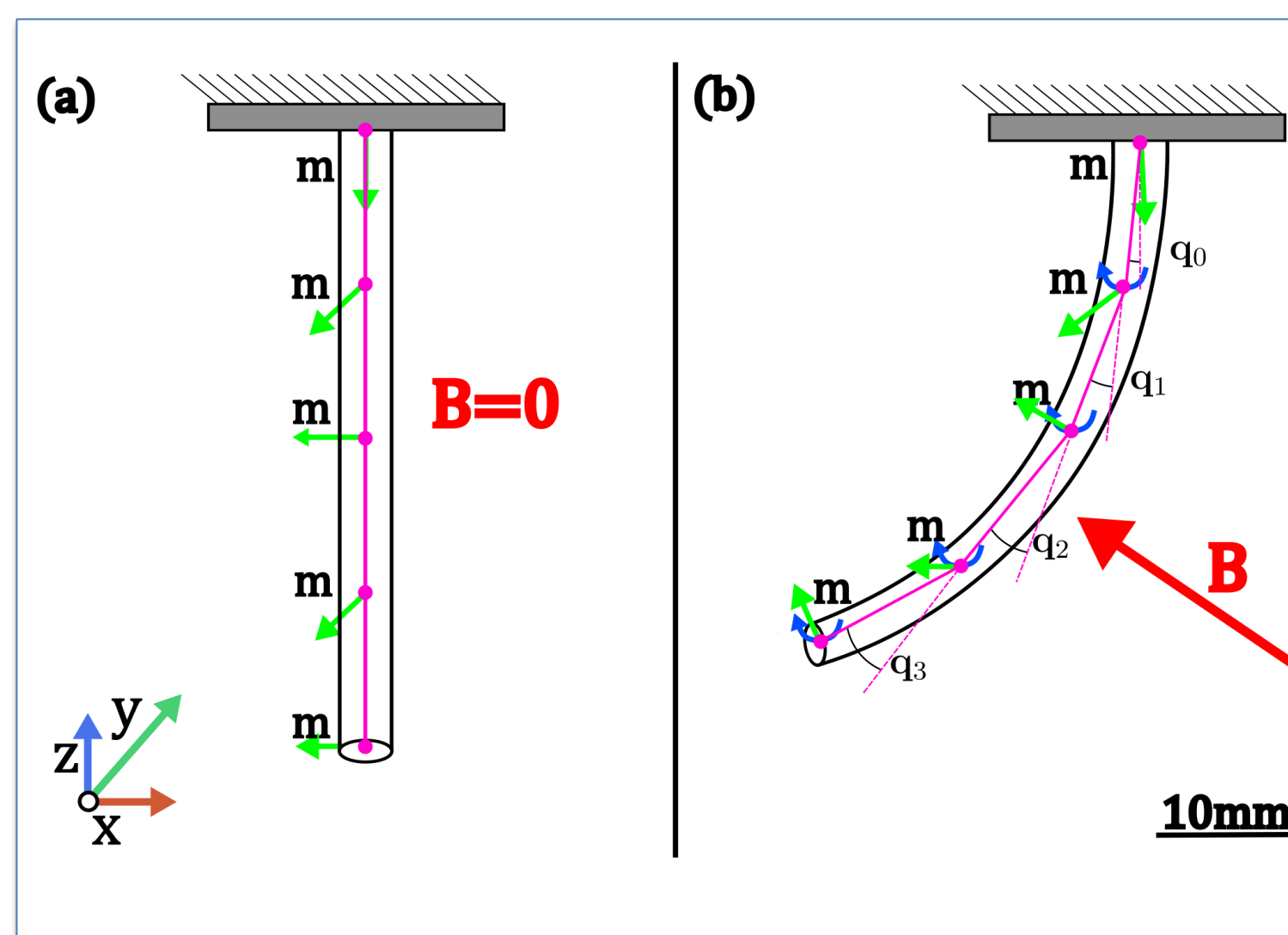


Figure 2: An MSCR discretised into Rigid Links both at rest (a) and under actuation (b). Green arrows depict the magnetisation programmed and red arrows depict the magnetic field applied.

III. Controller

- Using least mean square, the required magnetic field for a given configuration can be calculated.
- Thresholding can be used to isolate the MSCR from the scene.
- Path-find algorithms are used to determine the path to a user-specified goal, which is then fed as a set of desired angles.
- Insertion is handled

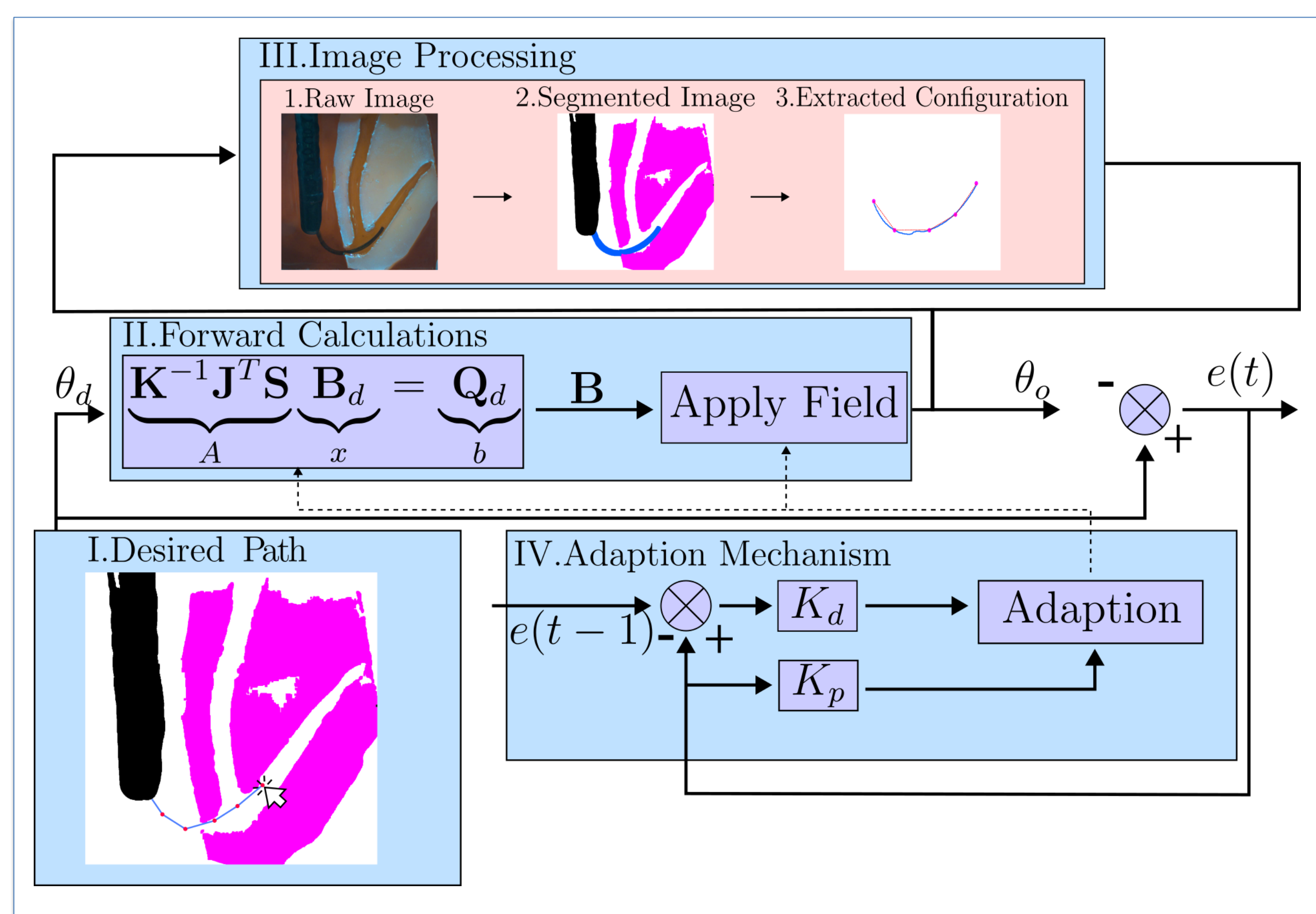


Figure 3: Control diagram implemented. A path is established between a user defined goal, which is then segmented into pseudo rigid-link coordinates. The first pseudo-rigid link is inserted, and an initial magnetic field is calculated and subsequently iterated over until the detected error reaches a minimum. The next pseudo-rigid link is the inserted.

IV. Experimental Setup

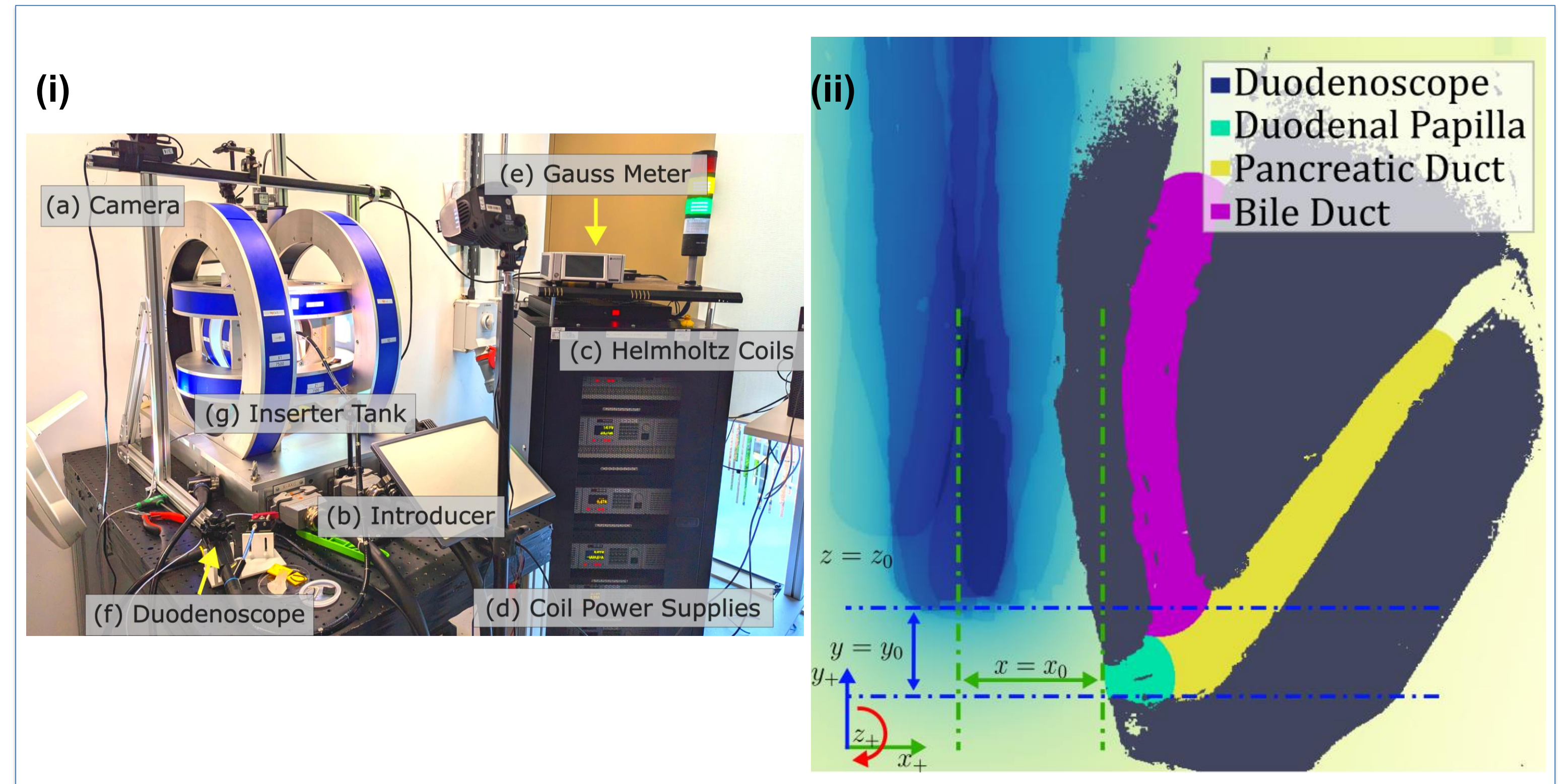


Figure 4: (i) The experimental setup used. Featuring a soft phantom and duodenoscope for insertion. (ii) the parametrisation convention used to uniquely describe studied duodenoscope configurations.

V. Results



Configuration			Closed Loop	Open Loop
x	y	z		
x_0	y_0	z_0	✓	✗
x_-	y_+	z_+	✓	✗
x_+	y_0	z_+	✓	✗
x_+	y_+	z_-	✓	✓
x_+	y_+	z_+	✓	✗

V. Conclusions and Future Work

- Closed loop shape forming has been tested in a soft phantom with a variety of inserting position and orientations, showing a clear improvement in cannulation of the pancreatic duct over open-loop approaches.
- Future work will implement clinically viable sensing modes (e.g. Fibre-Bragg Grating, fluoroscopy).

References

- [1] V. Francescon, N. Murasovs, P. Lloyd, O. Onaizah, D. S. Chaturanga, and P. Valdastrì, 'Closed-Loop Shape-Forming Control of a Magnetic Soft Continuum Robot', IEEE Robotics and Automation Letters, vol. 10, no. 6, pp. 6071–6078, Jun. 2025, doi: 10.1109/LRA.2025.3565124.

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