Mapping Breathing Induced Liver Movement Using Ultrasound

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Introduction

The main purpose of medical simulation is to educate students and practitioners in the health sector by using high technology simulators. According to the records published by Institute of Medicine, approximately 44000 to 98000 deaths were recorded primarily due unexpected mistakes during treatments (Institute of Medicine, 2000). Due to increased complexity of medical treatments, it is essential to tailor these simulators to provide specific and accurate information to the users. Providing the necessary information to users will help them to understand the nature of what they are working with and also in the case of errors, to understand their mistakes. The long term goal of simulators has been to replicate certain health conditions that may have minimum level of tolerance for human errors during treatments. In fact having these simulators minimizes the intervention of human beings in the first place during training purposes.

Objective

- Formulate a method to track induced liver motion due to respiratory and cardiovascular system; that could be further used in patient simulator system.
- Use of ultrasound imaging techniques to locate position and movement of liver segments.

System Modelling

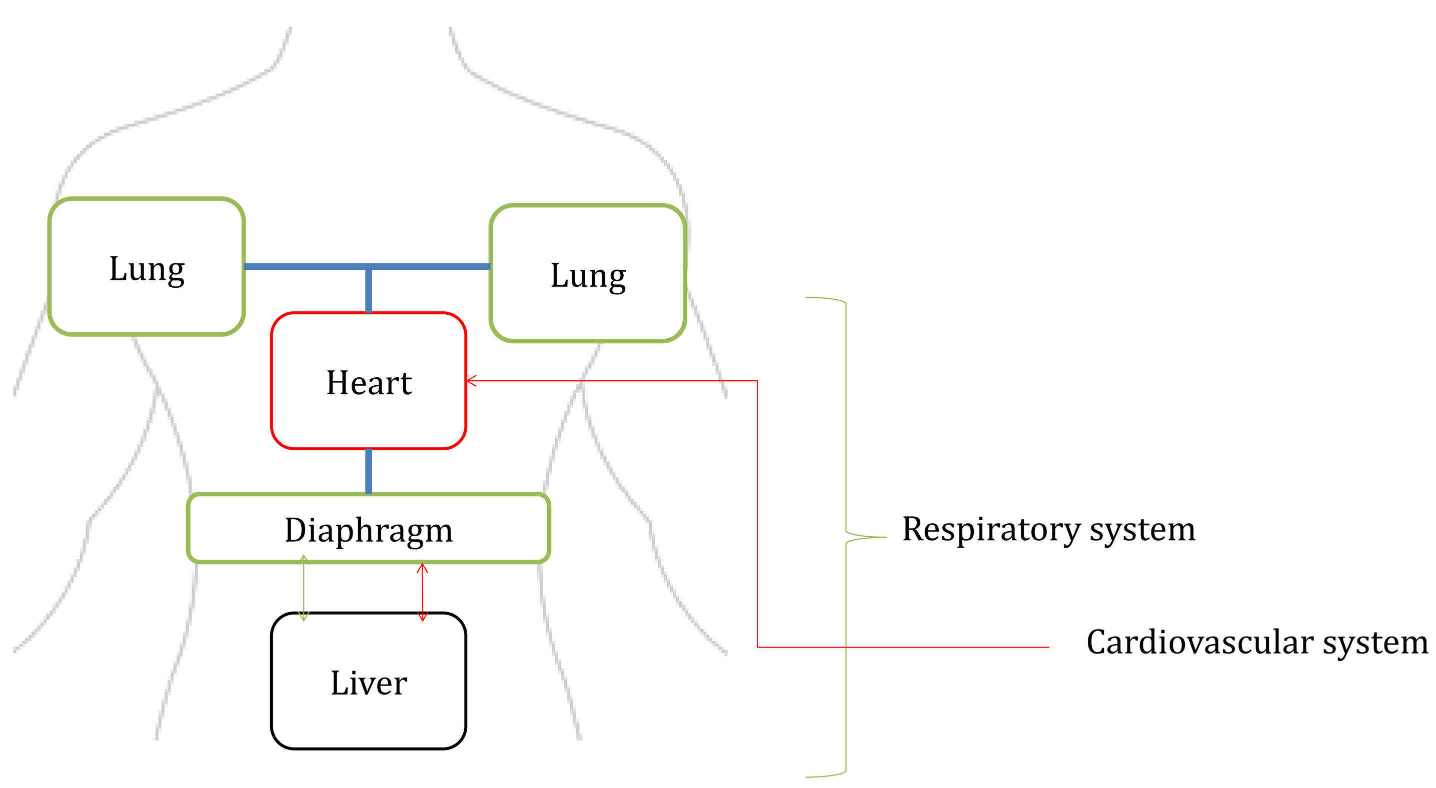


Figure 1 – Schematic diagram of modelled system

Motion of liver is affected by both respiratory and cardiovascular system

Respiratory system induced movement

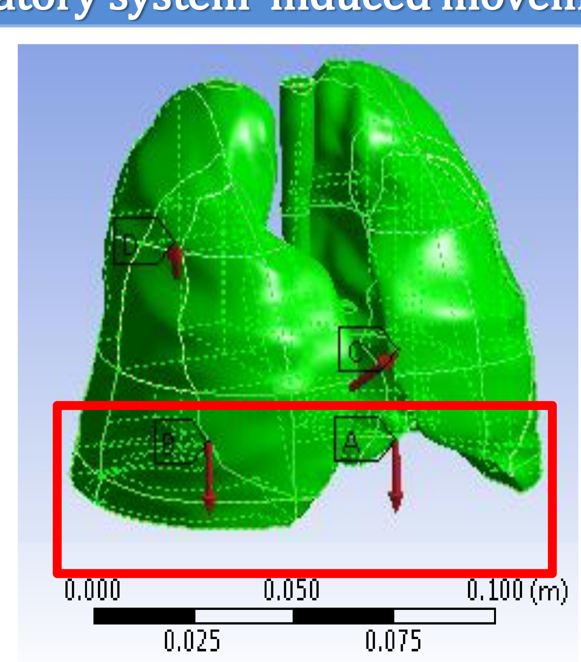


Figure 2 - Lung simulation and representation of external forces acted on lung surfaces. *(De Mel R, Chauhan S, 2015)*

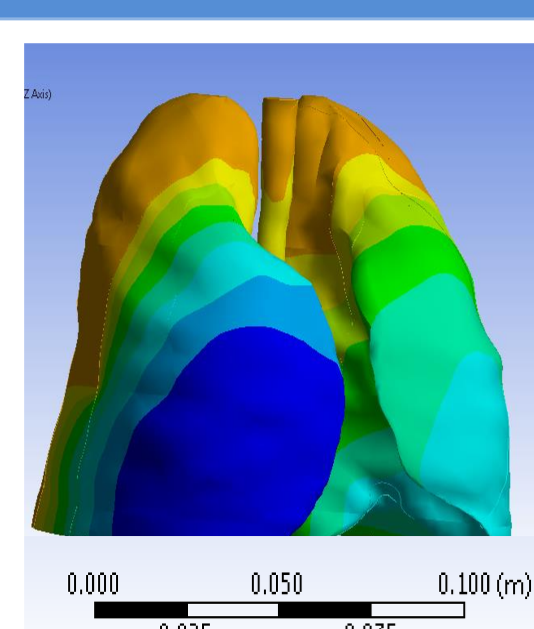


Figure 3 – Most effective lung deformation that is acted on liver *(De Mel R, Chauhan S, 2015)*

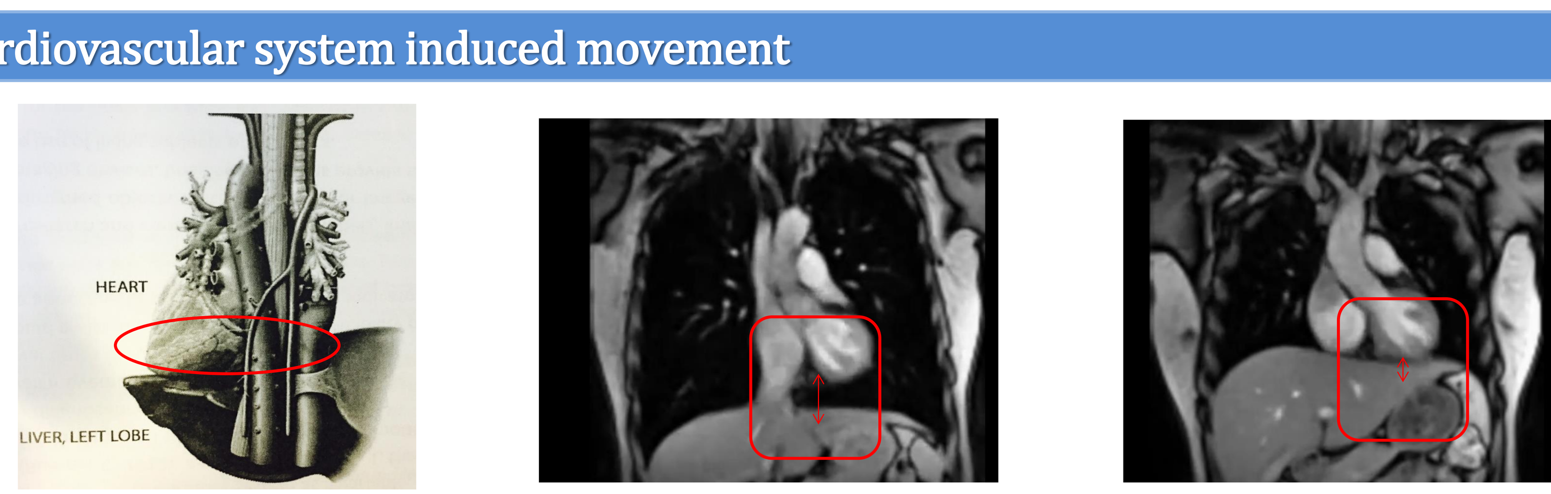
Resultant diaphragmatic displacement: 100 – 120 mm

Diaphragmatic force range: 3.84 – 46.12 N

Inhalation and exhalation causes chest cavity and diaphragm to expand /contract providing space for lungs to increase/decrease its volume.

Intermediate forces acting between lungs and diaphragm interface (forces A & D in fig.1) will ultimately cause a positive external force acted on the superior surface of liver.

Cardiovascular system induced movement



(a) (b) (c)

Figure 4 – (a) Interactions between heart and liver, (b) Inhale, (c) Exhale adapted from (Schunke 2006)

Deformation of liver due to heart movement is caused by the motion of liver during respiration. Heart is considered fixed with respect to liver.

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Motion modelling

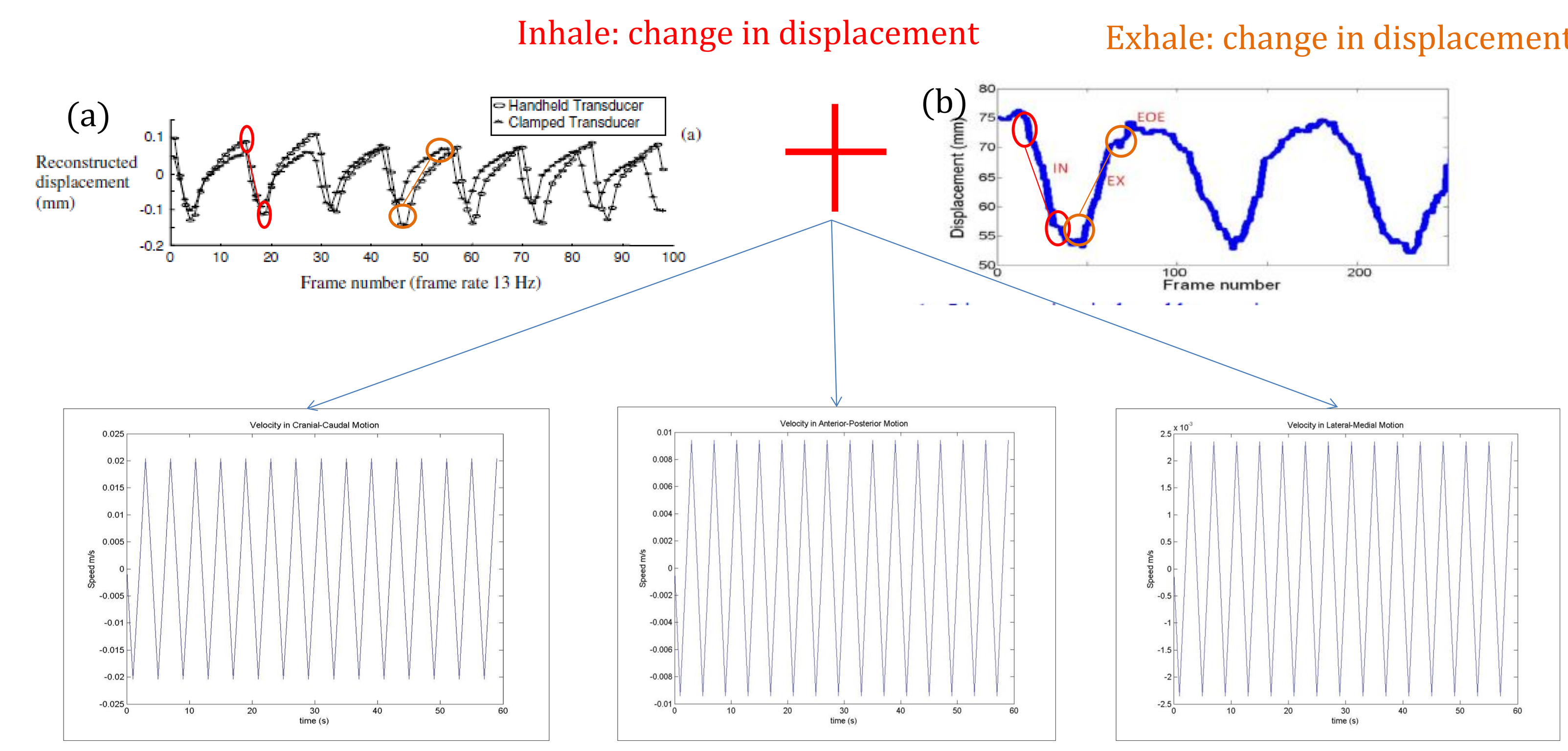


Figure 5 – (a)Motion component of lungs induced by heart adapted from (Alexander F. Kolen, N.R.Miller et al. 2004), (b)motion component of lungs induced by respiratory system adapted from (Ching-Kai Lin et al. 2012), (c) developed model based on integrated data (R. De Mel, I.S.Solomon, H.X.Pham, 2013)

Displacement model equation:

$$x(t) = dmax\omega cos(\omega t + \phi)$$

Velocity model equation:

$$v(t) = -dmax\omega \sin(\omega t + \phi)$$

X(t) is the path taken by the system for each axis of motion and V(t) is the velocity in during that path. 'dmax' is the maximum distance the model will travel at a given time frame and ideally Ø will be half of this value. Differentiating this equation yields velocity of the model at a given time; ω is the oscillation frequency.

Direction of motion	Magnitude (mm)
Cranial-Caudal	12-26
Anterior-Posterior	1-12
Lateral-Medial	1-3

Table 1 – An envelope for overall liver motion range

Mapping liver motion using real-time imaging ultrasound

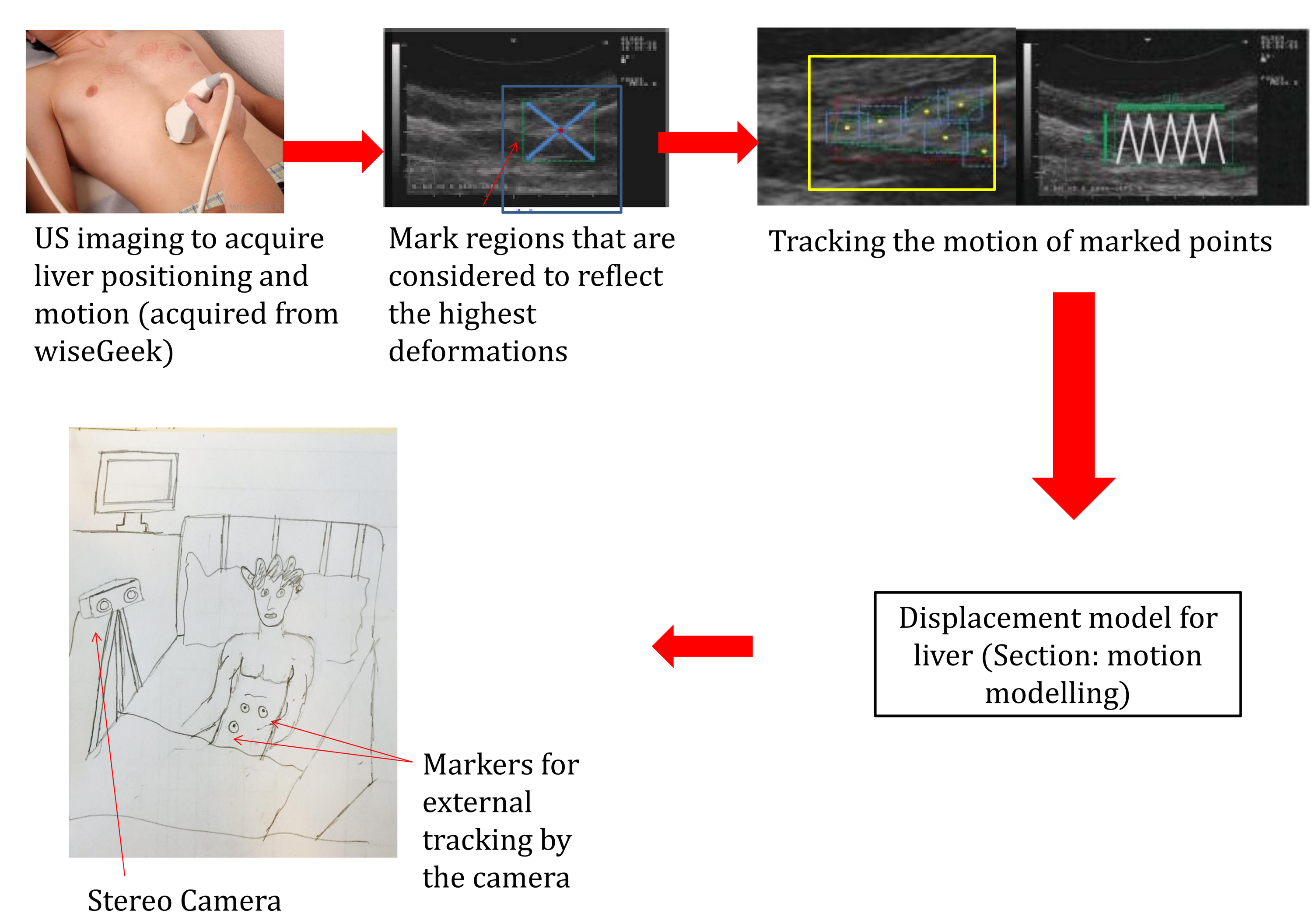
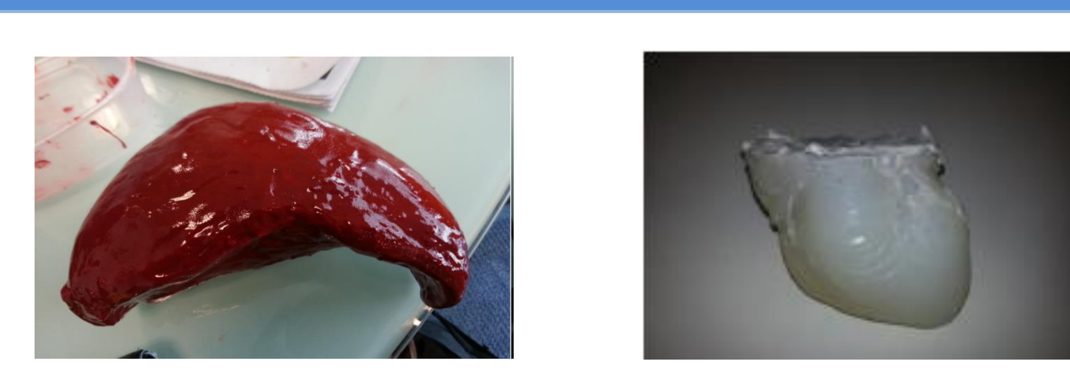


Figure 5 – Integration of ultrasound into external tracking of liver motion

Physical Simulation Models



(a) (b)

Figure 6 – Phantoms of liver (a) and heart (b) developed that could be used for external tracking and simulation purposes during training

Conclusion

For verification, given the respiration frequency combined with the US imaging frequency and maximum lung displacement envelope, a prediction of over motion could be attained. Predicted data can be compared with the real-time US image based data for consistency and reliable accuracy. However, it is quite evident that induced motion of liver is dominated by the respiratory system. The motion component from cardiovascular system is relatively insignificant thus could be neglected in extreme conditions.

References

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Kolen A.F, Miller N.R., Ahmed E.E, Bamber J.C. Charaterization of cardiovascular liver motion for the eventual application of elasticity imaging tothe liver in vivo. Physics in Medicine and Biology.2004;49(1):4187-4206

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