Magnetically Actuated Untethered Mobile Millirobots Using NdFeB and Fe_3O_4 Magnetic Particles

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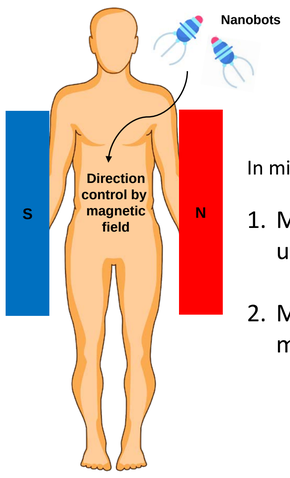
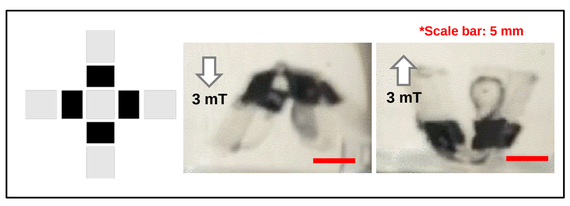
ABSTRACT



<Objective>

In millimeter scale,

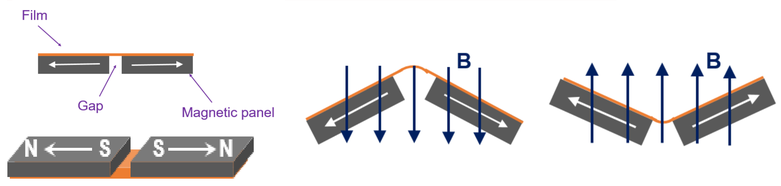
1. Making magnetically untethered robot
2. Making swimmer mobile robot



- Magnetically actuated untethered mobile robot is a technique devised to practice diverse clinical functions ***in vivo***. As the robot is remotely controllable outside the human body, it is easy to access to complex and small regions inside the body with minimal invasion. This advantage makes the untethered robot promising in various biotechnological fields such as drug delivery, minimally invasive surgery and etc.
- Here, in order to lay the stepping stone for the regarding field, we invented a **millimeter scale magnetically actuated swimmer robot** by using NdFeB and Fe_3O_4 microparticles respectively and checked its motion. We mimicked the swimming method of the frog to actualize the swimming motion in the fluid.
- Since the core element for the successful application of the technology is to carry out sophisticated motions, we concentrated on finding the most appropriate condition for the 'folding motion'. Furthermore, the fabricated robots are all tested inside the water in order to confirm whether they can move inside the fluid.

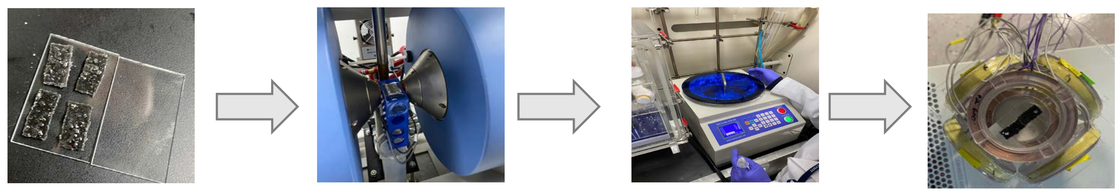
SCHEME

Magnetically Actuated Mechanism



The basic method used in this technology is the magnetically actuation mechanism. It utilizes the basic characteristic of the magnetized materials **to align** in a specific direction according to **their magnetization direction under the external magnetic field.**

Fabrication

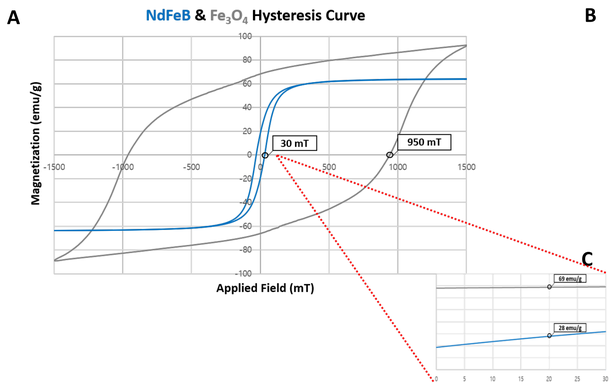


PDMS - Sylgard A:B = 10:1 **NdFeB powder** - volume fraction of 20%	**Magnetization** using Electromagnet	**Spin-Coating** using Ecoflex	Checking the basic motion of the robot using **Helmholtz Coil**.

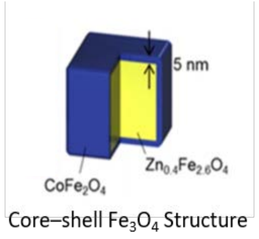
* In case of Fe_3O_4, the volume fraction was 50%

RESULTS

Material



B	NdFeB	Core-shell Fe_3O_4
Coercivity	950 mT	30 mT
Magnetic Moment (2 mT)	69 emu/g	28 emu/g
Biocompatibility	X	O

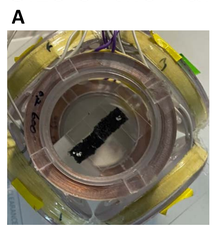


- The **core-shell Fe_3O_4 particle** shows 64 emu/g at 2 mT which is much higher than that of the 50 nm Fe_3O_4 particle (11 emu/g).
- The core and the shell of the core-shell Fe_3O_4 particle particle consists of $Zn_{0.4}Fe_{2.6}O_4$ and $CoFe_2O_4$ respectively.

Fig. 1. A. VSM result of NdFeB and Fe_3O_4 particle.
Fig. 1. B. Table illustrating the difference between NdFeB and Fe_3O_4 regarding coercivity, magnetic moment and biocompatibility.
Fig. 1. C. Core-shell Fe_3O_4 Structure .

Optimization

- Size of the Panel



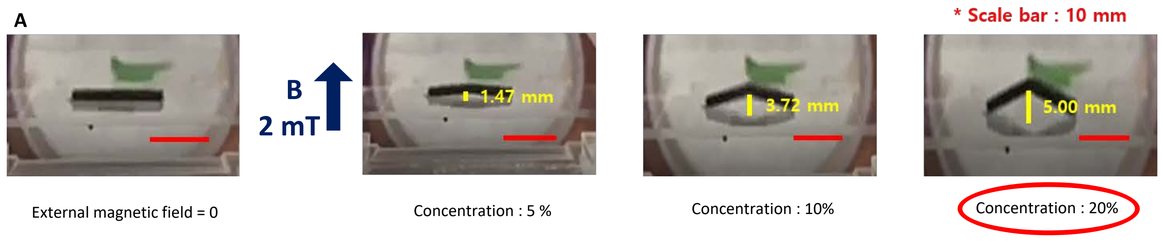
Limited size of the Helmholtz Coil

Scale Down

width: 15 mm → width: 7.5 mm
length: 7 mm → length: 3.5 mm
height: 2 mm → height: 1 mm

Fig. 2. A. 2-panel robot inside the Helmholtz coil.

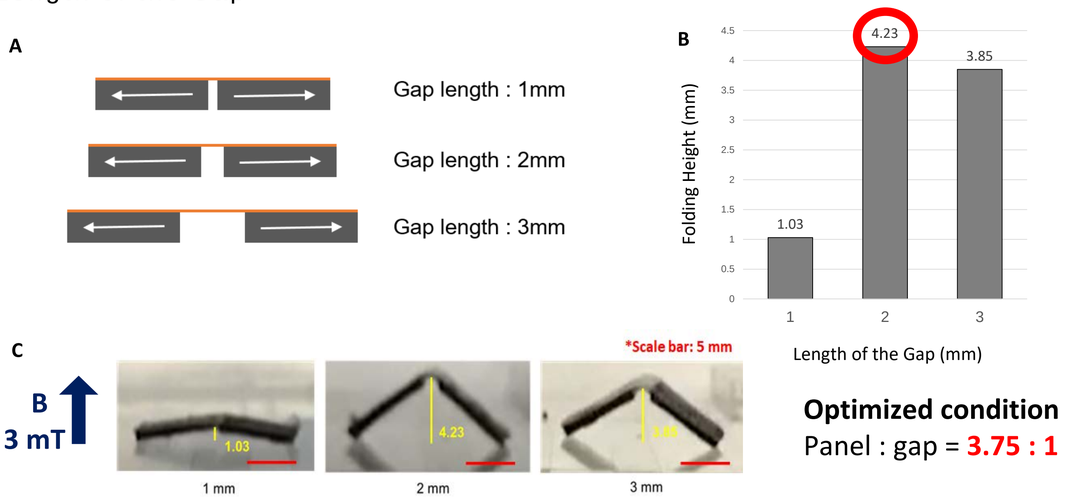
- Concentration of the magnetic particle



*In case of the Fe_3O_4 particle, the optimized concentration was 50%

Fig. 3. A. The folding height of the 2-panel robot was highest when the volume fraction of the NdFeB microparticle was 20%.

- Length of the Gap



Optimized condition
Panel : gap = **3.75 : 1**

Fig. 4. A. B. C. The result shows that the robot shows the most activated movement with 2 mm gap. Therefore, the optimized length ratio between the panel and the gap was **3.75 : 1**

4-Panel Swimmer

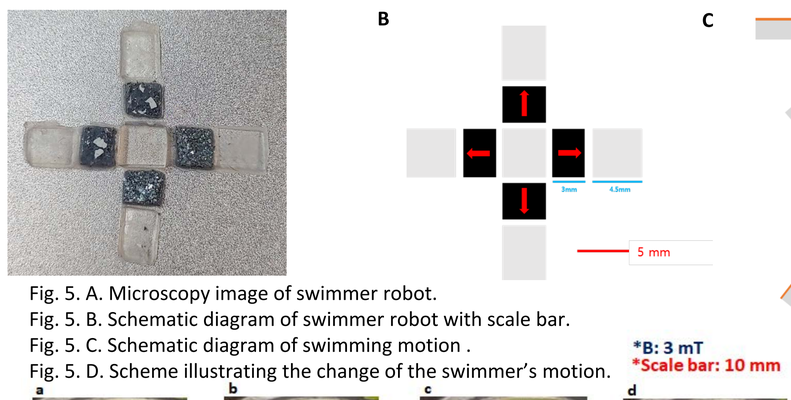
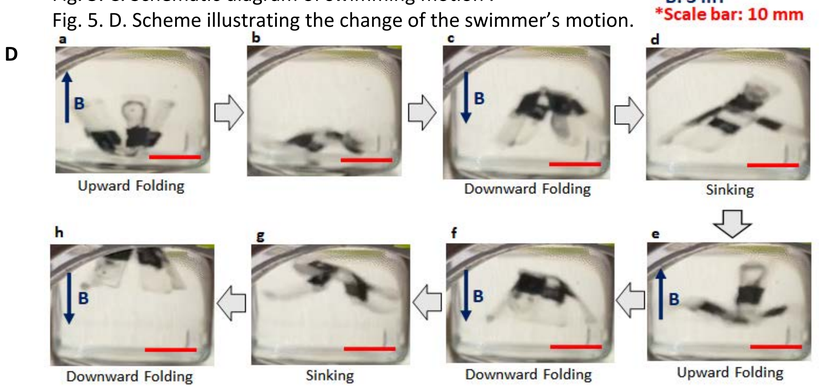


Fig. 5. A. Microscopy image of swimmer robot.
Fig. 5. B. Schematic diagram of swimmer robot with scale bar.
Fig. 5. C. Schematic diagram of swimming motion .
Fig. 5. D. Scheme illustrating the change of the swimmer's motion.

*B: 3 mT
*Scale bar: 10 mm



- a ~ e : Flapping
- f ~ h : Floating

Fig. 5. E. Swimming motion analysis over time

Fe_3O_4 Folding Motion

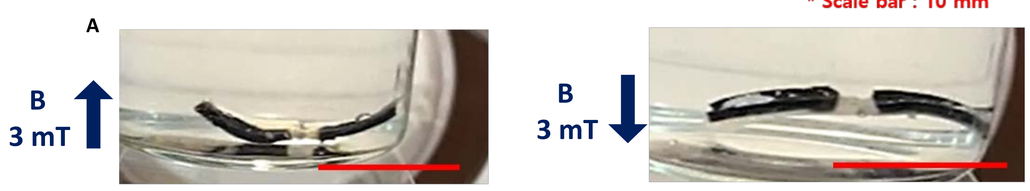


Fig. 6. A. 2-panel robot using core-shell Fe_3O_4

CONCLUSION & FURTHER STUDY

Our team conducted two kinds of experiments using **NdFeB and Fe_3O_4** micro particle to fabricate **the untethered mobile robot in millimeter scale**. At the first experiment, we confirmed the folding motion using NdFeB particle which has stronger magnetization based on **the magnetically actuated mechanism**. On top of that, we created swimmer robot which can provide moving force to variety of devices. Nevertheless, due to the toxicity of the NdFeB it is realistically hard to apply the robot directly to human body. In order to solve this problem, we replaced NdFeB to Fe3O4 which has much **higher bio-compatibility** to make milli-robot and checked the folding motion. Magnetically actuated Untethered Mobile Robot has a huge potential in the field of healthcare and bioengineering. Therefore inventing the technology that can shrink the size of the robot with full function will be the uttermost task in order to get the technology contribute to human health.

REFERENCE

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