Design and Manufacture of Anatomically Realistic, Actuated, Elastic Lung Inserts for PET/CT Phantom Studies with Respiratory Motion

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INTRODUCTION

Patient motion during Positron Emission Tomography (PET) scans can be a major detriment to image quality, leading to quantification errors and radiologists potentially missing malignant lesions. In order to analyse the impact of motion on image quantification and lesion detection, anthropomorphic phantoms with accurate anatomy and realistic motion are needed. In this work we present such a phantom, which builds off the state of the art in humanoid phantom anatomy by adding elastic lungs with a highly controllable, realistic breathing mechanism to an existing, proven anatomically accurate phantom [1].

Anthropomorphic phantom modified for mechanical breathing

AIM

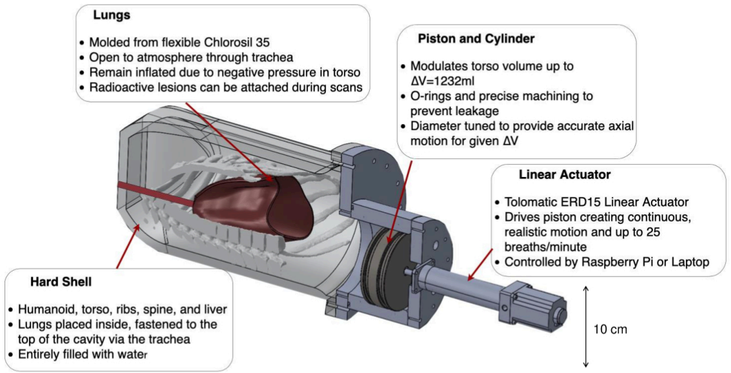
To build realistically-shaped, elastic lung inserts with an actuation mechanism for an anthropomorphic phantom for analysis of the effect of respiratory motion on quantification of PET/CT images.

METHOD

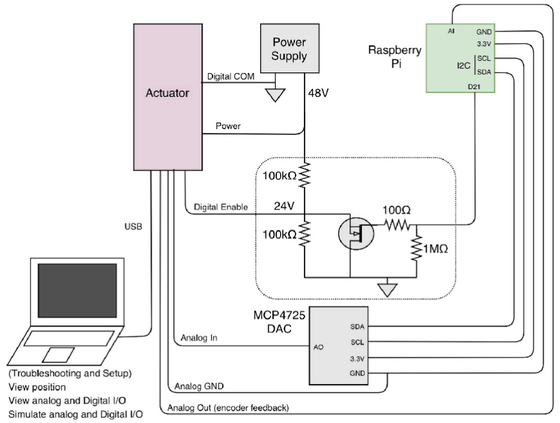
- A static anthropomorphic torso phantom [1] was modified to add accurate respiratory motion.
- The phantom's outer shell is cast as a single component with an open base, sealed by a polycarbonate plate and O-ring.
- The internal space and organs (excluding the lungs) are filled with radioactive water solutions to model natural tracer distribution in the body.
- Realistically shaped lungs were manufactured by rolling a silicone elastomer, Chlorosil-35 [2], onto a 3D-printed mold.
- A water-tight base was constructed for the phantom that includes a Delrin piston mechanism, mounted onto a waterjet-cut polycarbonate base plate.
- The piston mechanism is driven by a programmable linear actuator[3] to create a pressure differential inside the phantom, causing the lungs to inflate and deflate.
- A Python interface and control system were developed to simulate custom respiratory waveforms with the phantom via a Raspberry Pi.

RESULTS

All the components excluding the lungs have been fabricated, assembled and tested. Initial tests show the breathing mechanism to be realistic and reliable, with no leaks and little risk of failure. Tidal volumes of up to 1232ml can be achieved at up to 25 breaths per minute. At 0.5L tidal volume (relaxed breathing for adult male), the lungs extend 3cm axially, which is anatomically accurate [4]. At very large tidal volumes (>1L), extension is slightly larger than is realistic due to lack of ribcage expansion from intercostal muscles, which in reality causes additional lateral expansion. Due to COVID-19, lung fabrication has been delayed but is currently underway as restrictions are easing in British Columbia.



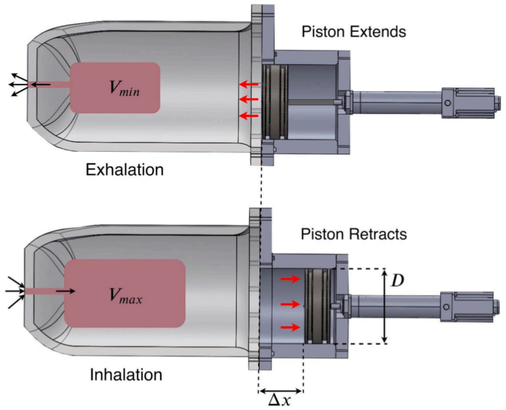
Overview of phantom components



Schematic of analogue position control set up

Respiratory Motion

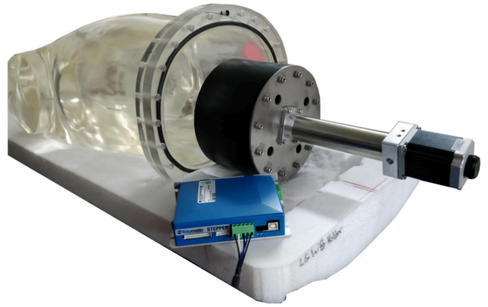
- Achieved by modulating the volume of the whole phantom.
- Phantom is sealed, and entirely filled with incompressible water, except for the air-filled lungs. Changing its volume by ΔV induces an equal volume change of ΔV in the lungs:
- To set up the phantom, the lungs are filled with air to their maximum inhalation volume and sealed. Then the phantom is filled and sealed, and the lungs are opened to the atmosphere.
- The lungs will not collapse under the pressure of the water since the water volume is constant, and cannot expand to fill the space created if the lungs were to collapse.
- This creates a relative negative pressure in the liquid above the lungs, just as human breathing relies on negative intrapleural pressure.
- Changing the volume of the torso by extending and retracting the piston will cause that volume of air to be expelled or sucked in from the atmosphere



Respiratory mechanism through piston actuated passive breathing

CONCLUSIONS

The existing anthropomorphic phantom was retrofitted with actuated lungs that have realistic shape and motion. The improved phantom can model a wide variety of respiratory waveforms, thus facilitating quantitative analysis of the impact of respiratory motion on the quantification and detectability of cancer lesions in PET images.



Assembled breathing mechanism with empty phantom

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REFERENCES

[1] D.J. Kadrmas, M.E. Casey, N.F. Black, J.J. Hamill, V.Y. Panin, M. Conti."Experimental Comparison of lesion detectability for four fully-3D PET reconstruction schemes." IEEE Trans Med Imaging. 2009, vol 28, pp. 523–34.
[2] Ottobock, Germany
[3] Tolomatic Inc., USA
[4] O.L. Wade. 'Movements of the thoracic cage and diaphragm in respiration'. Journal of Physiology. 1954, vol. 124, pp. 193–212.

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