Team 54
Portable MRI Device
ECE 445

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

5/21/2022
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
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

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

<table>
<thead>
<tr>
<th>Base Magnetic Field Design</th>
<th>90mT</th>
<th>160mT</th>
<th>90mT</th>
</tr>
</thead>
<tbody>
<tr>
<td>75mT</td>
<td>100mT</td>
<td>75mT</td>
<td></td>
</tr>
<tr>
<td>90mT</td>
<td>160mT</td>
<td>90mT</td>
<td></td>
</tr>
</tbody>
</table>

Zero position

<table>
<thead>
<tr>
<th>30 degree</th>
<th>90mT</th>
<th>120mT</th>
<th>90mT</th>
</tr>
</thead>
<tbody>
<tr>
<td>75mT</td>
<td>90mT</td>
<td>75mT</td>
<td></td>
</tr>
<tr>
<td>105mT</td>
<td>140mT</td>
<td>105mT</td>
<td></td>
</tr>
</tbody>
</table>

30 degree
Radiofrequency Coil Design
Functionality (transmitter)

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

Design Details

Atoms being excited 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 excited by the transmitting field.

Surface array-coil as receiver
## Requirement and Verification

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

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

MCIk output  AD9837 output
Larmor Frequency

<table>
<thead>
<tr>
<th>Position</th>
<th>Frequency 1</th>
<th>Frequency 2</th>
<th>Frequency 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero position</td>
<td>3.8322MHz</td>
<td>6.8128MHz</td>
<td>3.8322MHz</td>
</tr>
<tr>
<td></td>
<td>3.1935MHz</td>
<td>4.258MHz</td>
<td>3.1935MHz</td>
</tr>
<tr>
<td></td>
<td>3.8322MHz</td>
<td>6.8128MHz</td>
<td>3.8322MHz</td>
</tr>
<tr>
<td>30 degree</td>
<td>3.8322MHz</td>
<td>5.1096MHz</td>
<td>3.8322MHz</td>
</tr>
<tr>
<td></td>
<td>3.1935MHz</td>
<td>3.8322MHz</td>
<td>3.1935MHz</td>
</tr>
<tr>
<td></td>
<td>4.4709MHz</td>
<td>5.9612MHz</td>
<td>4.4709MHz</td>
</tr>
</tbody>
</table>

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

\[ f = \gamma \cdot B_0 \]

Where \( f \) is the Larmor frequency (MHz), \( \gamma \) refers to the gyromagnetic ratio for specific atoms, and \( B_0 \) is the base magnetic field strength (T).
Control Logic

Begin Operation

- Rotate Motors
- Send information to IMU

Rotation Count >= 10?

- No
  - Send Rotation count to each slave
  - Request information from each slave
- Yes
  - Rotate motors back to zero position
  - Finish operation (Halt)

Master Microcontroller

Slave Microcontroller

- Master sent rotation count?
  - Yes
    - Send digitized coil data to master
    - Collect data from each coil
  - No
    - Send corresponding Larmor frequencies
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

Fast Fourier Transform

DL Algorithm

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