Magneticky aktuovaný robotický systém pracující v jedné rovině

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Robotic System Based on Magnetically Guided Actuation on the Planar Surfaces

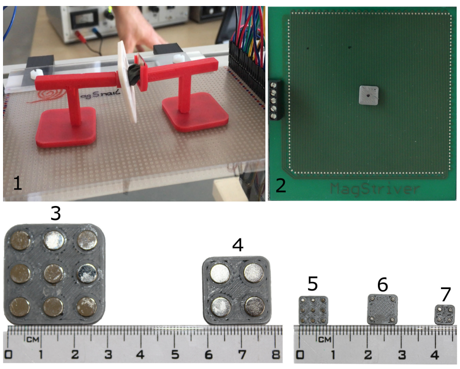
Abstract – **Presented research and development covers robotic system based on magnetically guided actuation of ferromagnetic bodies on planar surfaces. The major goal of this paper is to present selected results achieved on current laboratory prototypes and outline the directions of future research.**

Keywords – Position Control; Robots; Electromagnetic Forces; Dynamics.

I. INTRODUCTION AND MOTIVATION

Collaboration of large number of wireless microscale robots on macrostructures has been a long-term dream in both engineering and also scientific community. Nowadays, the system of wireless microrobots is the subject of numerous studies due to their potential for applications with impact on many fields, ranging from minimally invasive medicine and drug delivery [1], over automated laboratory manipulators [2], [3] to microscale and also macroscale manufacturing systems [4]. One of the state-of-the-art application of micromanipulation technique in the field of electrical engineering is perhaps pick-and-place die bonding of microchips or assembly of circuit boards [5].

Various actuation methods for microrobots are currently being investigated [1]. Out of all these technologies, magnetic actuation is one of the goals in various micro-applications where long stroke ranging from few micrometers to several millimeters with sub-nanometric precision is often required [4]. In addition, the possibility to combine significantly small size and low mass with high performance of permanent magnets [6] has led to the development of actuators capable of performing precise motion with high accuracy [4].



	MagSnail	MagStriver
Wire width	2 mm	0.5 mm
Insulation gap	0.5 mm	0.25 mm
Robot size	30 x 30 mm	8.6 x 8.6 mm
Robot weight	5.6 g	0.12 g
Max. robot load	4.8 g (187 %)	0.41 g (400 %)
Input power	20 W	1.5 W

***Figure I:* Comparison of developed prototypes: first prototype MagSnail (1) with its robots (3, 4) and second prototype MagStriver (2) with its robots (5–7).**

The major goal of the paper is to present our systems (MagSnail, MagStriver) for positioning of miniature passive robots (see Fig. I) and discuss future research directions.

II. Formulation of Technical Problem

Proposed electromagnetic system consists of miniature robots with permanent magnets and planar actuator created by the system of coplanar coils, which are placed on printed circuit boards (see Fig. II). Passive robots include several permanent magnets in non-magnetic form. They are actuated by electromagnetic field that is generated by coplanar coils (the robot is repelled by the magnetic field from its stable position achieved in previous actuation step). Robots move with two degrees of freedom.

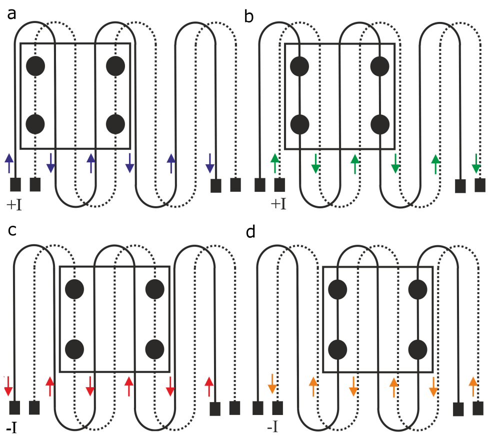


Figure II: **Simplified concept of proposed system and basic control sequence for robot actuation (figure shows movement in one direction).**

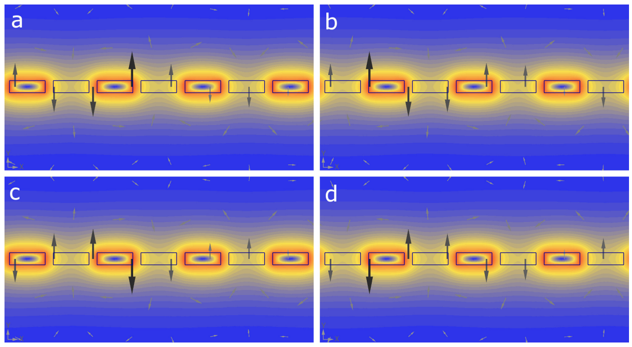


Figure III: **Distribution of magnetic flux density (average value at board surface is 1.6 mT) for individual steps of control sequence calculated for one layer of the coplanar coils. Particular plots correspond with Fig. II.**

III. Selected Results

Results of experimental verification are shown in the Fig. IV (for simplicity only 1D motion has been experimentally verified). Fig. IV shows comparison of numerical simulation and measurement of robot actual position $s(t)$ extracted by in-house motion detection algorithm based on high-speed camera frames of prototype MagSnail.

Numerical simulation was performed on a weakly coupled numerical model of static magnetic field and dynamics of robot motion [7]. Distribution of the magnetic flux density was calculated by finite element method (results are shown in Fig. III).

Figure V shows selected frames (from high-speed camera record) of robot linear motion on the MagSnail prototype. Captured motion shows one step and represents input data for Fig. IV. The highest reached robot speed is approximately 50 mm/s.

During the experiments, the major problem of current concept was uncertainty of robot positioning in cycle operation. This problem is illustrated on the pictures in Fig. VI which were captured on our prototype MagStriver. The main problem with uncertainty of robot control was speed of coils switching and applied current. Finally, Fig. VII shows oscillogram of the coplanar coil currents at prototype MagStriver. As can be seen in Fig. VII, the average coil current is approximately 0.6 A. Evolution of circuit board surface temperature is shown in Fig. VIII.

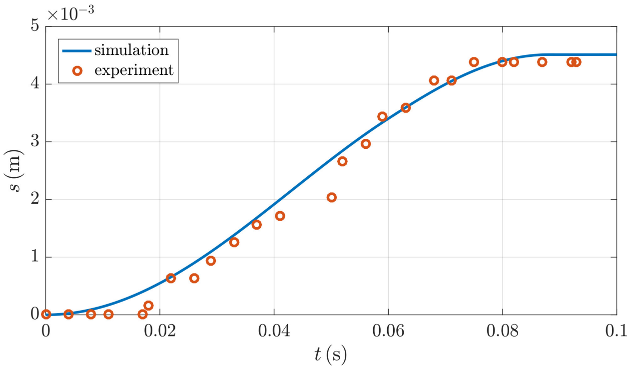


Figure IV: **Comparison of simulation and measurement of robot dynamics described by its actual position on the prototype MagSnail.**

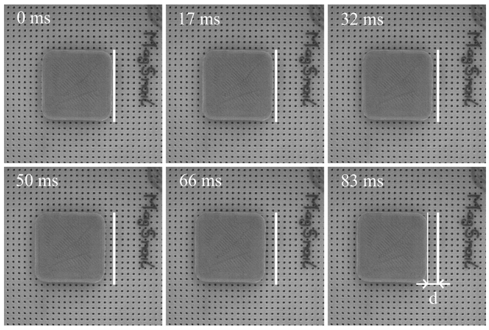


Figure V: **Robot dynamics captured by high-speed camera on the prototype MagSnail.**

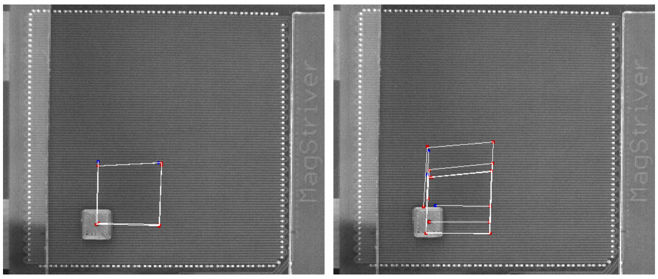


Figure VI: **Trajectory of robot and illustration of actuation uncertainty in cycle operation at MagStriver. Left picture shows actuation for step speed 50 ms and right picture for 25 ms.**

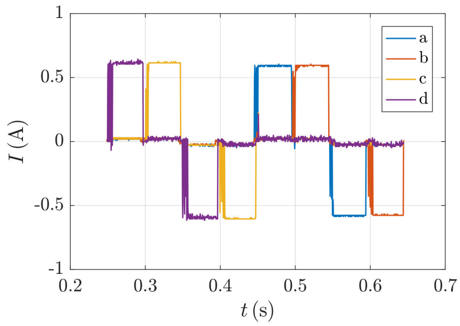


Figure VII: **Coils currents of MagStriver (step speed is equal to 50 ms, input voltage is 2.5 V).**

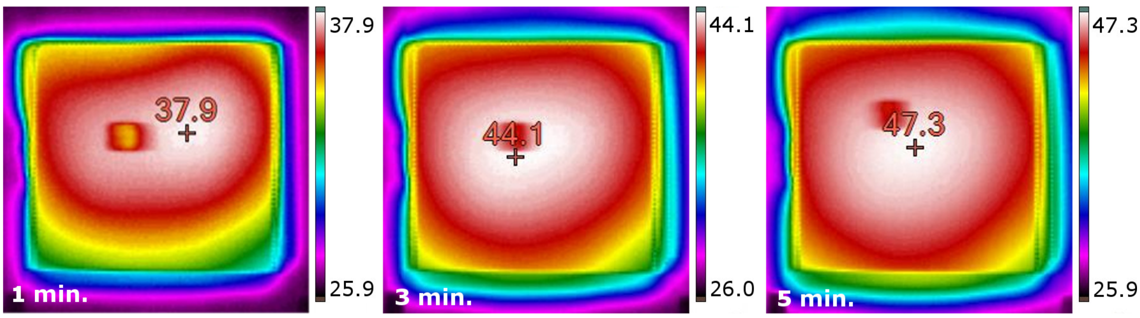


Figure VIII: **Distribution of temperature on the board surface captured by thermocamera in different times of continuous operation of the robotic system. Right picture (5 min.) represents the steady state.**

IV. Conclusion and Future Research

Concept of an electromagnetic system for precise positioning of miniature passive robots was presented. The concept was numerically studied and tested on the designed prototypes by experimental measurements. Proposed system seems to be up-and-coming and its development could have a significant impact in many industries, such as speeding up and miniaturization of manufacturing and industrial systems.

A. Parallel positioning

Yet, the current prototype does not allow parallel positioning. The easiest way how to achieve this is to have a lot of coils which could be controlled separately. The only problem is a difficult control of hardware. Our idea is to avoid large number of coils and try to use superposition of magnetic fields. It could be done by adding additional coils (simulations were done for two and four coils) into the current prototype. Using this principle can be created Field Free Points [8]. By moving these points, several strategies of independent movement of robots can be achieved.

B. Non-visual localization

Feedback is one of the most important part of all control systems. Most usual type of feedback in applications like this is visual localization using camera and image recognition algorithms. This type of localization brings two big problems which has to be solved–very precise position of camera with respect to actuator board and clear space between the camera and robot. Our future goal is to perform localization using electromagnetic field. It could bring more precise detection of position and no need of capturing device with power-consuming algorithms.

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