qMRI Motion Platform

Kendra Besser, Amber Schneider, Max Naslund, Jamie Flogel, Caspar Uy

Description of how the tool can be used to advance MRI research.

Quantitative magnetic resonance imaging (qMRI) is a promising paradigm shift to measure physical quantities with MRI instead of qualitative imaging. Healthcare professionals can utilize qMRIs to assist in many functions, such as detecting tissue characteristic changes over time, diagnosing and monitoring diseases, and determining treatment efficacy. In particular, fat quantification MRI has demonstrated potential for the noninvasive diagnosis and staging of steatotic liver disease. Current fat quantification protocols require the patient to practice breath holds during the imaging to mitigate motion artifacts. Breath hold techniques can be very challenging for pediatric, elderly, severely ill, and sedated patients. Developing a fat quantification technique that is robust to respiratory motion will help support patients that cannot perform breath holds. Our device, in conjunction with organ phantoms, can be used to test MRI protocols for motion robustness and contribute towards the validation of free-breathing techniques. The device replicates natural physiological motions to move organ phantoms.

Current competing designs vary in functionality and availability. The University of Texas Southwestern Medical Center developed a one-dimensional MRI compatible motion platform. The motorized stage could follow sinusoidal, harmonic, random, or user-defined trajectories; however, it is not on the market for outside use. The Vital Biomedical Technologies MRI Compatible Multi-Modality Motion Stage performs trajectories loaded from a micro-SD card.

This product is limited in phantom compatibility and cannot support the weight of a large phantom. The Quasar MRI Motion Phantom is an MR safe programmable phantom. It is intended to be used to test deep inspiration breath hold protocols. This design limits what phantoms can be used as it can only hold specific cartridges provided by the company. Both commercially available products are over $30,000, making them inaccessible to many research labs. The purpose of our design is to be accessible and easy to replicate. The motion platform was designed using commonly available fabrication techniques and commercially available parts. Additionally, the product was designed to accommodate a variety of phantom sizes and shapes.

Description of tools functionality and capabilities.

The MR safe product consists of two sub-assemblies connected together via a 5' driveshaft. One side of the driveshaft is the motor assembly which would sit on the end of the MRI bed outside of the bore. This motor assembly consists of a Tekceleo WLG-75-R piezoelectric motor held in place by a copper sheet. This copper sheet is screwed directly to the face of the motor and provides a means to cool the motor. The motor is connected through a waveguide to a microcontroller that sits outside of the MRI room. This microcontroller is where sinusoidal waves are input to in turn control the motor. The motor firmware can implement a variety of realistic breathing motions. It can generate a sinusoidal waveform with a frequency ranging between 4 to 20 cycles per minute and a range of motion between 1 to 6 cm. Rotational motion from the motor is transmitted down the driveshaft to the gearbox assembly which sits within the MRI bore. The gearbox assembly converts rotational motion to linear motion via a rack and pinion design. The translated linear motion oscillates a phantom bed on the linear slides and rails according to the input sinusoidal wave.

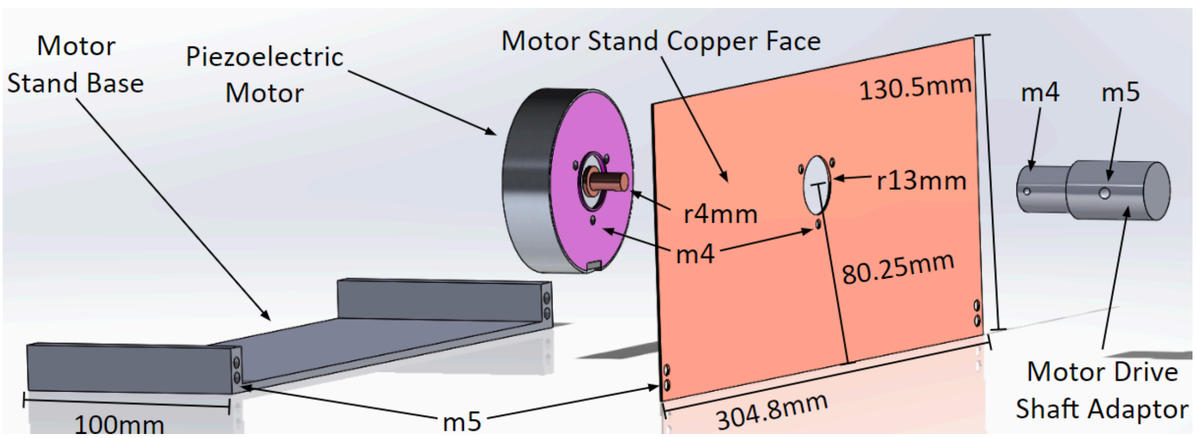

Figure 1. Motor Assembly SOLIDWORKS

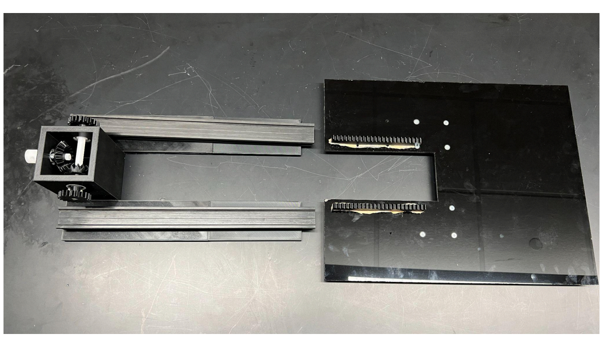

Figure 2. Gearbox Assembly Platform Removed

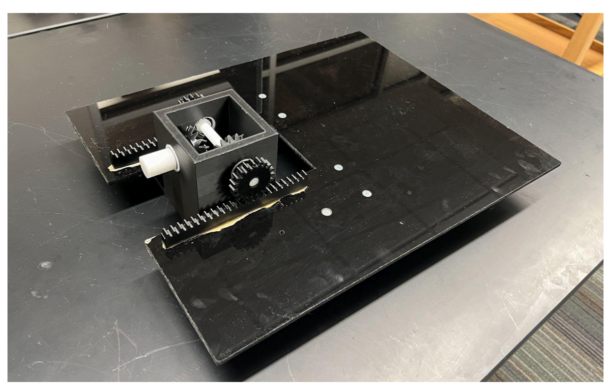

Figure 3. Gearbox Assembly Assembled

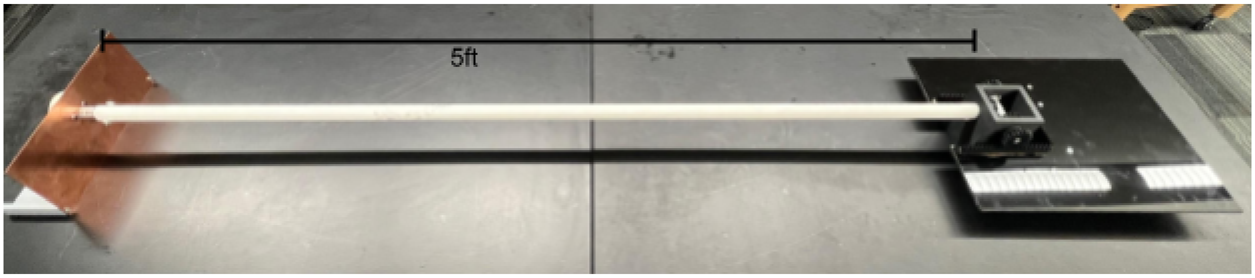

Figure 4. Final Assembly

After assembling the prototype, a sinusoidal motion test was run. This test produced period and peak to peak amplitude data of the platform's motion. Significant errors in these values lead to performing a motor RPM test. This test revealed issues with the RPM to voltage calculation in the motor code. Additionally, during operation the prototype exhibited unanticipated play between the gears, limiting the precision of the design. To account for these errors, the gearbox was redesigned with tighter tolerances and an updated gear ratio of 1.5:1. The software was experimentally calibrated to a more accurate conversion coefficient. After re-running the sinusoidal motion test, these modifications were proven to improve the precision and accuracy of the sinusoidal motion to within acceptable tolerances. The prototype was then tested with loads of 0, 1.5, and 3.5 kg. The results concluded that the period was consistently under 1.5% error and the amplitude was under 5.5% error. Final testing was done in the MR environment. The prototype was deemed MR safe and functioned properly within the MRI while running various scans.