Optimization of Electromagnetic Driven Origami Unit Actuator

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Background

Origami techniques have found diverse applications across various industries, demonstrating remarkable breakthroughs in aerospace, medical devices, solar technology, and packaging. The inherent attributes of origami, such as space efficiency and weight reduction, make it a particularly promising avenue for exploration within the field of robotics.

Leveraging electromagnetic propulsion presents an opportunity to streamline mechanical designs and economize on space utilization. This approach allows us to harness the full potential of origami principles in developing innovative robotic solutions, improving both space efficiency and maneuverability.

Considering these unique features, our project aims to harness the three degrees of freedom (DOF) inherent to the decided folding pattern(as Fig. 1) to design a modular robot driven by electromagnetic forces. This robot will exhibit capabilities such as crawling and rotation through the controlled actuation of its units. Our focus is on optimizing the interaction between the coils and the permanent magnetic field within the constraints of limited space and power, thus enhancing overall performance.

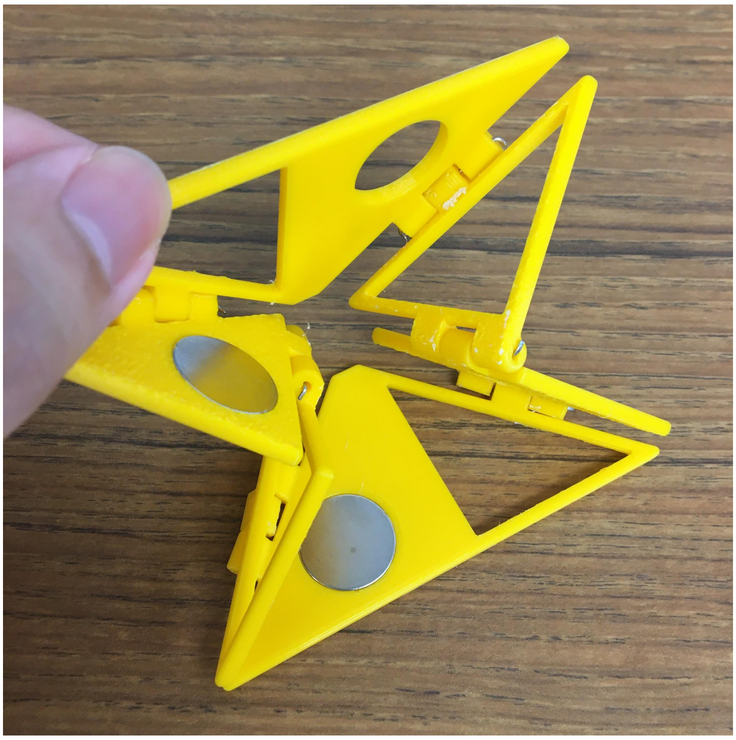

Fig. 1 3-DOF origami unit mechanism

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Problem formulation

Objective functions:
min f(N, S, D, I)=-B
Maximizing the magnetic field strength B at the same Power.

Design variables:

1. Number of Coil's Turns (N):
   - Affects Magnetic Field Distribution: Each turn of the coil creates a magnetic field, and the magnetic fields produced by each turn will add up, increasing the overall magnetic field strength.
   - Affects Inductance: The inductance is directly proportional to the square of the number of turns. A higher inductance stabilizes current and voltage in the circuit, preventing rapid changes in current. A lower inductance allows for faster current variations, which is beneficial for high-frequency operations.

2. Coil's Geometric Shape (S):
   When current flows through coils of different shapes, it leads to varying magnetic field distributions and directional characteristics, thereby affecting magnetic field strength.

3. Diameter of Coil Wire (D):
   As the diameter of the coil increases, the same current will be dispersed over a larger cross-sectional area, which may lead to a decrease in current density. The lower current density may affect the intensity and distribution of the magnetic field.

4. Input Current (I):
   This variable is designed because the magnetic field will change as the current changes.

Design parameters:

1. Material of coil's frame (M):
   The heat generated when the coil carries current can influence the material's performance. Therefore, it is important to choose a material with good heat dissipation properties.

2. Permanent Magnet Field Strength (Bp):
   Different levels of permanent magnet field strength affect the degree of opening and closing in this project.

Design constraints & design boundaries:

1. Thickness of the frame
   The thickness of the frame needs to fit the mechanism, too thick will make the hinge hard to design. The thickness limit constrains the number of coil turns and the diameter of the coil wire.

   $D \times N_L - T_0 \leq 0$

   N_L = number of layers

   $T_0 = frame\ thickness$

2. Input current limit
   Due to the power supply system and heat generation of the coil, the current is constrained not to exceed certain values I_u.

   $I - I_u \leq 0$

3. Magnetic field strength
   In order to actuate the mechanism, the magnet field generated by the coil needs to be strong enough. The strength(B) is determined by the total number of coils, the total thickness of the coil, and the current.

   $B_l - B \leq 0$

   $B = \mu \frac{N}{L} I$

   μ = magnetic constant

   N = total number of the coil $N = N_C \times N_L$

   L = coil total thickness ($= T_0$ frame thickness)

   I = current

4. Number of the coil
   The frame is in a triangle shape not in circle, one possibility of the design is to change the shape of the coil. One big circle coil, multiple small circle coils, and the composition of the different coils is all possibility. Due to the geometry of the frame, each design has an upper limit for the number of coils.

   $N_c \leq N_u$, N related to S

   N_c= number of coils of each layer

Assumptions

1. The magnet field generated by different coils can sum up.
   Because one design variable is the shape of the coil, multiple coils are possible. Assume the magnet fields generated by different coils can act as a big coil.

2. The gap inside the coil is close to zero.
   The coil is a composite of different layers of wire. To simplify the calculation, the gap between each wire and each layer is close to zero.

3. The coil is in ideal condition.
   Assume the behavior of the coil is close to the theorem instead of in reality.

4. The coils act like a solenoid.
   Assume the coils are acting like a solenoid so we can change the radius of the coils neglecting the ratio between the radius and the thickness of the coils.