MRI Compatible Motion Platform

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Problem Statement

Tissue phantoms used for the testing and calibration of quantitative magnetic resonance imaging (qMRI) are typically static replicas of the human body. However, these static models fall short in accurately capturing the continuous motion due to natural physiological processes, such as respiration and digestion. To address this limitation, a specialized MRI-compatible device capable of positioning a phantom and replicating physiological movements will be developed to enhance the accuracy of qMRI evaluations.

Motivation and Background

qMRI Technology

- Used to detect tissue composition, diagnose and monitor disease, and determine drug efficiency [1][2]
- Allows for earlier and noninvasive detection of diseases, such as steatosis [3]
- Phantoms are required to calibrate encoded techniques and test the accuracy and precision of imaging methods [4]

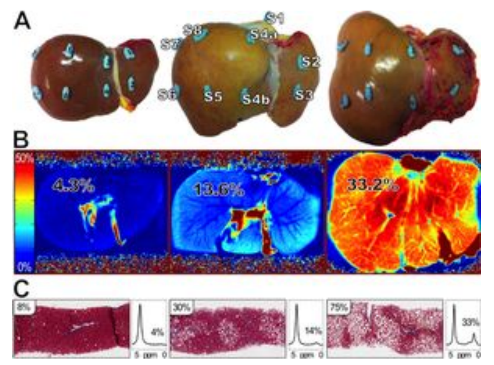

Figure 1. qMRI of Diseased vs Healthy Liver [7]

Current Solution – Breath Holds

- Required because respiratory motion produces image artifacts [5]
- Implications:
  - Short data acquisition time, typically 10 to 30s [5]
  - Children, severely ill, or sedated patients are unable to perform [6]

Motor Calculations

- Position = 3 cm × sin(2π×(8/60)×t)
- Velocity = 3 cm × (π×8/30) × cos(π×(8/30)×t)
- Acceleration = 3 cm × $(\pi\times8/30)^2$ × sin(π×(8/30)×t)
  - Max Acceleration = 2.1 cm/s^2
- Required Torque = r×m×a = 21.64 cm × 4 kg × 2.1 cm/s^2
  - Calculated = 1.82×10^{-3} N m
  - Motor Specification = 1.2 N m

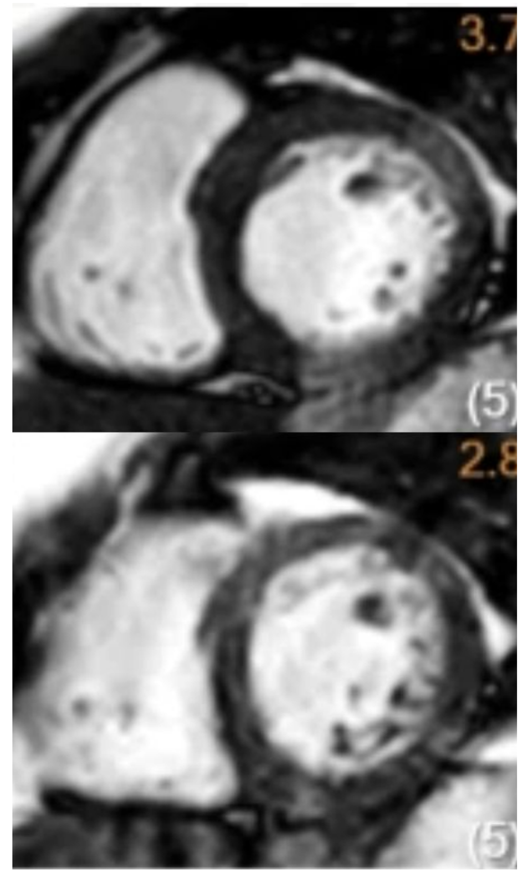

Figure 2. MRI with breath hold (top) and without (bottom) [6]

Design Criteria

Criteria	Specification
Accuracy	Sine wave of 8 cycles per min with an amplitude of 3 cm [8]
Reliability	Consistent sinusoid for 10-15 minutes to 5% deviation [9]
Accessibility	Non-complex fabrication techniques using commercially available parts
Weight	Needs to support at least 4 kg [10]
Size	Platform larger than 25 cm by 35 cm [10]
Cost	Within budget ($1000)
Safety	MRI compatible

Final Design and Prototype Fabrication

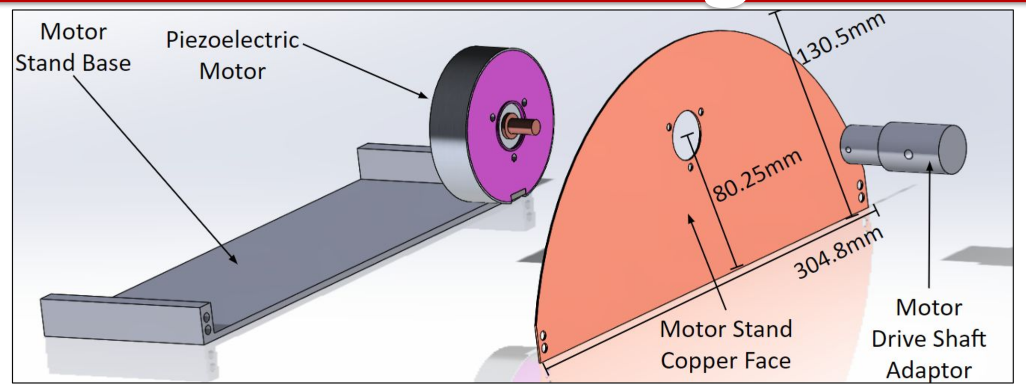

Figure 3. Motor Stand Assembly

Motor

Piezoelectric motor is fed sinusoidal waves by a microcontroller outside of the MRI room. Motor is placed 5ft from MRI bore and is held by a copper sheet. It transfers rotational motion to a pvc pipe driveshaft.

- Motor and microcontroller were provided by the client
- Copper face and motor to drive shaft adaptor were fabricated in the TEAM Lab
- Motor stand bottom was 3D printed in the Makerspace

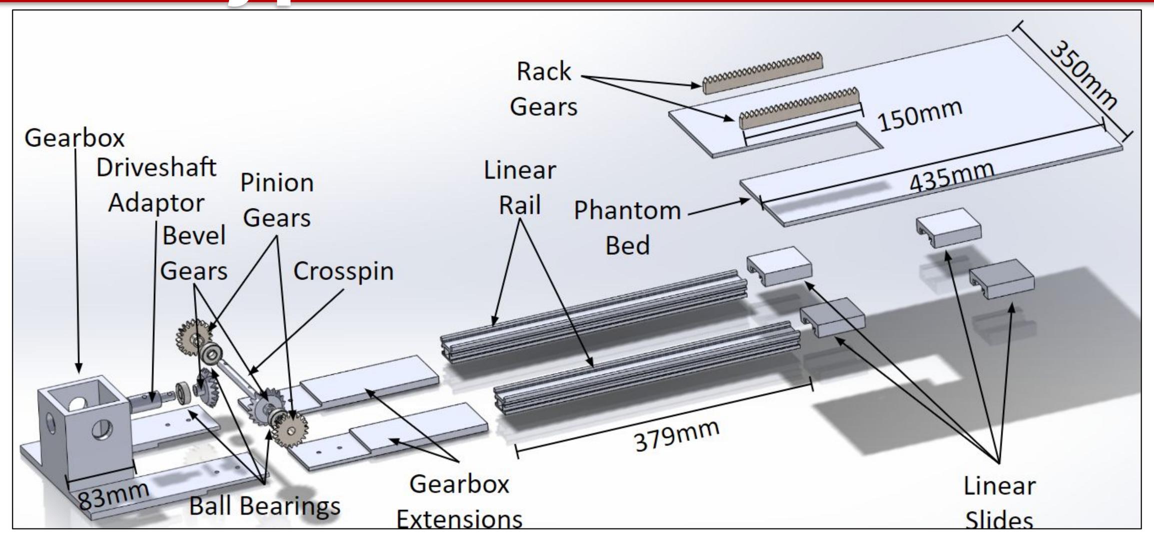

Figure 4. Gearbox and Platform Assembly

Gearbox

Rack and pinion takes rotational motion from the motor and converts it to linear motion efficiently for the phantom bed to oscillate to. To be MR compatible and to not affect image quality, the gearbox assembly contains no metal.

- Gearbox, Extensions, Bevel Gears, and the Rack and Pinion were 3D printed in the Makerspace
- Driveshaft Adaptor, Crosspin, and the Phantom bed were fabricated in the TEAM lab
- Linear Rail, Slides, and bearings were provided by the client

Testing and Results

Sinusoidal Motion Test

Motor Control: V = A×sin(2π×f×t)

- A = 10 RPM = 2.705 cm/s
- f = 8/60 cycles/s

Expected Displacement: D = A/(2π×f×t)×cos(2π×f×t)

Kinovea Software

- Track displacement of point on platform
- Export tracking data to Excel

Time between Peaks **(T = 7.50 s)**

- 0kg: 7.50 ± 0.4 s | 3.87% error
- +4kg: 7.50 ± 0.7 s | 7.30% error

Peak to Peak Amplitude **(A_{P-P} = 5.41 cm/s)**

- 0kg: 4.619 ± 0.07 cm | 14.63% error
- +4kg: 4.685 ± 0.05 cm | 13.39% error

Motor RPM Test

- 20 RPM ⟶ 15.6 ± 2 RPM
- 40 RPM ⟶ 26.6 ± 1 RPM
- 60 RPM ⟶ 50.7 ± 10 RPM

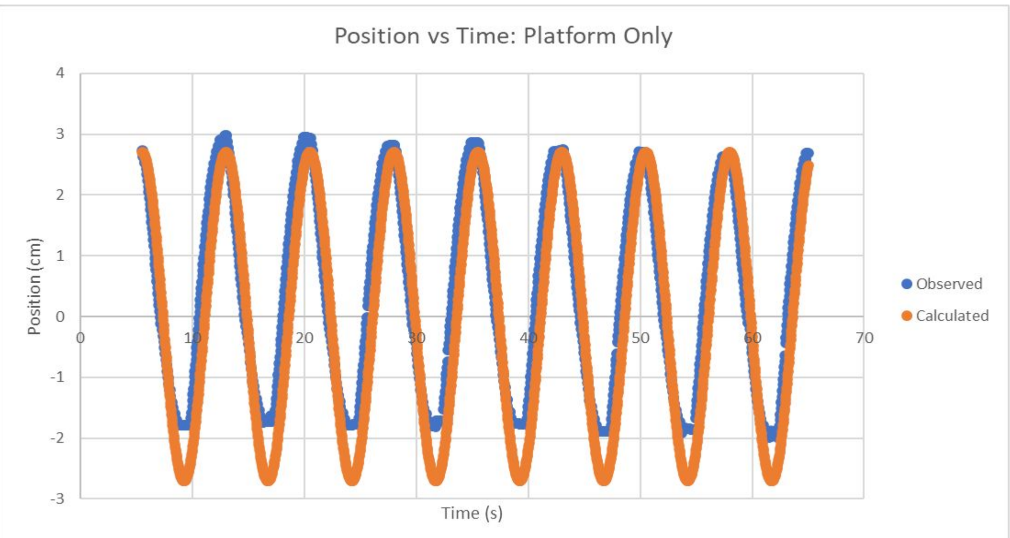

Figure 5. Platform movement during sinusoidal motion

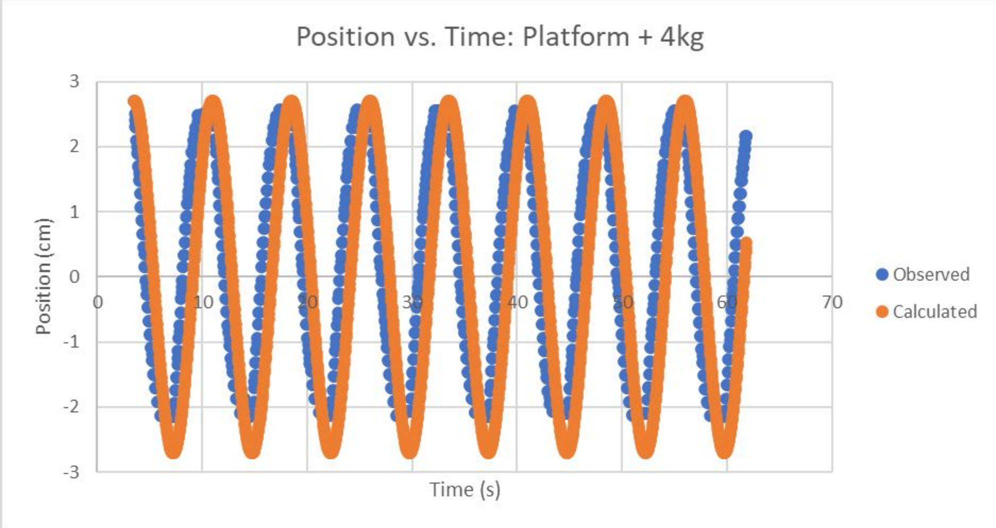

Figure 6. Platform movement with additional 4kg weight

Discussion

Result Implications

- Expected displacement is not consistent with experimental displacement
- Wave lags expected position as weight is added
- RPM is slower in reality than code expects

Sources of Error

- RPM to Voltage conversion
- Kinovea tracking software
- Motor Acceleration
- Friction between rails and sliders
- Play between gears

Figure 7. Kinovea tracking

Future Work

- Incorporate required changes
  - Improve RPM to Voltage conversion in code
  - Create feedback loop using absolute position reading from encoder
  - Improve design to reduce friction and optimize gear interactions
  - Assemble with non-magnetic screws
- MRI Testing
  - Repeat sinusoidal motion test in MRI setting
  - Imaging test with known phantom
  - Compare performance with competing design
- Potential directions
  - More advanced sinusoidal motion
  - Additional degrees of freedom
  - Full construction manual

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References

[1] A. Seiler et al., "Multiparametric Quantitative MRI in Neurological Diseases," Front. Neurol., vol. 12, 2021, Accessed: Oct. 09, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fneur.2021.640239

[2] K. E. Keenan et al., "Recommendations Towards Standards for Quantitative MRI (qMRI) and Outstanding Needs," J. Magn. Reson. Imaging JMRI, vol. 49, no. 7, pp. e26–e39, Jun. 2019, doi: 10.1002/jmri.26598.

[3] P. Bannas et al., "Quantitative magnetic resonance imaging of hepatic steatosis: Validation in ex vivo human livers," Hepatology, vol. 62, no. 5, pp. 1444–1455, Nov. 2015, doi: 10.1002/hep.28012.

[4] W. T. Reichert, "A Simple Multi-Parametric Quantitative MRI Phantom".

[5] D. A. Feinberg, N. M. Rofsky, and G. Johnson, "Multiple breath-hold averaging (mba) method for increased snr in abdominal mri," *Magn. Reson. Med.*, vol. 34, no. 6, pp. 905–909, 1995, doi: 10.1002/mrm.1910340617.

[6] M. Kocaoglu, A. S. Pednekar, H. Wang, T. Alsaied, M. D. Taylor, and M. S. Rattan, "Breath-hold and free-breathing quantitative assessment of biventricular volume and function using compressed SENSE: a clinical validation in children and young adults," *J. Cardiovasc. Magn. Reson.*, vol. 22, no. 1, p. 54, Jul. 2020, doi: 10.1186/s12968-020-00642-y.

[7] "Nonalcoholic fatty liver disease - Symptoms and causes," Mayo Clinic. Accessed: Oct. 09, 2023. [Online]. Available: https://www.mayoclinic.org/diseases-conditions/nonalcoholic-fatty-liver-disease/symptoms-causes/syc-20354567

[8] J. Tang, J. Rice, J. Gwertzman, S. Reeder, A. Roldán-Alzate, and D. Hernando, "Development of an MR-Compatible Motion Phantom to Evaluate Motion-Robust Quantitative MRI", Accessed: Sep. 11, 2023. [Online]. Available: https://uwmadison.app.box.com/s/fp4knxj8nk4ww1j3frqtb91l75v0v2a0

[9] J. Nofiele et al., "An MRI-Compatible Platform for One-Dimensional Motion Management Studies in MRI," Magnetic resonance in medicine, vol. 76, no. 2, p. 702, Aug. 2016, doi: 10.1002/mrm.25903.

[10] "Liver Phantom — The Phantom Laboratory." https://www.phantomlab.com/liver-phantom (accessed Sep. 22, 2023)