

Design and Experimental Validation of an Impedance Based Position Sensor for Magnetic Microrobots

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Summary:

Magnetic microrobots are investigated for minimally invasive applications, but their use remains limited by the lack of robust localization methods. An impedance-based sensing platform using a multiplexed electrode array is presented for spatial localization and tracking of a conductive magnetic milli-gripper in physiological saline solution. Experimental results demonstrate localized impedance variations that shift consistently with milli-gripper position across electrode pairs. Continuous measurements further enable real-time tracking during controlled displacement inside the sensing chamber.

Keywords: impedance tomography, microrobots, localization, electrode array, real-time tracking

Title

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Background, Motivation and Objective

Magnetic microrobots are increasingly explored for minimally invasive manipulation, targeted drug delivery, and microscale interventions, but their use in conductive media remains limited by the lack of robust and scalable localization methods. Optical tracking is constrained by line-of-sight limitations, while imaging-based approaches increase system complexity and are difficult to integrate into compact platforms [1].

Electrical impedance tomography offers an alternative by reconstructing conductivity perturbations induced by objects, enabling non-invasive localization from boundary electrode measurements [2]. Recent studies have shown its suitability for real-time tracking of microrobots using low-cost instrumentation [3].

This work aims to develop a compact impedance-based sensing platform for real-time localization of a magnetic microrobot in a conductive saline environment using a multiplexed electrode array.

Description of the New Method or System

The proposed system integrates a magnetic microrobot platform, a conductive liquid sensing chamber, and a multiplexed impedance acquisition architecture.

The microrobot used in this study consists of a conductive magnetic milli-gripper measuring $7 \times 7 \times 1 \text{ mm}^3$, including a titanium body with two embedded NdFeB magnets (see Fig.1). Helmholtz coils generate homogeneous magnetic fields enabling orientation, while Maxwell coils produce magnetic field gradients allowing translation within the liquid environment. Variations of the magnetic field amplitude generate magnetic torques enabling controlled opening of the gripper, while passive closing occurs when the external field is removed.

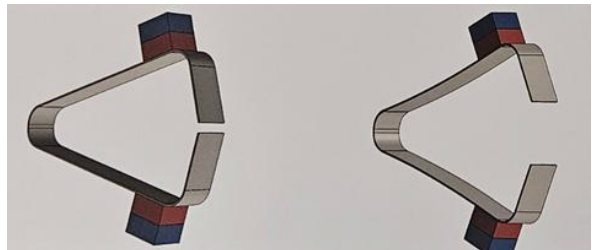


Fig. 1. 3D rendering of the magnetic milli-gripper illustrating its closed (left) and open (right) states.

The sensing chamber consists of two parallel plates, each integrating eight planar electrodes (4 mm^2) arranged in opposing pairs and is filled with physiological saline solution (0.9% NaCl). The channel length is 30 mm, with two tested inter-plate distances of 10 mm and 15 mm.

The electronic architecture relies on multiplexed electrode selection using analog multiplexers controlled via an I²C interface. A dedicated impedance front-end generates an AC excitation signal and performs synchronous acquisition. Measurement frequencies between 40 kHz and

60 kHz were selected to minimize capacitive effects.

Experimental validation was conducted by magnetic actuation of the milli-gripper within saline-filled chambers, while continuous impedance measurements were acquired across electrode pairs (see Fig.2). The resulting impedance variations were quantified according to eg. (1), where Z_0 is the baseline impedance, i.e. only saline solution between measurement electrodes, and Z is the impedance measured in the presence of the milli-gripper.

$$\Delta Z = \frac{|Z - Z_0|}{Z_0} * 100 \quad (1)$$

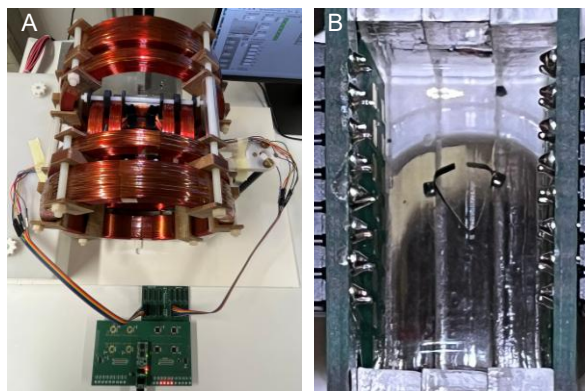


Fig. 2. (A) Complete system including magnetic field coils, external electronic board, and central measurement chamber. (B) Close-up of the chamber showing the eight electrode pairs and the milli-gripper positioned at its center.

Results

Results demonstrate that the presence of the milli-gripper induces localized decreases in impedance centered around electrode pairs closest to its position.

In the 10 mm chamber configuration, typical impedance variations of approximately 2 to 3 percent were measured at electrode pairs located directly near the milli-gripper. Adjacent electrode pairs exhibited smaller variations in the range of 1 to 2 percent, while more distant pairs showed variations below 1 percent. This spatial distribution confirms that impedance perturbations remain localized around the object position. Similar localization behavior was observed in the 15 mm chamber configuration, with impedance variations remaining within comparable ranges. Table 1 summarizes the impedance variations measured with the microrobot positioned at E2 for chamber width of 10 mm and 15 mm.

Continuous acquisition demonstrated real-time tracking capability, where the microrobot position is estimated by identifying the electrode pair with maximum impedance variation. The

temporal evolution of impedance maps showed coherent spatial shifts during controlled displacement of the milli-gripper. No mutual interference was observed between magnetic actuation and impedance-based localization, confirming reliable parallel operation.

Electrode pairs	Width: 10 mm ΔZ [%]	Width: 15 mm ΔZ [%]
E1	1.5	1.8
E2	3.1	2.7
E3	1.5	1.9
E4	0.6	0.8
E5	0.6	0.3
E6	0.6	0.3
E7	0.3	0.3
E8	0.3	0

Tab. 1. Relative impedance variation (ΔZ) measured for each electrode pair with the milli-gripper positioned at E2, for chamber width of 10 mm and 15 mm. Green (>2%), orange (1–2%), and red (<1%).

Conclusion

The proposed impedance-based sensing system enables reliable localization and tracking of a conductive magnetic milli-gripper in saline environments using paired electrode measurements. Local impedance variations of 2–3% consistently identify the microrobot position in 10 mm and 15 mm chambers. Continuous acquisition enables real-time tracking during controlled motion, demonstrating the feasibility of a scalable impedance-based approach for microrobot localization in conductive media.

References

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