MRI Compatible Motion Platform

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Tissue phantoms used for the testing and calibration of quantitative magnetic resonance imaging (qMRI) protocols are typically static replicas of the human body. However, these static models fall short in accurately portraying continuous motion found in natural processes, such as respiration and digestion. To address this limitation, a specialized MR-compatible device capable of positioning a phantom and replicating physiological movements was developed to allow for the recalibration of qMRI protocols to account for respiratory motion. The sinusoidal motion of qMRI is a new and developing MR technique that measures specified characteristics of the tissues being imaged. Existing qMRI protocols require patients to perform breath holds during scans to reduce image artifacts, a task that proves challenging for many. To develop robust qMRI techniques, an MR compatible phantom motion platform is necessary for validation.

Existing commercial products exhibit limited scope and high costs. Vital Biomedical Technologies produces a motion platform which can be loaded with a variety of trajectories by the user, but has restricted phantom compatibility. The Quasar MRI Motion Phantom is another MR safe programmable phantom. This device can only operate using specialized phantom cartridges purchased from the company. Both of these products cost over $30,000.

To begin the project, the client provided key MRI compatible materials and ideal ranges for the platform design to achieve. A Product Design Specification (PDS) was developed to include these restrictions, along with tolerances defined to measure our progress against during prototyping. An initial gear ratio of 1:1 was selected to accommodate the client’s piezoelectric motor, while 8 cycles/minute and 2.705 cm amplitude were programmed into the sinusoidal motion function. A rack and pinion was custom printed to convert the rotational motion of the motor to linear motion. The motor was connected to a 3D printed gearbox via a PVC drive shaft to distance the motor from the bore of the MRI, preventing imaging artifacts. Within the bore sits a plastic platform on carbon fiber linear rails and slides. It can support phantoms weighing up to 4 kg and a base area of 25 cm^2.

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 that was then analyzed. Significant error 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 values within the tolerances specified in the PDS. 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 of liver phantoms. For the broadest application, this design supports a large variety of phantoms and can produce sinusoidal motion of varying frequencies and amplitudes. This design is significantly less expensive than current commercially available devices, making it more accessible to researchers. This project will continue as an open-source resource for universal use in MR research applications.