Magnetic Slime Robots: Innovations in Drug Targeting and Foreign Object Removal

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Abstract: ***Magnetic small soft-bodied robots are perfect for targeted medication administration, micromanipulation, and minimally invasive surgery because they provide non-invasive access to confined locations. Presently available magnetically operated small soft robots are based on elastomers (silicone) and fluids ferrofluid or liquid metal however, they have drawbacks. Robots built on elastomers have trouble deforming, which makes it challenging for them to manoeuvre in extremely constrained spaces. Although they may deform more easily, fluid-based robots have unstable forms and limited environmental adaptation. The non-Newtonian fluid,based magnetically actuated slime robots shown in this work combine the notable deformation capabilities of fluid-based robots with the flexibility of elastomer-based robots. These slime robots can move on different surfaces in intricate surroundings and navigate via tiny channels as little as 1.5 mm in diameter. They carry out tasks include transporting, ingesting, and gripping solid items. Magnetic slime robots, combining the properties of non-Newtonian fluids and elastomers, offer promising solutions for targeted drug delivery and minimally invasive surgeries. These robots can maneuver through small and complex environments, perform tasks such as transporting, ingesting, and gripping solid objects, and adapt to various surfaces. This review discusses the design, preparation, and applications of magnetic slime robots, highlighting their potential in revolutionizing biomedical operations despite challenges related to stability and biocompatibility.***

Keywords: Slime magnetic robots, Non-Newtonian fluid, Targeted drug delivery system, Elastomer, Ferrofluids, Personalized medicine

1. Introduction

Robots that are little and react to outside signals are more user-friendly and less intrusive,[1] making them thrilling candidates for biomedical applications [2] such as targeted drug delivery systems with Negligible invasive surgery and cell transplantation. For small-scale robot control, an external magnetic field is a potential solution because of its safety, accuracy, and fast reaction time. Soft elastomers combined with hard magnetic particles are used to create the majority of magnetically actuated soft-bodied robots.

Figure 1: Representation of Slime Robots

Such soft body robots are made for performing multiple locomotive functions. Soft robots composed of elastomers are constrained by their rigid forms, which are immutable once created. They are also not very flexible, which makes it hard for them to fit through openings that are considerably smaller than their actual size.[3] Conversely, new research indicates that smaller fluid-based robots—such as those composed of ferrofluid or liquid metal perform better.[4] Soft robots with fluid bases are softer and more pliable than those with elastomer bases. They can readily move through extremely small and constrained locations because to their fluid flow characteristics without endangering the biological tissues nearby.[5]

Basic Property of Slime Robots –

1) Non- Newtonian Fluid –

Slime robots basicially follows the principle of Non-Newtonian fluids for changing its viscosity for different stress levels, it can either become solid or liquid at different levels [6]

Ferro magnetic fluid: Basically ferro magnetic fluid moves in a earthworm peristaltic locomotion movement, and magnetic fluid shows that kind of property. [7]

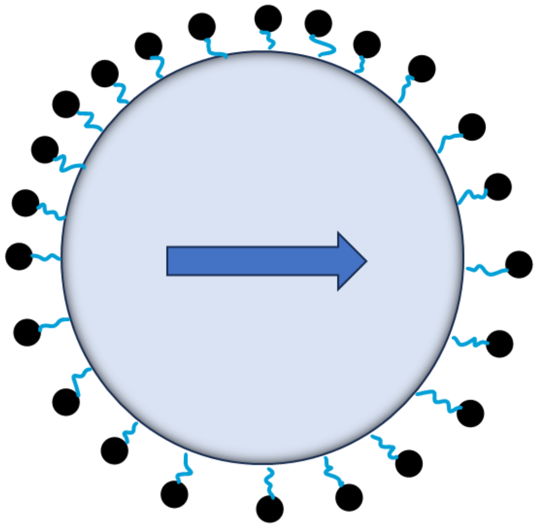

Figure 2: Representation Ferrofluids particle arrangement

2) Elastomers

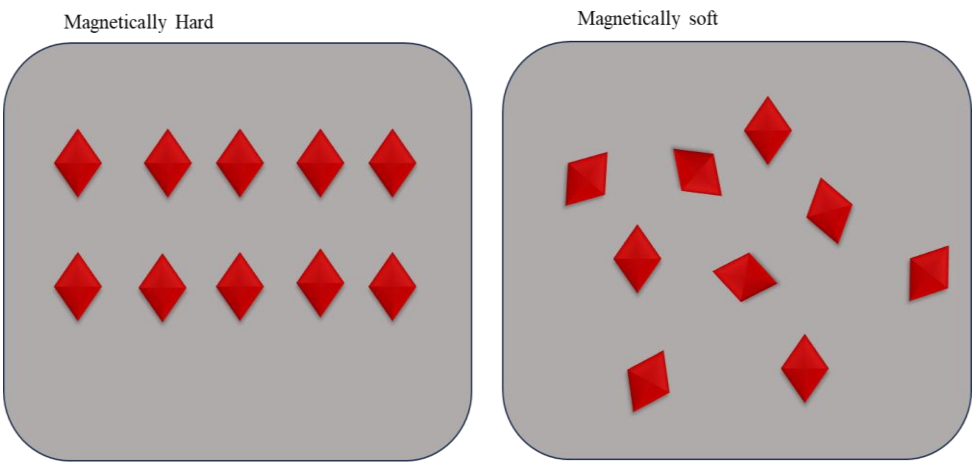

Figure 3: Representation of Elastomers in the range of strength of magnetic field behavior of the particle

A material that has magnetic particles blended with a non-magnetic substance that resembles rubber is called a magnetorheological (MR) elastomer. [8]

Concept and Design of Magnetic Slime Robots-

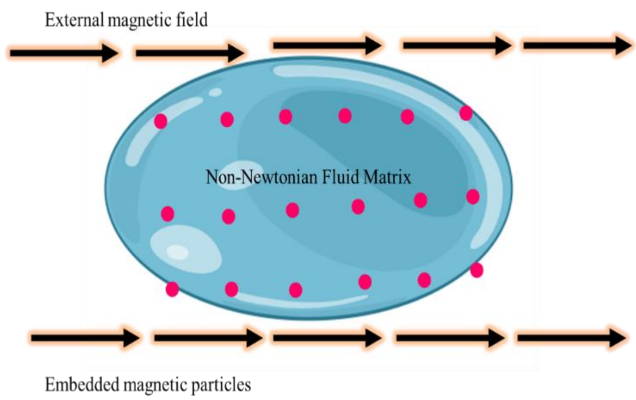

Figure 3: Locomotive representation of Slime Robots

The concept behind the slime robotic technology is based on 3 categories-

1) **Non-Newtonian Fluid matrix** -Represented by the blue ellipse, this is the base material that can change its viscosity response to different upcoming force, making the suitable for the robot to adapt changes in shape [9]
2) **Embedded Magnetic Particles**- The red dotted particles represents the external magnetic particles. These particles have the ability to response to the external magnetic filed, which enables precise control of robot movements [10].
3) **External magnetic fields-** The black arrows represents the external magnetic field applied to control the robot, where the magnetic field directs the robot through various task

Preparation of Slime Robots

A polyvinyl alcohol (PVA) solution is mixed with magnetic particles (NdFeB) and borax sequentially to create magnetic slime. The essential processes required to create the magnetic slime are depicted in the inset of Figure. The primary reason of the slime formation is the interaction between tetrafunctional borate ions and PVA's −OH group. These borate ions are produced when borax is hydrolyzed. Crucially, the magnetic slime is essentially a hydrogel since it contains over 90% water. Images captured by scanning electron microscopy (SEM) reveal that the magnetic slime is composed of a three-dimensional porous network of magnetic

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particles connected by fixed polymers. The slime may stretch and react more rapidly because to its porous nature. We also investigated the slime's cytotoxicity. Non-magnetic slime is exceedingly biocompatible, as demonstrated by the fact that it is not hazardous to NIH 3T3 cells at doses up to 400 µg/mL (Figure). The magnetic slime containing 30% NdFeB is not biocompatible due to the poisonous nature of the magnetic particles. SiO2 was applied to magnetic particles by the Stober technique. The 35 nm SiO2 layer on the NdFeB particles was revealed by transmission electron microscopy . The magnetic slime was then created by mixing these particles with the PVA solution. Tests for cytotoxicity revealed that the 400 µg/mL NdFeB@SiO2 magnetic slime was not harmful to cells. Both actively and passively, magnetic slime may alter its form. Its flow qualities allow it to adapt to its surroundings or be modified by an external magnetic field. A rheometer was used to measure the slime's characteristics. A dynamic strain sweep test ascertained In seventy-one seconds, the slime expanded to 60 mm. COMSOL Multiphysics software was also used to model this stretching process (see Figure 1i and Movie S1). The magnetic field and friction with the surface hold the slime in place while its capacity to alter form allows it to expand. The magnetic slime may also take on the shape of "CUHK" by tracing the path of a permanent magnet, as seen in Figure .[11]

Mechanism Of Action-

First of all incision is done in the body and the slime robot is allowed to penetrate to go through the body with the help the control the external magnet the researchers stated that if the external force is applied on the slime is greater than it act as Non Newtonian fluid but if the external force is gentle it act as a soft ferro fluid. **Prof. Li zhang *et al* (2022)**

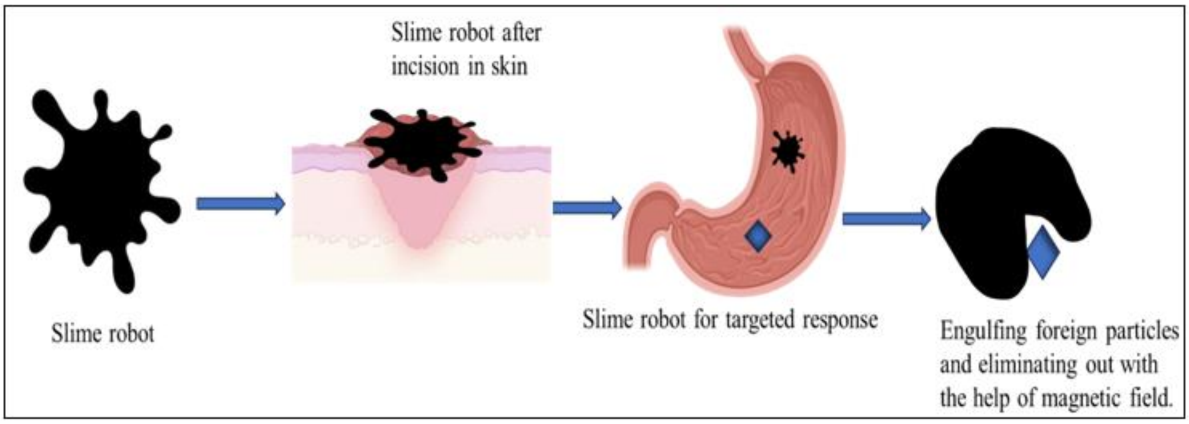

Figure 4: Representation of Mechanism of action

The slime undergo the affected parts and act as targeted drug delivery also if there is foreign substances are present inside the body the slime robots starts to engulf the foreign particle and capture it and drag it out from the body with the help of external magnetic field

Adaptability Towards Environment –

Magnetic slime's exceptional versatility allows it to travel across a variety of surfaces, something that traditional liquid-based robots are unable to accomplish. The structure of the slime combines the deformability of liquid-based robots with the flexibility of elastomer-based robots, without the disadvantages of either design. The usage of liquid-based robotics, such as ferrofluids or liquid metals, is restricted because they need certain environments, such as alkaline solutions or hydrophilic surfaces. On the other hand, our magnetic slime is effective on a range of surfaces. Eight typical surfaces were used for testing: paper, paper, silica, silicon, polydimethylsiloxane, metal, plastic, glass, and hydrogel. a 500 µL slime can trace the phrase "SLIMEBOT" on these surfaces when it is pushed by a permanent magnet.[12]

Controlled Manipulation of Slime Magnetic Robots –

Slimes may vary their form in addition to responding to many complicated surfaces due to their flow qualities by doing two curling test modes

a) Curl mode with time

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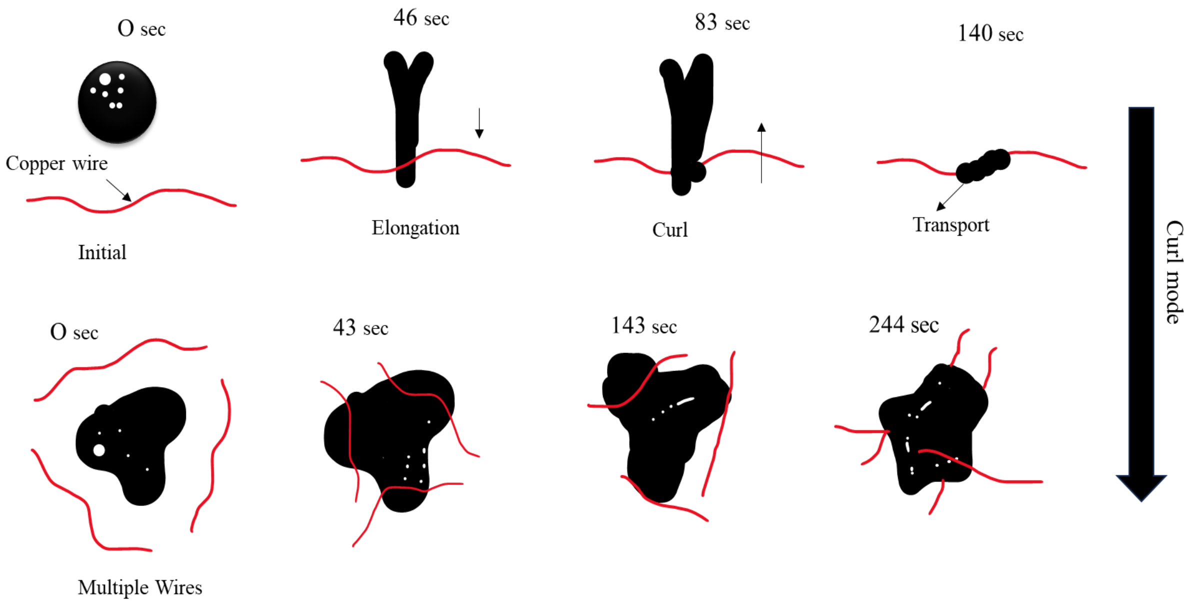

Figure 5: Representation of Curl mode with time variation

b) Endocytosis mode with time

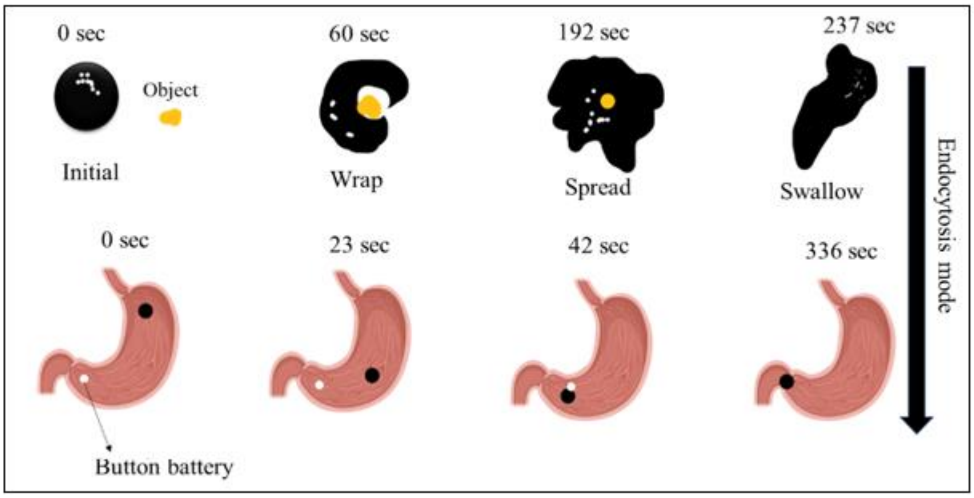

Figure 6: Representation Of Endocytosis mode with time

Advantages of Magnetic Slime Robots-

1) It acts in specific targeting sites.
2) Easily controllable from outside.
3) Most efficient mode of detoxification of the foreign particle inside the body
4) Better than handling conventional drug delivery system or conventional surgical techniques.

Limitation of Slime Robots-

1) Slime robots might degrade in harsh environment.
2) Stability issues might be there.
3) Forming complexation among with the components.
4) Sometimes it is difficult to achieve good manipulation of the biocompatibility of the components.

Magnetic Slime Application

According to the research, as the slime robots have ability to locate sites specific it can also be used in drug targeting as it is very much precise in locating the target ,Since it has also have the ability to engulf the particular foreign target after incision on the body ,by various direction it can move and locomote in each direction where the particular magnetic field is applied .

Choosing Magnetic Carriers, For Specific Clinical Needs-
Because of their consistent quality, high magnetic response, and ease of manufacture, Fe3O4 magnetic nanoparticles are widely utilised in magnetic resonance imaging, magnetic separation, magnetic hyperthermia for tumour treatment, and targeted drug administration. Human body excretes Fe3O4 magnetic nanoparticles in an appropriate amount. Fe3O4 magnetic nanoparticles may be produced using a number of techniques, such as hydrolysis, chemical co-precipitation, and micro-emulsion.[13]

Future Directions and Innovations-The review synthesizes recent advancements in the design, preparation, and application of magnetic slime robots. It evaluates their performance based on various studies and experiments conducted to test their adaptability, maneuverability, and effectiveness in biomedical applications.

Ferromagnetic slime can be used to cancer cells [14] Microrobot applications in medicine are seen to be extremely promising. These little robots have the potential to transform medicine as we know it and increase the effectiveness of diagnosis. They have already been successful in moving small quantities of materials into the body, which is only one of their numerous functions. Powerful imaging techniques like magnetic resonance imaging (MRI) mircobot can identify a variety of physiological signs, including blood flow, temperature, strain, and oxygen levels.

Enhanced accuracy is a key benefit of utilising MRI in conjunction with robot-assisted surgery. Because they employ precise controls and synchronised motions, robots can increase placement precision and consistency. To ensure that the procedure proceeds according to plan, MRI can track the motions of tissues and surgical instruments. Better surgical results are achieved by using this imagery to follow instruments and modify motions in real-time. [15]

Purpose of this article & Graphical Abstract –

This article reviews the advancements and potential applications of magnetic slime robots in targeted drug delivery and the elimination of foreign objects in medical treatments. The development of magnetic slime robots marks a significant leap in minimally invasive medical operations, offering a novel approach to targeted drug delivery and the elimination of foreign objects with higher precision and flexibility.

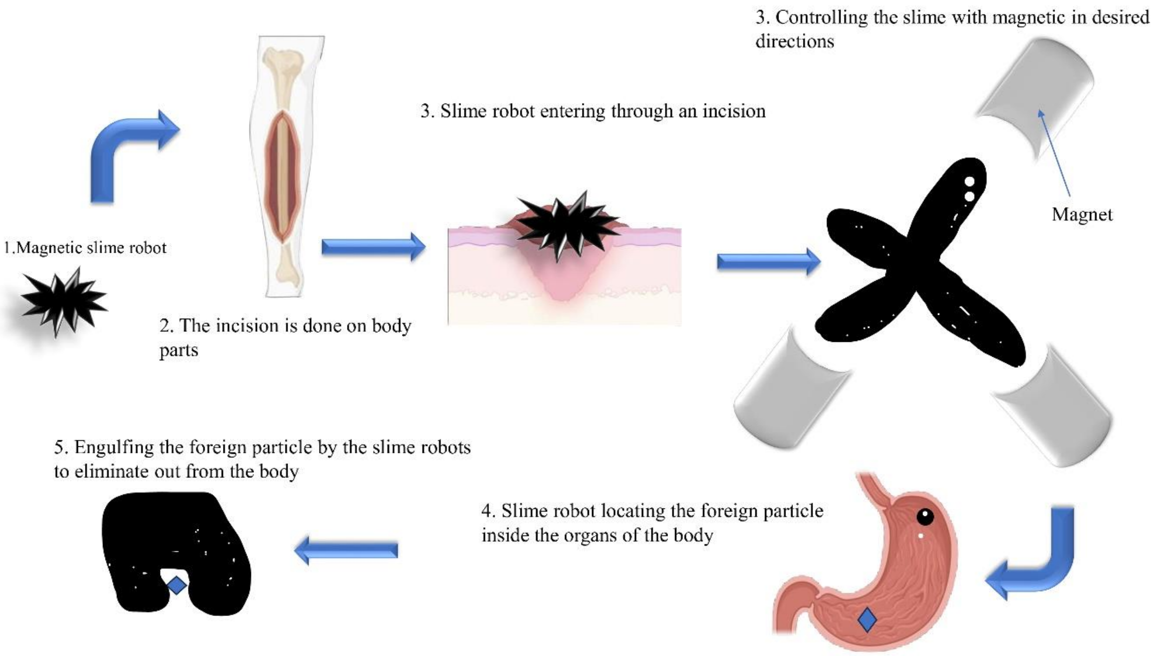

Figure 7: Representation of Graphical abstract of the slime robots

2. Conclusion

Magnetic slime robots offer innovative solutions for targeted drug delivery and minimally invasive surgeries, combining the adaptability of fluid-based robots with the flexibility of elastomer-based robots. Despite challenges related to stability and biocompatibility, further advancements in this technology could revolutionize biomedical applications, providing more efficient and precise therapeutic approaches. These cutting-edge robots combine the deformability of fluid-based robots with the flexibility of elastomer-based robots to conduct precise micromanipulation tasks, navigate through extremely small and complicated settings, and deliver drugs precisely to specific locations. Notwithstanding their remarkable capacities, problems like stability in challenging conditions and preserving biocompatibility must be resolved. The advancement and enhancement of magnetic slime robots possess significant potential to transform many biomedical applications, opening doors for more efficient and minimally invasive therapeutic approaches.

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