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Abstract

This paper presents a shape-adaptive gripper concept based on a 3D-printed structure made from TM5MED, filled with magnetorheological fluid (MRF). The gripper utilizes electromagnets to control the viscoelastic properties of the MRF, allowing for rapid shape adaptation. High-performance strain sensors made from flexible carbon nanotube (CNT) films measure pressure and deformation at the contact surface and along the sides, allowing for nuanced force control. This design concept is particularly suited for robotic applications that require flexible and safe object handling.

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A Concept for Form-Adaptive and Force-Controlled Gripping with Magnetorheological Material

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Summary: This paper presents a shape-adaptive gripper concept based on a 3D-printed structure made from TM5MED, filled with magnetorheological fluid (MRF). The gripper utilizes electromagnets to control the viscoelastic properties of the MRF, allowing for rapid shape adaptation. High-performance strain sensors made from flexible carbon nanotube (CNT) films measure pressure and deformation at the contact surface and along the sides, allowing for nuanced force control. This design concept is particularly suited for robotic applications that require flexible and safe object handling.

Keywords: Shape-adaptive gripper, smart material, magnetorheological material, strain gauge, Carbon nanotubes

Introduction

Handling fragile objects with different shapes is one of the main challenges in robotics [1]. Different grippers based on flexible materials, such as powder-filled vacuum grippers, have been developed to address this issue [2].This work presents a shape-adaptive gripper that can dynamically adapt to different object shapes. The gripper is based on a 3D-printed lattice structure and uses magnetorheological fluid (MRF), which changes its viscosity when exposed to a magnetic field.
Advances in materials science and manufacturing are enabling the development of flexible grippers that offer high precision and flexibility [1] [3]. MRF-based grippers achieve stiffness modulation with a trigger time at the millisecond level, substantially enhancing their efficiency in handling complex objects. 3D printing is also proving to be a key technology for producing complex gripper structures and customised designs [4] [5].
Control in adaptive grippers could potentially be enhanced by incorporating flexible and stretchable strain and pressure sensors made from Polymer/CNT (Carbon Nanotube) nanocomposites. These sensors aim to provide continuous data on deformation and applied force, which is crucial for the careful handling of delicate materials. Due to their flexibility and ductility, these sensors can adapt to the movements and shape changes of the gripper, making them highly suitable for dynamic gripping tasks. Integrating these sensors into robotic systems could significantly improve force control, thereby increasing the stability and safety of the gripping process. Initial research results indicate that this technology could further improve the handling of complex or fragile objects [6] [7].

Gripper design

The shape-adaptive gripper consists of a 3D-printed pad with an inner lattice structure and an outer shell made from TM5MED material. The sponge-like lattice structure (see Fig. 1) provides elasticity and ensures an even distribution of the magnetorheological fluid, preventing sedimentation. The stiffness of the MRF is intended to be controlled by a 24 V DC electromagnet, which regulates the material's rigidity through a magnetic field. The choice of a 24V system was made to make optimal use of the existing power supply in standard robotic systems.

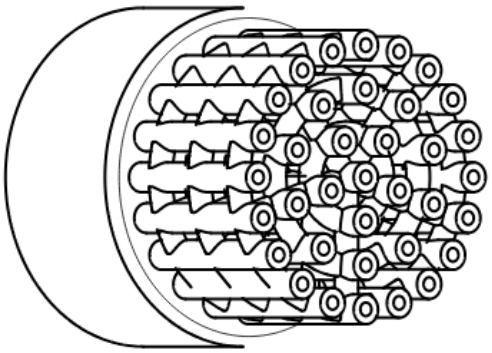

Fig. 1: Computer-aided design (CAD) model of the gripper's internal sponge-like architecture and electromagnet.

To enhance force control and prevent collisions, flexible strain and pressure sensors based on functionalized graphene nanoparticles were integrated, see Fig. 2. These sensors continuously detect deformation and applied forces, allowing adaptation to object shapes and preventing damage to the gripper from overload or

collisions [6]:

- **Strain Sensors**: Positioned on the outer side of the gripper, these sensors measure the overall deformation of the structure, ensuring the gripper adapts to the object's shape without compromising structural integrity.
- **Pressure Sensors**: Positioned at the contact interface, they measure the force exerted on the object, enabling immediate adjustment to prevent damage, particularly when handling fragile or irregularly shaped objects.

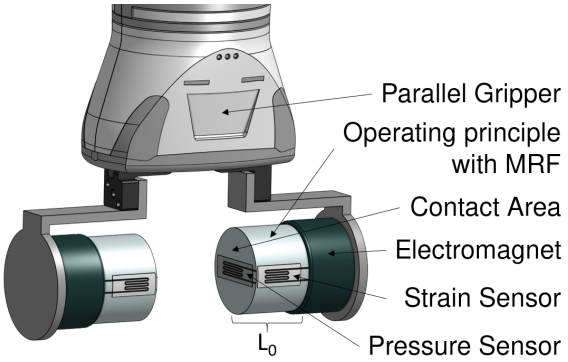

Fig. 2: Modeling Sketch of a parallel gripper.

Methods

The graphene-based strain and pressure sensors provide feedback to control the gripping process. The following methodology is employed:

Strain Measurement: Strain is calculated using the formula (1), where ϵ is the strain, ΔL is the change in length, and L_0 is the original length. This data helps adjust the MRF stiffness in real-time, allowing the gripper to conform to the object's shape.

$$\epsilon = \frac{\Delta L}{L_0} \tag{1}$$

Pressure Measurement: Pressure is measured by (2), where P is the pressure, F is the force applied, and A is the contact area. This enables force adjustment, ensuring a secure grip without damaging sensitive objects

$$P = \frac{F}{A} \tag{2}$$

Sensor response: The relative change in resistance of the graphene sensor, as described in equation (3), provides continuous feedback on strain and pressure. This feedback converts mechanical changes into electrical signals. This enables the gripper operation to be adapted.

$$\frac{\Delta R}{R_0} = f(\epsilon, P) \tag{3}$$

Discussion

Integration of flexible strain sensors and MRF in the shape-adaptive gripper is intended to enable controlled flexibility and force modulation, with the sponge-like structure considered a critical component. Internal tubes may exert excessive pressure under load or even rupture. The MRF volume may be insufficient to achieve the required stiffness. Additionally, there is a risk of uneven MRF distribution and sedimentation, which could impair adaptability. Validation of structure and flexibility is required for safe handling.

Conclusion

The shape-adaptive gripper utilizes MRF within a 3D-printed sponge-like structure, promoting even MRF distribution and preventing sedimentation. Strain and pressure sensors allow for variable stiffness and adaptation to object contours, facilitating a secure grip during handling. This technology is particularly suited for robotic applications requiring high adaptability and force control, especially when handling delicate or complex-shaped objects.

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