Mobi-Mag: A compact device for medical research using wireless control of magnetic microrobots

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1 Background

Continuous efforts towards the development of less invasive surgical procedures and targeted therapies have led to experimental studies on the possible use of microrobotic agents (Fig. 1a) in medicine [1]. Due to their small size, these microrobots could navigate to deep-seated regions within the human body and perform a wide range of accurate tasks, e.g., micro-surgery [2], micromanipulation [3] and targeted pharmacotherapy [4]. Nonetheless, at the present time only a limited number of research centers posses the control setups which are required for research and development (R&D) of such novel applications. Within this context, a compact device for wireless control of magnetic microrobots, hereafter referred as Mobi-Mag, is introduced (Fig. 1b). Its components were conceived in order to allow biologists and clinicians to carry out practical studies that could take advantage of using magnetic microrobots. On that account, Mobi-Mag provides:

- A "plug and play" and modular design,
- Means of integration with clinical imaging equipment, such as a variety optical microscopes and ultrasound transducers [5],
- A waterproof suitcase for easy transportation,
- Electrically insulated electronics for increased safety in biological laboratory environments.

In order to carry out experiments with Mobi-Mag, the microrobots and the samples to be manipulated are placed in a water-based solution. A petri-dish of 4 cm diameter and 1.5 cm height is provided as the default reservoir for the solution. Additional types of reservoirs could also be used by modifying the open-source dish holder design. Furthermore, to illustrate the capabilities of Mobi-Mag, an example application is presented. The application consists on transporting synthetic mockups of biological cells to a desired location. These cell mockups, hereafter called microbeads (Fig. 1c), were made to facilitate the development of cell manipulation schemes, by minimizing the handling and storage requirements typical of biological tissues. The microbeads are composed of polystyrene and have an oval shape with an average diameter of 300 µm. In order to push the microbeads, biodegradable micro-particles of 100 µm diameter (PLA-M-redF-plain, Micromod Partikeltechnologie GmbH, Germany) were employed as microrobotic agents. The experimental results showed that the microbeads could be transported to a target location at an average speed of 130 µm/s and with an average position tracking error of 50 µm.

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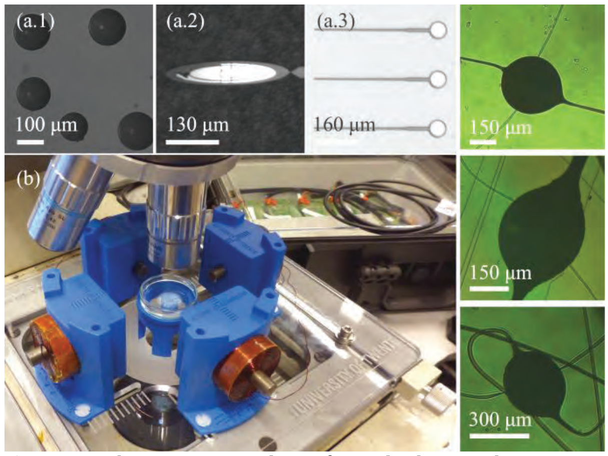

Figure 1. Mobi-Mag compact device for medical microrobotics research: (a) examples of microrobots (microparticles (a.1), microrobot (a.2), and MagnetoSperm (a.3)), (b) main hardware components, c) pictures of microbeads

2 Methods

In order to successfully fulfill the objectives of the Mobi-Mag device, two main components required particular design considerations: 1) the electromagnetic array, 2) the electronics and the base control software for development of microrobotic applications. First, since the device was conceived to manipulate small tissue samples or cells, the Mobi-Mag device has a small footprint (allowing an easy integration with optical microscopes) and requires very low magnetic field intensities (< 15 mT) for microrobotic control. A COMSOL Multiphysics model (COMSOL Inc., Burlington, USA) of the electromagnetic array was developed in order to optimize the dimensions of the coils. The coils were designed to guarantee that a magnetic field intensity of 10 mT is generated in the middle point of the workspace, whenever the current in one of the coils is set to 1 A (Fig. 2). The use of hollow iron cores for the upper and bottom electromagnets is a key feature to easily integrate common microscopic objectives (equipped with IEEE 1394 and/or USB cameras and their light sources) as the default source of feedback for the control system. Furthermore, the four plastic coil holders can be repositioned (Fig. 3), in order to integrate additional imaging equipment (e.g., a lateral microscopic objective or ultrasound transducer) in new application developments.

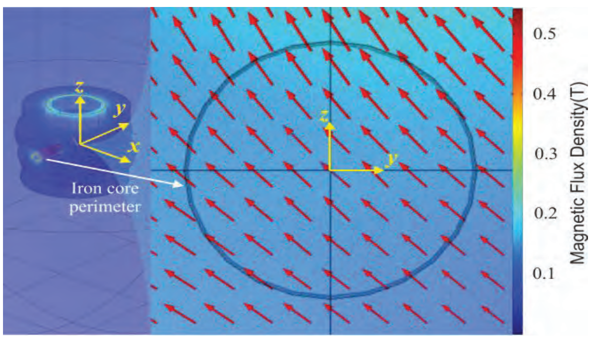

Figure 2. COMSOL simulation of the magnetic field flux due to a current of 1 A applied at the top and left coils

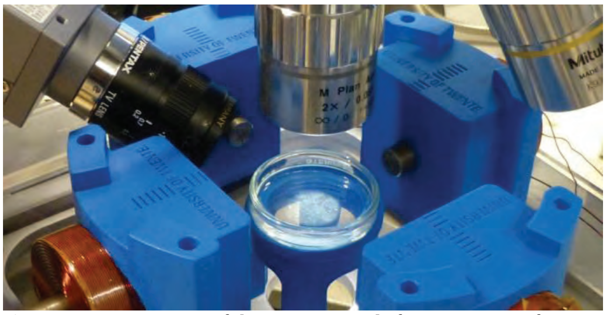

Figure 3. Repositioning of the magnetic coils for integration of additional imaging equipment

As for the control of the electromagnetic currents, the only interface required by the host personal computer (PC) to operate Mobi-Mag is an universal-serial-bus (USB) port. Once the Mobi-Mag software is installed in the host PC, the user can chose to employ the provided Cartesian PID position control (Fig. 4) and the OpenCV-based visual tracking C++ libraries, or to develop his own controllers by directly setting the electromagnetic coil currents through the device's software library. Both, Windows and Linux operating systems are currently supported.

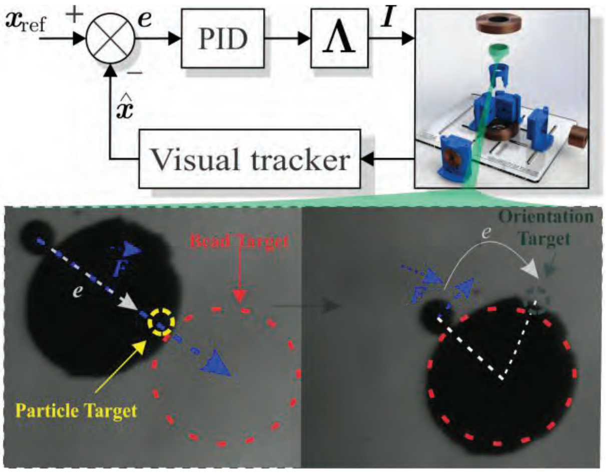

Figure 4. Cartesian PID control scheme included in the base Mobi-Mag software libraries. The errors (P_{ref-} P_{curr}) and (θ_{ref-} θ_{cur}) are fed back into the PID controller to control the position and orientation of the particle and bead

3 Results

Open-loop and closed-loop transportation of microbeads was carried out using Mobi-Mag. Magnetic microparticles were used to push the microbeads towards predefined targets (Fig. 5). In the open-loop scenario, a joystick was integrated into the control system using the SDL Library (Microsoft Inc., Seattle, USA). The use of the joystick allowed the user to manually control the position of the magnetic particles that interact with the microbeads. In the closed-loop scenario, the Cartesian PID controller (provided with the setup) and a simple task planner were used to automatically reposition the particle at predefined locations, while simultaneously controlling the orientation of the microbeads. In this latter case, the targets could be specified by the user by clicking with the mouse on the screen, or a pre-programmed task consisting of transporting the beads towards 5 targets with predefined locations and orientations in the image could be performed. The latter closed-loop control experiments revealed that the microbeads could be transported towards at a desired pose at an average speed of 130 µm/s and with a position tracking error of 50 µm when using the Mobi-Mag device and the base software.

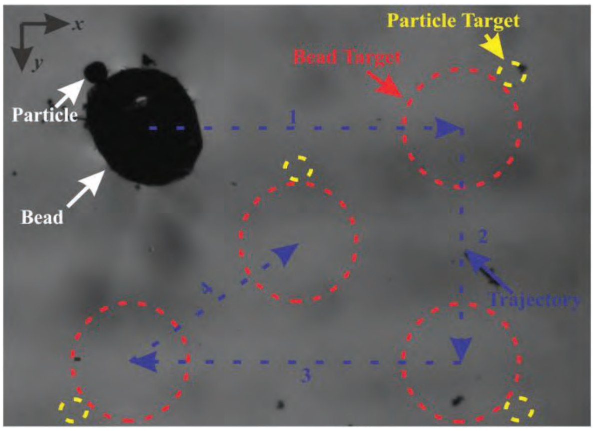

Figure 5. Pre-programmed task for automatic transportation of a microbead towards 5 different target locations and orientations

4 Interpretation

An easy-to-use compact device for magnetic control of micro- and nano-sized magnetic agents has been presented. This device is intended to facilitate the development and in-vitro testing of novel medical technologies that could take advantage of such magnetically controlled agents. An example application illustrating the manipulation of a cell mockup has also been provided. Drug delivery experiments will be carried out next using the different microrobots supported by the presented device, including swarms of magnetotatic bacteria, microjets and janus particles.

References

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