A Simple-to-Build and Cost-Efficient MR-Compatible Phantom for the Simulation of Non-Rigid Motion

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TARGET AUDIENCE

Researchers in the field of 4D MRI, MR motion correction and MR-based multi-modal motion correction.

PURPOSE

Phantom studies are very helpful in the absolute evaluation of motion correction algorithms. While the simulation of rigid motion is relatively straight-forward, reproducible non-rigid motion is more difficult to mimic, especially when MR-compatibility is required. Existing models are either very sophisticated and thus hard to reproduce [1] or require medical equipment such as respirators [2]. To overcome these problems, we suggest an easy-to-build and cost-effective motion phantom which is driven by compressed air. It is controlled by simple stand-alone electronics which controls a solenoid valve, switching between inspiration and expiration.

METHODS

The pneumatic circuit, which controls the phantom, is shown in Fig. 1. The main component, a 3-way solenoid valve, is controlled electronically and determines the respiration phase (inspiration/expiration). An additional, manually operated needle valve (top) can be used to pre-fill the phantom. Two flow limiter valves (bottom) can be used to individually control the velocity of the inspiration and expiration phases and thus the total period as well.

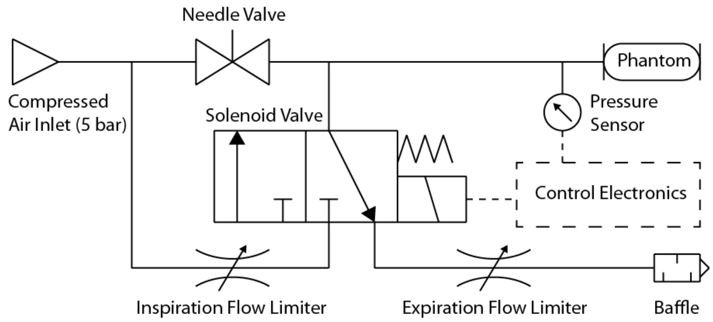

Fig. 1: The pneumatic circuit driving the respiration phantom. The control electronic monitors the pressure in the phantom and controls a solenoid valve switching between inspiration and expiration. The needle valve at the top can be used to pre-fill the phantom, the two flow limiter valves at the bottom are used to control the inspiration and expiration velocity.

The pressure in the phantom is measured using a piezoelectric pressure sensor. Due to pressure waves, which occur when switching on the solenoid valve, it is important to place the sensor far from the valve to guarantee stable operation. This is done conveniently by splitting the tube close to the phantom and using a second tube to connect the pressure sensor outside the scanner. This has the advantage of adding a lowpass-behavior to the measured signal. The electronics implements a simple 2-point control, switching the valve at user-defined bottom/top pressure values, thus controlling the motion amplitude.

The phantom consists of a water-filled cylindrical acrylic glass tank with detachable lid. The balloon's air supply tube exits the phantom through a water-proof cable fitting in the lid. The fitting also serves as the balloon's mechanical fixation.

RESULTS

For evaluation of the phantom's repetition accuracy, a Compressed Sensing accelerated single-slice 2D spoiled gradient echo sequence (TE = 2.04 ms, TR = 4 ms) was continuously measured for 4 min (0.3 s time resolution). From these images, a single line, showing the air/water-transition was chosen and plotted over time (Fig. 2). From this image, the mean and standard deviation of the motion period was measured to $T = 4.31 \pm 0.17$ s (coefficient of variation (CV) = 0.041) and the amplitude to $\Delta x = 8.22 \pm 0.51$ mm (CV = 0.062).

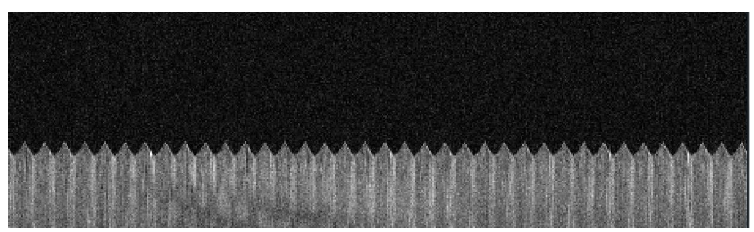

Fig. 2: Respiration image obtained by plotting one line of a repeatedly measured 2D spoiled gradient echo image over time.

DISCUSSION

We propose a building scheme for a MR-compatible motion phantom, which simulates reproducible non-rigid motion. The fluctuations in both period and amplitude are very low. More complex motion can be achieved by adding multiple water/oil-filled cushions into the phantom. In enabling other groups to easily copy the described design, we will provide a detailed building instruction and the source code of the control electronics. To facilitate easy firmware changes and make additional programming hardware obsolete, the required electronics will be implemented as Arduino shield.

CONCLUSION

A simple-to-build respiration phantom is proposed, which can be helpful for researchers in the field of non-rigid motion monitoring and correction.

REFERENCES

[1] Fieseler M, et al. *Nucl Instrum Methods Phys Res A.* 2013;702:59-63. [2] Tokuda J, et al. *Magn Reson Imag*.2008;59:1051-61.