2010 IEEE International Conference on Robotics and Automation
Anchorage Convention District
May 3-8, 2010, Anchorage, Alaska, USA

New magnetic rotational drive by use of magnetic particles with specific gravity smaller than a liquid

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Abstract— **This paper presents a new type of magnetic fluid and the rotational drive with simple magnetic field. We have proposed a driving principle and developed the verification models and the generator of magnetic field. It became clear that our proposed driving principle results from collision of the magnetic particles to the outer cover, deformation of the whole form of magnetic particles and movement of the center of gravity. We have succeeded to drive a rolling model by simple magnetic field control.**

I. INTRODUCTION

Magnetic fluid has unique properties[1], by which it can, not only be attracted, but also solidified by magnets. Many researchers have proposed useful applications for these properties, such as in dampers, sensors, actuators [2][3] and medical applications[4]-[6]. J.Furusho et al. [7] developed MR-Fluid Actuator, controlled it by use of torque Feedback. He also developed 6-DOF Rehabilitation System driven by ER-Actuator[8]. The functional fluid has performed well in clinical use. However, as all Magnetic fluids have a greater specific gravity than liquids like water, the applications are restricted.

Therefore, we have developed a lighter one than liquid, mixed it with liquid, and created a new impetus in this research.

This paper presents a new type of magnetic fluid and a rotational drive using a simple magnetic field. Several experiments and analysis of the rotation have been carried out. Some applications using the new drive are shown.

II. PRINCIPLE OF MAGNETIC DRIVE

This chapter explains the magnetic drive principle by use of floating magnetic fluid and a simple magnetic field.

Fig.1 shows the schematic diagram of the rolling object that is driven by the proposed magnetic drive

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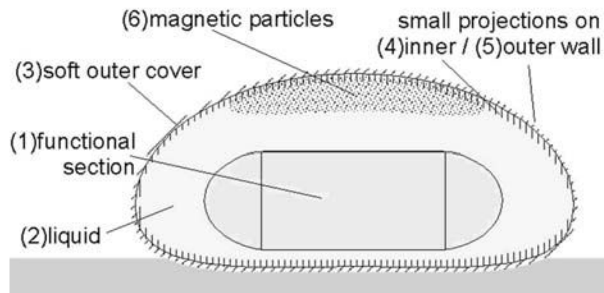
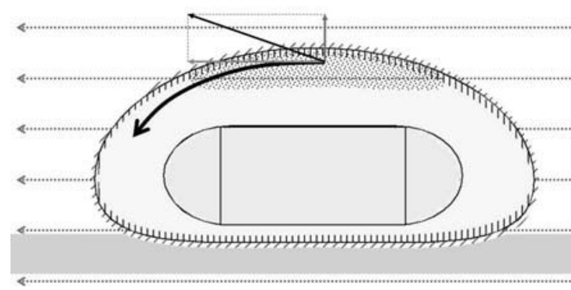
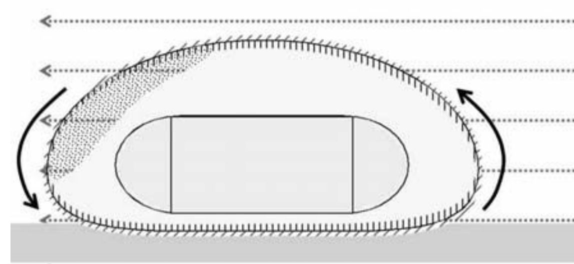


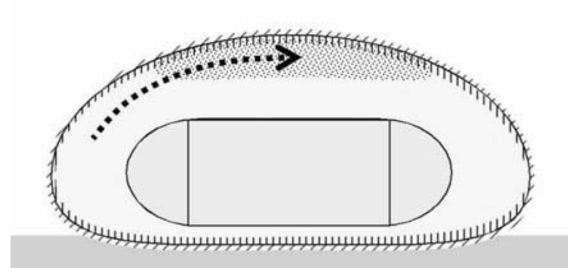
(a) Structure of a rolling object driven by magnetic field



(b) Particles move in the direction of a magnetic field quickly



(c) Object rolls and moves



(d) Magnetic particles return to the upper part slowly

Fig. 1. Magnetic drive principle with simple magnetic field

principle. The functional section(1) and the liquid(2) are sealed in the interior by the outer cover(3).

The inner wall(4) and outer wall(5) of the outer cover are covered with the small projections or a textured material. The projections play the role of creating friction. We employ floating magnetic particles(6) in a magnetic field. The specific gravity of these magnetic particles is smaller than the liquid, so they gather in the upper part of the rolling object when no magnetic field is applied.

When a magnetic field is applied, the magnetic particles will move in the direction of the magnetic field quickly. The path they take is just inside the outer cover, because both the magnetism and buoyancy are working on the magnetic particles. The particles collide with the projections on the inner wall of the outer cover (Fig.1(b)).

The external side of the outer cover does not slip on the ground, because there is friction between the ground and the outer wall. Consequently, the rolling object moves in the direction of the magnetic field (Fig.1(c)). After the magnetic field is removed, the magnetic particles will return to the upper part of the rolling objet slowly (Fig.1(d)), the rolling object stayed at the same position. By repeating the above, the rolling object can move a long distance.

If the specific gravity of a magnetic particle is larger than the liquid, the object rotates in the opposite direction (Fig.2). The movement becomes unstable because it may move in the opposite direction to the magnetic field.

III. VERIFICATION EXPERIMENT AND DISCCUSION

A. Float magnetic particle

In order to realize the above-mentioned principle of operation, magnetic particles with a specific gravity smaller than the liquid are required. Fig.3 shows a photograph and schematic diagram of the particles. The diameter of each particle is 1 - 2 [mm]. The particles are composed of magnetic iron oxide 4.5[%], Kerosene 95.2[%] and Additive 0.3[%].

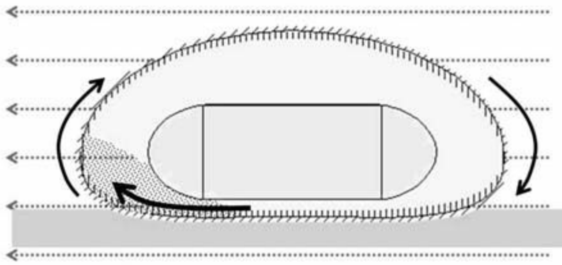


Fig. 2. Reverse drive. If the specific gravity of a magnetic particle is larger than a liquid, the rolling object rotates conversely.

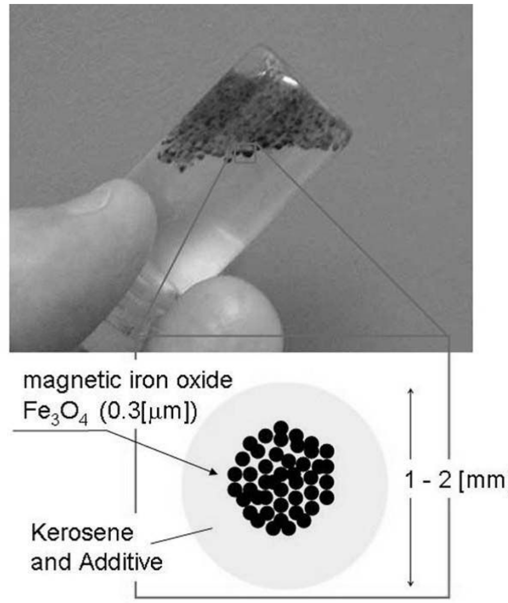
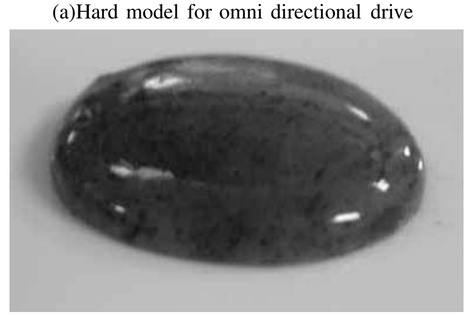


Fig. 3. Photograph and schematic diagram of a magnetic particle with specific gravity smaller than a liquid

(a)Hard model for omni directional drive



(b)Soft model for crawling on an uneven surface

Fig. 4. Two types of the model for the verification of the above-mentioned principle

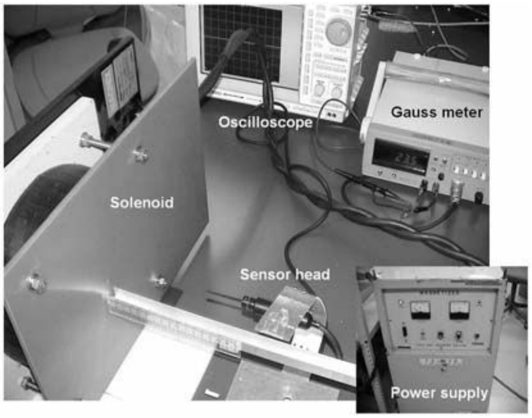


Fig. 5. Total system of generating the impulse to the magnetic field for driving the models

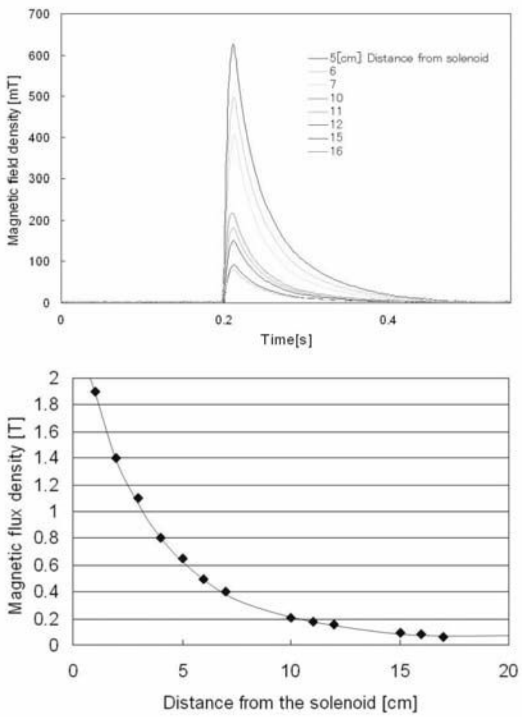


Fig. 6. Graph of the magnetic field produced by the system, about 2[T] can be generated.

B. Verification models

Fig.4 shows the photograph of two types of the model used for the verification of the above-mentioned principle. Fig.4(a) is a hard model for multi-directional drive on a solid surface, and Fig.4(b) is a soft model for crawling on uneven ground.

C. Generator of magnetic field

Fig.5 shows the total system for generating the impulse magnetic field to drive the models. The system is composed of a solenoid (Outer diameter: 100 [mm], inner diameter: 50 [mm], length: 100 [mm], Cross-section dimension of coil line: 2x5 [mm], 163 [turns]), the power supply (applied voltage: 50-900[v], capacitance of capacitor: 10[mF], Maximum permissible current: 10000[A]), three axis flux meters and so on. Fig.6 shows the graph of the magnetic field produced by the system; about 2[T] can be generated.

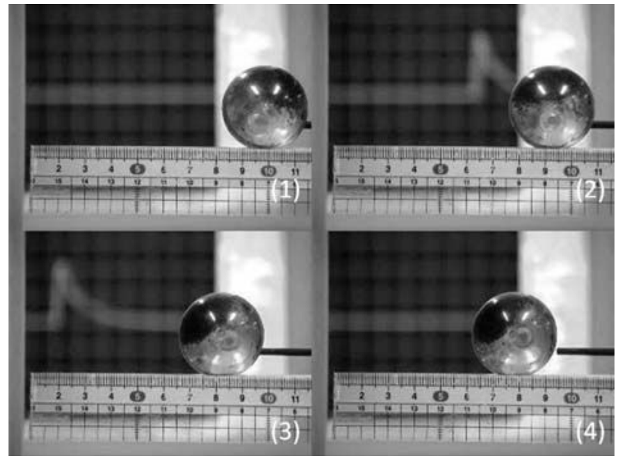


Fig. 7. Captured motions of the rolling model. The magnetic flux density:150[mT] was generated horizontally. The monitor in back shows the value of flux density.

D. Results and discussions

In order to verify the drive principle, an experiment to drive a solid model as shown in Fig.4 (a) was conducted. At first, The magnetic flux density:150[mT] was generated horizontally. The model motions captured by camera are shown in Fig.7. The monitor in the captured image shows the value of the flux density. The magnetic particles were shifted to the upper part of the solid model by magnetic force, contacting the inside of the outer cover. All the particles were moved a distance of 2[cm] by one 150[mT] magnetic field impulse. As a result, this experiment demonstrated the practicality of the magnetic drive principle using a simple magnetic field.

Next, a magnetic flux density of 150 [mT] was generated obliquely downward. The magnetic particles were shifted obliquely downward and didn't contact the inside the outer cover, so the model didn't move.

Fig.8 and Fig.10 show the model motions captured by camera, when the magnetic flux density was generated horizontally. Magnetic particles clumped together and adhered to the inside wall.

The form of the clump did not disintegrate when shaken and the center of gravity of the clump was

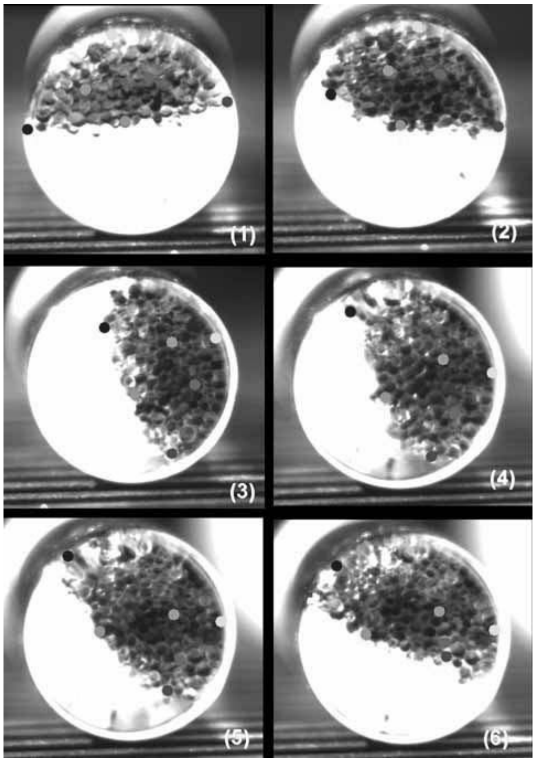


Fig. 8. Captured motion which there is slide in the particle

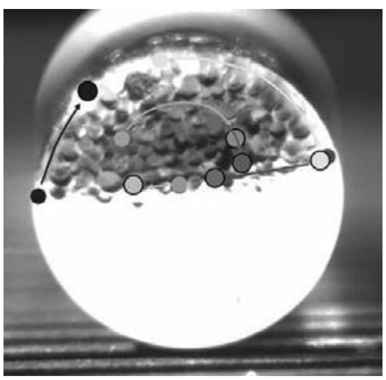


Fig. 9. Move Path of each particle

maintained (Fig.8(1)). When a magnetic field was applied, the model began to rotate and roll in the direction of rotation, with the clump maintaining its form (Fig.8(2)(3)). When the inclination of the clump in the model became large, each particle began to move separately due to its buoyancy, and the shape of the clump changed (Fig.8(4)(5)). The position of the center of gravity became stable, so the rotation stopped (Fig.8(6)). If the form did not change, the model turned back to its original position (Fig.10, left-side figures).

Fig.9 shows the path of each particle. The particles were circulated by convection, that is, a sequential

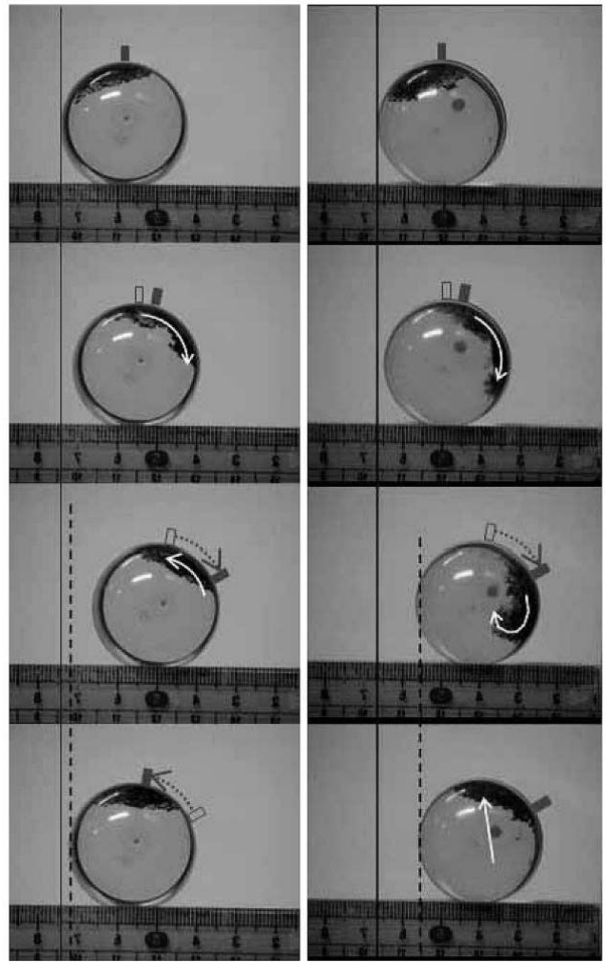


Fig. 10. Captured motion which there is slide in the particle and the inner wall.

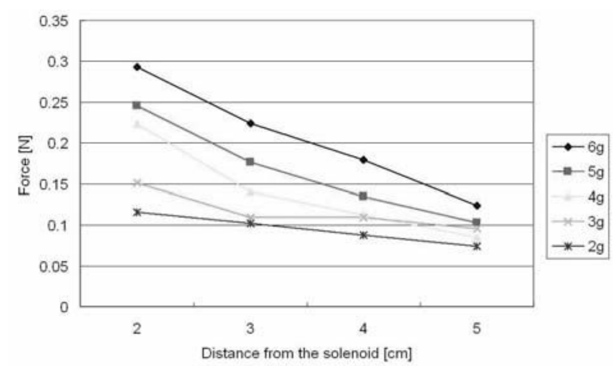


Fig. 11. The graph of the measured magnetic field produced by the equipment of Fig.5. The values are measured by the gauss meter for every mass of a magnetic particle.

convection current can cause sequential rolling. This result says that there is another magnetic wave pattern in addition to the impulse one shown in Fig.1. As a result, it became clear that our proposed driving principle results from not only collision of the magnetic particles with the outer cover but also the flow resistance between the particles and the cover. Equation 1 shows the force F produced on the magnetic particles by the external magnetic field.

$$F = M\, dH / dr = [wb\ m]\ [N/wb]/[m] = [N] \quad (1)$$

M is the magnetic moment, H is the magnetic field strength and r is position. Fig.11 shows the graph of the measured magnetic field produced by the equipment in Fig.5. The mass, of each magnetic particle is measured using the gauss meter.

IV. APPLICATIONS

This chapter introduces some mechanisms that make use of the magnetic drive principle.

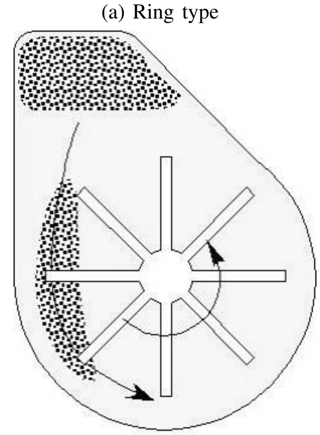
(1)Ring type (Fig.12(a)) This mechanism consists of an outer cover in ring form and an axis of rotation. The torque can be taken from the main axis.

(2) Propeller type (Fig.12(b)) After a magnetic field is applied and the magnetic particles flow downward, the particles then float back up due to buoyancy. When a particle contacts a propeller, torque is generated.

Fig.13 shows the prototype of Ring type (Fig.12(a)), Fig.14 explains the principle of driving. In order to verify the drive principle, an experiment to drive a simple model was developed. Fig.15 shows the model motions captured by camera, when the magnetic flux density was generated horizontally. Magnetic particles pushed the inside wall of the cross wheel, rotated the wheel, then the model drove itself forward.

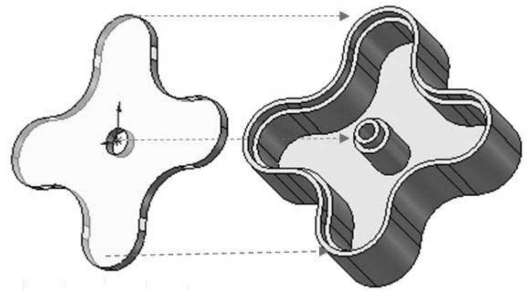
This driving principle could be applied to medical robots shown in Fig.16. One impulse of magnetic force produces 90 degree rotation of cross wheel. This mechanism can realize controlling the travel distance, little influenced by friction and viscosity of organs[9]. In addition, No actuator and no battery are requirements for devices inserted in the body. The external magnetic field is suitable for supplying the rotating or driving force to the device. This application has the advantage over a capsule robot that has a permanent magnet mounted in its interior.

(a) Ring type



(b) Propeller type

Fig. 12. Mechanisms which applied the magnetic drive principle



(a)Design of cross wheel

(b)Prototype fabricated by 3D printer

Fig. 13. Prototype of ring type (cross wheel)

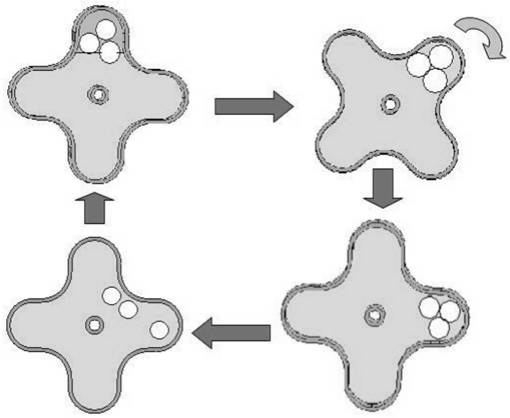


Fig. 14. Driving Principle of cross wheel

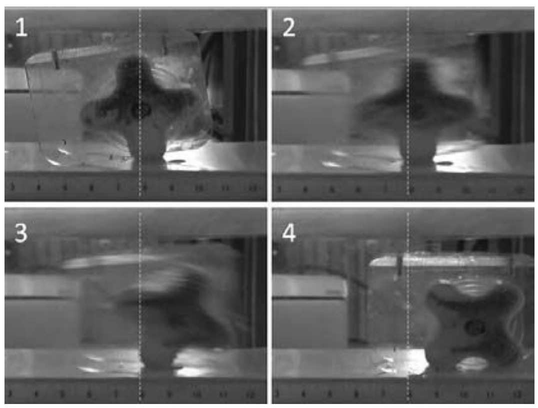


Fig. 15. Motions of cross wheel captured by camera

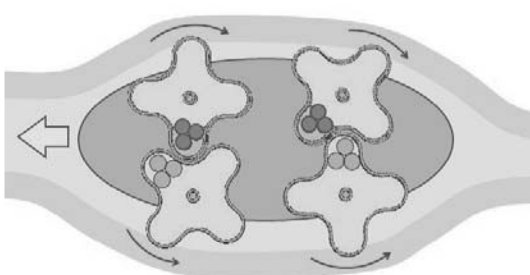


Fig. 16. Schematic diagram of internal medical robot in bowel

V. CONCLUSIONS

This paper presents a new type of magnetic fluid and a rotational drive using a simple magnetic field. It is clear that our proposed driving motions are created by collision of the magnetic particles with the outer cover and the flow resistance between the particles and the cover. The drive for the rolling model was achieved from a small-scale external magnetic field generator and a simple magnetic field control. The device in this study could be applied to new mechanical elements and micro internal rolling objects as a useful medical tool.

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