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MagMites - Microrobots for Wireless Microhandling in Dry and Wet Environments

D. R. Frutiger, B. E. Kratochvil, and Bradley J. Nelson

***Abstract*— Central to the challenge of building sub-mm robots, or microrobots, is the development of effective power storage and locomotion mechanisms. In 2007 we introduced the Wireless Resonant Magnetic Micro-actuator (WRMMA) and its application in a successful microrobotic platform, the *MagMite*.**

The term *MagMite* is derived from *Magnetic Mite*—a tribute to the underlying magnetic propulsion principle and the micro-scale dimensions of the robot. The device harvests magnetic energy from the environment and effectively transforms it into impact-driven mechanical force while being fully controllable. It can be powered and controlled with oscillating fields in the kHz range and strengths as low as $2\ \mathrm{mT}$, which is only roughly 50 times the average earth magnetic field. These microrobotic agents with dimensions less than $300\ \mu\mathrm{m} \times 300\ \mu\mathrm{m} \times 70\ \mu\mathrm{m}$ are capable of moving forward, backward and turning in place while reaching speeds in excess of $12.5\ \mathrm{mm/s}$ or 42 times the robot's body length per second. The robots produce enough force to push micro-objects of similar sizes and can be visually servoed through a maze in a fully automated fashion. The devices exhibit an overall degree of flexibility, controllability and performance unmatched by other microrobots reported in the literature. The robustness of the *MagMites* leads to high experimental repeatability, which in turn enabled them to successfully compete in the RoboCup 2007 and 2009 Nanogram competitions.

In this video contribution we offer an integrated explanation of the non-intuitive *MagMite* actuation principle. This is achieved with the help of computer animation in direct comparison with real experimental footage. Furthermore, new recordings of the microrobots operating under dry and wet conditions while performing automated microhandling tasks are presented.

I. INTRODUCTION AND ACTUATION PRINCIPLE

Biomedical microrobots have the potential for "noninvasive" procedures, offering less injury and faster recovering times to the patient in comparison to current laparoscopic techniques. The possible application areas of such microrobots include diagnosis, targeted drug delivery, material removal, and the implantation of active structures in the human body. While many technologies must be developed and synergistically integrated in order to realize the types of applications envisioned, the primary aspects are effective power supply and actuation. These aspects remain challenging to date since both onboard batteries and classical wireless power transmission using, for example, electromagnetic coupling between coils are inefficient for microdevices due to scaling effects. As a result, veritable microrobotic systems featuring wirelessly controlled agents with principle dimensions in the sub-mm range have only emerged in recent years [1]–[8].

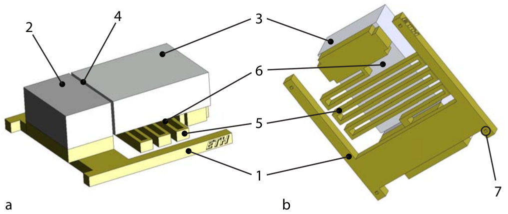

Fig. 1. CAD model of a second-generation prototype 07g2. This robot type was used in the RoboCup Nanogram Demonstration competition of 2007. a) top/side view, b) bottom/side view. 1) gold base frame resting on dimple feet, 2) nickel attractor attached to base frame, 3) nickel swinging mass separated by 4) a 10–20 µm gap and suspended above ground by 5) a meander gold spring which in turn is attached to the base frame about 6 µm above ground, 6) air gap between compression spring and nickel hammer allowing for larger springs and masses, 7) $5\ \mu\mathrm{m} \times 5\ \mu\mathrm{m} \times 0.75$–$2.0\ \mu\mathrm{m}$ dimple.

In 2007, we introduced the wireless resonant magnetic microactuator (WRMMA) [5] and its application in the *MagMite* microrobots [9]. The device consists of two nickel masses connected through a gold spring (Fig. 1). One mass—the body—rests on a gold support structure which in turn has frictional contact with the driving substrate, whereas the other one—the hammer—is lifted above the ground and can move freely without friction.

An in-depth discussion of design principles, fabrication methods, experimental characterization of tethered and mobile devices, and their application and control can be found in [10]. However, the non-intuitive modes of operation are more accessible to the reader in the form of animation and video recordings of the devices in action. As a real-time observation of moving microdevices with internal motions in the kilohertz range is close to impossible, theoretical models and computer animations must be used to understand and describe the actual dynamics [11]. Animation sequences throughout the video illustrate how the initially nonmagnetic nickel bodies become magnetized when an external magnetic field is applied (Fig. 2): the combined shape of the two soft-magnetic bodies are designed in such a way that they will always align with the external field as the nickel bodies are fixed in a serial arrangement, as illustrated by animation and experimental footage in the video. The two nickel bodies are separated by a narrow gap in the order of 10-20µm. As a result, strong attractive magnetic forces arise between the two opposing magnetic poles of the bodies. While the gap is closed, the spring is compressed and it effectively stores the

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The authors are with the Institute of Robotics and Intelligent Systems, ETH Zurich, 8092 Zurich, Switzerland. e-mail: {dfrutiger,bkratochvil,bnelson}@ethz.ch.

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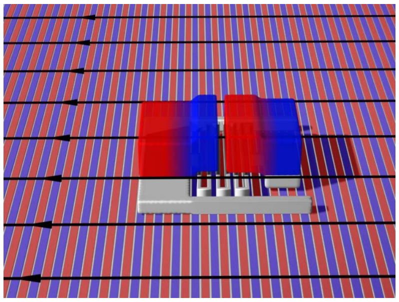

Fig. 2. Video still frame of the animation of the MagMite actuation principle: black arrows illustrate the external magnetic field while the resulting magnetization of the nickel bodies is shown. The insulated electrical feeds in the driving substrate provide a means for friction control through phase-shifted electrostatic clamping.

energy until it is quickly released when the magnetic field is turned off again. Pulsed magnetic fields with frequencies in the range of 2–8 kHz are used to induce oscillatory motion in the hammer which will effectively propel the robot forward or backward in a stick-slip fashion. The direction of motion depends on the friction, the frequency and amplitude of the driving magnetic field. An additional electrostatic clamping force between the body and insulated power feeds in the floor rectifies the oscillation by controlling the friction between the robot and the ground. By designing actuators for operation at their natural resonant frequency, power consumption can be decreased. Furthermore, the simultaneous control of individual devices becomes possible by using frequency modulated signals.

II. FOOTAGE OF EXPERIMENTAL RUNS

Primary responses and driving behaviors have been experimentally characterized [10] and the overall performance was observed to be as intended by design: firstly, reliable turning behavior thanks to alignment with the external magnetic field, secondly controlled forward and backward motion at the same frequency near resonance thanks to rectification with a phase-shifted clamping potential in the substrate. Besides the expected behaviors, less intuitive modes of operation such as driving without any need for a clamping signal and even driving upside down could be observed and is shown in the video. Ever since the early conceptional stage, the focus of the *MagMite* microrobotic platform has been on real-time applications in a common environment, i.e. operating robots in microhandling tasks in dry and wet conditions. Examples of such applications are illustrated with recordings of robots during fully automated path-planning and microhandling tasks under dry and wet conditions (Fig. 3).

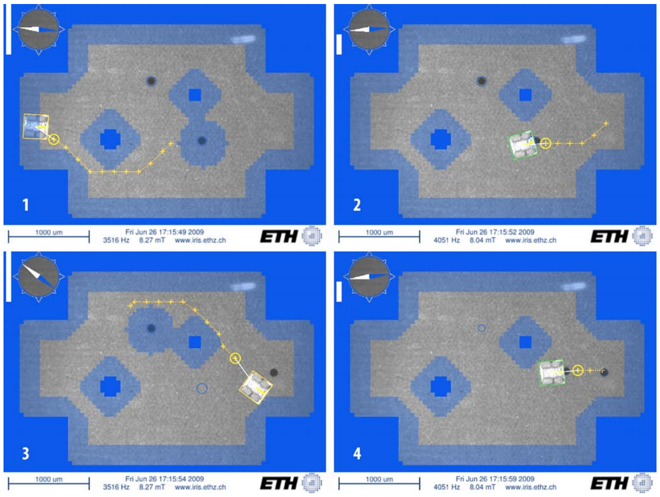

Fig. 3. Sequence of a visually servoed dry micro-object handling task: two silicon disks of 100 μm diameter (black circles) are pushed from their random initial positions into the goal area on the right. A 07tj-MH *MagMite* robot starting from the left (gray square with tracked boundaries highlighted in orange) performs this task in a fully automated fashion while avoiding any collision with obstacles or field walls (dark blue). 1) The robot is being tracked (orange box and arrow) in its initial position while the path planner identifies a curved trajectory (orange dotted line) around the obstacle keep-out regions (light blue). The task planner decides which ball to push first based on path length and collision risk. A temporary keep-out region (light blue) around the selected ball prevents the consideration of any paths that could lead to premature collision with the ball. The robot is then driven backwards (higher speed) up to the attack position in front of the ball (not shown) where it is turned again to face the ball. 2) The selected ball is pushed along the trajectory towards the target. 3) After reaching the target position, the robot sets back and releases the ball. The system then identifies the next ball and plans a new trajectory. 4) The second ball is successfully pushed into the goal while keeping clear of any obstacles on the way.

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