Bachelor Project

Czech Technical University in Prague

F3

Faculty of Electrical Engineering
Department of Control Engineering

Ferrofluid display

Lukáš Pospíchal

Supervisor: Ing. Jiří Zemánek, Ph.D.
Field of study: Cybernetics and Robotics
May 2019

Acknowledgements

Primarily, I thank my supervisor, Ing. Jiří Zemánek, Ph.D., for his guidance and extreme patience. Secondly, I am thankful to all of the AA4CC team for all kinds of support and mentorship. Lastly, I owe a lot of gratitude to my friends and family, who supported my desire to pursue education, especially those with whom I share a home.

Declaration

I declare that this work is all my own work and I have cited all sources I have used in the bibliography.

Prague, May 18, 2019

Abstract

The ferrofluid display is a culmination of experimental research into ferrofluid manipulation in a liquid environment. After a short experimental period where various methods of manipulation were tested, and possible feasibility found using existing hardware, it was decided that a dedicated platform is desired. A four-month design phase followed, and eventually, the final device was prototyped and tested.

This thesis aims to document each phase of the project, and present a fully functional prototype. Eventually, it evaluates its advantages to pre-existing platforms and discusses its limitations.

The display itself is a 16×8 modular coil array with adjustable intensity of magnetic field over each coil which allows for programming of simple animations visualised with a ferrofluid submerged in a liquid.

Keywords: ferrofluid, display, electromagnet, array, manipulation, control

Supervisor: Ing. Jiří Zemánek, Ph.D.
Karlovo náměstí 13/E,
12135 Praha 2,
Czech Republic

Abstrakt

Displej s ferrofluidem je zakončením experimentálního výzkumu manipulace s ferrofluidem v kapalném prostředí. Po krátké experimentální fázi, kde byly otestovány různé metody manipulace a s užitím existujícího hardwaru byla nalezena možná proveditelnost, bylo rozhodnuto, že dedikovaná platforma je žádoucí. Následovala čtyři měsíce dlouhá fáze návrhu a nakonec byl postaven a otestován prototyp.

V této práci jsou zdokumentovány fáze tohoto projektu a finální plně funkční prototyp. Nakonec je tento displej porovnán s dosud existujícími a jsou vyšetřena jeho omezení.

Samotný displej je modulární pole elektromagnetů v 16×8 konfiguraci s nastavitelnou intenzitou magnetického pole nad každou z cívek. Toto umožňuje programování jednoduchých animací, které jsou vizualizovány ferrofluidem ponořeným v kapalině.

Klíčová slova: ferrofluid, displej, elektromagnet, pole, manipulace, řízení

Překlad názvu: Displej s Ferrofluidem

Contents

Figures

Tables

Chapter 1

Introduction

1.1 Focus

This thesis focuses on the motivation behind, experimental research necessary for, and description of the development process of a ferrofluid display visualised in Figure 1.1, internally called *MiniMag*. Subsequently, it briefly touches on the implemented and possible ferrofluid control and some of the potential for future development of the platform.

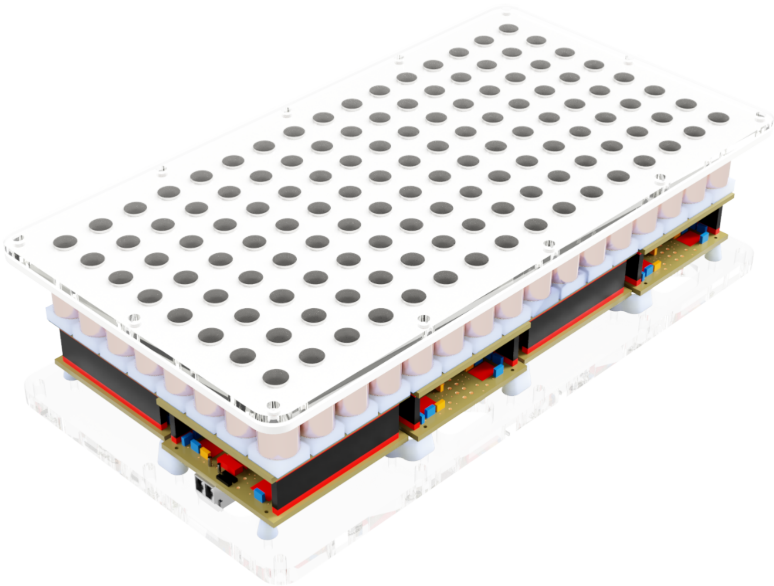


Figure 1.1: A 3D model of MiniMag

1.2 Motivation

As part of longtime research into magnetic manipulation at the Department of Control Engineering under FEE[1], CTU in Prague[2] I have been tasked by Ing. Jiří Zemánek, Ph.D. to investigate, if an electromagnetic manipulator seen in Figure 1.2, previously developed by the AA4CC[3] research team, internally called *MagMan*[1] could be used for ferrofluid manipulation. Aside from it being an assignment, the curious and captivating nature of ferrofluid and the patterns it creates when placed in a magnetic field were great motivators towards researching it and eventually designing and building a new platform.

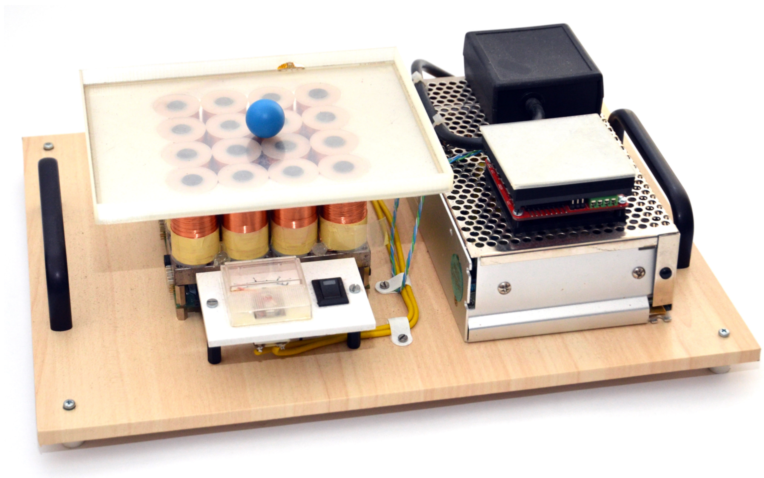


Figure 1.2: MagMan platform[4]

During my initial research, I have found a lack of existing publication regarding the topic. The primary source of inspiration was a paper by Zelf Koelman, Mark J. de Graaf and Hans J. Leeuw of the Eindhoven University of Technology[2]. Their research was heavily focused on the artistic interpretation of the movement of ferrofluid and less on the technological aspect of the construction of their display[5] shown in Figure 1.3. Given the fact that they decided to keep the platform itself private and did not publicly release any schematics or detailed information about the construction and development process and that the platform is now commercially available under the name *Ferrolic*, I can only assume, they did not intend for their project to be recreated by other parties. This motivated me to later develop a new platform, that would be designed with accessibility in mind and potentially a better performance as well.

[1] Faculty of Electrical Engineering
[2] Czech Technical University in Prague
[3] Advanced Algorithms for Control and Communications
[4] Image from [1]
[5] http://www.ferrolic.com/

Figure 1.3: Ferrolic[6]

When it came to open source projects I could build upon the most notable was Ferrobot by Lucas Zeer[4]. He documented the development process as well as gave information on the suspension liquid. The quality of the final platform was lower compared to the previously mentioned, however.

1.3 Short description

As for the MiniMag itself, it is an array of 126 coils with metal cores positioned in a 16×8 grid. The platform is divided into eight separate modules, and the voltage to each coil is applied through its dedicated H-bridge on the relative module. The communication with the modules is handled through an I^2C bus[3], and so commands can be sent to the platform from any I^2C capable device (such as RaspberryPi or similar).

The ferrofluid itself is intended to be placed in a tank on top of the coils submerged in a liquid, which can collect above the coils' cores when current passes through them and a magnetic field is generated.

[6]Image from http://www.ferrolic.com/where-digital-meets-nature/

1.4 Structure

The thesis is split into chapters that chronologically detail main stages of the development of MiniMag. The phases consist of:

- The motivation behind the project;
- Experimental findings using existing hardware;
- The PCB[7] and MiniMag design;
- Prototyping;
- Testing;
- Control schemes;

[7]Printed circuit board

Chapter 2

Ferrofluid in a liquid environment

2.1 Container and suspension

My initial attempts to recreate the solution in which the ferrofluid would float inertly did not succeed. Reasons for this included:

- Inadequate type of container;
- Lack of accessible public research on the solution in which the ferrofluid is to float - questionable sources;
- Unknown composition of ferrofluid used;
- Insufficient knowledge of chemistry.

2.1.1 Container

I started the experiments in plastic Petri dishes. This turned out to be a fatal mistake since the imperfections in the plastic surface resulted in the dish getting stained by the oily ferrofluid immediately. Once I tried using a glass container, the conditions improved drastically, and the staining was minimal, yet prevalent. The type of glass was also crucial for reasons not entirely clear to me. A food grade glass (a glass jar) fared significantly better than an ordinary glass plate used in windows. I hypothesize that a food grade glass has fewer imperfections in its surface.

Glass jars I had access to, however, did not meet my dimensional needs as they were too small to cover the whole MagMan platform. I opted to use a glass bath I constructed from ordinary glass plates joined by a silicon-based glue used for home aquariums.

2.1.2 Suspension

In some sources, the solution for the suspension liquid is a mixture of water and sugar[1]; in others, it is a mixture of water and rubbing alcohol. Lucas Zeer made a comparison video[2] of a number of these solutions which was

[1] https://www.instructables.com/id/How-to-make-a-ferrofluid-display/

[2] https://www.youtube.com/watch?v=8rbCXedGv_0

very helpful. I have tested these and many more recipes I could find, and eventually the solution that worked best with my sample of ferrofluid turned out to be a 55% solution of isopropyl alcohol in distilled water and a small amount of sugar, which helped a little with staining of the glass container. I cleaned the glass thoroughly with acetone first and then poured in the solution followed by the ferrofluid. The oil from the ferrofluid stained the glass in places where it hadn't been cleaned properly or where the glass had structural flaws in its surface.

This solution was sufficient for testing but was unusable for a permanent display with a sealed container as the solution dissolved the oil in ferrofluid and left only iron sawdust, which had lost its liquid properties.

2.1.3 The ferrofluid

The composition of the ferrofluid being unknown to me did make me question whether I should inquire into buying a more expensive alternative with proper documentation. In spite of this drawback, being able to do tests was satisfactory, and therefore, I did not further explore this option.

2.1.4 The chemistry

Trying to find a perfect solution for ferrofluid to float in, I have been invited by RNDr. Jan Havlík, Ph.D. to a laboratory at IOCB Prague[3]. He ran a few tests to find the properties of my sample of ferrofluid, and he agreed to help me find a more stable agent in which it could be submerged indefinitely. We found dimethyl sulfoxide to be a very promising liquid, and when diluted with distilled water, the submerged ferrofluid had perfect properties. I took a sample seen in Figure 2.1 and left content only to find, after a day or two, the ferrofluid in the sample hardened and was unusable. When confronted, Dr Havlík assured me that his sample, which was supposed to be identical to mine, did not show this kind of behaviour. I have no hypothesis to offer regarding this phenomenon. I kept on using the open container for my testing.

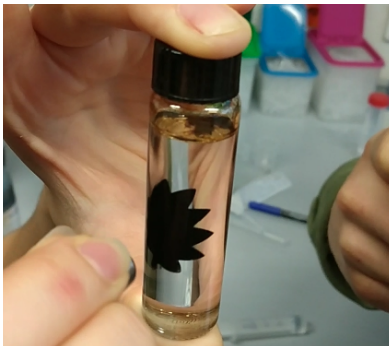


Figure 2.1: Ferrofluid in dimethyl sulfoxide.

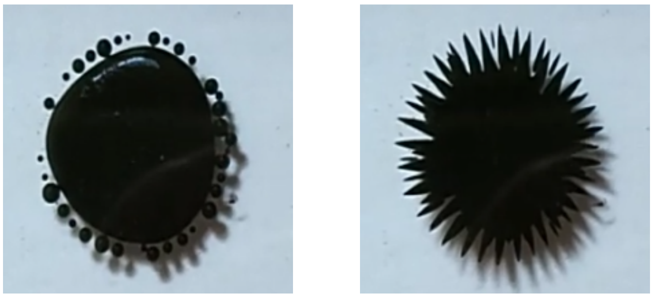
[3]Institute of Organic Chemistry and Biochemistry of the CAS

2.2 Experiments

Using MagMan and the arrangement described in section 2.1 I achieved to manipulate individual drops of ferrofluid as intended and found new ways to do so as well.

2.2.1 Initial observations

The most straightforward test I could do was to change the strength of the magnetic field generated by a single coil and observe the changes in the shape of the ferrofluid above. When the field was barely strong enough to hold the ferrofluid in place, the shape resembled a simple oval drop, as shown in Figure 2.2a. As the field intensified, the drop produced the spikes seen in Figure 2.2b ferrofluid is known for.



(a) : Weak field **(b) :** Strong field

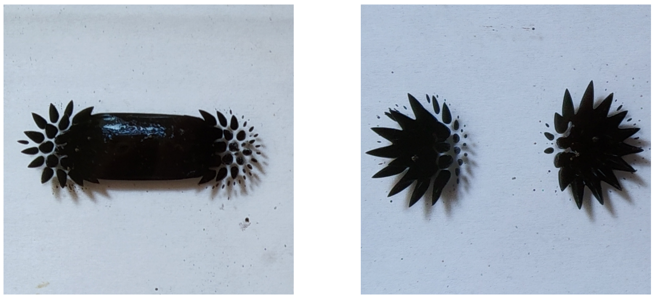
Figure 2.2: Ferrofluid in a magnetic field

2.2.2 Two-coil observations

When two adjacent coils were turned on with opposite polarities, the ferrofluid connected the two regions above the coils, as illustrated in Figure 2.3a. When the electromagnets were switched on with the same polarity, the two drops of ferrofluid seemed to repel each other, as shown in Figure 2.3b. This phenomenon took place even when the two coils in question were adjacent diagonally.

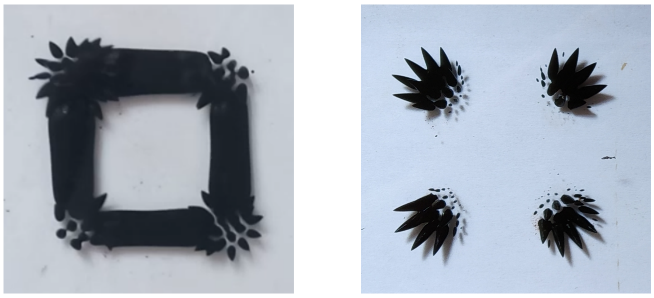
2.2.3 Four-coil observations

As with the two-coil example, I have tried to make a stable configuration of coil polarities where the ferrofluid would connect four closest coils in a 2×2 formation. This turned out to be most likely impossible with a static polarisation of the coils as it only created the two-coil configurations on the sides of the square, as shown in Figure 2.4, but did not cover the inside.



(a) : Opposite polarity (b) : Same polarity

Figure 2.3: Ferrofluid over two adjacent coils



(a) : Empty square (b) : Repelled corners

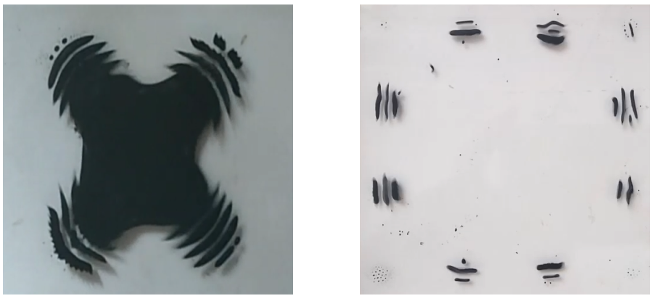
Figure 2.4: Ferrofluid over four coils

2.2.4 Slow animations

With these basic shapes, I was able to make transitions between different configurations and manipulate the ferrofluid in such a way that it created interesting animations. I was able to program the animations to achieve any desired ferrofluid distribution, which was a combination of the above mentioned.

2.2.5 Fast animations

The slow animations lacked in the ability to immediately show desired ferrofluid distribution. I hypothesised that if a pseudo-chaotic animation were to be played on a very high frequency the ferrofluid would uniformly disperse over the coils. This animation could then be superimposed over a slow animation showing the desired ferrofluid distribution, and the ferrofluid would coalesce in the intended configuration. This could then be used to quickly transit from one image to another without having to plan the path between the two pictures. The subsequent experiments shown in Figure 2.5b supported the hypothesis to a satisfying degree.



(a) : Full square **(b) :** Fast animation

Figure 2.5: Distributions achieved through high frequency switching

Using these animations, I have found a way to fill a 2×2 area bounded by four coils, as shown in Figure 2.5a and mentioned in subsection 2.2.3. I switched between two configurations where the two diagonal pairs had opposite polarisations, and I inverted the coils' polarity with frequencies above 25 kHz. This was initially meant to make the animation inaudible but was later found to be essential for the ferrofluid to stay in the spread out formation in a stable fashion.

For such a method of manipulation, the MagMan platform ended up being insufficient.

Chapter 3

Module and display design

3.1 Reasons for MiniMag development

As described in subsection 2.2.5 the MagMan platform was suboptimal for my further experimentation and also the coils were too big. Being designed to manipulate with solid objects, the diameter of individual coils in its design did not serve the same role as is the case with ferrofluid manipulation. For these reasons, I started conceptualising a miniaturised version of the platform that would serve as a better alternative to its predecessor. Smaller coils would enable the electromagnetic array to function as a display with a higher resolution for the animations it could then produce.

3.2 Desired qualities

The main desired specifications of the new hardware were:

- Modularity;
- Small diameter coils;
- Fast polarity inversion capability;
- Simple communication using established technology;
- Compact design;
- Future extendibility.

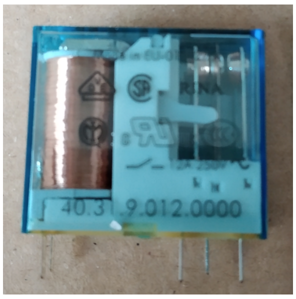
3.3 Design process

3.3.1 Resolution selection

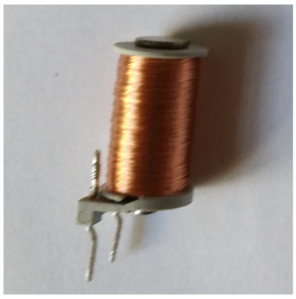
I started by questioning the resolution required to display alphanumeric symbols and simple text. I found the resolution necessary to produce a clock in digital format using the known methods of manipulation was 17×5. Therefore I decided to use eight 4×4 modules that would align to create a 16×8 display. Such a display can show four symbols at the same time.

3.3.2 Part selection

With the known resolution, I could start selecting coils. Due to time limitations, I have decided not to make the 128 coils myself. I have not been able to find a seller that would satisfy my requirements, and therefore I have opted to remove coils shown in Figure 3.1b from commercially available 12 V DC relays[5] seen in Figure 3.1a. These coils already had contact pins soldered to them and were 1 cm in diameter, both of which were very desirable.



(a) : Selected relay



(b) : Extracted coil

Figure 3.1: Relay with a coil

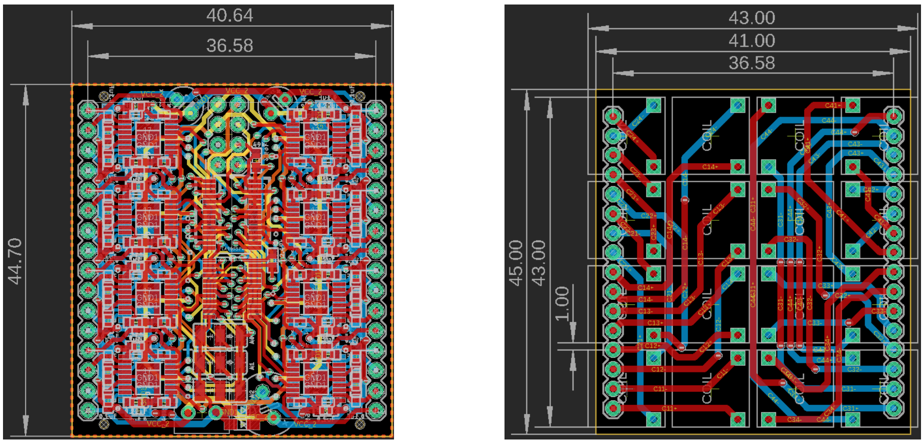
With the coil dimension, the size of the whole display could theoretically be 16×8 cm, or 4×4 cm for one module. This would be equivalent to miniaturisation from the MagMan platform by a factor of 6.25 areawise.

I decided to use the same H-bridges with drivers[6] that were used in the MagMan platform for the coil switching since I did not plan to use higher currents and therefore it saved a lot of time in the designing process. These H-bridges would be enabled by a 16 channel PWM generator[7] and the polarity would be controlled by a 16 channel I/O expander[8] both of which receive instructions through an I^2C bus.

3.3.3 PCB design

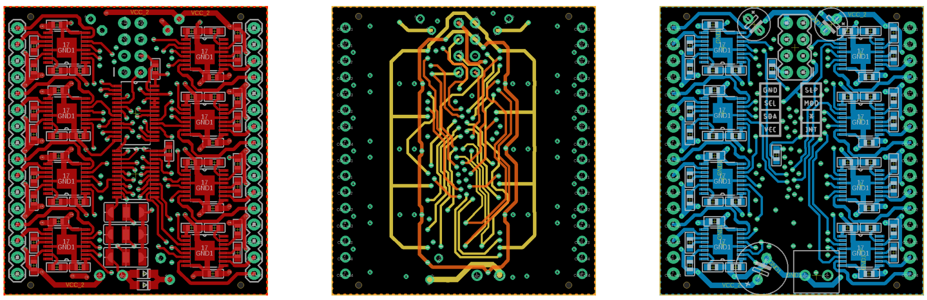
The design seen in Figure 3.2of a module is split into two printed circuit boards, one for the coils and another for the rest of the parts. These two boards attach onto one another, as illustrated in Figure 3.4, and this has two reasons. Firstly, it enables the adjacent coils from different modules to be as close to each other as coils on a single module, which is 1 mm, and secondly, it allows for the module to be used for other future applications as well as it makes the design less prone to fatal mistakes. Should the coils turn out to be inadequate, the whole process does not have to be repeated. Unfortunately, the former could only be achieved in such a way that any two adjacent modules have to be rotated 90° to each other. This is caused by the dimensional properties of the coils.

The lower board houses 16 H-bridges with drivers, one for each coil, a 16 channel PWM generator and an I/O expander as well as a plethora of resistors and capacitors and a few diodes. It also features three solder pads determining the lowest three I^2C address bits for the components. This gives every module a different address and enables up to eight modules to be connected to the same bus. Eight was chosen due to the fact that, if there were more, the communication speed would noticeably decrease. Should the use of more than eight modules be desired, more dedicated I^2C buses have to be used.



(a) : Lower board　**(b) :** Upper board

Figure 3.2: Design of the two boards



(a) : Top layer　**(b) :** Middle layers　**(c) :** Bottom layer

Figure 3.3: Detail of the lower board layers

The design of this board was time intensive since I initially aimed for the board to have only two copper layers. I failed in this endeavour and was forced to redesign the board multiple times using four copper layers visualised in Figure 3.3. Had I started with four layers, the design could have been more streamlined and possibly a few more components could have been placed on the board. A complete design overhaul was, however, impossible due to time limitations.

The module has nine connection pins described in Table 3.1.

Pin name	Description
V+	Up to 32 V for the coils
V-	Ground
VCC	5 V reference voltage for the components and communication
GND	0 V reference voltage for the components and communication
SDA	I^2C data
SCL	I^2C clock
MOD	Mode of H-bridge switching
NSLEEP	Turns H-brigdes on, security function
INT	Error output signal

Table 3.1: Input and output pins of a module.

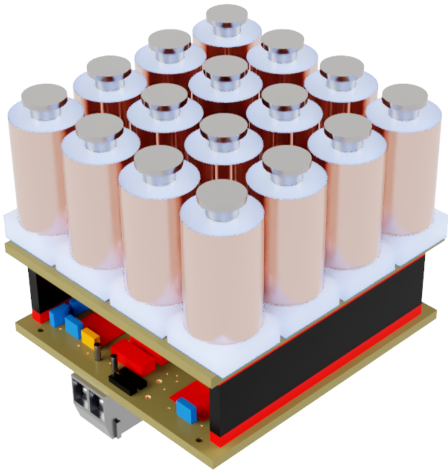


Figure 3.4: 3D model of a module

3.3.4 MiniMag design

The MiniMag platform uses eight modules in a 2×4 configuration, as shown in Figure 3.5 which results in an 8×16 display resolution. The modules are placed between a bottom panel made of 4 mm thick acrylic glass and a top cover made of 2 mm thick white plastic. I designed both of these parts in a 3D modelling software. To minimise the distance between the cores of the coils and ferrofluid, the top cover has holes through which the cores are inserted in the coils below. This also perfectly aligns the cores. The container with the ferrofluid is then designed to be placed directly on top of the cores. The bottom and top plates are designed to be screwed tight using a ⌀3 mm coil rod.

Figure 3.5: The orientation of individual modules

Chapter 4

Assembly and programming

4.1 Coils

The assembly process started with 128 relays' casings being carefully cut open. Then I broke the plastic base to which the coils were glued to. This enables a safe extraction of the coil as shown in Figure 4.1. This was time intensive and required patience and dexterity.

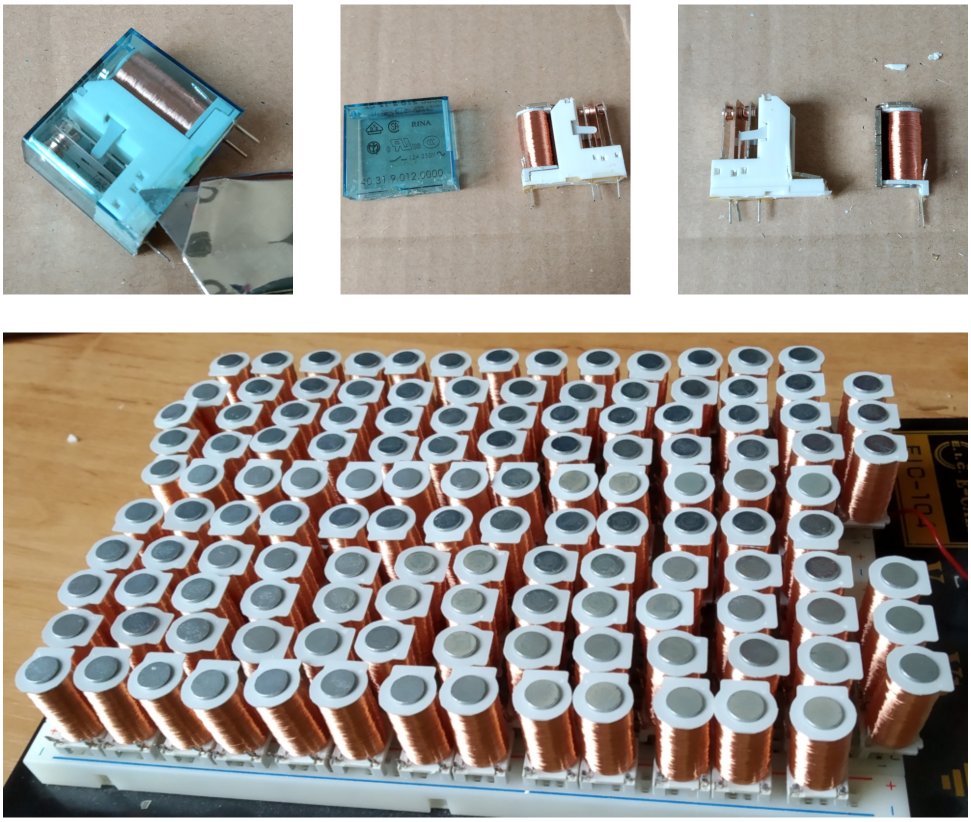


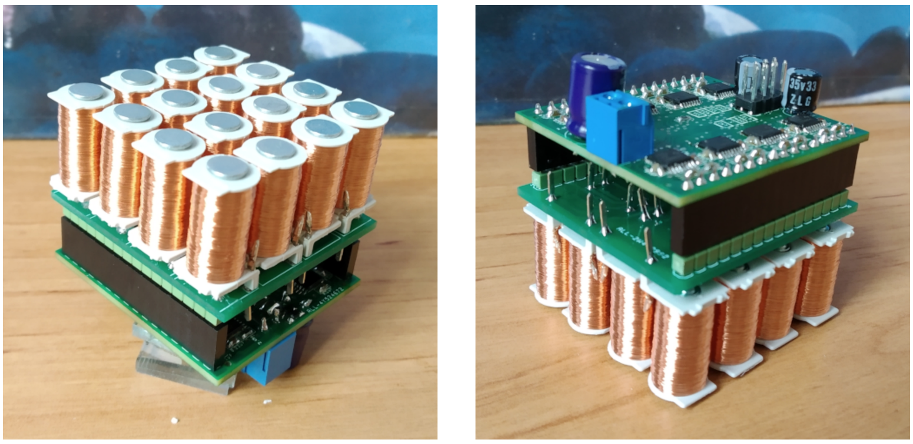
Figure 4.1: Coil extraction process

4.2 Components mounting

I manually mounted all the components onto the PCBs. The H-bridge drivers, PWM generators and O/I extenders were mounted using a soldering station and a solid solder, and for the rest of the SMT[1] parts, I used a solder paste and a heat gun. After a meticulous quality check under a microscope, I installed the THT[2] components using, again, the soldering station. Finally, since I planned to use more than one module on the same bus, I had to solder the address pins and give each module a unique address as described in subsection 3.3.3.

4.3 Module assembly

When the PCBs were populated and the contact pins soldered on, I attached the two boards together, as demonstrated in Figure 4.2. In this state, the module should be fully operational and can be used as is. The coils' metal cores are not firmly attached and can move, even fall out and so further adjustments need to be made should one want to use the modules individually.



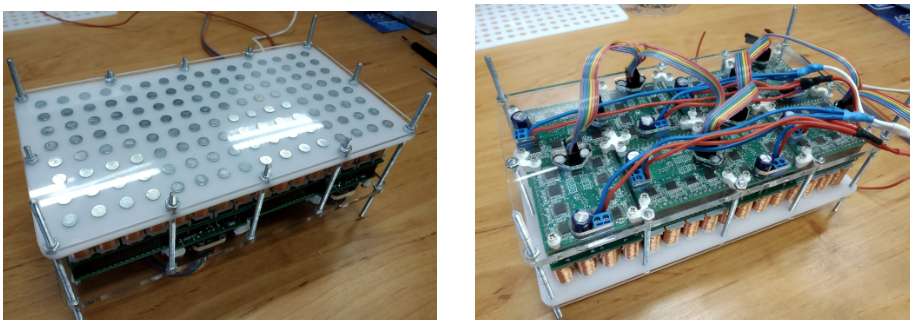
(a) : Top side view **(b) :** Bottom side view

Figure 4.2: Assembled module

[1] Surface Mount Technology
[2] Through Hole Technology

4.4 MiniMag assembly

The modules were inserted without cores into the bottom panel onto which I had screwed 3D printed spacers. This makes installation of a module in a wrong orientation impossible. Then I placed the top panel over the modules and secured their position. Afterwards, I inserted the cores through the holes in the top panel and over them put a protective panel, which is intended to be removed before the use of the platform and only secures the cores in place for manipulation. This finalised the construction of MiniMag shown in Figure 4.3.



(a) : Top side view **(b) :** Bottom side view

Figure 4.3: Assembled MiniMag

4.5 MiniMag Python library

I created basic function library in Python for the module and implemented it in the construction of the MiniMag Python class that implements such operations as a safe initialisation and termination of MiniMag operation as well as transforms intended patterns to be displayed correctly on the variably rotated modules, and it also handles the display procedure itself.

Chapter 5

MiniMag Testing

5.1 Testing for functionality

The first method I used to examine the correct functionality of the individual modules was the *i2cdetect* command. This returns all the occupied addresses on the bus. Should one module be assembled incorrectly, its address would not be returned. Once every module passed this test, I felt comfortable supplying a higher voltage to the board to test the H-bridge drivers and coils functionality using a magnetic film. This helped me to find all non-functional coils that were somehow broken during the assembly process. A certain amount of damage was to be expected given that they were manually extracted from relays with a retractable utility knife.

Once all the broken coils were replaced, I made a ferrofluid bath with a suspension made of water and soap, which is ideal for quick tests and started making simple animations.

5.2 The animations

The animations were all programmed using the function library mentioned in section 4.5. This makes the programming of simple animations fast and easy. The library also handles all the necessary communication initialisation, which makes the programming safer and leaves little room for error that could damage the modules.

5.2.1 Dispersion

The first animation I programmed was a pattern that disperses the ferrofluid across the platform. It is made of two pictures where each is a mosaic structure like a checkerboard, where all the adjacent coils to an active coil are switched off and vice versa as shown in Figure 5.1. The second picture is an inverse of the first. This was intended to be used to create a uniform distribution of ferrofluid before the start of other animations.

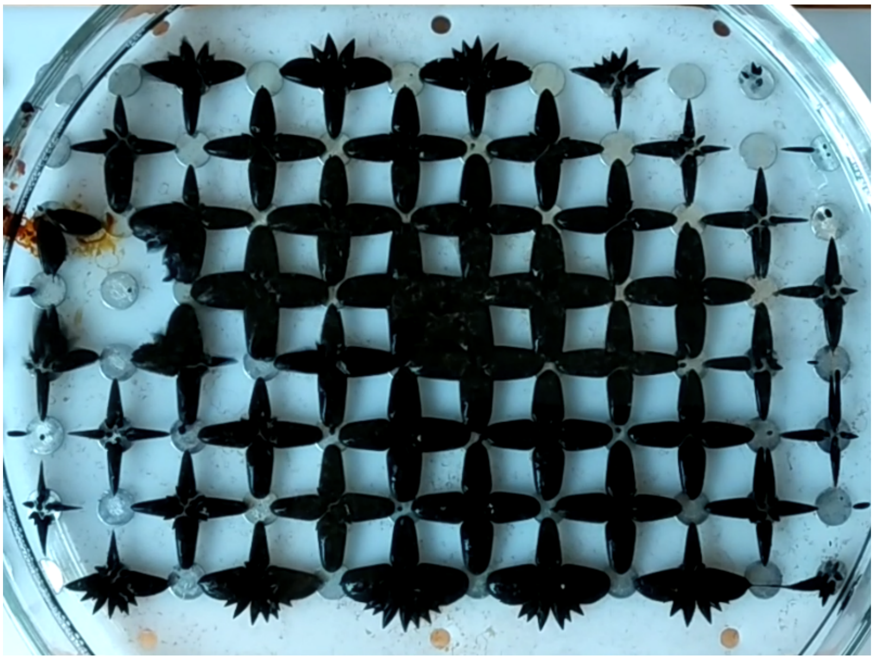


Figure 5.1: Image from the dispersion animation

5.2.2 Random walk

Subsequently, I created an animation shown in Figure 5.2 that tested the manipulation of individual drops of ferrofluid. The code uses a pseudorandom choice for the direction of movement. And enabled me to test the intensity of the magnetic field needed to manipulate the ferrofluid reliably. Later I added the support for more than one agent, which is an excellent illustration of how individual drops can merge and split.

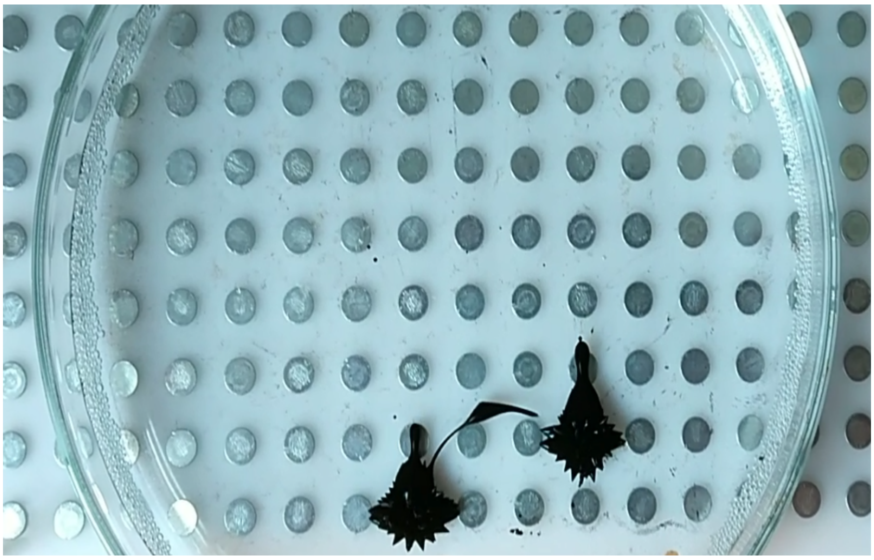


Figure 5.2: Image from the random walk animation

5.2.3 Symbols

To demonstrate the ability to visualise simple text and other alphanumeric strings, I showed the text: "FEL" from the dispersed ferrofluid, as shown in Figure 5.3. The resolution of MiniMag enables up to four symbols to be displayed. The size of the tank, however, enabled displaying only three letters. Yet, this animation fully demonstrates the intended capabilities of the MiniMag platform.

Figure 5.3: Demonstration of a simple text

5.3 Limitations

I powered the coils from a 15 V power source during my tests in section 5.2. The voltage caused the coils to heat up, especially in the centre of the module. This had no effect on the functionality of the hardware, but it heated the ferrofluid solution, which in turn started do chemically react and ruined the sample. The coils overheating did, however, take place after approximately ten minutes of all the coils having current passing through them at the same time. I expect this issue to be less severe under typical use.

The capability of high-frequency animations has not yet been tested. However, it should be possible by design with the use of sequential writing in the registers of the I/O expanders. I have not yet implemented such a feature in the MiniMag python library. Currently, the polarity of a single coil can be switched with a frequency of 16 kHz. Should all the coils need to be inverted, the frequency would be insufficient. With the use of fast-mode I^2C, which is supported, and sequential writing, I expect the number of coils that can be used for high-frequency animations to be sufficient. This needs to be experimentally verified, however.

Chapter 6
Control

6.1 Feedforward control

Without the knowledge of the distribution of the ferrofluid over MiniMag, there are three ways of control.

Firstly, one can use the slow methods I researched using the MagMan platform described in section 2.2. These animations can be used as a kind of a set of animations that the controller can use to move ferrofluid in and out of various patterns. The speed with which these animations can change is dependent on the suspension and strength of the magnetic field. These values have to be manually set in order for the control to be effective. All my implemented animations use this method of control.

Secondly, the use of a collector can be used, whether it is an external one or an internal one, such as the one the Ferrolic display uses is omittable. In this scenario, the ferrofluid always has the same starting position, and the controller can use schemes to add ferrofluid to the animation when needed, and all the scattered ferrofluid safely returns to the reservoir.

Lastly, the control currently unimplemented in the MiniMag but supported is the one discussed in subsection 2.2.5. This scheme works without the knowledge or the assumption of the distribution of the ferrofluid and instead scatters the ferrofluid as much as possible and catches the ferrofluid in the desired positions. This makes the method of control probabilistic in nature but can be very effective when used with larger quantities of ferrofluid. Also, this method is preferable when the animation requires fast transitions between very different patterns.

6.2 Feedback control

This type of control requires the knowledge of the distribution of the ferrofluid. The best and maybe only approach how to measure the position of droplets of ferrofluid is a computer vision implementation. A camera would be pointed at the platform from above, and the video would be analysed in real time. This information would then be used by the controller to adjust the magnetic field generated by the coils to achieve the desired distribution. This approach is relatively complicated, and therefore, I opted not to further hypothesise on the details of an implementation of such a method without further research into the matter.

Chapter 7

Conclusions

I successfully designed, built and tested the MiniMag platform to a satisfying degree. The tests that I conducted showed its capability to display various animations and simple alphanumeric text. From a hardware standpoint, the platform is fully complete, and aside from a cooling, system any adjustments to the construction that I desire to make in the future are strictly aesthetic. MiniMag meets the desired goals, specifically:

- The resolution has been raised, which is a significant shortcoming in most of the platforms this one is influenced by or based on.
- The modular design enables the construction of an arbitrarily large display without the need to repeat the whole design process.
- The upper board housing the coils being detachable enables the platform to be altered for different use. Larger or differently positioned coils can be easily used for different effects. Examples include magnetic levitation and spatial manipulation.

The project as a whole was successful in its goal to test the limits of electromagnetic ferrofluid manipulation in liquid suspensions as well as to document this process for future endeavours.

Future of the project should make a fully sealed ferrofluid container a priority. The subsequent focus of the project should be research into the implementation of a feedback control mechanism. Should the module be redesigned in the future, I suggest to place diagnostic LEDs onto the bottom side of the lower board and should a source of more convenient coils be found I advise to design the upper board symmetrically in such a way that the modules do not need to be rotated to fit together neatly.

In conclusion, I have designed the MiniMag platform and found suitable methods of control of ferrofluid in liquid suspension to be used by the platform and doing so I have fulfilled the goals this thesis set out to accomplish.

Bibliography

[1] Zemánek, J. (2018). Distributed manipulation by controlling force fields through arrays of actuators.

[2] Koelman, Z., de Graaf, M. J., and Leeuw, H. J. (2015). From meaning to liquid matters. In ISEA 2015. *Proceedings of the 21st International Symposium on Electronic Art.*

[3] I^2C *https://www.i2c-bus.org/* [online] (May 2019)

[4] Zeer, L. Ferrobot. *https://github.com/The-Brainery/FerroBot* [online] (May 2019)

[5] Datasheet (PL) *https://www.tme.eu/Document/74b681bf519d2a39358db9468d4d1b6d/S40newPL.pdf* [online] (May 2019)

[6] DRV880x DMOS Full-Bridge Motor Drivers. *http://www.ti.com/lit/ds/symlink/drv8800.pdf* [online] (May 2019)

[7] 16-bit Fm+ I^2C-bus LED driver. *https://www.nxp.com/docs/en/data-sheet/PCA9635.pdf* [online] (May 2019)

[8] TCA9535 Low-Voltage 16-Bit I2C and SMBus Low-Power I/O Expander with Interrupt Output and Configuration Registers. *http://www.ti.com/lit/ds/symlink/tca9535.pdf* [online] (May 2019)

ČVUT ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Pospíchal** Jméno: **Lukáš** Osobní číslo: **465813**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra řídicí techniky**

Studijní program: **Kybernetika a robotika**

II. ÚDAJE K BAKALÁŘSKÉ PRÁCI

Název bakalářské práce:

Displej s Ferrofluidem

Název bakalářské práce anglicky:

Ferrofluid display

Pokyny pro vypracování:

Design and build a system for manipulation of ferrofluid droplets using an array of coils
1. Design electronics for driving a higher number of coils (for example, 64) that would allow setting the values and directions of the currents through individual coils. The system has to be modular and extendable.
2. Build a system that will work as a display with ferrofluid and would allow showing, for example, time and various patterns or animations.
3. Find suitable ways of motion control for the droplets. Consider both feedforward and feedback control.

Seznam doporučené literatury:

[1] Koelman, Z., de Graaf, M. J., & Leeuw, H. J. (2015). From meaning to liquid matters. In ISEA 2015. Proceedings of the 21st International Symposium on Electronic Art.
[2] https://github.com/The-Brainery/FerroBot [online]

Jméno a pracoviště vedoucí(ho) bakalářské práce:

Ing. Jiří Zemánek, Ph.D., katedra řídicí techniky FEL

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) bakalářské práce:

Datum zadání bakalářské práce: **15.02.2019** Termín odevzdání bakalářské práce: **24.05.2019**

Platnost zadání bakalářské práce:
do konce letního semestru 2019/2020

Ing. Jiří Zemánek, Ph.D. podpis vedoucí(ho) práce	prof. Ing. Michael Šebek, DrSc. podpis vedoucí(ho) ústavu/katedry	prof. Ing. Pavel Ripka, CSc. podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Student bere na vědomí, že je povinen vypracovat bakalářskou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v bakalářské práci.

.

Datum převzetí zadání Podpis studenta