DYNAMIC FERROFLUID LAMP

By

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Abstract
Our dynamic ferrofluid lamp models a new medium of artistic display, which could automatically manipulate the ferrofluid instead of having to modify it manually using a magnet. It allows multiple dimensions of control over the ferrofluid, and involves a programmable interface to allow ferrofluid pattern design for users. The display also includes adjustable lighting effects. Each individual dimension of control over ferrofluid is well-behaved, whereas the combined dimensions are not synchronized.

Contents

1. Introduction

1.1 Background

Ferrofluid is a special kind of liquid whose shape can be changed based on different magnetic field strengths. Invented in 1963, ferrofluid was originally intended to be used to allow liquid rocket fuel to be drawn toward a pump inlet in a weightless environment [1]. It is only in the recent two years that the properties of ferrofluid have been explored and taken advantage of in fields of artistic display. However, due to the relatively new concept of using ferrofluid for art, currently existing methods of displaying and manipulating ferrofluid remain crude and unrefined. Human interaction is always required to change the shape of the ferrofluid, meaning that people can only manipulate the ferrofluid by manually moving around a magnet in order to create different magnetic field strengths.

1.2 Statement Of Purpose

Our project aims to refine the design of artistic ferrofluid display. In particular, our goal is to create a hands-free, programmable ferrofluid lamp that enables the manipulation of ferrofluid by automatically modifying the magnetic field strengths around it. Electromagnets are used to provide the necessary magnetic fields, and are arranged such that the ferrofluid can be channeled in both horizontal and vertical motions. The display also involves adjustable light effects by enabling users to change the LED display pattern.

2 Design

2.1 Introduction

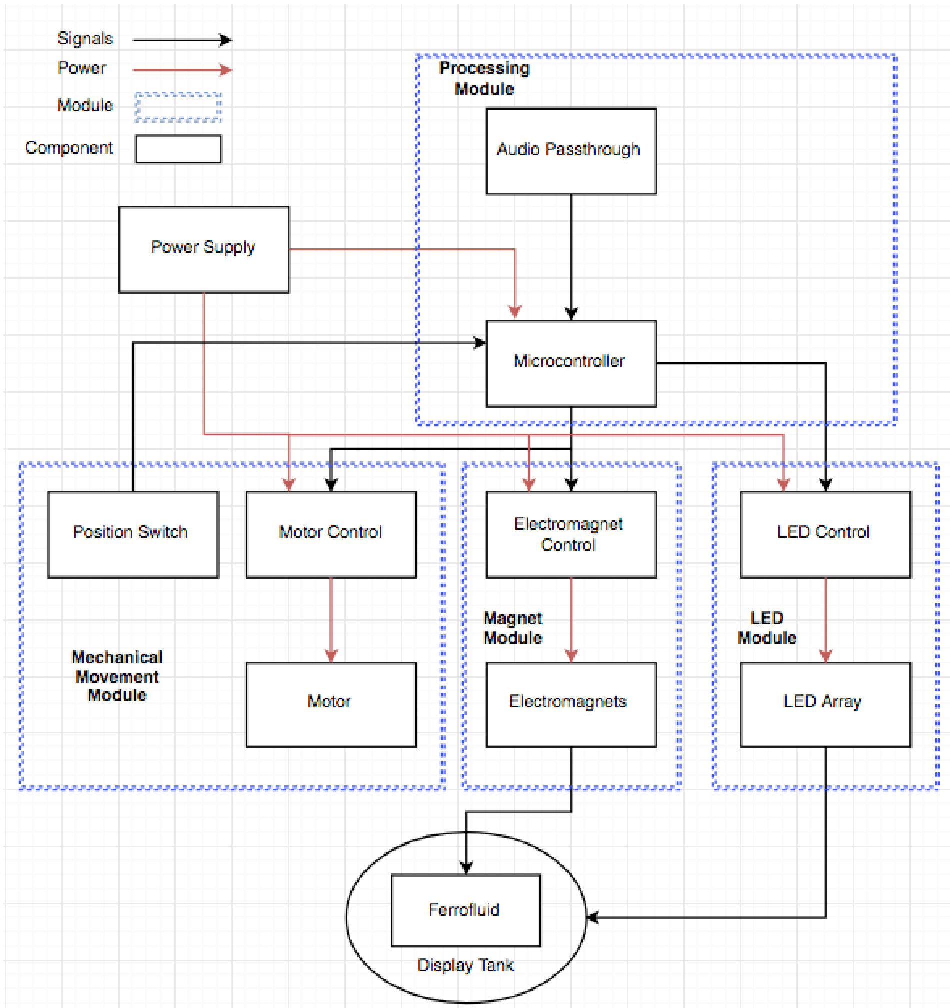

Figure 1.1: Block Diagram

As Shown in Figure 1.1, the project is split into four main modules: the “Mechanical Movement Module”, the “Magnet Module”, the “LED Module”, and the “Processing Module”. The Processing Module houses the microcontroller and provides processing power to the device; the LED Module provides control to the LED array; the Magnet Module provides the magnetic fields for manipulating the ferrofluid and moving it horizontally; and the Mechanical Movement Module, via a linear actuator and central platform, provides the Magnet Module with vertical motion and in turn moves the ferrofluid up and down.

These Modules work together to move the ferrofluid in two dimensions. The maximum electrical current must be within 2.25 amps, and the total cost of parts should not exceed 200 dollars.

It should be mentioned that one modification from the original design is that the power module was changed from being manufactured in house to utilizing existing 12V power supplies on the market for convenience.

Due to the Mechanical Movement Module and the Magnet Module being designed in conjunction with each other to optimize the effect of manipulating ferrofluid, these two modules will be described in section 2.2 as "Physical Design."

2.2 Design Procedure

2.2.1 Physical Design

Physical design of the project proved to be one of the most time consuming portions. Due to our goal of achieving both horizontal and vertical movements, a simple and elegant design is not easily achievable.

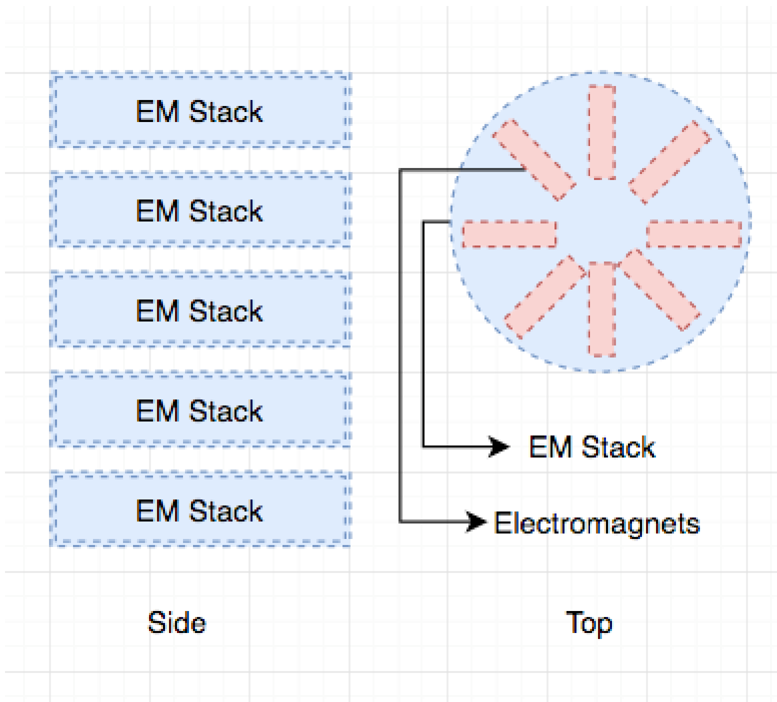

Figure 2.1: Physical Design 1

Shown in Figure 2.1 is one of the first designs that were considered. In the central cylinder rests a stack of electromagnets, each stack consists of eight electromagnets aligned radially with respect to the central axis as shown in the top view of Figure 2.1. The benefits of this design is that vertical and rotational motion can be achieved without any moving parts. However, this design requires the use of eight pulse width modulation(PWM) signals per layer of electromagnet stack. This is not viable due to affordable microcontrollers usually not having more than six PWM output pins. Even if selection signals were used to select between stacks, two layers must be controlled at the same time to achieve the effect of ferrofluid moving up or down. Moreover, this design requires the need of a number of electromagnets equal to eight times the number of electromagnet stack layers. This would largely increase the cost in electromagnets. Thus, this design was not used in the final design.

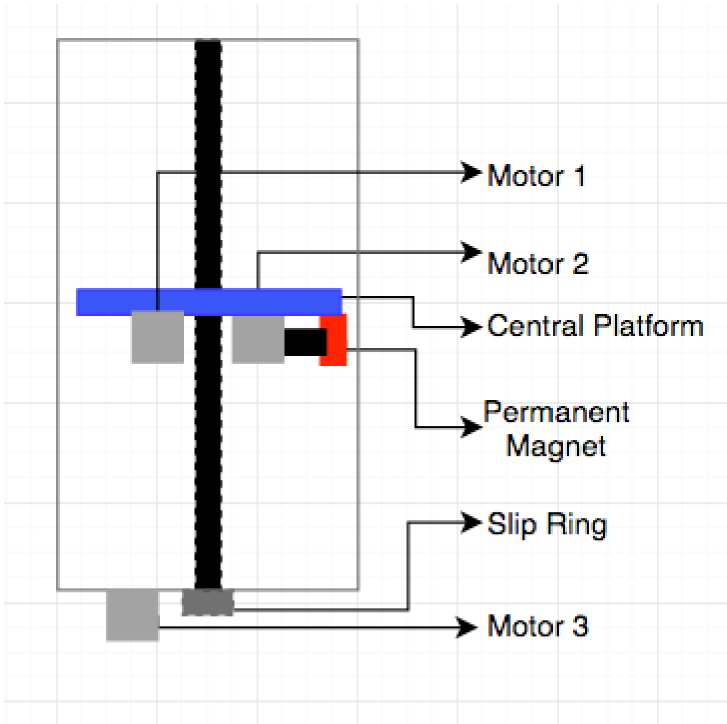

Figure 2.2: Physical Design 2

Another design for the physical design used purely permanent magnets, linear actuators, and motors. Described in Figure 2.2, Motor 1 provides linear motion to the central platform and motor 2 provides linear motion to the permanent magnet, which indirectly provides change in magnetic field strength due to change in distance from the permanent magnet to the inner cylinder wall. Motor 3 provides rotational motion to the boxed system. The slip ring creates a pathway for power and control signals to transition from a stationary frame of reference to a rotating frame of reference. This design has the benefit that it takes no power to hold ferrofluid still and only requires one single permanent magnet. Control signals are used efficiently in this design since only three PWM signals and three direction signals are needed for the motors. These benefits come at the cost of more moving parts and a more complicated physical design. This will lead to more potential points of failure and difficulty during manufacture. From a displaying perspective, this design can only have one piece of ferrofluid move at a time, decreasing the variety of display patterns possible.

The final design chosen was a hybrid design of the above two systems: a linear actuator provides vertical motion to a central platform, where one single electromagnet stack resides to provide rotational motion. This design allows the movement of multiple portions of ferrofluid at the same time without an overly complicated mechanical setup. Control signal usage of this design is more than that of the design in Figure 2.2, but less than that of the design in Figure 2.1. Although this design cannot hold ferrofluid still without consuming power, it is not an essential objective for this project.

2.2.2 Processing Module

The most important decision regarding the processing module was the issue of the microprocessor not having enough PWM pins to control all eight electromagnets and the motor, since most low-priced microcontrollers do not have over six PWM output pins.

The first proposed solution for the problem was two use two cheaper microcontrollers in a master slave configuration and gain access to the PWM switches pins of a second microcontroller. This proposition was quickly discarded since the lag introduced by communication interfaces between the microcontrollers will make it difficult to synchronize eight electromagnets that are controlled by two different microcontrollers.

A second way of getting around the PWM pin limitation was utilizing external 12C interfaced PWM controller chips such as the PCA9685. While this is a good way being able to control all PWM devices with only the SCL and SDA pins, this solution does not avoid the problem of communication delay whenever the magnitudes to the electromagnet module is changed. This introduces unpredictable delays for each electromagnet driver call and may cause difficulties with the synchronization of different modules during ferrofluid display.

The design that was eventually settled on was to use four PWM pins to control eight electromagnets with four more selection pins to select between the activated electromagnet in a PWM shared pair. This limited the variety of displayable patterns, but with the specific pairing shown in section 2.2.2, a large amount of display possibilities can be achieved without apparent drawbacks.

2.2.3 LED Module

Early designs took into consideration the limited resource of output pins and utilized two eight bit shift register in series to to provide a serial in parallel out interface that only used two pins from the microcontroller to control any sixteen LEDs. The outputs of the shift registers would be ANDed with a PWM signal to control the entire brightness of the LED array. This posed limitations such that the LED array had to be of one singular brightness level at a time, and individual LEDs could only be toggled on or off. Also, additional AND gates and MOSFETs needed to be integrated in the PCB for this design to work.
After more thorough evaluation, it was decided to utilize high powered shift registers to directly power the LEDs and implement the PWM in software. Although different portions of code in software will make it difficult to implement a perfect PWM simulation easily, a rough PWM simulation is acceptable since small variations in PWM duty cycles will only produce a small difference in brightness that will be hard to perceive. Because this design could easily control individual brightness and in turn enable more LED patterns, it was adopted in final design consideration.

2.3 Design Details

2.3.1 Processing Module

The Processing Module utilizes an ATMega328 chip as the microcontroller.
0 - 4MHz@1.8 - 5.5V, 0 - 10MHz@2.7 - 5.5.V, 0 - 20MHz @ 4.5 - 5.5V

Microcontroller	ATmega328
CPU Speed	20 MIPS
Digital I/O pins	14 (6 PWM)

Analog I/O pins	8

Table 1: ATmega328 Specs [2]

This chip was chosen due to its high CPU throughput and abundance of PWM pins for our design as shown in Table 1. The analog pins on the processor provide opportunities to utilize audio signals passed in through the audio jack.

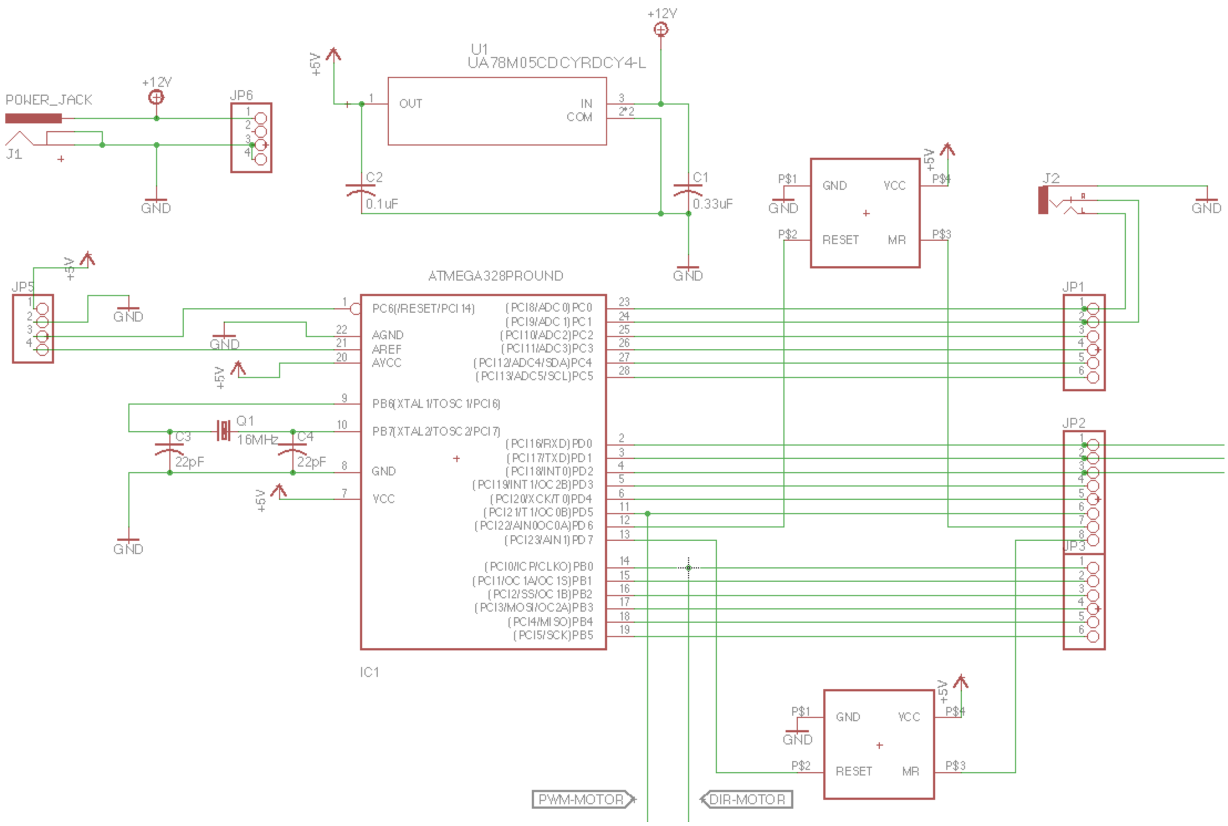

Figure 3.1: Processing Module Schematic

Shown in Figure 3.1 is the schematic for the control module. Designs for the 16 MHz crystal oscillator are from the recommendations of the ATMega328 datasheet [2].

The Voltage regulator used is the UA78M05CDCYR, with a 0.5 Amp maximum current at 5V [3]. Buffer circuit is also designed referencing the datasheet of the UA78M05CDCYR.

Due to the Mechanical Movement Module requiring position switches for the software to calibrate vertical zero, reset circuits (MAX6381 [4]) with timeouts are used as debouncers to ensure the software acts correctly when the central platform reaches the top and bottom.

The software audio pass-through interface provides users with the ability to interact with the ferrofluid by modifying the magnetic field intensities around it. The basic idea is that a list of different types of music is programmed ahead into the interface. Since each type of music has its own frequency, the interface would extract these different frequencies and map each of them into a unique pattern that could generate different magnetic field intensities around the ferrofluid. However, due to the high complexity and limited amount of time for this project, we had to abort this functionality and incorporate it in future improvements.

2.3.2 Magnet Module

Inputs:

PWM signals from the microcontroller.
Select signals from the microcontroller.

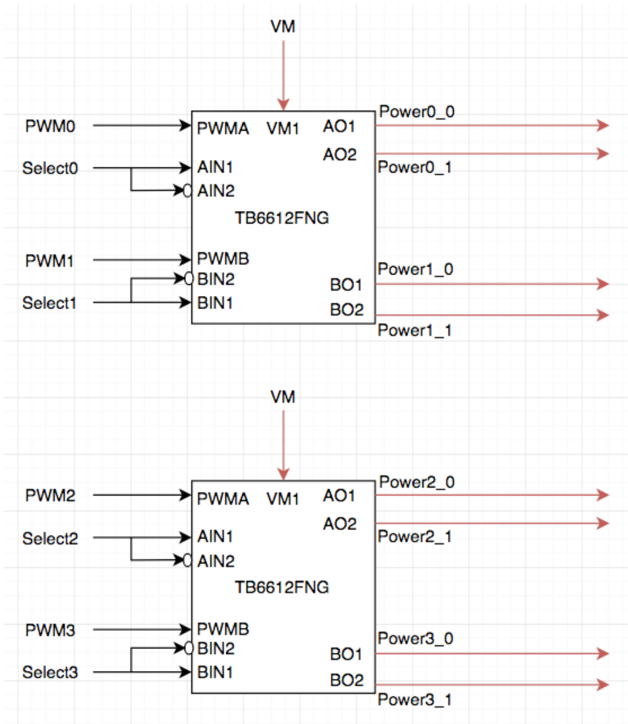

Figure 4.1: Electromagnet Control

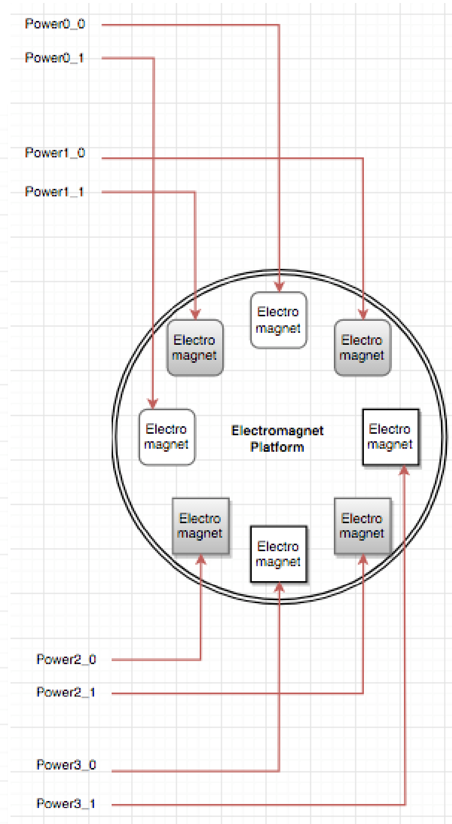

Figure 4.2: Electromagnet Layout

As shown in Figure 4.1, the electromagnets are controlled by the PWM and selection signals from the Processing Module via the H-bridge chip TB6612FNG [5]. The TB6612FNG chip has two H-bridges per chip and each H-bridge can control two electromagnets.

In Figure 4.2, the specific layout of the shared PWM pairs are shown. Electromagnets represented in the same color and same shape share a PWM signal and thus cannot both be active at a given time. In this configuration, effects such as one ferrofluid piece rotating and two ferrofluid pieces rotating on opposite sides can be achieved. The pre-defined pattern upon demonstration of this project is for a single piece of ferrofluid to rotate in a clockwise manner. Specifics of how this is achieved is discussed in detail in Appendix C.

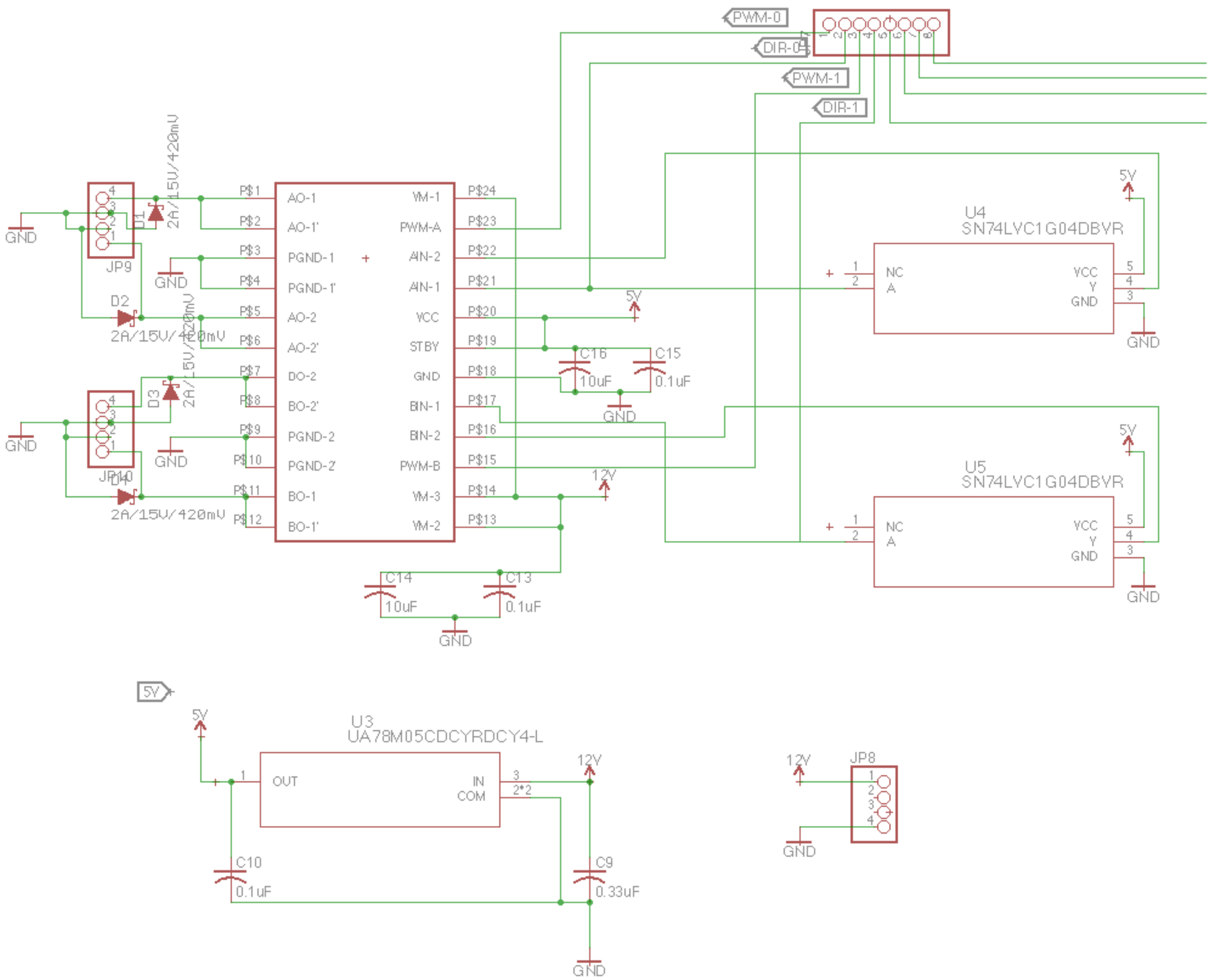

Figure 4.3: Electromagnet Control Schematic (Half)

Figure 4.3 shows the connections for one of the TB6612FNG chips. Inverters are integrated to the PCB to save microcontroller output pins and Diodes are used to prevent back-EMF when abrupt changes in electromagnet intensities occur.

2.3.3 Mechanical Movement Module

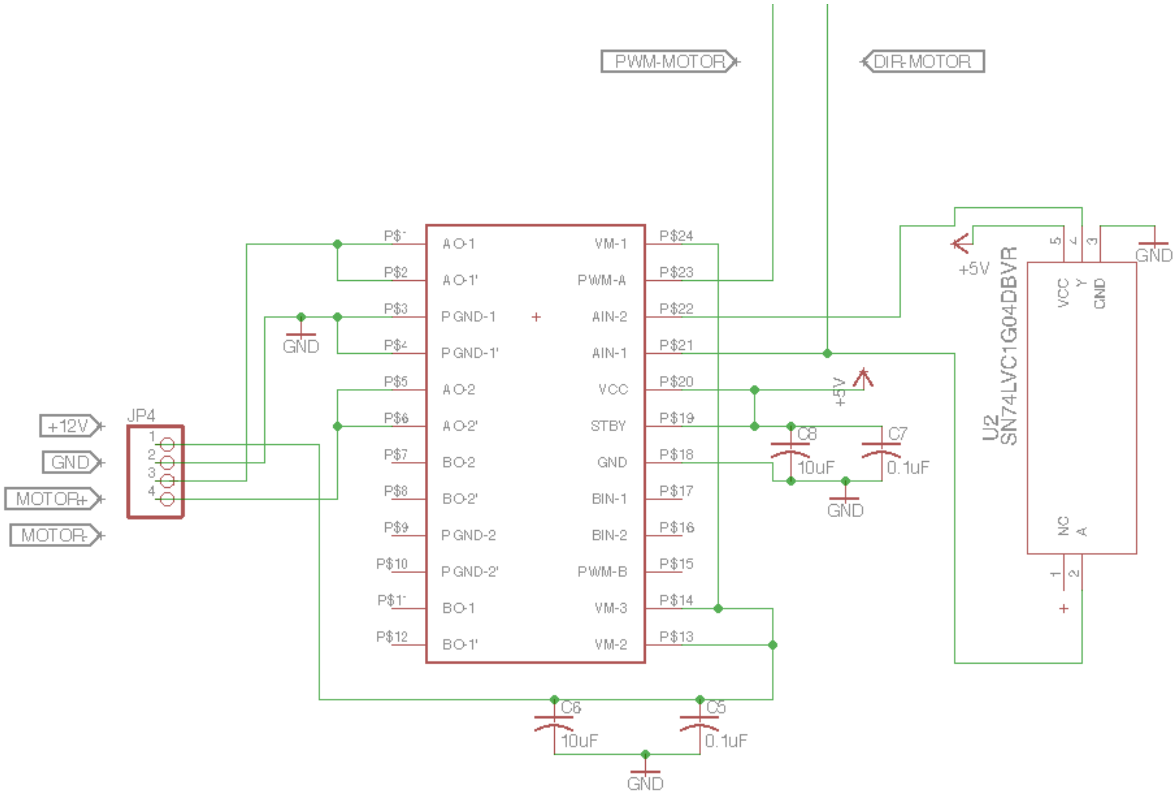

Figure 5.1 Motor Control Schematic

The Mechanical Movement Module control logic uses the same H-bridge chip as the electromagnet control logic. However, since the motor needs to spin in both directions, the circuit is connected slightly differently in such a way that AO-1 is connected to the positive terminal of the motor and AO-2 is connected to the negative terminal of the motor.

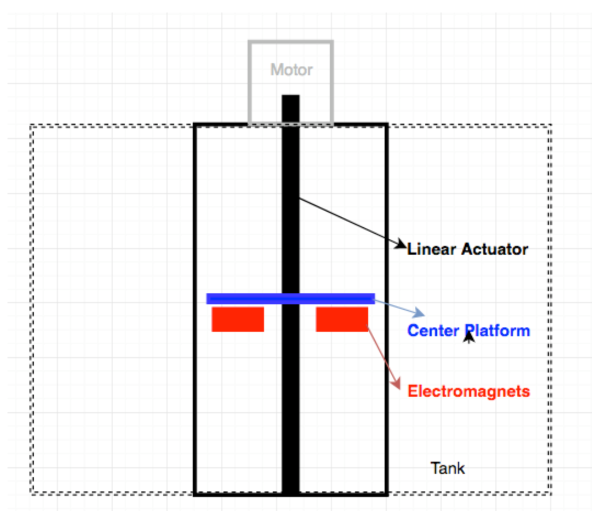

Figure 5.2: Mechanical Movement Module Diagram

Figure 5.2 shows how the Mechanical Movement Module provides vertical motion to the ferrofluid. The Motor drives the linear actuator, which in turn moves the center platform up and down. With the electromagnets active, this moves the ferrofluid vertically.

Both the pre-defined pattern and the interface for users to define their own pattern are achieved in software. A code snippet is provided in Appendix B. The software interface of the Mechanical Movement Module takes speed/direction/time as inputs from users, and outputs speed/direction/time outputs for the microcontroller. The linear actuator has five different speed levels: 50 (slowest), 100, 150, 200, and 250 (fastest). It also has two directions: 1 (up) and 0 (down). Essentially if no user input is provided, then the linear actuator will move following the pre-defined pattern, which is as follows:
1) move up with speed 50 for 10 seconds until it hits the top switch
2) move down with speed 250 for 5 seconds
3) move up with speed 50 for 1 second
4) move down with speed 100 for 2 seconds
5) move up with speed 150 for 3 seconds
6) move down with speed 200 for 4 seconds
7) when it hits the bottom switch, move up with speed 250 for 5 seconds
If users want to set up their own motor pattern, they need to specify and provide with the speed, direction, and time variables to the setPattern() interface, which will then change the behavior of the linear actuator based on the specified user input.

2.3.4 LED Module

The lighting effect is an add-on feature that provides users with lighting. The LED module controls the 9 LEDs and allows users to adjust the on/off pattern of each LED and the intensity of the whole LED grid. The important tradeoff and decision making are already discussed in section 2.2.3, and we will discuss the software interface that provides users with the ability to set their own LED pattern and intensity. A code snippet of the interface is provided in Appendix B. The interface takes a 1-D array[9] with 1(on) or 0(off) state for each LED and an Intensity value for the whole LED grid. If no user input is provided, then the whole grid of LED will blink every 1 second. If users specify the specific LED pattern they want to blink and an intensity, the resulting LEDs will then blink as user-defined pattern with user-defined intensity.

2.3.5 Ferrofluid and Suspension Liquid

Both the ferrofluid and suspension liquid for the ferrofluid are important, because they determine the force that is needed to move the ferrofluid as well as whether the ferrofluid sticks to the walls of the tank. After communicating with last semester's group 32 members [6], we found that EFH-1 ferrofluid was a good choice to use for display and a mixture of water and isopropyl alcohol constituted a good suspension liquid.

To test how much the ferrofluid sticks to a glass container, we designed the following experiment. For different ABV (alcohol by volume) concentrations of carrier liquid, five milliliters of EFH-1 ferrofluid were added. After the ferrofluid dropped to the bottom of the glass container, the container was tilted to a thirty-degree downward incline for the ferrofluid to slide along the side of the glass container. After the ferrofluid slid to the top of the glass container, the stickiness, which is defined as the ratio of the length of the side of the glass container that is not clear of ferrofluid to the total length of the side of the glass container. Tests for each alcohol concentration were done five times and averaged. The results are shown in Figure 6.

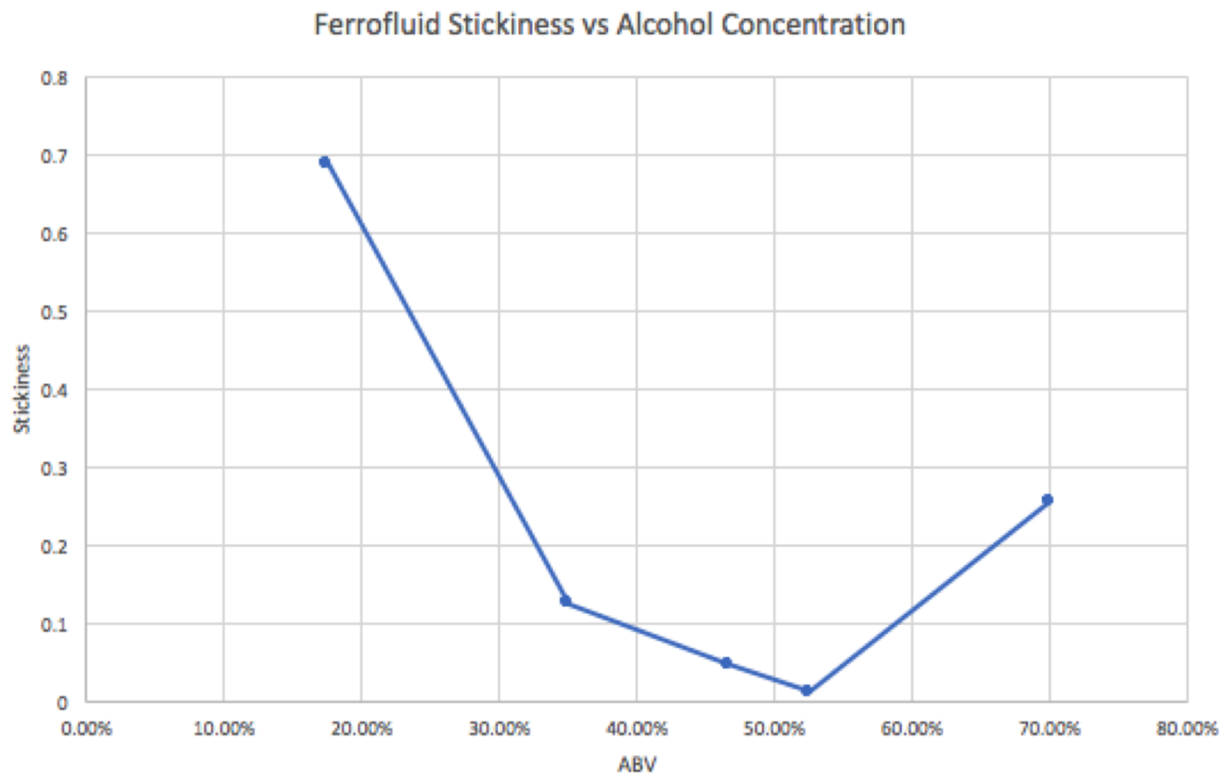
Ferrofluid Stickiness vs Alcohol Concentration
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Stickiness
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
ABV

Figure 6

3. Costs

3.1 Labor Cost

Total labor cost for each member = hourly rate * hours spent * 2.5

Name	Hourly rate($)	Total hours(hrs)	Total($)
Chen Huang	30	200	15,000
Chong Lu	30	200	15,000
			30,000

Fig. 3-1. Labor Cost

3.2 Parts Cost

Part	Manufacturer	Retail Price ($)	Quantity	Total ($)
ATmega328	ATmel	1.90	1	1.90
UA78M05CDCYR	Texas Instruments	0.62	2	1.24
MAX6381	Maxim Integrated	2.40	2	4.80
Linear actuator	SCIPLUS	24.50	1	24.50
Nut	SCIPLUS	5.07	1	5.07
EFH-1 ferrofluid (50ml)	Innovating Science	33.62	1	33.62
Isopropyl alcohol(16oz)	First Aid Only	3.80	2	7.60
TB6612FNG	Toshiba	2.11	3	6.33
TPIC6B595N	Texas Instruments	1.65	2	3.30
Audio Jack	AmazonBasics	4.99	1	4.99
24 AWG Copper Wire	Small Parts	20.00	1	20.00
Power Supply	CanaKit	8.89	1	8.89
High Power LED(20pc)	Unbranded	8.85	1	8.85
PCB Manufacture(5pc)	Advanced Circuits	5.00	1	5.00
				136.09

3.3 Total Cost

Labor Cost($)	30,000
Parts Cost($)	136.09
Total Cost($)	30,136.09

4 Conclusion

4.1 Accomplishments

We have achieved all of the designed functionalities of the dynamic ferrofluid lamp, except for the audio pass-through. If user input is specified, the ferrofluid could be automatically manipulated both vertically and horizontally based on the user-defined pattern; if no user input is provided, the ferrofluid could be automatically manipulated based on the pre-defined pattern. Also, users are able to provide input as a 1-D array and intensity level for the LED grid, thus achieving adjustable lighting effects.

However, due to the complexity of audio pass-through, we had to postpone it into future design refinement. Also, combined horizontal and vertical pattern for ferrofluid manipulation was not synchronized. Therefore, the ferrofluid could move either horizontally or vertically at a given time, but could not achieve these two dimensions simultaneously.

4.2 Uncertainties

The biggest uncertainty associated with our project is whether the ferrofluid could be pulled up when the device starts to run. Because the ferrofluid is depositing at the very bottom of the container, the central platform must be low enough in position to pull up the depositing ferrofluid. Otherwise, only the motor moves up and down with different speeds with no ferrofluid being pulled up and down. Nevertheless, users are able to reset the central platform to its bottom position by moving the linear actuator down before each run.

4.3 Ethical Considerations

Because ferrofluid is a relatively new area when related to aesthetics, it still has a lot to be explored. During our experiment with the ferrofluid, we will follow closely to the IEEE Code of Ethics, #3, “to be honest and realistic in stating claims or estimates based on available data.” [7] We will not include any unrealistic data or result in our report to make it look good or persuasive, we will be honest and respectful to the data we have acquired even if it is not perfect.

We choose ferrofluid-related field as our primary research project because we are interested and want to dive deeper into it. Thus, we will closely follow the IEEE Code of Ethics, #5, “to improve the understanding of technology; its appropriate application, and potential consequences,” [7] as we work along with our project. Our intention is to understand more about the properties of ferrofluid and how it can be applied in real industry to further contribute to our society.

Although our ferrofluid lamp is a product of aesthetics, it unavoidably comes with several potential safety hazards. The first safety issue comes with the nature of the ferrofluid. Because ferrofluid itself is dangerous to manipulate with depending on its type, we will only select safe ferrofluid to play and test with. We will gather reliable information about various ferrofluids from different sources, narrow down to the one that is relatively safe in its nature, and investigate it carefully throughout the entire project.

Another important safety issue comes with the fact that we are experimenting with the current and water/alcohol combination. The maximum possible current passing through the wires could potentially reach ~2.25 Amps, which is already lethal to humans under certain conditions. Worst of all, if the inner cylinder breaks, the liquid might leak into it, resulting the wires to be exposed to water/alcohol. This is dangerous because of the potential electric shock it could cause to humans and the flammable nature when current encounters alcohol. Therefore, we would have to be extremely careful when testing our experimental setup. We understand the safety issues associated with our project, thus promise that we will only be testing in a watertight non-conducting box, and potentially wear non-conducting gloves to eliminate the risk as much as possible. Most importantly, we will have an instructor and another TA approved before plugging in our physical device. We will not bring any parts of the device home, and will only experiment under a TA's supervision in senior design lab.

4.4 Future Work

As mentioned in the Achievements section, the first improvement we would like to make is to incorporate the audio pass-through functionality into the dynamic ferrofluid lamp. This provides users with the ability to interact with the ferrofluid by allowing them to modify the magnetic field strengths based on frequencies of different types of music.

Another enhancement we could potentially do is to better synchronize the horizontal and vertical dimensions of motion, such that the ferrofluid can be pulled up and rotated simultaneously. This can be done by making stronger electromagnets and arrange them more compactly to minimize the switch time between adjacent electromagnets. However, this approach might further increase the amount of current passing through the electromagnets, and needs to be performed very carefully.

References

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Acknowledgements

[1] Luke A. Wendt, ECE 445 Teaching Assistant, Electrical and Computer Engineering

[2] Scott A. McDonald, Electrical and Computer Engineering Machine Shop, 1049 ECE Building

Appendix A Requirements & Verification Table

Requirement	Verification	Points assigned
At any given time, under 12V, the total current going through all electromagnets must be within 2.25A	Use multimeter to monitor the real-time current at any given time to make sure the current does not exceed the threshold	5
The ferrofluid/suspension liquid ratio is good enough such that the ferrofluid does not stick to the walls	Monitor closely the ferrofluid and its state to make sure that it does not stick to the walls	10
The inner cylinder must be watertight and non-conducting	1. Look inside through the outer cylinder. If any apparent gap or crack is detected, abort the experiment and report to an instructor/TA immediately 2. If no visual crack is detected, fill in the ferrofluid and suspension liquid	0
The 9 LEDs must be able to blink every 1s following the specific pattern users have assigned	Monitor the LEDs and they should blink based on the user-defined pattern	5
The top and bottom position switches must be de-bounced, and upon pressed, must change the direction of the linear actuator	1. Let the linear actuator move following its pre-defined pattern, it should first hit the top switch then bottom switch 2. Monitor the behavior of the linear actuator when the central platform hits both switches	5
The linear actuator must be able to move towards different directions at different speeds for different amounts of time. If no pattern is assigned by users, the linear actuator must move following the pre-defined pattern; otherwise, the linear actuator must move following the user-specific pattern	1. Start the device and let it run following the pre-defined pattern 2. Input a user-specific pattern, and monitor the linear actuator to make sure it behaves as the pattern specifies	10

The on-off state/duty cycle of each electromagnet must be controlled by the PWM signals from the microcontroller, such that the ferrofluid is driven in a clockwise motion	Look closely at the movement of the ferrofluid, which should be driven in a clockwise direction	10
Cable management: the cables must not mix up with the linear actuator, and must not obstruct the functionality of top and bottom position switches	Closely monitor the cables in the inner cylinder, and make sure the functionality of the top and bottom switches is correct	5

Appendix B   Code to drive LEDs, Motor, and Electromagnets

LED Driver Interface

```
/**
    LED Interface
    Input:
        int array[]: array[9] with 1(on)/0(off) for each LED
        int intensity: intensity for the whole LED grid
    Output:
        On/off state and intensity outputs for microcontroller
**/
struct ledDriver {
  int pattern[NUM_LED];
  int pwm;
  ledDriver() {
    pattern[0] = 1;
    pattern[1] = 1;
    pattern[2] = 1;
    pattern[3] = 1;
    pattern[4] = 1;
    pattern[5] = 1;
    pattern[6] = 1;
    pattern[7] = 1;
    pattern[8] = 1;
    pwm = 0;
  }
  void setPattern(int array[]) {
    for(int i=0;i<NUM_LED;i++)
      pattern[i] = array[i];
  }
  int setIntensity(int intensity) {
    pwm = intensity;
    analogWrite(LED_PWM, pwm);
  }
};
struct ledDriver ledControl;
```

Motor Driver Interface

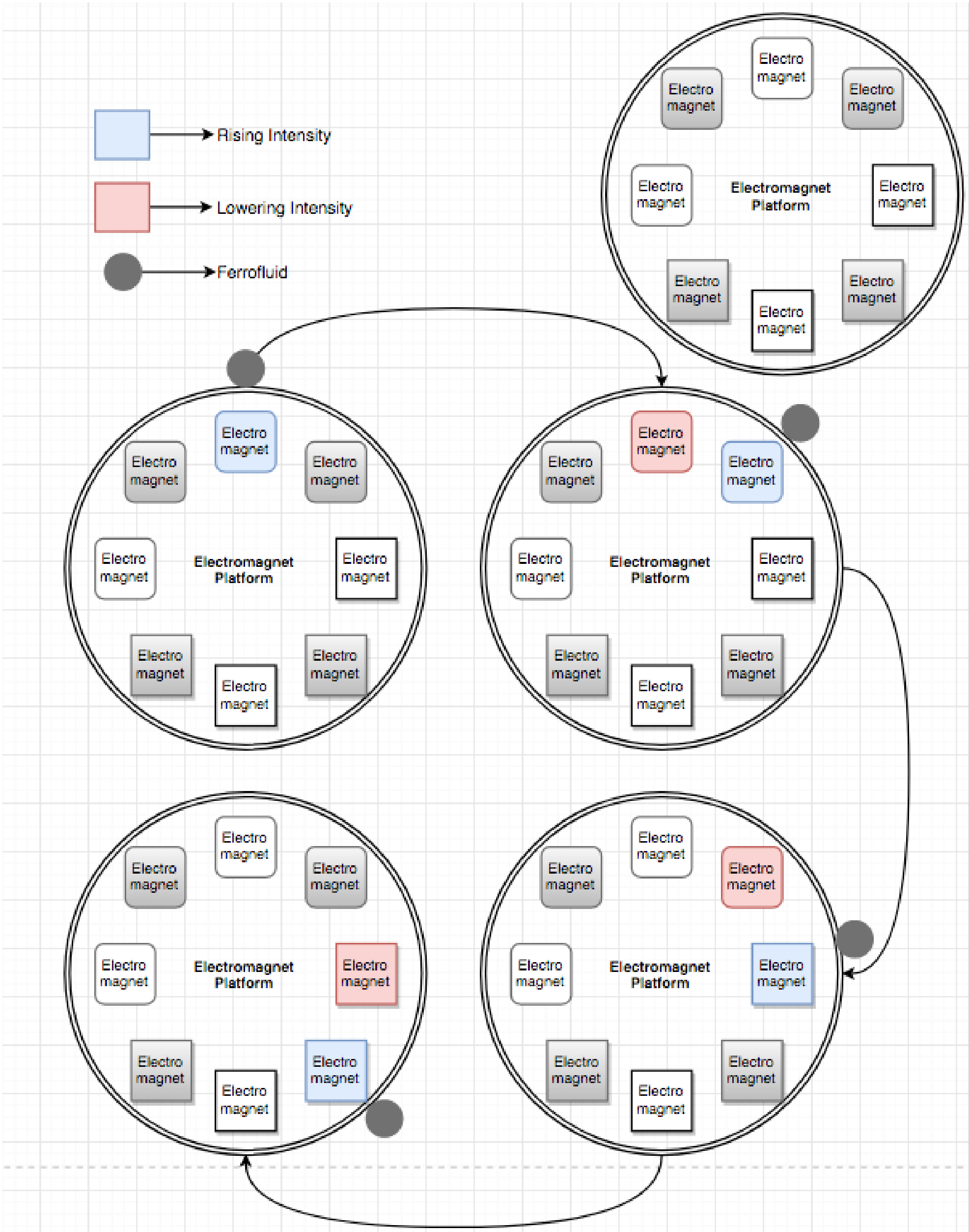
```
/**
    Motor Interface
    Input:
        int s: speed of the motor
        int d: direction of the motor
               clockwise = 0 = down/counterclocksiwe = 1 = up
        int t: how many seconds the linear actuator move up/down
        set to -1 if no change
    Output:
        Speed & direction & time outputs for microcontroller
**/
struct motorDriver {
  int pwm;
  int dir;
  int tim;
  //initialization (127, 1, 10)
  motorDriver() {
    pwm = 127;
    dir = 1;
    analogWrite(MOTOR_PWM, pwm);
    digitalWrite(DIRECTION, dir);
    globalmotorflag[0] = 1;
    }
  void setPattern(int s, int d, int t) {
    if(s != -1)
      pwm = s;
    if(d != -1)
      dir = d;
    if(t != -1)
      tim = t;

    analogWrite(MOTOR_PWM, pwm);
    digitalWrite(DIRECTION, dir);
  }
};
struct motorDriver motorControl;
```

Electromagnet Pattern

There is not an explicit interface dedicated to modify the magnetic field strengths of the eight electromagnets, but below is part of the code to set up the pattern for each of the eight electromagnets.

```
void em_pattern1() {
  if(initialemflag == 1) {
    globalemtime = millis();
    initialemflag = 0;
    globalemflag[0] = 1;
  }

  if(globalemflag[0] == 1)
  {
    if(millis() - globalemtime >= EM_INTERVAL) {
      digitalWrite(A0, 0);
      analogWrite(EM0_PWM, 50);

      globalemtime = millis();
      globalemflag[0] == 0;
      globalemflag[1] = 1;
    }
  }

  if(globalemflag[1] == 1)
  {
    if(millis() - globalemtime >= EM_INTERVAL) {
      digitalWrite(A1, 0);
      analogWrite(EM0_PWM, 25);
      analogWrite(EM1_PWM, 50);

      globalemtime = millis();
      globalemflag[1] == 0;
      globalemflag[2] = 1;
    }
  }

  if(globalemflag[2] == 1)
  {
    if(millis() - globalemtime >= EM_INTERVAL) {
      digitalWrite(A3, 1);
      analogWrite(EM0_PWM, 0);
      analogWrite(EM1_PWM, 25);
      analogWrite(EM3_PWM, 50);

      globalemtime = millis();
      globalemflag[2] == 0;
      globalemflag[3] = 1;
    }
```

Appendix C Example Electromagnet Display Capability



Ferrofluid moving in a clockwise manner

The pre-defined pattern upon demonstration of the project is for a single ferrofluid piece to rotate in a clockwise manner, which is achieved in software. A code snippet is also provided in the Electromagnet Pattern section in Appendix B. To achieve this effect, the electromagnet in blue in top left piece of the graph is turned on at time t0, which will pull the ferrofluid up at the very beginning; at t1, the electromagnet in blue in top right is turned on and the electromagnet in red reduces to half of its original intensity. This shifts the ferrofluid rightward; at t2, the electromagnet in blue in bottom right is turned on, the electromagnet in red reduces to half of its intensity, and the red one in top right is completely shut down. This continues to drive the ferrofluid rightward, but prevents the current from being too high. This pattern continues until the ferrofluid is rotated back to its original position in top left piece.