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Open-LIFU Transducer Localization Accuracy Study

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Introduction:

This report describes the use of photogrammetric reconstruction for localizing the position of an ultrasonic transducer on a subject, and co-registrating the transducer position with the subject's MRI image. Photogrammetric reconstruction is a technique that creates a 3D surface mesh from images captured by a camera. The procedure described here consists of using Openwater's cell phone application to acquire images of a mannequin wearing an Open-LIFU 2X headset at a known position, reconstructing photogrammetry meshes of of the mannequin using the acquired images, and co-registering the meshes with the mannequin's MRI and with a model of the transducer. In this way, the position of the transducer with respect to the subject's internal anatomy is determined. Two separate reconstruction methods are tested. The accuracy and precision of the two methods are reported.

Test Method:

A 3D model of a mannequin head was created from an individual's MRI using the 3D Slicer imaging platform[1,2]. This model was imported into a CAD software (Fusion360), and edited to create a slot in the head (Figure 1A). This slot was created to fit precisely with a 3D printed model of an Open-LIFU transmit module that had been modified to have an extension. The extension is connected to an Open-LIFU 2X transducer housing such that when the extension sits in the designated slot location (Figure 1B) the position of the housing is known. This slot location was used to determine a transformation matrix (Table 1) for the headset, which specifies its rotation and translation relative to the origin of the mannequin head.

Next, we acquired 30 scans of the mannequin head wearing the Open-LIFU 2X housing. The mannequin was placed on a stand in a room with uniform, warm lighting. The images were captured on a Google Pixel 5 phone using the Open-LIFU photogrammetric application. The mannequin's face was positioned in the center of the camera before capture. For each scan, approximately 120 images were acquired while walking in a circle around the mannequin's head. Data acquisition took approximately one to two minutes per scan.

Two photogrammetry reconstruction methods were used for analysis. With the first method, the reconstruction was generated on a local computer using Meshroom, an open-source AliceVision software[3]. The camera setting used in the photogrammetry application for this method was the Android "capture_mode_maximum_quality" mode, which prioritizes high-resolution output and device-native computational photography. This method took about 10-12 minutes to generate a mesh and was tested using an Intel Core i5-14400F, with the NVIDIA High Performance Graphics settings enabled. With the second method, the reconstruction was generated in the cloud using Apple Composer Pro. This method only took about 20 seconds to generate a mesh using the Android “capture_mode_minimum_latency” mode, which prioritizes speed and reduces in-camera processing. These features are also device-native.

Figure 1: (a) Rendering of the mannequin with a slot for positioning the transducer and (b) transducer housing with extrude that fits into the slot.

0.985	0.024	0.171	1.528
0.163	-0.468	-0.869	90.09
0.059	0.883	-0.465	67.10
0	0	0	1

Table 1: Transformation matrix specifying the known position of the transducer housing when positioned in the slot.

The Open-LIFU desktop application co-registers the transducer with a subject’s MRI by aligning both the MRI and a numerical model of the transducer with the photogrammetry mesh. Thus, co-registration is performed in two steps. In the first step, the photogrammetry mesh is aligned with the subject’s MRI. (In this case, the MRI used to generate the mannequin). To do this, the software generates an outer surface of the subject’s head from the 3D MRI image. Then, the user places the same three fiducials on both the photogrammetry mesh and the MRI surface. The fiducial locations are the tragus of the right ear, the naision, and the tragus of the left ear. These fiducials are used for an initial alignment between the MRI and the mesh. Once the alignment is complete, an ICP (iterative closest point) algorithm is applied to the mesh and MRI to further enhance the alignment. The region of interest used by the ICP algorithm consists of a band across the subject from one tragus to the other. A check is performed to ensure that the transducer (which is present in the photogrammetry mesh but not the MRI) is not included in the region of interest (Figure 3). In the second step, the Open-LIFU 2X headset model is aligned with the photogrammetry mesh. The initial alignment of the headset model is completed manually through the desktop application interface. The model is moved as visually close as possible to the mesh. Then, an ICP algorithm is applied to the mesh and model to improve alignment. For both steps, the ICP algorithm used a 50% sampling density of mesh points, and a convergence criterion of 0.01 mm maximum mean distance between paired surface points on the two meshes.

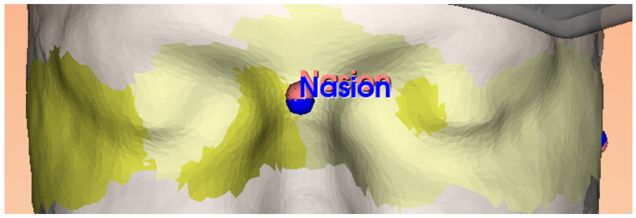

Figure 3: ROI used in the photogrammetry to MRI alignment shown in yellow. Note the transducer, upper right, is not included. The user selected nasion position is shown.

These layered registrations produce a final transformation matrix, describing the transducer's position relative to the MRI origin. Figure 4 provides a pictorial representation of the workflow.

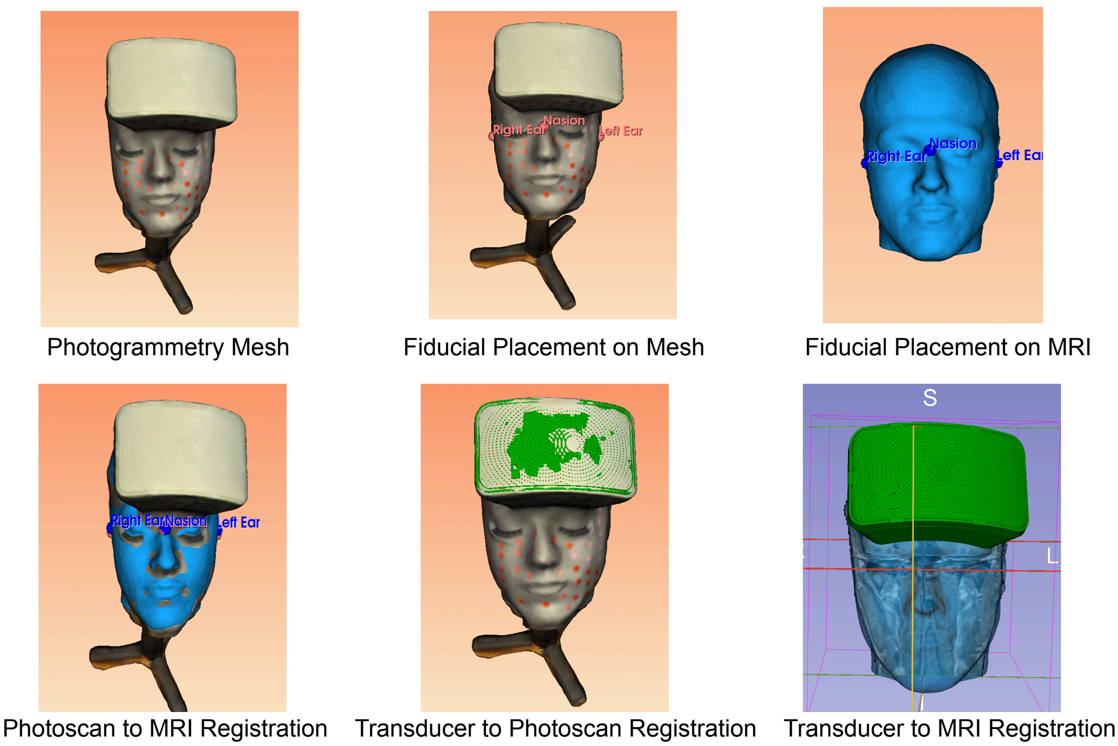

Figure 4: Pictorial representation of the co-registration workflow from left to right showing the photogrammetry mesh, the fiducials on the mesh, the same fiducials on the MRI, mesh to MRI alignment, mesh to transducer model alignment, and the final alignment of the transducer to the MRI.

<u>Results:</u>

Each transformation matrix of the transducer that was extracted from the Open-LIFU desktop application was compared with the expected CAD position of the transducer seated in the mannequin head, with the R (Right), A (Anterior), and S (Superior) directions compared across the 30 scans. The difference between the calculated and known transducer location was less than 1 mm in all directions using the Apple Composer Pro (online) photogrammetry algorithm Using the Meshroom (offline) photogrammetry algorithm resulted in a slightly higher average error in all three directions, with errors of up to 3 mm. The standard deviation of the repeated trials was only 1-2 mm in all directions with both algorithms, demonstrating very repeatable co-registration. These results are summarized in Table 2 and Figure 5.

Average Error from Expected Values

Reconstruction Type	**Average Error in R**	**Average Error in A**	**Average Error in S**	**Std. Dev in R**	**Std. Dev in A**	**Std. Dev in S**
Online	-0.676 mm	0.622 mm	0.350 mm	1.52	1.82	2.12
Offline	-1.89 mm	2.49 mm	3.32 mm	1.36	2.58	1.29

Table 2: Error and standard deviations between the expected transducer position (Table 1) and the measured transducer positions in the R (Right), A (Anterior) ,and S (Superior) directions across 10 scans.

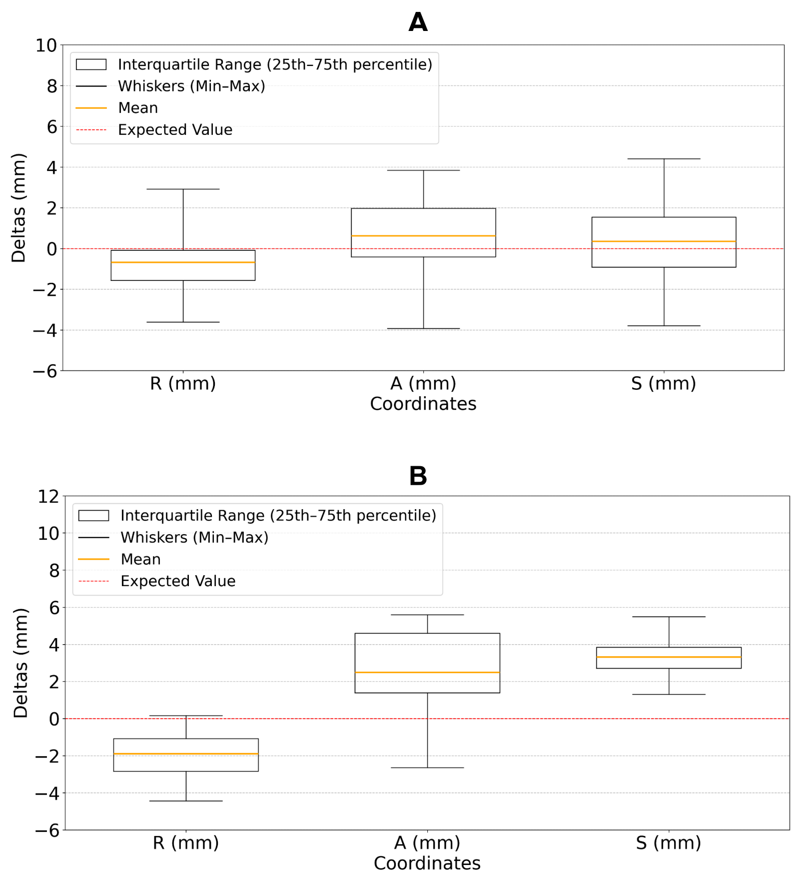

Figure 5: Translational error and precision in the R, A, and S directions using (a) the online Apple Composer Pro photogrammetry reconstructions and (b) the offline Meshroom photogrammetry reconstructions and in the alignment process.

Discussion:

Reported registration and targeting errors for clinical neuronavigation systems are typically on the order of 1-3 mm, which is generally considered acceptable for routine neuronavigation procedures [4]. Maintaining an error that is within this range is essential, as this affects the device's position relative to its target. The average errors of <3 mm suggest that both online and offline photogrammetric reconstruction methods are adequate methods to use for subject registration in the Open-LIFU desktop application. The observed standard deviation of around 1-2 mm also indicates there is good repeatability of the alignment process. The co-registration using online photogrammetry reconstruction has an error of less than 1 mm, a better error outcome relative to the co-registration using the offline photogrammetry reconstruction by roughly 2 mm. Visual inspection shows that meshes reconstructed using the online Apple Composer Pro algorithm are smoother and have less noise than meshes produced by the offline Meshroom reconstruction. The smoothness and lack of geometric irregularities allowed for better alignment and ICP registration.

Conclusion:

This study evaluated the accuracy of a phone-based photogrammetry method to co-register an Open-LIFU transducer to a subject's anatomy. The ICP-based alignment method revealed an error of less than 1 mm using an online photogrammetry reconstruction algorithm, and less than 3 mm using an offline photogrammetry algorithm. The findings suggest that photogrammetric reconstruction is a sufficient method for the neuronavigation process used in the Open-LIFU desktop application.

Citations/References:

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4) Widmann G, Schullian P, Ortler M, Bale R. Accuracy of stereotactic and neuronavigation systems. *Acta Neurochirurgica (Wien)*. 2006;148(4):355–367.