Drug Delivery System using Magnetic Microrobots

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Abstract **– A magnetically controlled untethered microrobot is an effective tool for the targeted delivery of drugs. In this paper, the total structural and functional unit of the proposed design of such a microrobot has been discussed, with elaboration on the materials that can be used for effective design. The functioning of the magnetic propulsion system and the drug delivery system of the robot has been discussed.**

Keywords – Microrobots, magnetic actuation system, microrobot structure, microrobot propulsion system

I. INTRODUCTION

Small-scale robotics is a flourishing field with continuous development of intelligent and mobile machines in the micro and nanometer range. Such devices show promise in medicine as potential new instruments both inside and outside the operating room. Due to their size, microrobots could operate in inaccessible areas of the body that are difficult to reach with existing tools, including the circulatory, urinary, and central nervous systems. In contrast to existing surgical devices, which are typically operated mechanically from outside the body, magnetic microrobots can be operated wirelessly and untethered, resulting in less invasive procedures and a lower risk of complications [1][2].

In addition, these robots can be fabricated to react to various chemical environments inside a subject's body and can be designed to leverage the natural composition inside the subject to their advantage. Further advantages include small or no incisions, lower risk of infection, shorter hospital stays, less pain and blood loss, faster recovery times, minimized scarring, and less reliance on narcotics. Moreover, these robots can be used for the effective delivery of drugs. They will be able to precisely target the desired area and deliver minimal amounts of drugs necessary [3][4].

In this paper, we will illustrate the mechanics of microrobots and discuss their structural and functional units. This includes the structural components, the drug delivery system, the guidance system, and the propulsion system.

II. STRUCTURE

The robot will consist of a polyurethane body embedded with magnetic material like nickel, as shown in Fig. 1. The head is also embedded with nickel elements. Polyurethane is chosen because it is biocompatible. The selection of materials used in the construction of prostheses and implants focuses on their ability to maintain mechanical, chemical, and structural integrity and on various characteristics that allow these materials to substitute any organ or tissue properly and exhibit safe, effective performance within the body.

For many years, biocompatibility has been defined as the ability of a material to perform with an appropriate host response in a specific application [5][6][7]. Under this definition, which can be relatively ambiguous and vague, a material used satisfactorily in orthopedic surgery may be inappropriate for cardiovascular applications due to its thrombogenic properties. Similarly, a widely used material might have deleterious effects if used under stress-strain conditions because of wear particle generation. Biocompatibility is not a measurable entity. It can be simulated by comparing a material's behavior to reference materials under standardized experimental conditions. As these robots must be injected into a person's bloodstream, it is essential that the build material does not react adversely to the subject's internal environment or cause the host's body to reject the material.

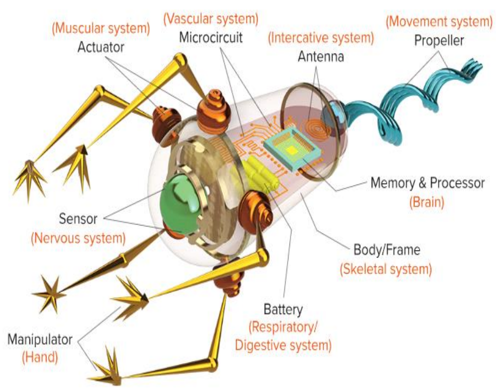


Fig. 1. Basic structure of a Microrobot

Nickel syringes are attached to the exterior of the body, connected to silver containers that are also attached to the body. Controlled hinges are used to connect the syringes to the containers. The containers are responsible for holding the drug to be delivered. The syringes will deliver the drugs from the containers to the targeted area. Nickel is chosen for its biocompatibility and its ability to resist corrosion in the natural environment of the subject's bloodstream. Nickel is economical to manufacture, has good tensile strength, and is resistant to deterioration and high temperatures. With a tensile strength of 45 megapascals (MPa), the syringes can withstand the journey through the bloodstream. Silver is chosen for the drug containers due to its proven non-reactivity, which ensures that it doesn't affect the chemical composition of the drugs. The tensile strength of silver is 140 MPa, which prevents the rupture of the containers due to external trauma. Two flexible silver tails are attached at the base of the polyurethane body and act as propellers, as shown in Fig. 2. These flagella-like appendages can survive in the internal environment of the bloodstream due to silver's tensile strength, and silver's malleability makes it ideal for designing flexible tails. The frame consists of a transmitting Integrated Circuit (IC) used for detecting the location of the microrobots inside the subject's body. This IC will also be responsible for controlling the hinges that hold the syringe arms. A small cell is attached to power the IC and the hinge mechanism.

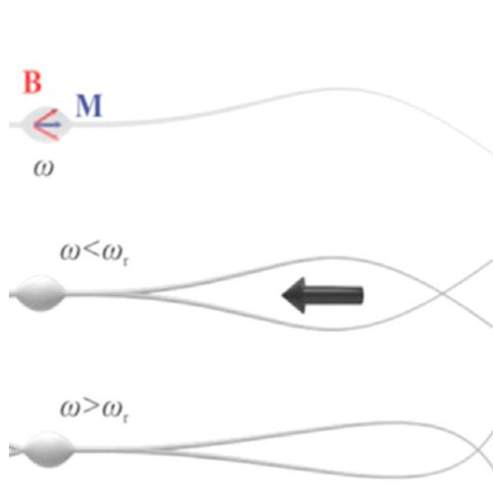


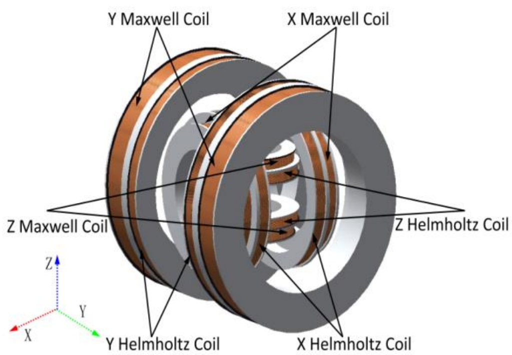
Fig. 2. Silver tail of the microrobot

The whole structure is designed to be under 1 millimeter (mm) in size, which is sufficient to pass through the majority of the human circulatory system. This is because the average diameter of arteries and veins is about 4-5 mm (with the maximum size reaching up to 25 mm in the pulmonary artery). This size ensures that drug delivery can be performed throughout the human body.

III. PROPULSION

A set of triaxial Helmholtz coils, depicted in Fig. 3(a) and 3(b), generates a rotating magnetic field for the actuation of the swimmer. A three-dimensional magnetic actuator system is used to generate oscillating motion, as shown in Fig. 4. As a result of this rotating magnetic field, the nickel head and the embedded nickel in the body rotate, causing the silver tail to deform and rotate in such a way as to produce a whipping rotational motion, resulting in the propulsion of the swimmer, as illustrated in Fig. 5 and Fig. 6.

The swimmer can transport spheres ranging from 500 nm to 2.5 µm, with researchers noting that particle size affects the speeds achieved by the swimmer. An interesting observation was that when the swimmer carried particles of 1.25 µm, there was an increase in speed compared to when it bore no load. Although the load of magnetic drug-containing particles increases viscous drag, it also sets up a rotating field due to the motion of these particles, which consequently affects the propulsion speed of the nanoswimmer. Therefore, when the size of drug particles is approximately 1.25 µm, the speed of the nanoswimmer actually increased. However, a further increase in the size of drug particles leads to a reduction in the speed of the nanoswimmer.



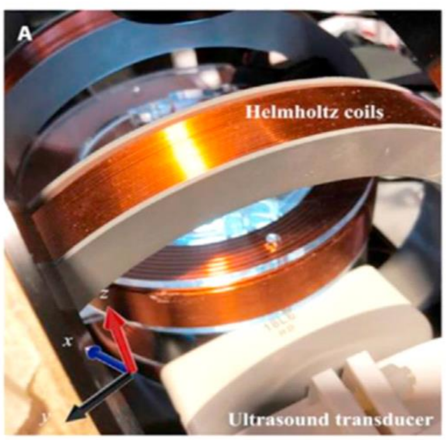


Fig. 3. Helmholtz coil (a) Schematic diagram of a Helmholtz coil and (b) Triaxial helmholtz coil

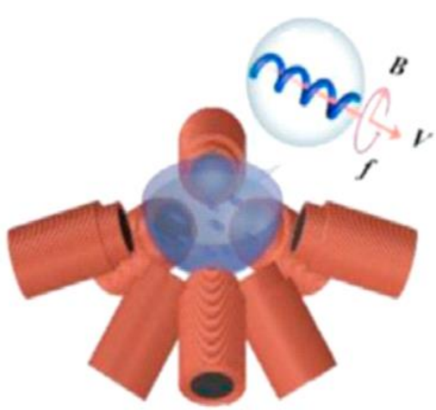


Fig. 4. Helmholtz Coil

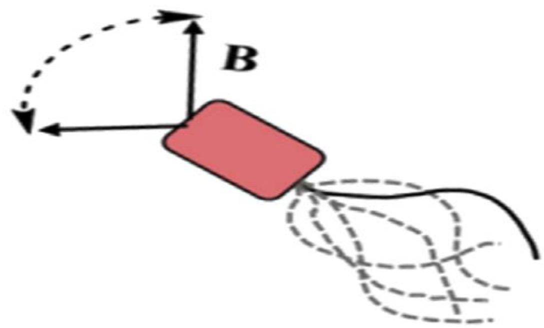


Fig. 5. Motion of a microrobot under oscillating magnetic field

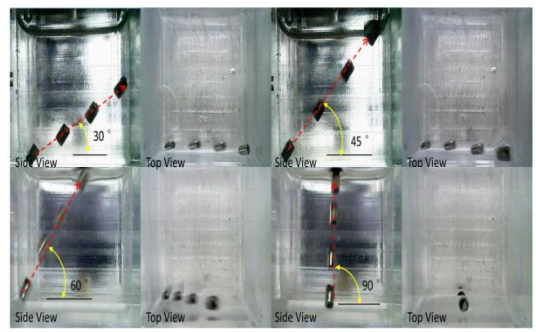


Fig. 6. Observed motion of microrobots under varying magnetic field

IV. DRUG DELIVERY SYSTEM

After being successfully guided to the target area with the help of the actuation system, the tracking system associated with the integrated chip inside the body will assist the external controller in determining the bots' position. Once the microrobot reaches the desired location, the IC receives a signal to release the drugs from the silver containers on the body. A micromotor drives pistons inside the containers, which release the drugs into the target area.

This method of drug delivery offers several advantages: it reduces the need for surgery or other invasive procedures, thereby decreasing patient discomfort. Additionally, the amount of drugs required for such a localized delivery is significantly less than with traditional methods, which lowers the effective cost of medicine. The targeted approach also enhances the effectiveness of the medicine, as it is delivered directly to the intended site rather than being dissolved throughout the entire bloodstream.

V. CONCLUSION

In this paper, we designed a microrobot that is effective in targeted drug delivery, thereby reducing both the overall cost and discomfort for the subject. We developed a magnetic actuation system for precise navigation and a drug delivery system for accurate medication dispensing. The proposed design is non-toxic to the human body.

Additionally, this system can release clots in the circulatory system by directly administering thrombolytics at the clot's location. Consequently, these robots could be used to treat cardiovascular ailments such as stroke and myocardial infarction, which typically require heavy medication or even surgery. Thus, microrobots present a plethora of applications in the medical industry and offer economical alternatives to otherwise costly procedures.

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Conflict of Interest: The authors declare that they have no affiliations or involvement, whether financial or non-financial with any organization or entity regarding the subject matter discussed herein.

VI. REFERENCES

[1] Q. Zhang et al., "Motion Control of Magnetic Microrobot Using Uniform Magnetic Field," *IEEE Access*, vol. 8, pp. 71083-71092, 2020, doi: 10.1109/ACCESS.2020.2986089.

[2] S. P. Woods and T. G. Constandinou, "Wireless Capsule Endoscope for Targeted Drug Delivery: Mechanics and Design Considerations," *IEEE Transactions on Biomedical Engineering*, vol. 60, no. 4, pp. 945-953, April 2013, doi: 10.1109/TBME.2012.2228647.

[3] Y.-G. Yue and P. He, "A Comprehensive Survey on the Reliability of Mobile Wireless Sensor Networks: Taxonomy, Challenges, and Future Directions," *Information Fusion*, vol. 44, pp. 188–204, Nov. 2018.

[4] J. Li, B. Esteban-Fernández de Ávila, W. Gao, L. Zhang, and J. Wang, "Micro/Nanorobots for Biomedicine: Delivery, Surgery, Sensing, and Detoxification," *Science Robotics*, vol. 2, no. 4, Mar. 2017, Art. no. eaam6431.

[5] B. J. Nelson, I. K. Kaliakatsos, and J. J. Abbott, "Microrobots for Minimally Invasive Medicine," *Annual Review of Biomedical Engineering*, vol. 12, no. 1, pp. 55–58, 2010.

[6] L. Zheng, L.-G. Chen, H.-B. Huang, X.-P. Li, and L.-L. Zhang, "An Overview of Magnetic Micro-Robot Systems for Biomedical Applications," *Microsystem Technologies*, vol. 22, no. 10, pp. 2371–2387, Oct. 2016.

[7] C. Dahmen, K. Belharet, D. Folio, A. Ferreira, and S. Fatikow, "MRI-Based Dynamic Tracking of an Untethered Ferromagnetic Microcapsule Navigating in Liquid," *International Journal of Optomechatronics*, vol. 10, no. 2, pp. 73–96, Apr. 2016.