Scalable ultrasound calibration phantoms made from LEGO® bricks

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Purpose: In tracked ultrasound-guided systems, spatial calibration between the image and tracker coordinate space is a prerequisite, which is accomplished with precision machined phantoms. Perhaps the most widely used type of phantom is the N-Wire configuration [1], which nowadays is typically manufactured through 3D printing. This method is costly, requires access to a 3D printer, and does not allow easy modifications to the model. An alternative construction method is to use LEGO® bricks for the structure of the phantom. LEGO® bricks are manufactured with an error below 0.05 mm, and such a high level of accuracy and consistency offers an opportunity to construct ultrasound calibration phantoms from LEGO® bricks. In addition, the materials are easily accessible, cost effective, configurable and scalable. The premise of an ultrasound calibration phantom made from LEGO® bricks was previously introduced as an accessible, affordable tool that used the N-Wire calibration method [2]. The build repeatability across multiple users and the calibration precision were evaluated against a printed N-Wire phantom. The objective of this paper is to examine the viability of calibration phantoms made from LEGO® bricks, customized and scaled for different ultrasound transducers used in different clinical settings.

Methods: We present the assessment of the precision of ultrasound calibrations performed with two different ultrasound transducers and differently sized N-Wire phantoms made from LEGO® bricks, through comparison with standard 3D-printed phantoms. The two phantoms made from LEGO® bricks were close replications of existing 3D-printed phantoms [1, 3]. Of the phantoms made from LEGO® bricks, one accommodated a deeper imaging depth of 18 cm and the other accommodated a shallow imaging depth of 4.5 cm. All phantoms are shown in Figure 1 before wiring.

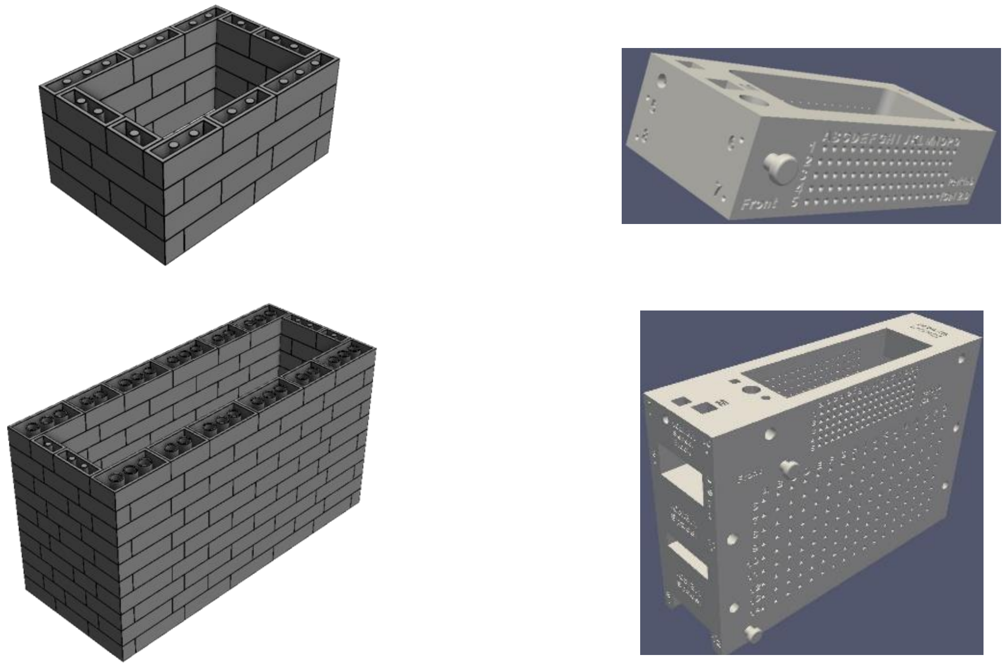

Figure 1: Ultrasound calibration phantoms made from LEGO® bricks and their size comparable 3D-printed equivalents. Top: Smaller phantoms accommodating shallow imaging depths. Bottom: Larger phantoms accommodating deeper imaging depths.

To test calibration precision, we used the Public Software Library for Ultrasound Research Software (PLUS) Toolkit (http://www.plustoolkit.org) [3], with a SonixTablet (Ultrasonix, Richmond, British Columbia, Canada) ultrasound scanner and a SonixGPS (Ultrasonix) electromagnetic tracking system. With the shallow phantoms, we used a L14-5/38 Ultrasonix linear probe. With the deep phantoms we used a C5-2/60 Ultrasonix convex probe. We performed all calibrations in water at room temperature.

Results: Five calibrations were performed with each phantom, and the 3D reprojection error average and standard deviation were recorded for each calibration. The 3D reprojection error was defined as the root mean square difference between calculated ultrasound probe-to-image transformations at different probe positions. In each calibration 50 different probe positions were used. The results are shown in Tables 1 and 2.

Table 1: 3D reprojection error for calibrations performed with the shallow phantoms

Phantom	**3D reprojection error average (mm)**	**3D reprojection error standard deviation (mm)**
LEGO® brick phantom	0.77	0.13
Printed phantom	0.80	0.11

Table 2: 3D reprojection error for calibrations performed with the deep phantoms

Phantom	**3D reprojection error average (mm)**	**3D reprojection error standard deviation (mm)**
LEGO® brick phantom	1.73	0.29
Printed phantom	2.54	0.52

An unpaired t-test was performed for the shallow and deep phantoms comparing the phantom made from LEGO® bricks to the 3D-printed phantom. The test examined the reprojection error from the 50 positions captured per trial, giving a sample size of 250. The results are summarized in Table 3.

Table 3: Statistical significance of improvement of LEGO bricks over standard 3D-printed phantoms, computed with an unpaired t-test

Shallow phantoms	$P = 0.0479$	
Deep phantoms	Statistically extremely significant	$P = 0.0001$

The phantoms made from LEGO® bricks were a statistically significant improvement to the 3D-printed phantoms. The significance increased for the larger deep phantoms. This could be attributed to how the large printed phantom was printed in part due to size limitations of the available printer. The improvement of the calibrations when performed with the phantoms made from LEGO® bricks can possibly be as a result of the high tolerance of LEGO® bricks and the static positioning of the wires when fixated between two bricks.

Conclusion: The implications of this study are that LEGO® bricks are a viable material for constructing ultrasound calibration phantoms of different sizes. A detailed methodology, design and build instructions for creating custom phantoms made from LEGO® bricks can be found online as part of the open source PLUS Toolkit (www.plustoolkit.org).

References

[1] Carbajal G, Lasso A, Gómez Á, Fichtinger G, Improving N-Wire Phantom-based Freehand Ultrasound Calibration, International Journal of Computer Assisted Radiology and Surgery 2013 Nov;8(6):1063-72

[2] Walsh R, Soehl M, Rankin A, Lasso A, Fichtinger G, Design of a tracked ultrasound calibration phantom made of LEGO® bricks, SPIE Medical Imaging, Conference on Image-Guided Procedures, Robotic Interventions and Modeling, Proc. SPIE 9036, Medical Imaging 2014: Image-Guided Procedures, Robotic Interventions, and Modeling, 90362C (March 12, 2014)

[3] Lasso A, Heffter T, Pinter C, Rankin A, Ungi T, Fichtinger G, PLUS: open-source toolkit for ultrasound-guided intervention systems, IEEE Transactions on Biomedical Engineering, Vol 61, Issue 10, pp. 2527 – 2537, 2014