Team 54
Portable MRI Device

ECE 445

Yaokun Shi, Zexuan Cheng, Yujiang Han
Professor: Victoria Shao
TA: Amr Ghoname

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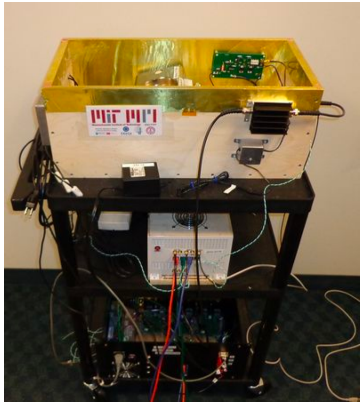
Introduction

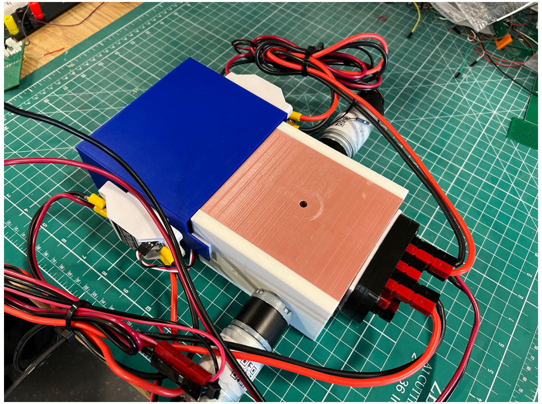
Current Problem for MRI Devices

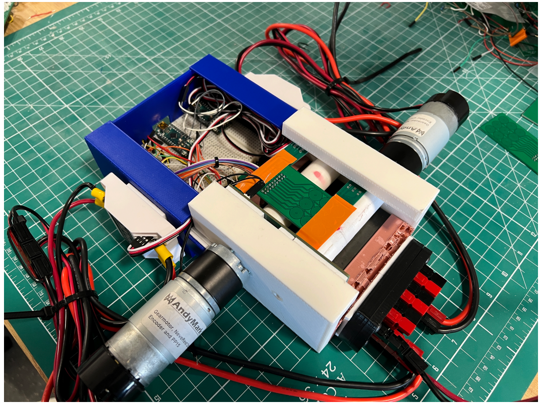
- Purchase and Installation cost can average between 1 million to 3 million USD
- Takes tremendous area of space as well as extensive maintenance
- Scan time is approximately 15 to 90 minutes

Attempts: Low-field MRI, Portable MRI

- Poor imaging quality
- Difficult to transport







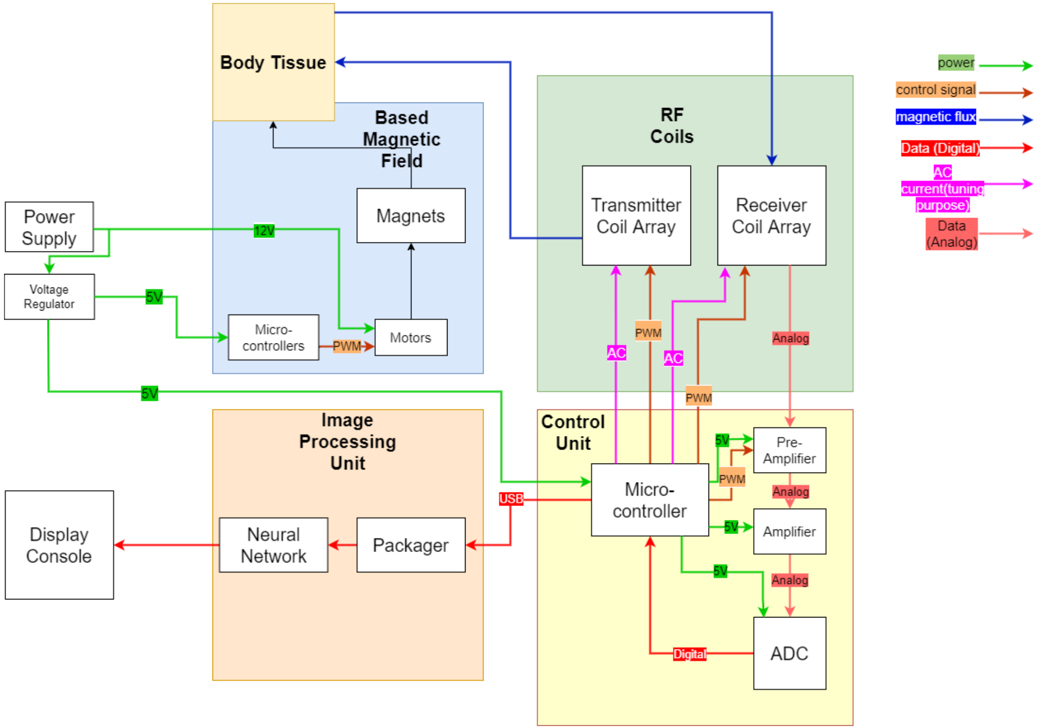
Our solution:

A low cost, portable MRI device that generates intelligible image with the help of Deep Learning techniques

High-level Goals:

- Device dimensions: 0.3m x 0.3m x 0.3m
- Device weight: <= 10kg
- Power consumption: <= 500W
- Overall scan time: <= 15 minutes
- Image quality SSIM: >= 0.5

Introduction



Top-level Block Diagram

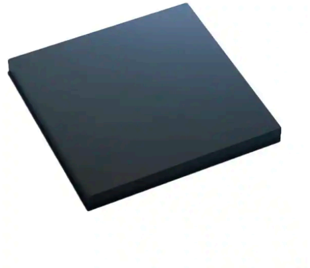
Base Magnetic Field Design

Base Magnetic Field Design

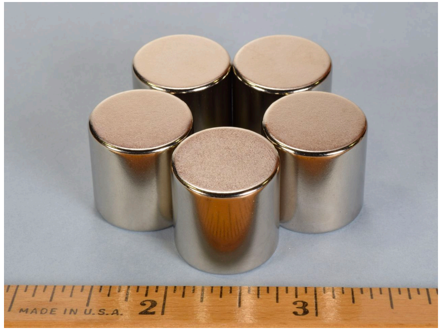
Functionality

Provide Non-homogeneous magnetic field through rotation in the imaging volume to create unique spatial encodings for radiofrequency coils.

Design Details



Ferrite Plate



Diametric Magnet

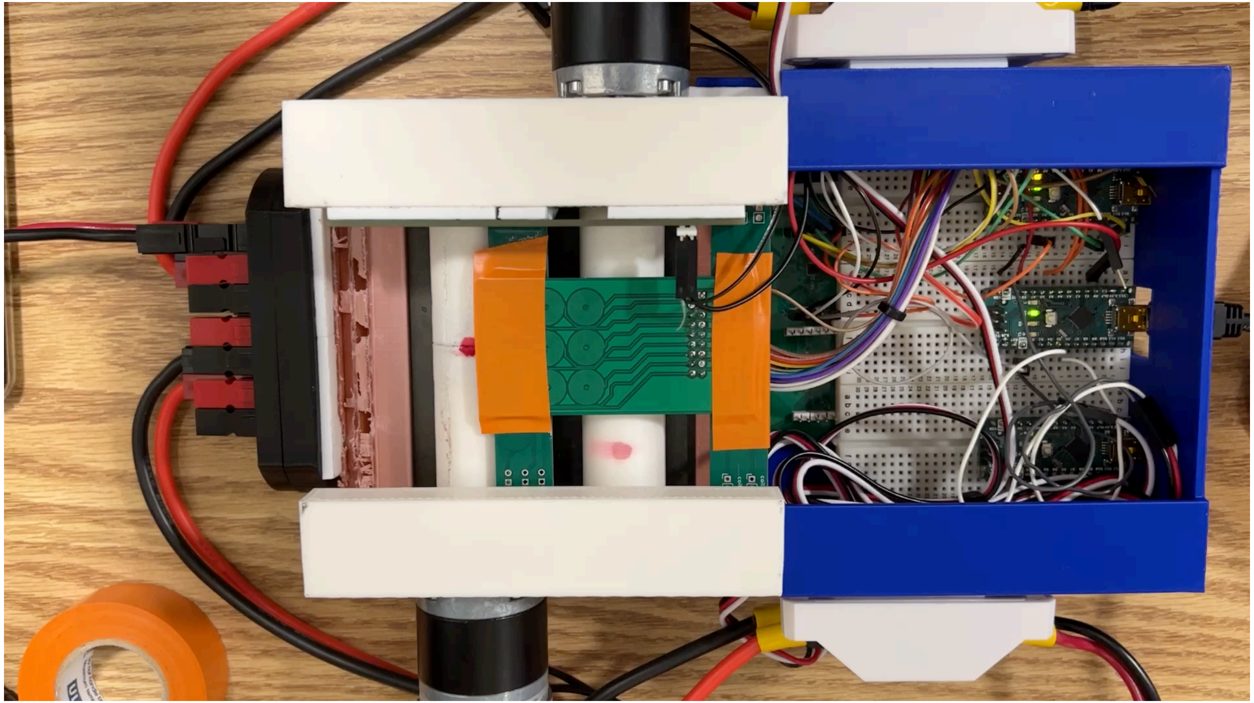
Gearmotor & Power Distribution Board

Motor Driver

Requirement and Verification

Requirement	Verification	Verified?
Power distribution board equally delivers input voltage to both channels for motors	Use multimeter to probe at each output channel on the power distribution board.	Yes
Maximum current in motor control loop does not exceed 10A	Perform one imaging operation, and use multimeter to probe each motor to record maximum current	Yes
Magnetic field strength across the imaging volume is between 1mT to 200mT	Use Gauss meter to probe each imaging voxel in rotating manner, and record maximum reading	Yes
Motor shaft rotates for 30 degrees in each imaging iteration	Perform one imaging step, and measure the angle of motor shaft movement	Yes/No

Motor Rotation



Measured Magnetic Field Strength

90mT	160mT	90mT
75mT	100mT	75mT
90mT	160mT	90mT

Zero position

90mT	120mT	90mT
75mT	90mT	75mT
105mT	140mT	105mT

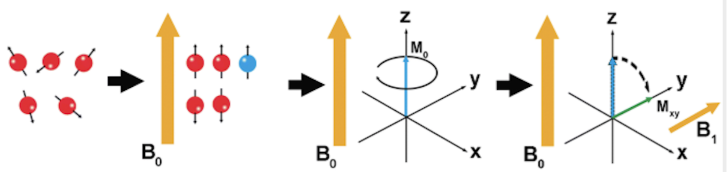
30 degree

Radiofrequency Coil Design

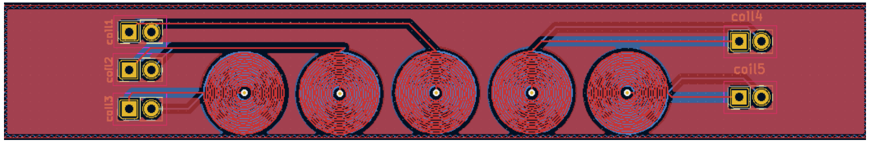
Functionality (transmitter)

Transmitter coils are designed to excite the atom, tilting the rotation direction.

Design Details



Atoms being excite by the transmitting field.

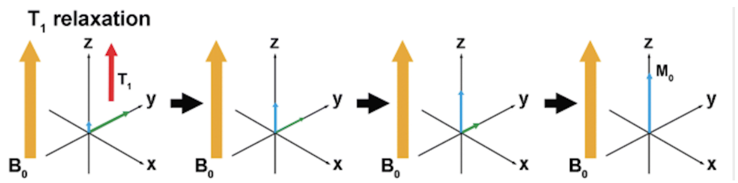


Surface coil-array as transmitter

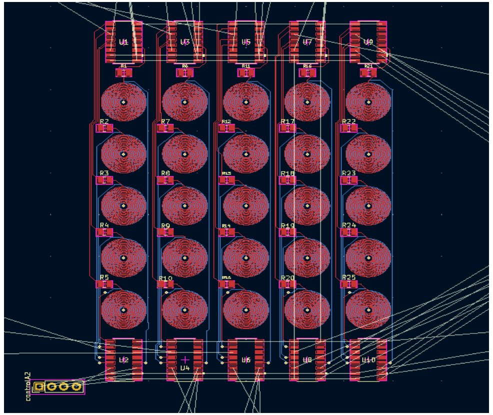
Functionality (receiver)

Receiver coils are designed to catch the power from the atoms’ relaxation and send it to the control unit

Design Details



Atoms being excite by the transmitting field.

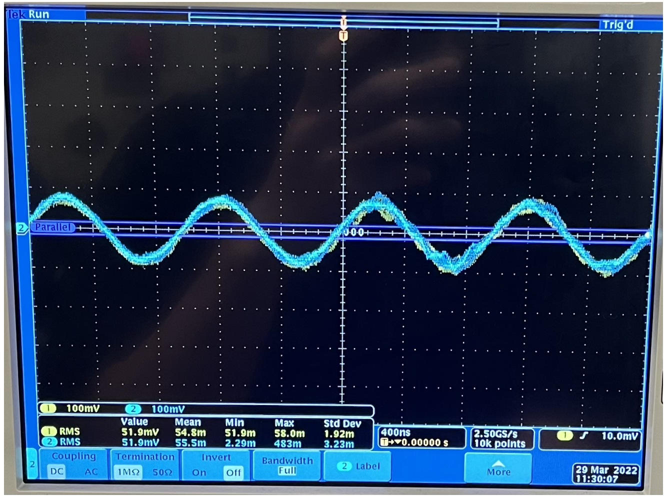


Surface array-coil as receiver

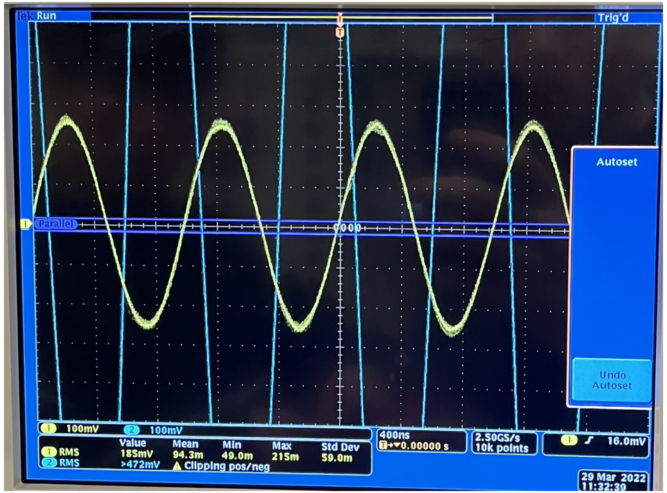
Requirement and Verification

Requirement	Verification	Verified?
Transmitter and receiver are tuned to the corresponding Larmor frequencies	Use oscilloscope to measure the frequency of the signals through the coils	Yes
Receiver can be coupled with transmitter and receive signal under the same frequency	Under the same frequency, the amplitude of the signal through receiver should increases while transmitter is nearby	Yes
Receiver won’t catch the power directly from transmitter while scanning	Receiver is able to obtain a clear signal while transmitter is off	No

Coupling between transmitter and receiver

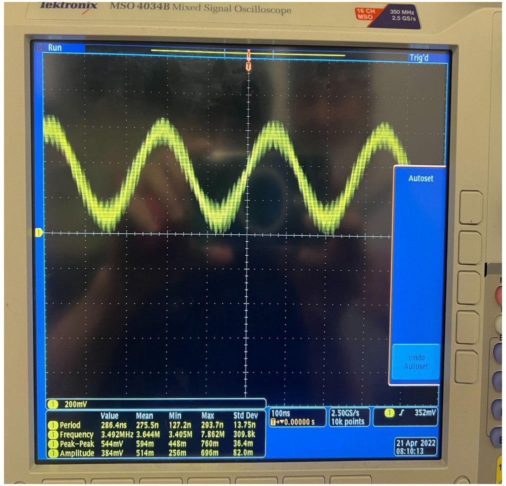


Receiver not coupled with transmitter

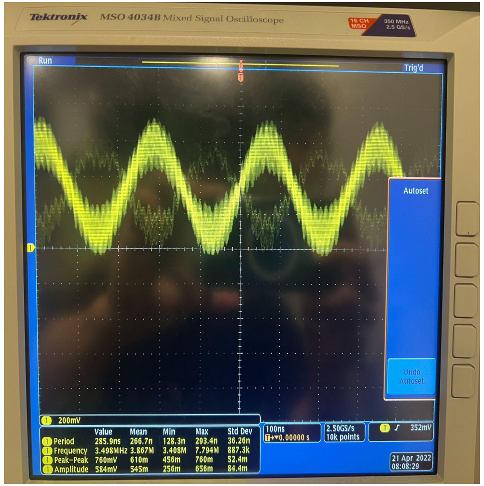


Receiver coupled with transmitter (yellow channel opened for reference)

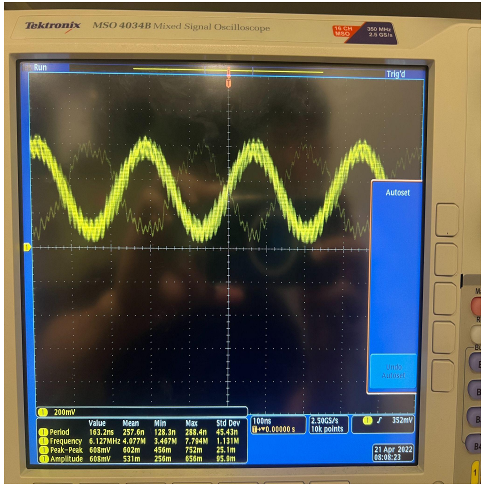
Signals captured by receiver



Signals before scanning



Signals while scanning water



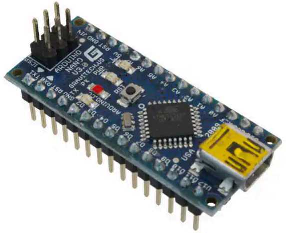
Signals while scanning air

Control Unit Design

Functionality

Control motor rotation, drive and program on-chip waveform generator, read coil data through built-in ADC and serially transmit data to Image Processing Unit

Design Details



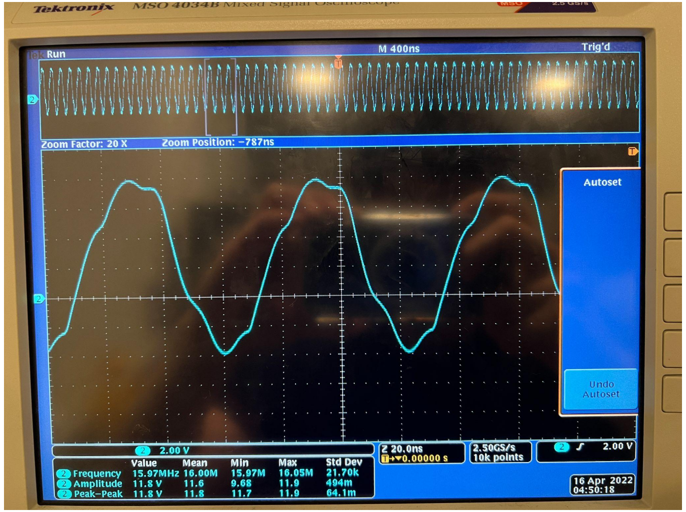
Arduino Nano Dev board

AD9837 Waveform Generator

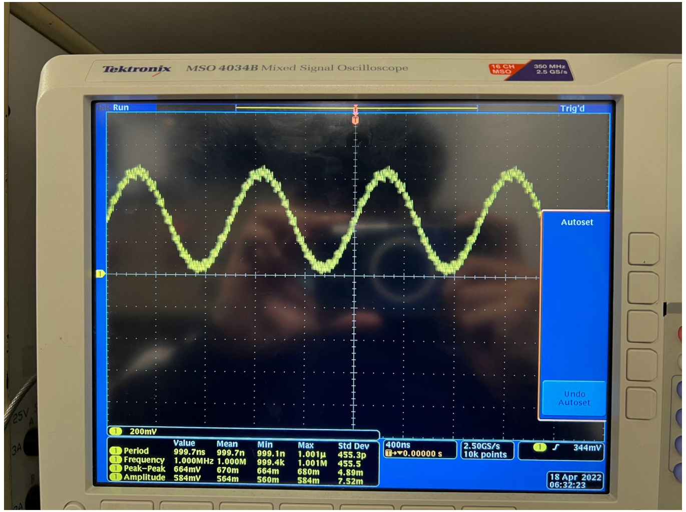
Requirement and Verification

Requirement	Verification	Verified?
The microcontroller can generate correct control signals	Verify and monitor the signal output using the oscilloscope	Yes
I2C communication between Master and Slave control units are established and functional	Send information from master, and use serial monitor to check for slave receiving information. Repeat for other way around	Yes
Microcontroller outputs master clock at 16MHz for on-chip waveform generator	Use oscilloscope to monitor output at D8 pin	Yes
On-chip waveform generator should be able to output correct analog sine signal	Use oscilloscope monitor the output signal of on-chip function generator	Yes

Master Clock and Waveform Generator Output



MClk output



AD9837 output

Larmor Frequency

3.8322MHz	6.8128MHz	3.8322MHz
3.1935MHz	4.258MHz	3.1935MHz
3.8322MHz	6.8128MHz	3.8322MHz

Zero position

3.8322MHz	5.1096MHz	3.8322MHz
3.1935MHz	3.8322MHz	3.1935MHz
4.4709MHz	5.9612MHz	4.4709MHz

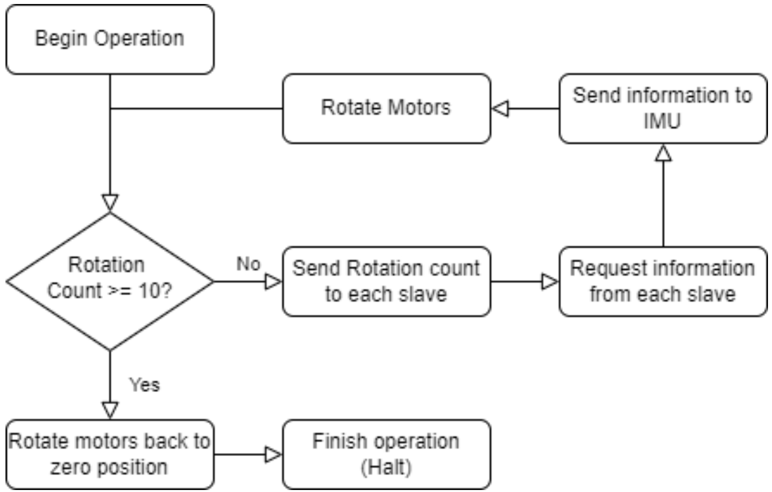
30 degree

Each coil at given position works at the Larmor frequency given by:

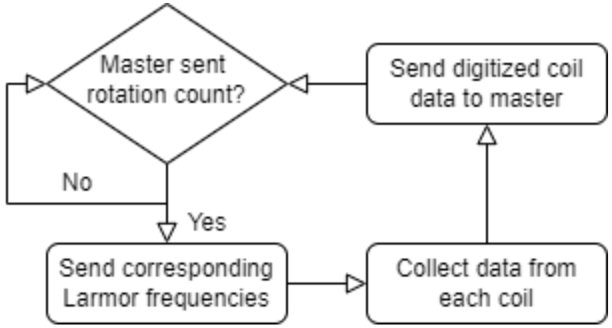
$$\mathbf{f = \gamma \cdot B_0}$$

Where f is the Larmor frequency(MHz), refers to the gyromagnetic ratio for specific atoms, and B0 is the base magnetic field strength(T).

Control Logic



Master Microcontroller



Slave Microcontroller

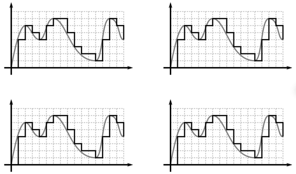
Image Processing Unit Design

Image Processing Unit Design

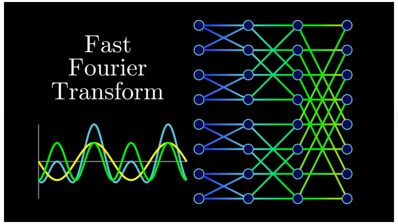
Functionality

Package serially transmitted data into data structures, and perform DSP as well as Deep Learning algorithms to reconstruct the output image.

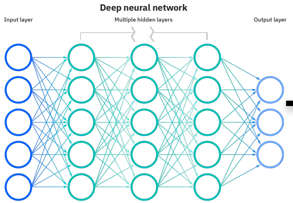
Design Details



Digital Signal from individual coils



DSP Algorithm



DL Algorithm

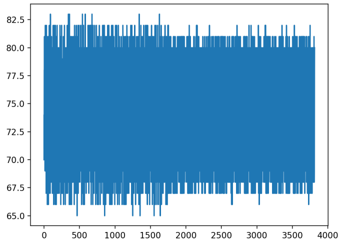
Reconstructed image

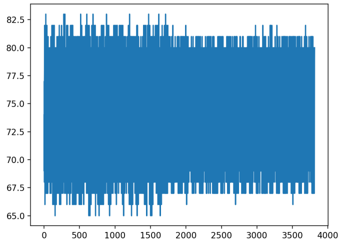
Requirement and Verification

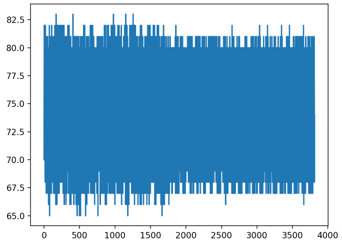
Requirement	Verification	Verified?
Image Processing Unit receives digitized signal from the Control Unit	Establish serial connection through USB and transmit dummy data to Image Processing Unit	Yes
Data can be packaged and displayed in the time domain	Collect data from each coil individually, and plot the digital signal	Yes
DSP algorithm correctly transforms data in time domain into frequency domain	Send a test digital signal from coils and plot the resulting frequency domain image	No
Deep learning algorithm takes frequency domain data and reconstructs final image on the gray scale	Convert frequency domain data into a grayscale raw image, send it to the MoDL neural network, and check SSIM of the reconstructed image	No

Data acquisition (Water)

Data from one coil detecting energy change in water is being collected and processed by the control unit, which is then sent to the image processing unit and being plotted.

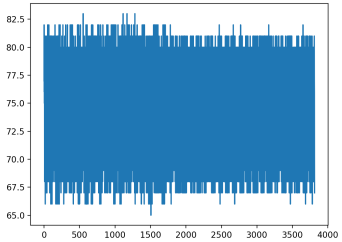


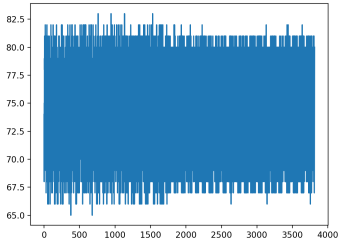


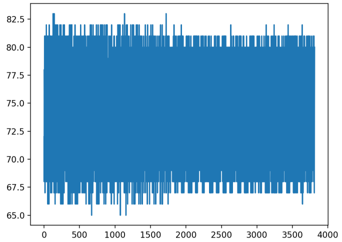


Data acquisition (Air)

Data from one coil detecting energy change in air is being collected and processed by the control unit, which is then sent to the image processing unit and being plotted.







Summary

Summary

Success

- MCU communication and control signal generated
- Motor control and base magnets rotation
- On-chip function generator implementation
- Coil excitation and pairing
- Transmitter and Receiver coils' functionalities
- MRI phantom testing
- Preliminary feedback reading and signal processing

Challenges

- Soldering QFN packaged components
- Coil performance was unstable
- Limited funding
- Limited amount of backup components
- Delay of the components
- Insufficient background knowledge in Magnetic field and RF coils
- Lack of experience in mechanical design

Lessons Learned

- PCB design and layout using Kicad
- Generate spiral shaped coils in Kicad script file
- I2C communication protocol between master and slave controllers
- SPI communication between control unit and subordinate modules (eg. waveform generator IC)
- PWM control over motors' rotation direction and speed
- QFN package soldering experience
- CAD modeling, STL slicing, and 3D-printing experience

Recommendations for Further Work

- Finish DSP and DL algorithms to construct images, so that the quality of the image can be examined and potentially improved through parameter tuning
- Further integrate the PCB design to minimize space and weight cost
- Explore different coil designs (i.e. different area, multi-layer coils) to optimize both the coil sensitivity as well as image resolution
- Implement more sophisticated feedback control loop for the gear-motors to achieve precise control motions such that the rotational angles can be accurately measured
- Embed more powerful microcontrollers to expedite data transmission rate, which would further reduce the overall scan time of the device
- Embed more powerful ADCs to increase the conversion rate of coil signals
- Implement pre-amplifier and amplifiers to enhance signal received by the control unit

Thank you!

Please feel free to ask any questions.

Contact Information:
Yaokun Shi: yaokuns2@illinois.edu
Zexuan Cheng: zexuanc2@illinois.edu
Yujiang Han: yujiang3@illinois.edu

The Grainger College of Engineering

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN