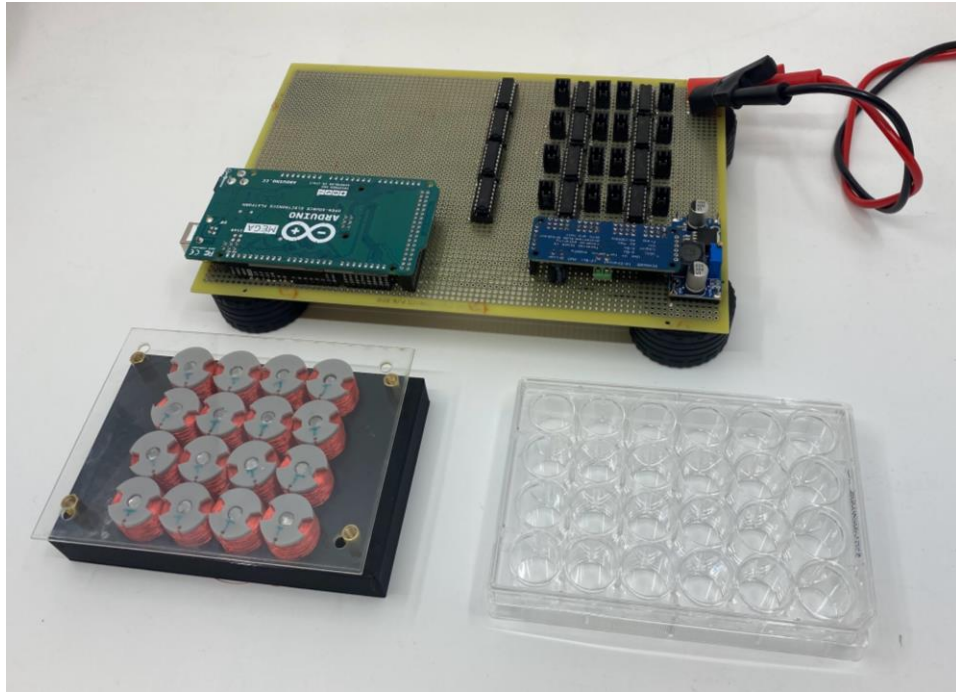# Magnetic Actuation Board

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Background

The Bio-Inspired Materials (BIM) Laboratory at the University of Michigan[1] focuses on creating, developing and testing materials composed of organic substrates for implementations in biomedics, robotics, and other specialized applications.

At the BIM Lab, the Magnetic Actuation research team develops projects that revolve around magnetically actuated materials with physical properties that can be modified via exposure to magnetic fields. Testing these materials requires platforms with the ability of creating spatially heterogeneous, time-dependent and dynamic magnetic fields.

Introduction

To achieve this, the laboratory developed a specialized platform with an open-loop control system along with an interface that would allow users to easily produce numerous types of magnetic fields and time varying patterns; this is the Magnetic Actuation Board.

The board functions as an array of individually commanded electromagnets. This arrangement allows for precisely configured magnetic fields produced on its workspace. It also has the capability of producing programmed sequences in order to create dynamic magnetic field patterns.

The Magnetic Actuation Board can be adapted for specific applications such as the movement of small objects across the board, controlled manipulation of different structures, microrobotic swarm patterns, systematic strain testing, among other applications depending on the needs of future projects.

Methodology

There are multiple interconnected layers of requirements to be covered in order to produce the desired platform, which meant that the design process was crucial. These requirements included what use cases the device could cover, choosing and designing suitable parts, covering power requirements, determining what control system would be used, among other specifications.

In order to have a starting point for the prototype, a practical test case was chosen by the magnetic actuation team in the lab. This use case would be testing Magnetically Actuated Structured Hydrogels[2] developed in-lab that required specific testing parameters and magnetic field distribution patterns.
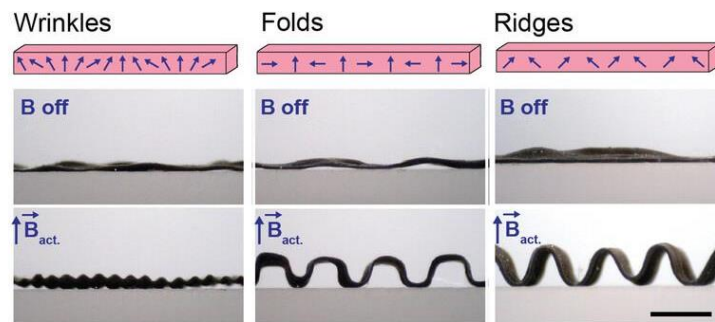

Figure 1. Magnetically Actuated Structured Hydrogels

These hydrogels would be exposed to different magnetic fields in a well plate arrangement with minimal separation between samples (<1cm) and require a range of a magnetic field from -20 to 20mT for actuation testing. These physical constraints would serve as starting points for the design of the board's dimensions.

From here, we broke down the parts that needed to be developed into four main components; coil design, system design, control, and actuation methods. These sections were tackled individually, and the systematic approach allowed for an effective development process.

<u>Coil Design</u>

The main actuators on the board are the underlying solenoids. When designing these, we had four main priorities: Increase the magnitude of the magnetic field, reduce the diameter to fit the working area of the initial testing dimensions, reduce the power consumption (mostly to limit heat dissipation, but also for efficiency) and concentrate the magnetic field to reduce crosstalk between samples.

For testing the hydrogels, a single solenoid had to produce more than 20mT. Considering a limit on power usage for safety purposes, we considered a maximum of 5 Amperes when running all solenoids at its maximum intensity. We also set a functional voltage limit of 12 Volts.

We used a diameter that would fit the standard well plates that hold the hydrogel samples, which have wells with a diameter of 18mm. The dimensions of the solenoid impacted the field they could produce, so we chose a solenoid height and a wire diameter to increase the magnetic field output without jeopardizing the steady state impedance of the solenoids for minimal power consumption.
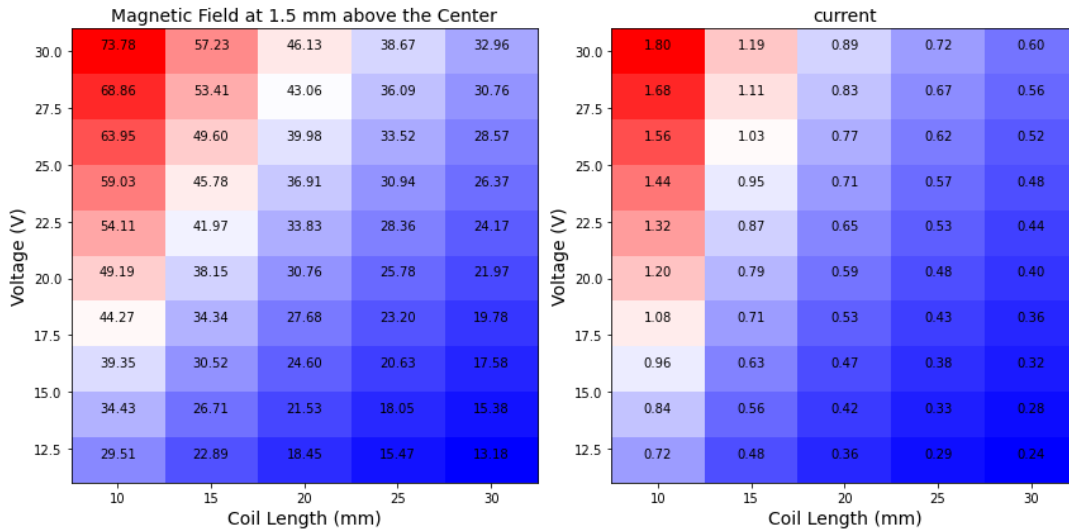

Figure 2. Theoretical |B| [mT] and current drawn [A]

For optimizing the solenoids we calculated the theoretical values that would result from different solenoid dimension, e.g., in figure 2 on the left we have the theoretical magnetic field magnitude [in mT] and on the right the current drawn [in Amps] by solenoids with different input voltages and lengths at a constant diameter of 20mm. From here we obtained an optimal peak that maximized the magnetic field and satisfied dimension and power requirements.

The solenoids have a diameter of 20mm and a height of 20mm, a soft iron core with a diameter of 5mm and a magnetically inert resin structure to hold the solenoid together. The solenoids are wound with 32 AWG wire. At a steady state, they have an impedance of 56Ω.
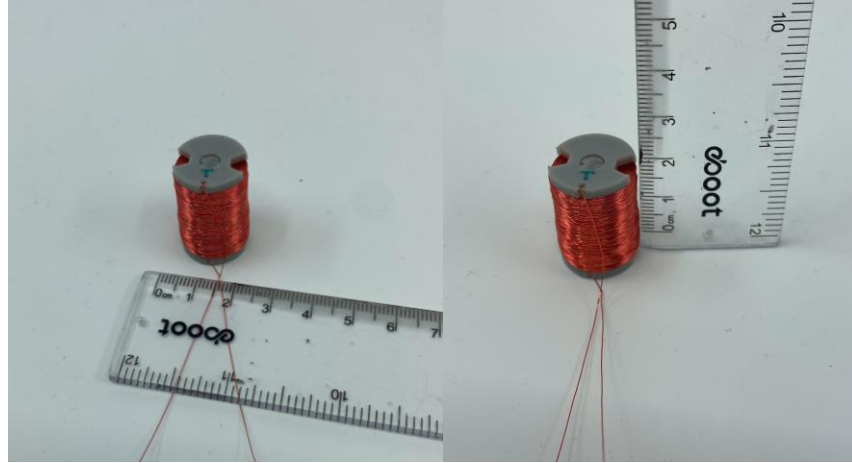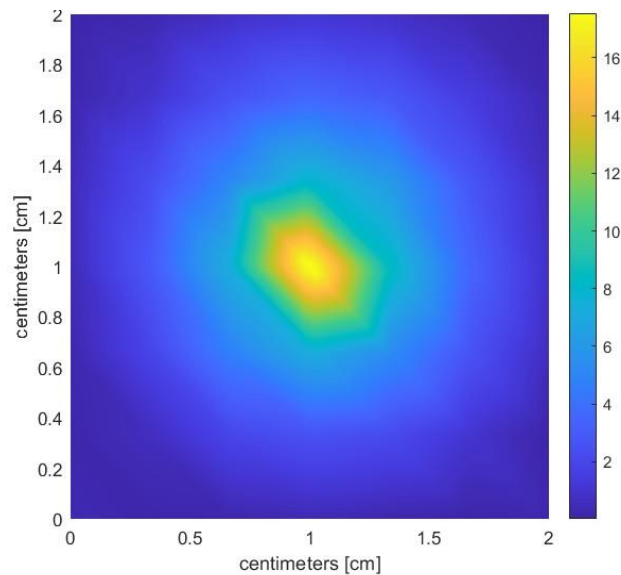
Figure 3a, 3b. Individual solenoid

Figure 4. Magnetic field profile of a single solenoid; measured at height Z = 0mm, 12V at a steady state

The coils produce a centralized magnetic field around the soft iron core with a maximum output of 20mT at a steady state, differing from simulation data by 45%. This difference is due to the multiple non-ideal characteristics of the manufactured solenoids that were not taken into consideration, like the inherent resistance of the copper wire, inefficient wire packing when winding the coils, the inductance of the solenoid, and the heat dissipation that increased the impedance.

Nonetheless, the coils produce the required magnetic field magnitude, so they were used for the initial prototype. Even though the coils are set up near each other, the crosstalk is minimal. The solenoids were then assembled on a 4x4 arrangement held in place by a 3D printed stand.

The Magnetic Actuation Board has separate sections that control different aspects of the actuation. The hardware allows for swapping the solenoids on the board to other designs depending on the needs of the material tested, it supports manipulating the spatial arrangement of the magnetic array, and has open I/O connections for future expansions.
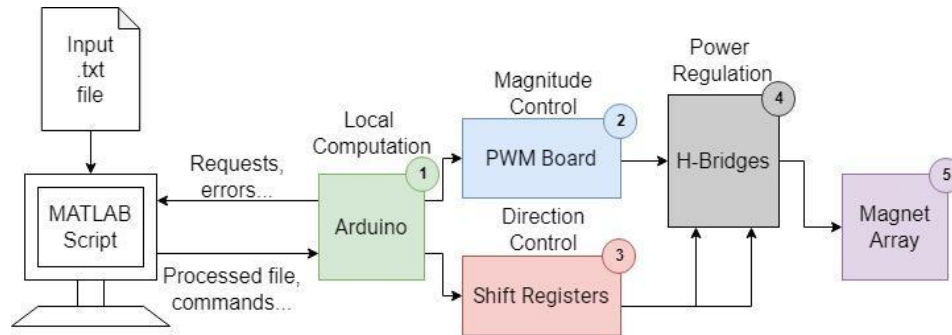

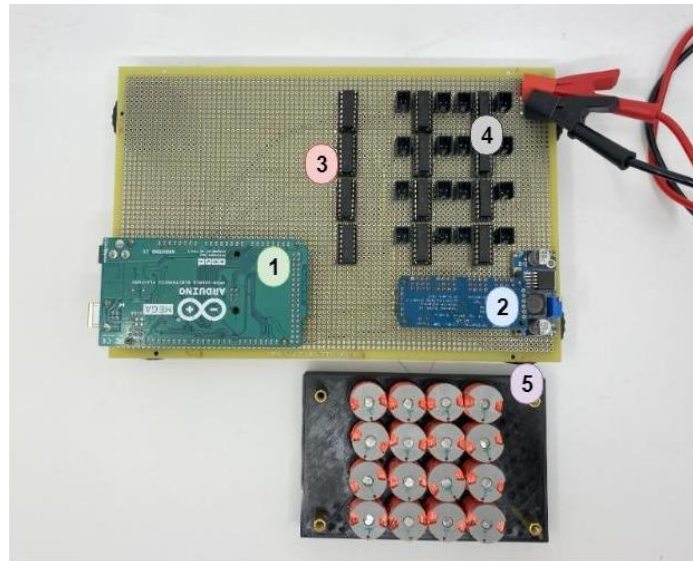**Figure 5. High Level Schematic of Magnetic Actuation Board**

Figure 6. Labeled layout of components

Initially, a MATLAB script processes an input .txt file with a given format in order to produce any desired pattern. The commands in the .txt file allow for the control of individual solenoids or sections of the board for outputting a magnetic field intensity and direction at a given timestep. These commands are interpolated and communicated to the board system.

The board uses an Arduino Mega as the main microcontroller with an ATmega2560 processor and 54 pins to allow for expansion and minimize output latency. The microcontroller handles

USB communication and includes software libraries that allow easy interfacing with a desktop computer.

The system integrates peripheral devices for serial-parallel data conversion, such as the shift registers and the PWM board. These are used to control the direction and magnitude of the individual solenoids on the board.

Even though the initial setup was designed to keep the input voltage at 12V and have a maximum current draw of 5A total, the L293D H-bridge IC packages are able to handle up to 35V and 2A per solenoid so that other more powerful electromagnets can also be controlled by the board.

It is also able to be modified for other applications depending on the needs of future projects, and the layout is expandable for increasing the support of a bigger electromagnet array.

Control

To command the individual solenoids and to produce patterns on the board, a file format was created to set the field output at a given time, allowing the user to write a script commanding the board to produce a pattern.

```
1    # Example file, 4x4 board
2    # Change options
3    % interpolate false
4    # Sequentially set all magnets to 100% intensity
5    # producing a positive B field
6    @ 0.5 magnet(1,1) 100
7    @ 1 magnet(1,2) 100
8    @ 1.5 magnet(1,3) 100
9    @ 2 magnet(1,4) 100
10   @ 2.5 magnet(2,1) 100
11   @ 3 magnet(2,2) 100
12   @ 3.5 magnet(2,3) 100
13   @ 4 magnet(2,4) 100
14   @ 4.5 magnet(3,1) 100
15   @ 5 magnet(3,2) 100
16   @ 5.5 magnet(3,3) 100
17   @ 6 magnet(3,4) 100
18   @ 6.5 magnet(4,1) 100
19   @ 7 magnet(4,2) 100
20   @ 7.5 magnet(4,3) 100
21   @ 8 magnet(4,4) 100
22   @ 8.5 section(1:4,1:4) 0
```

Figure 7. Example input file for control

The files also allow you to control if the output between two commanded intensities will be time interpolated. This functionality can produce heterogeneous magnetic fields that would be used in particular applications such as strain testing.

<u>Actuation Methods</u>

Currently, the project continues developing testing procedures for the magnetically actuated materials. These will be done as the project continues.

Testing

The key data points are measured with electronic tools that were used while building the device (voltmeters, magnetic field sensors, power supplies, schematic design, etc).
These key values could be the precise values of the magnetic field at certain points on the board, how the magnetic field spreads throughout the board itself, and how much power is required to power the board.

Other values will be the results obtained from testing materials, and their reaction depending on the applied magnetic field. These results will vary depending on the materials tested, and therefore will be measured accordingly.

Results

The prototype for the Magnetic Actuation Board has been successfully developed and tested, and it serves as a platform for initial runs that will allow the team to come up with testing procedures that their materials could benefit from.

Future Additions

Testing procedures are being developed to be tested on the board. In the future, the board will be expanded to include an array of 8x8 electromagnets, and the solenoids will be reduced in size to increase the resolution of the area controlled.

References

1. BioInspired Materials Lab: University of Michigan. https://www.apenafrancesch.com/

2. Roy, A., Zhang, Z., Eiken, M.K., Shi, A., Pena-Francesch, A. and Loebel, C. (2024), Programmable Tissue Folding Patterns in Structured Hydrogels. Adv. Mater. 2300017. https://doi.org/10.1002/adma.202300017