Project Proposal for Senior Design Project ECE 445

Programmable Ferrofluid Display

Team 45 — Bradley Anderson, Hao-Jen Chien, and Thomas Coyle
Teaching Assistant: Luke Wendt
February 8th, 2017 (spring)

I. Introduction

1.1 Objectives

We propose to build a lower cost programmable ferrofluid display than is currently available. We would be building upon the work of the team which worked on a similar project last semester in order to make a more feature-filled device. The previous group's project used an array of permanent magnets which moved by electromagnets along tubes to manipulate the magnetic fluid. Instead, we propose to build a device with at least a 5x5 grid of permanent magnets attached to small servos. These will function as pixels, and will be able to hold ferrofluid in place over them.

We would also like to add a layer of IR sensors in an array between the magnets and the fluid. We can then use these sensors to return information about fluid distribution within the display. This will allow software controlling the display to more accurately maneuver the ferrofluid.

All of the magnets and sensors would be wired into a microcontroller, which will have an IO port for control from a computer. The microcontroller will provide an API for the computer to interact with the display, which will include functions for enabling/disabling individual magnets, returning whether individual sensors are covered by ferrofluid, and moving ferrofluid to any pixel on the display.

1.2 Background

Ferrofluid is a type of liquid that, when in the presence of a magnetic field, becomes strongly magnetized. Invented by Steve Papell of NASA in 1963, it was first incepted as a liquid rocket fuel. The idea was to draw the fluid towards a pump inlet by applying a magnetic field in a weightless environment. Ferrofluid is considered a colloidal liquid composed of nanoscale ferromagnetic particles suspended in a carrier fluid (mainly water or some organic solvent). Each particle has a surfactant coat that disfavors clumping. Strong clumps of magnetic dust, however, can be created when a strong enough magnetic field is introduced. [1]

Our idea for a programmable project was greatly inspired by the Ferrolic display. Ferrolic is a high-end ferrofluid display that seeks to connect digital screens and tangible reality into a beautiful magnetic painting. It functions by utilizing a basin that allows ferrofluid to be manipulated freely. Behind this aquarium, strong electromagnets control the shape of fluid. Ferrolic is controlled in software by an internal system that is web-browser accessible. This allows users to create unique animations through the display. As for its characteristics, Ferrolic is completely silent and produces zero light. Its best qualities are represented through time and text displays. Currently, Ferrolic is in ongoing development and is projected to be quite expensive. [3] Ferroflow is another ferrofluid display but operates on a much simpler scale. [2]

Another area of inspiration was from a past ECE 445 group that worked with ferrofluid in which they attempted to create a ferrofluid clock. Some noted information is discussed above in the Objectives. Ultimately, they utilized electromagnets to manipulate an array of permanent magnets, thus allowing movement of the ferrofluid. So far, their extensive reports have given us vital information on how to approach our project and will likely provide more insight in the future.

1.3 High-level requirements list

The following is a list quantitative characteristics that this project must exhibit to be considered successful.

- The project must be able to respond to computer input to move ferrofluid to any pixel on the display within 5 seconds of receiving the command
- The project must be able to accurately return whether ferrofluid is positioned over any pixel on the display to a computer upon request with at least 90% accuracy.
- The project must be able to operate with at least 12 of the display's 25 pixels active (holding ferrofluid) at once (48%)

II. Design

2.1 Block Diagram

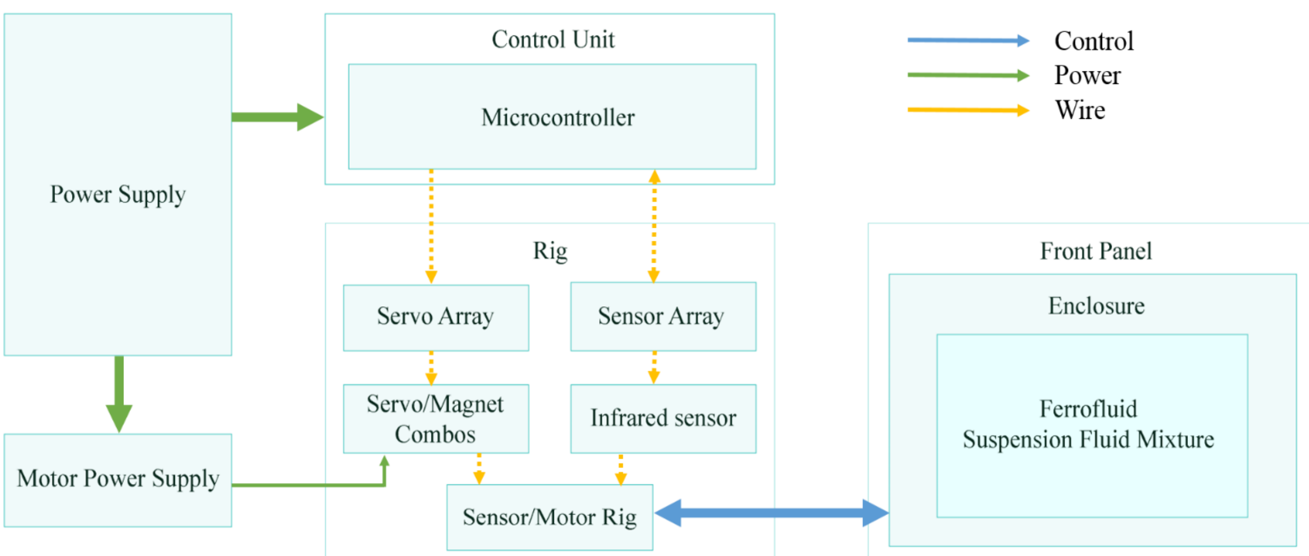

Figure 1 Block diagram of design

The design consists of a liquid display of a mixture of ferrofluid and a suspension fluid, contained within a clear enclosure. Behind this is our Sensor/Motor Rig, which contains all our infrared sensors and permanent magnets attached to servos, each arranged in an even grid. This rig is controlled by our microcontroller, which receives information from the sensors. It also moves the magnets closer and farther from the display using the servos, which will from now on be referred to as enabling and disabling magnets. The microcontroller is powered by a power supply which also supplies power to the servo array through a current-limiting circuit. The microcontroller has an I/O port for control from a computer. Upon receipt of a command from the computer to turn a pixel on, the micro-controller will enable and disable magnets in order to move ferrofluid to the pixel, and will disable the pixel's magnet when instructed to turn the pixel off. We will optimize the spacing and strength of our magnets to maximize the rate at which we can move the ferrofluid into position. The microcontroller will also respond to queries from the computer about the state of a pixel by returning whether the infrared sensor at that pixel detects an amount of reflected infrared light above a threshold value or not. This will be calibrated to ensure that the display maintains at least 90% accuracy with these readings. Finally, the display will include a large enough amount of ferrofluid in the enclosure to ensure that there is enough ferrofluid to allow for at least 12 of the pixels to be active at once.

2.2 Physical Design

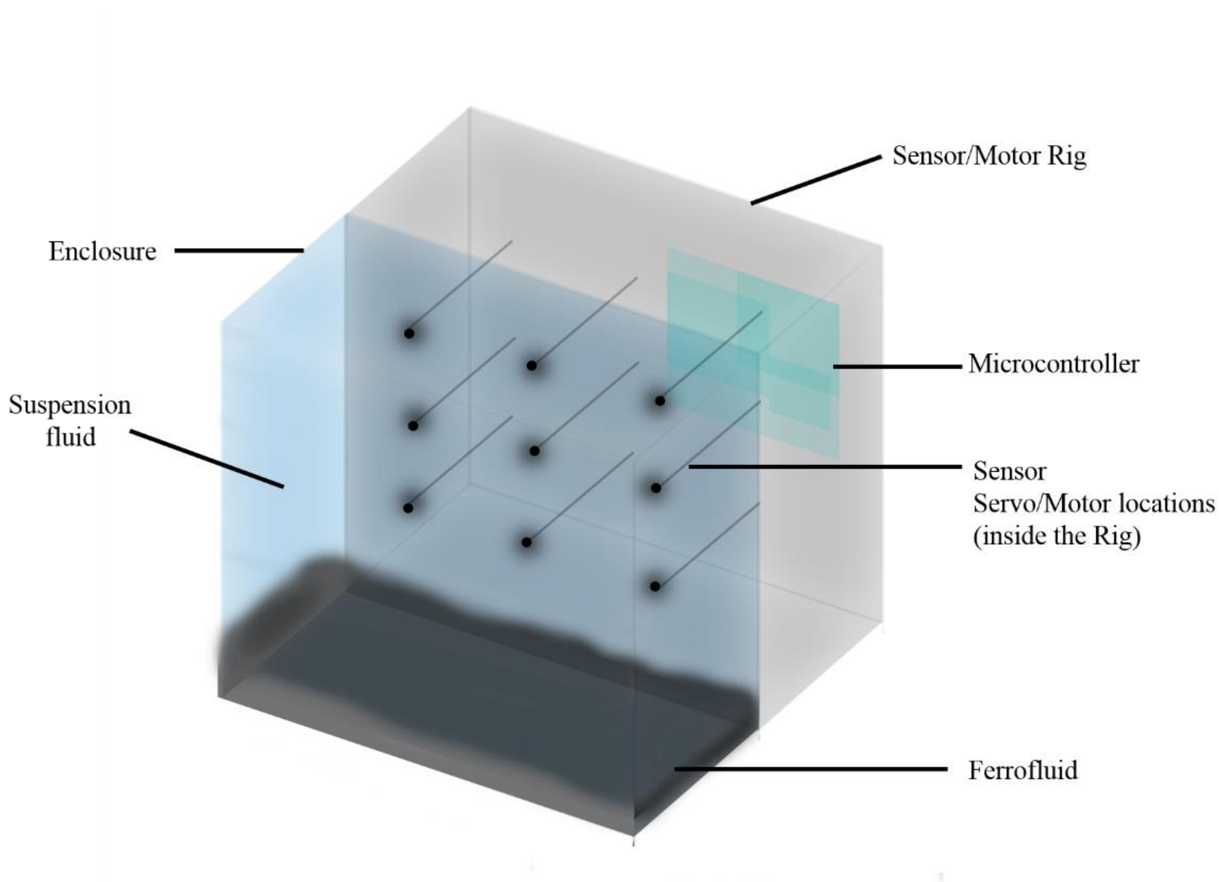

Figure 2 Physical diagram of display

As Fig. 2 shows, our project will consist of two distinct interconnected sections: the enclosure and the sensor/motor rig. The two parts include the programmable liquid (ferrofluid and suspension fluid) and the hardware (sensors, servos, and magnets), respectively. The servo array, sensor array, and microcontroller will be mounted behind the sensor/motor rig and are not included in the diagram.

2.3 Functional Overview

2.3.1 Power Unit

Power Supply
The PSU provides continuous and steady power to the device. It will convert 110V AC from a standard wall socket to the 5-9V DC required by the microcontroller. The PSU will also provide the DC voltage used to power the servos through the motor power supply.

Motor Power Supply
The motor power supply is a circuit designed to provide a consistent, appropriate voltage and current to each of the servos. It receives power from the main power supply and converts it to power suitable for supplying the servos.

2.3.2 Control Unit

Microcontroller
The microcontroller is the brains of the display. It will run a software program that manages the display state and provides a high-level API to a computer. This can be plugged into the microcontroller through an I/O port and allow for drawing to the display. The microcontroller will be able to query the state of the 25 sensors and set the state of the 25 servos through a set of pins. It will be able to interpret values returned from the IR sensors as either covered or uncovered by comparing the read value to that of a decided threshold. The microcontroller will also move ferrofluid to any pixel on display by enabling/disabling magnets along a path while querying sensor data to determine the liquid's location. Lastly, the controller will be wired into the servo and sensor arrays and will be powered by the power supply.

2.3.3 Rig Unit

Infrared Sensors
The infrared sensors provide the microcontroller with information of the display state. There will be 25 infrared sensors to be mounted at the sensor/motor rig. The devices emit IR light beams into the enclosure. If ferrofluid is suspended in front of the sensor, light will be uniquely reflected and an amount can measured at its output. These outputs of the IR sensors can be queried by the microcontroller through the sensor array to which each is connected. This will allow the microcontroller to determine ferrofluid position is in the display: necessary information for allowing the microcontroller to properly move the liquid.

Servo/Magnet Combos
The servo/magnet combos serve as the individual components the microcontroller will control in order to manipulate the enclosed ferrofluid. There will be 25 mounted to the sensor/motor rig, and they are each composed of a single magnet attached to the arm of a servo. The servo will toggle the rotation of the arm between 0o and 180o, with 0o defining the magnet away from the display and 180o defining the magnet close to the display. These will be wired into the servo array.

Sensor Array
The sensor array describes the interface between the microcontroller and the IR sensors. It acts as a multiplexer, allowing the microcontroller to address individual sensors for output access without the necessity of a separate pin for each sensor. This will greatly reduce the complexity of our project. The component will receive five pins of input from the microcontroller and will return one pin of analog output to the microcontroller. The input

pins will be used for addressing each of the 25 sensors, and the output pin will return the infrared value read by the addressed sensor to the microcontroller. The servo array will then handle enabling and disabling the servos which will each be wired into it.

Servo Array
The servo array is the interface between the servos and the microcontroller. It acts as a multiplexer, allowing the microcontroller to address individual servos for enabling/disabling without the need for separate pins. This will greatly reduce the complexity of our project. The component will receive six pins of input from the microcontroller: five of which will be used for addressing each of the 25 servos and the remaining will be utilized for setting the state of the addressed servo. The array will then enable and disable the servos wired into it.

Sensor/Motor Rig
The sensor/motor rig is a static, fabricated rig upon which the servos and sensors will be mounted. It will provide mounting points with which the components are attached. This rig will be connected to the enclosure and will ensure that the components do not move relative to one another or the enclosure.

2.3.4 Display Unit

Enclosure
The enclosure contains the ferrofluid and suspension mixture. It is a clear, waterproof tank with a removable but sealed lid, with a silicon sheet in the back. The purpose of the silicon sheet is to provide an aesthetically pleasing background to the display. We will use silicon because it is opaque to light in the visible spectrum, but transparent to light in the infrared spectrum so it will not interfere with our infrared sensors. The enclosure will be attached to the front of the sensor/motor rig.

Ferrofluid
The ferrofluid is the medium with which our project will manipulate to form images on display. It is a black, magnetic fluid which we will manipulate through the enclosure by shifting permanent magnets. It will be contained within a suspension mixture. This mixture will be a transparent liquid that will allow the ferrofluid to freely traverse through the enclosure. This liquid must be of similar density to the ferrofluid.

Suspension Mixture
The suspension mixture is a transparent liquid which will be mixed with the ferrofluid inside the enclosure. This liquid must be of similar density to the ferrofluid. We will also need to choose a fluid which will not react in any way with the ferrofluid. We currently plan on using a mixture of alcohol and oil, since this mixture worked well for the group who did this project last semester.

2.4 Block Requirements

The table I represents the requirements of each block.

Table I Block requirements

Blocks		Requirements
Power supply		1. Must be able to supply 5-9V of DC power with adequate current to power the microcontroller, 25 servos, and 25 infrared sensors.
Motor Power Supply		1. Must be able to supply a constant voltage and current to each of the 25 servos while 2 servos are simultaneously toggling states.
Front Panel	Ferrofluid	1. Must have enough fluid in the display to allow for at least 12 of the 25 (48%) pixels to be active at once. 2. Must reflect at least 50% of infrared light received.
	Suspension Mixture	1. Cannot oxidize the ferrofluid and have chemical reaction with ferrofluid. 2. Doesn't make the ferrofluid deposit on the enclosure. 3. Transparent to IR, absorbs/reflects no more than 5% of infrared light received.
	Enclosure	1. Does not leak any liquids. 2. Cannot be magnetized to prevent manipulating the ferrofluid. 3. Transparent to IR, absorbs/reflects no more than 5% of infrared light received.
Rig	IR sensor	1. Sensitive enough to detect ferrofluid in front of sensor with 90% accuracy.
	Servo/Magnet Combos	1. Magnets must be strong enough to manipulate ferrofluid through the walls of the enclosure. 2. Servos must provide enough torque to move the magnets quickly enough to be able to move ferrofluid from the bottom of the enclosure to the top within 5 seconds.
	Sensor Array	1. Must be able to multiplex 25 inputs.
	Servo Array	2. Must be able to multiplex 25 inputs.
	Sensor/Motor Rig	1. Must provide evenly spaced mounting points for 25 servos and 25 infrared sensors.
Control Unit	Microcontroller	1. Must have at least 11 digital output pins and 1 analog input pin available to connect to servo and sensor arrays. 2. Must have I/O port for control from external computer.

2.5 Risk Analysis

The greatest risk to the successful completion of our project is clearly the servos and magnets. It is essential to our project's functionality that the magnets manipulate the ferrofluid reliably, which requires precise optimization of magnet spacing. Since we are unable to locate data sheets for most of the ceramic magnets found, physical characteristics will be difficult to calculate; therefore, we will need to experiment to determine this data. Furthermore, interactions between magnets could become problematic and increase the torque required of servos to move the magnets. This could potentially force us to use more powerful servos than initially planned, which will increase project cost as well as power consumption. We do not envision these difficulties causing serious problems as far as project completion is concerned; however, the difficulties could become quite high and will require extensive trial and error to solve.

III. Ethics and Safety

Our project has a couple components which will require special care to ensure our safety. The first of these is the liquid mixture. Ferrofluid can be messy and stains easily, but most ferrofluid can be safely handled and will not cause serious harm unless ingested. We should be mindful of what we use for the suspension mixture. Certain liquids, when mixed with ferrofluid could become toxic or react in other dangerous ways. We will need to research to make sure we use a safe material for our suspension mixture which will not interact with the ferrofluid, which is transparent, and which will not corrode the enclosure. This aligns with the #1 of the IEEE code of ethics. We want to mitigate potential harm of our project and disclose and safety or health issues that could arise from its use or misuse. [4]

Our other area of concern is the power supply. We must ensure that currents running through our circuits stay within safe levels. This is especially important since our project includes a liquid tank, which could spill onto our electronics if we are not careful. We should be able to avoid issues with this because none of our components should require high currents, and the entire display should consume very little power except when motors transition between states. Also, the liquid issue should be reduced because we plan to use a mixture of oil and alcohol for our suspension mixture, and neither of those fluids conduct electricity. Unfortunately, both of these fluids are extremely flammable, so we will need to be careful to avoid exposing our project to extreme heat.

We do not envision our project having any potential ethical issues, since it is intended solely for entertainment. Aside from the potential issue of someone removing the liquids from our display and ingesting them, or lighting the project on fire, there should be very few risks to anyone arising from our project.

Overall, our project encompasses the statement presented in the IEEE Code of Ethics, #5. We want to improve the understanding and use of ferrofluid technology. Its lack of use in the consumer industry and its often outrageous price range are factors that inspire us to better engineer the magnetic display. [4]

IV. References

[1] *Ferrofluid, Wikidepida*, 3 Feb. 2017 at 11:02, [Online].

[2] *Ferrowflow*, 3 Feb. 2017, [Online]. http://www.ferroflow.com

[3] Ferrolic.com, *'Where Digital Meets Nature'*. [Online] Available: http://www.ferrolic.com/where-digital-meets-nature. [Accessed: 2-8-2017].

[4] Ieee.org, *"IEEE IEEE Code of Ethics"*, 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 2-7- 2017].