Reproducibility of freehand calibrations for ultrasound-guided needle navigation

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ABSTRACT

PURPOSE: Spatially tracked ultrasound-guided needle insertions may require electromagnetic sensors to be clipped on the needle and ultrasound probe if not already embedded in the tools. It is assumed that switching the electromagnetic sensor clip does not impact the accuracy of the computed calibration. We propose an experimental process to determine whether or not devices should be calibrated on a more frequent basis.

METHODS: We performed 250 calibrations. Of these, 125 were performed on the needle and 125 on the ultrasound. Every five calibrations, the tracking clip was removed and reattached. Every 25 calibrations, the tracking clip was exchanged for an identical 3D-printed model. From the resulting transform matrices, coordinate transformations were computed. Data reproducibility was analyzed through looking at the difference between mean and grand mean, standard deviation and the Shapiro-Wilks normality constant. Data was graphically displayed to visualize differences in calibrations in different directions.

RESULTS: For the needle calibrations, transformations parallel to the tracking clip and perpendicular to the needle demonstrated the greatest deviation. For the ultrasound calibrations, transformations perpendicular to the sound propagation demonstrated the greatest deviation.

CONCLUSION: Needle and ultrasound calibrations are reproducible when changing the tracking clip. These devices do not need to be calibrated on a more frequent basis. Caution should be taken to minimize confounding variables such as bending the needle or ultrasound beam width at the time of calibration.

KEY WORDS: Calibration, reproducibility, ultrasound, spatial tracking, freehand.

1. INTRODUCTION

Ultrasound (US)-guided needle insertions are a common image-guided medical procedure. The US image is used to visually guide the needle to the intended destination. Possible applications of US-guided needle insertions include biopsies and drug deliveries. Benefits include increased work speed and fewer needle reinsertions. Spatial tracking of the needle and US probe allows the needle tip to be readily located. Electromagnetic (EM) tracking systems may be used as the tracking method. In EM tracking a transmitter generates an EM field that EM sensors detect. The needle and US probe require spatial calibration for the tracking to be accurate. Calibration is the process of computing the position of the device relative to the tracked sensors so the system can determine the spatial position of the device. Pivot calibration is the process of computing the position of the needle tip relative to the needle-mounted EM sensor. US calibration is the process of computing the position of the image relative to the EM sensor attached to the US transducer.

Electromagnetic sensors are not always embedded in clinical tools. In this case, tracking clips must be used to affix the EM sensors in place (Figure 1). Devices are calibrated once and may be used for a prolonged period of time without recalibration. Users of EM-navigated procedures may adjust the clip for a variety of purposes, such as swapping out broken or damaged clips, or for sanitization. It is assumed that the computed calibration can be reused when an identical clip is changed. There is no established recommendation for tracking clip calibrations. Below, we will present preliminary data to aid in producing such recommendations.

Ultrasound calibration accuracy has been extensively studied.[1,2] A particular study under EM tracking measured the variance in spatial US calibrations with a pointer tool.[2] This study found a variance of x: 0.10 mm, y: 0.10 mm and z: 0.43 mm.[2] However, this study did not analyze the potential confounding variable of changing the tracking clip and can be used as comparative data for our study. Data was not found on the consistency of open-source (3D-printed) or commercially available general purpose tracking clips.

We are addressing this issue by measuring the reproducibility of needle and US calibrations when changing the tracking clip. The importance of this is to determine if these devices need to be recalibrated more frequently, such as when the tracking clip is changed. If the calibrations are reproducible, the computed calibration transformations along the x, y and z axes (Figure 3) should indicate a minimal difference between mean ($\bar{x}$) and grand mean (GM). There should be minimal standard deviation (σ) as well. Similarly, the Shapiro-Wilks normality constants (W) for each distribution should approach one as the distributions are more normal. A normal distribution is an indicator that there may be no systematic error in our experimental design and that the deviation is only caused by random factors. A significant result ($p <= 0.01$) from this test indicates that there is evidence that the data are not normally distributed.

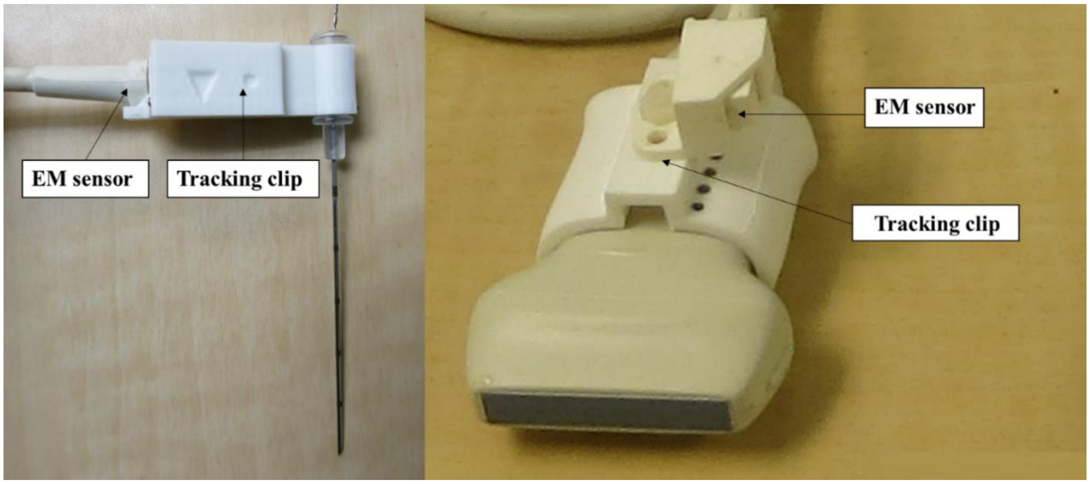

Figure 1. *Left:* Tracking clip on needle. *Right:* Tracking clip on US probe

2. METHODS

2.1 Needle calibration experiment

The spatially tracked system used to acquire pivot calibrations for our experiment consisted of a computer running 3D Slicer (www.slicer.org), a SonixTouch (Ultrasonix, Richmond, BC) EM tracker, EM field generator and EM sensor clipped to a needle. Data was sent from the hardware to the computer via the Public Software Library for Ultrasound (PLUS) (www.plustoolkit.org).[3] Pivot calibrations were computed using the SlicerIGT (www.slicerIGT.org) module *Pivot Calibration*. In total, 125 pivot calibrations were performed. Every five calibrations, the tracking clip was removed and reattached. Every 25 calibrations, the tracking clip was swapped to an identical 3D-printed model. All calibrations were saved as transform matrices. The x, y and z coordinate transforms (Figure 3) were computed from needle tip to the needle-mounted EM sensor.

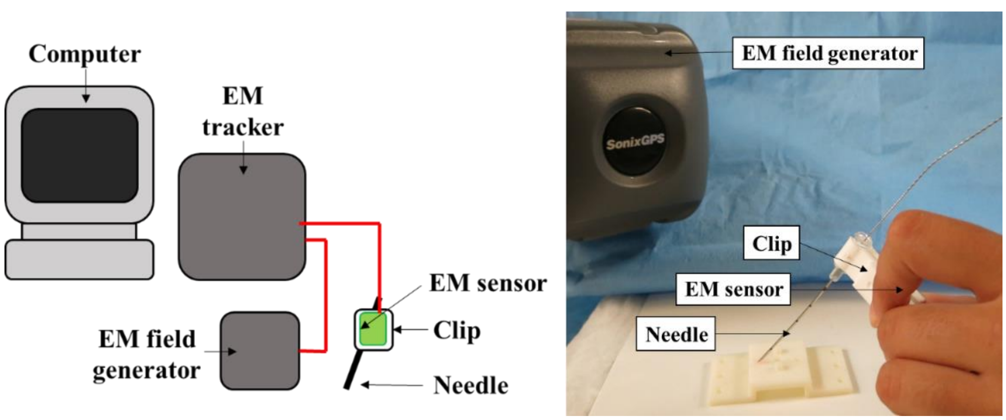

Figure 2. *Left:* Schematic diagram of needle calibration. *Right:* Experimental set-up.

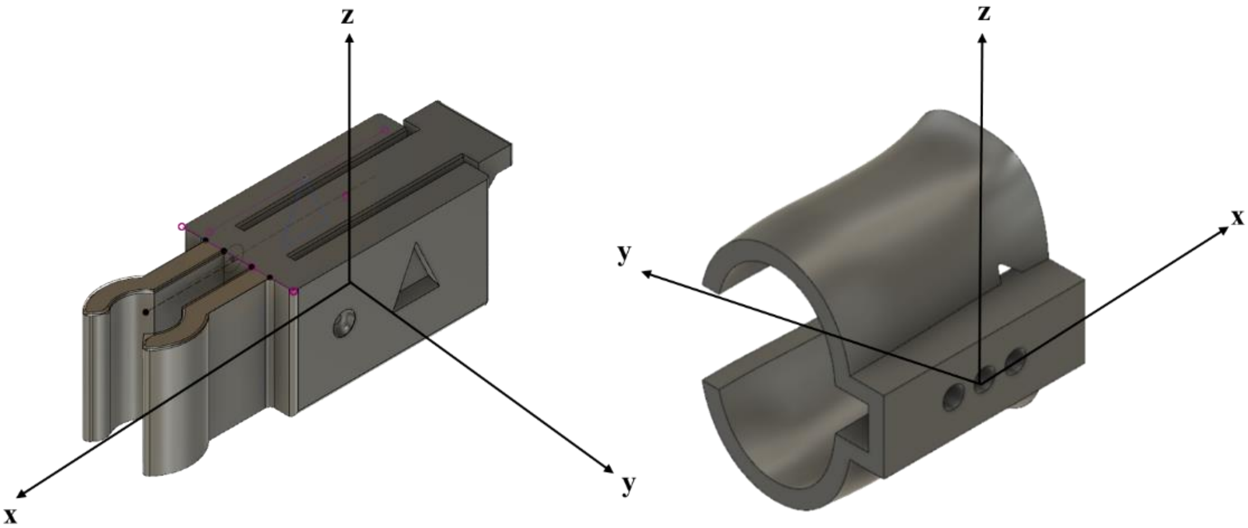

Figure 3. *Left:* Axes diagram for needle tracking clip. *Right:* Axes diagram for US tracking clip.

2.2 Ultrasound calibration experiment

The spatially tracked system used to acquire US calibrations for our experiment consisted of a computer running 3D Slicer, a Telemed MicrUs (Telemed Medical Systems, Lithuania) portable US machine with a linear transducer, an Ascension TrakSTAR EM tracker (Northern Digital Inc., Waterloo, ON), an EM field generator and two EM sensors, one clipped to a hooked stylus and another to the linear transducer (Figure 4). Data was sent from the hardware to the computer using PLUS.[3] Data collection was performed using the Sequences module *Sequence Browser*. In total, 25 recordings were collected. Every recording, the tracking clip was removed and reattached. Every five recordings, the tracking clip was exchanged for an identical 3D-printed model. Ultrasound calibrations were computed using the SlicerIGT module *Fiducial Registration Wizard*. Each recording was calibrated five times. In total, 125 US calibrations were performed. Coordinate transforms in the probe coordinate system were computed from saved transform matrices.

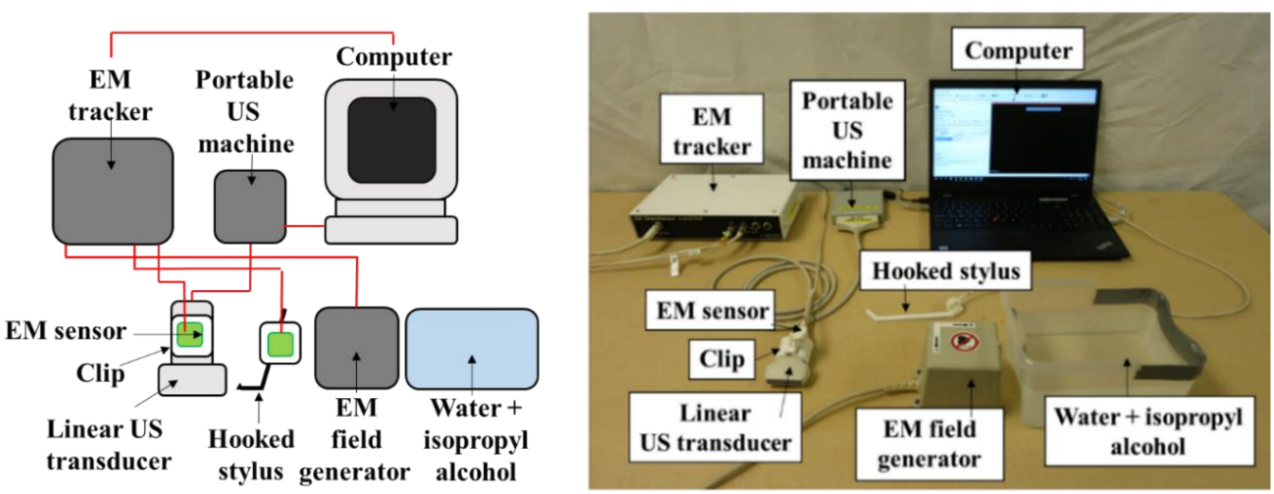

Figure 4. *Left:* Schematic diagram of US calibration. *Right:* Experimental set-up.

3. RESULTS

3.1 Needle calibration results

The results from the needle calibrations are shown here in Table 1 and Figure 5. The overall mean subtract grand mean averages to zero across the calibrations on all axes. The average standard deviation by clip for the x-translations was 0.85 [0.62 – 1.11] mm, y-translations was 0.29 [0.22 – 0.35] mm, z-translations was 0.79 [0.49 – 0.67]. The average value of W by clip was 0.99 for each of the the x, y and z-translations.

Table 1. Metrics for x, y and z translations for needle calibrations, where n = 25 per clip and n = 125 overall. The metrics include the difference between the mean ($\bar{x}$) and the grand mean (GM), standard deviation (σ) and the Shapiro-Wilks normality constant (W) where an asterisk (*) indicates significance.

Clip #	**x**			**y**			**z**		
	$\bar{x}$ – GM (mm)	**σ (mm)**	**W**	**$\bar{x}$ – GM (mm)**	**σ (mm)**	**W**	**$\bar{x}$ – GM (mm)**	**σ (mm)**	**W**
1	-0.06	0.63	0.96	0.13	0.22	0.96	0.43	0.61	0.95
2	-0.12	0.84	0.98	0.09	0.24	0.95	0.51	0.67	0.90
3	0.07	0.95	0.88*	-0.08	0.29	0.92	-0.09	0.65	0.98
4	0.26	1.11	0.95	0.05	0.35	0.98	0.05	0.66	0.97
5	-0.14	0.62	0.95	-0.18	0.25	0.98	-0.90	0.49	0.96
Overall	0	0.85	0.99	0	0.29	0.99	0	0.79	0.99

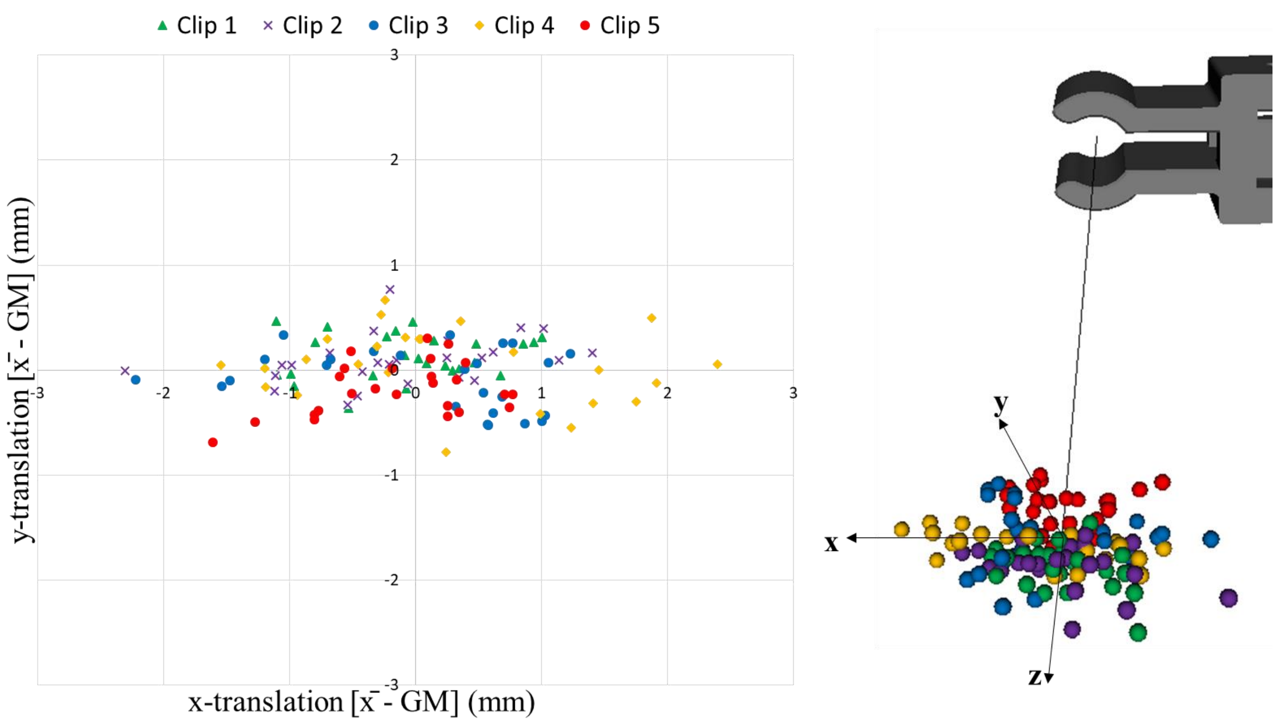

Figure 5. *Left:* Mean ($\bar{x}$) subtract the grand mean (GM) of translations in the x-y plane for needle calibration. *Right:* 3D point cloud.

3.2 Ultrasound calibration results

The results from the US calibrations are shown here in Table 2 and Figure 6. The overall mean subtract grand mean averages to zero across the calibrations on all axes. The average standard deviation by clip for the x-translations was 0.41 [0.17 – 0.43] mm, y-translations was 1.56 [1.09 – 1.81] mm and z-translations was 0.46 [0.14 – 0.66] mm. The average value of W was 0.97 for the x-translations, 0.99 for the y-translations and 0.98 for the z-translations.

Table 2. Metrics for x, y and z translations for ultrasound calibrations, where n = 25 per clip and n = 125 overall. The metrics include the difference between the mean ($\bar{x}$) and the grand mean (GM), standard deviation (σ) and the Shapiro-Wilks normality constant (W) where an asterisk (*) indicates significance.

Clip #	**x**			**y**			**z**		
	$\bar{x}$ – GM (mm)	**σ (mm)**	**W**	**$\bar{x}$ – GM (mm)**	**σ (mm)**	**W**	**$\bar{x}$ – GM (mm)**	**σ (mm)**	**W**
1	0.07	0.27	0.91	0.33	1.74	0.93	-0.07	0.66	0.89
2	-0.21	0.28	0.88*	0.32	1.09	0.89	-0.16	0.40	0.86*
3	-0.42	0.17	0.93	0.13	1.04	0.96	0.14	0.14	0.97
4	0.27	0.43	0.91	-0.82	1.81	0.91	-0.29	0.36	0.68*
5	0.30	0.32	0.91	0.04	1.78	0.94	0.38	0.21	0.97
Overall	0	0.41	0.97*	0	1.56	0.99	0	0.46	0.98

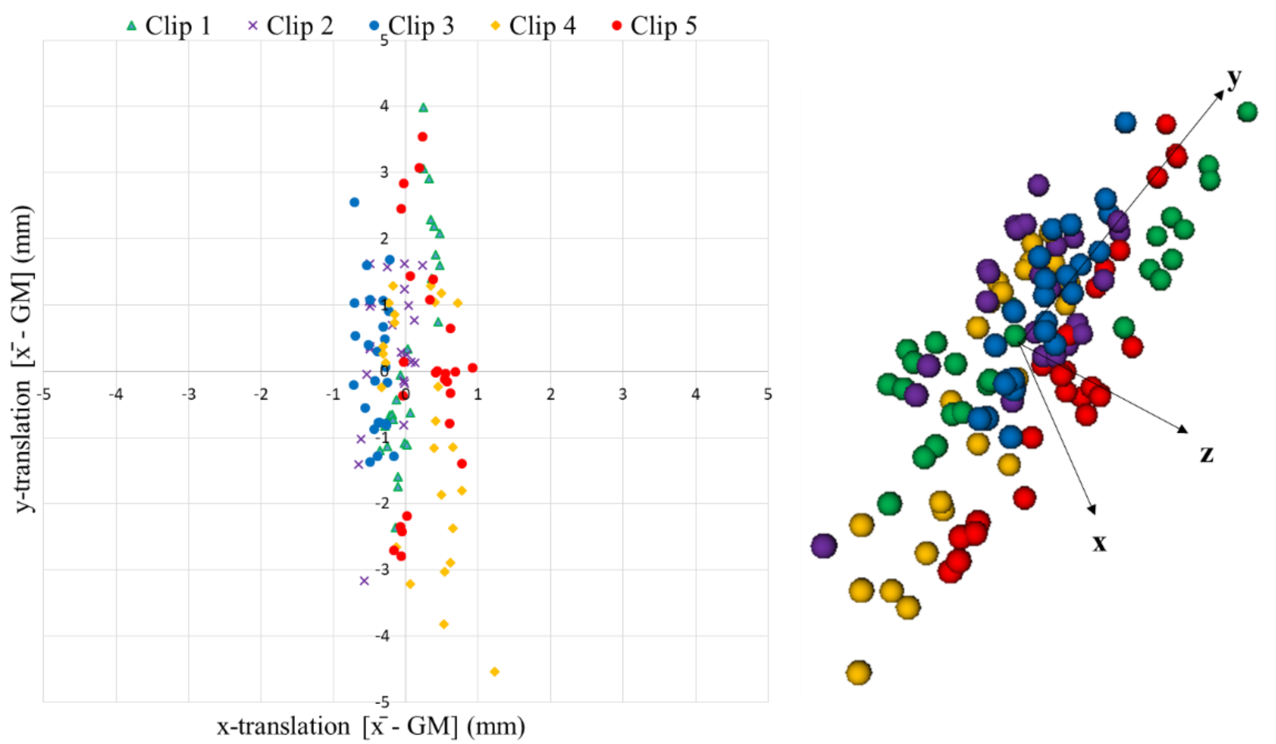

Figure 6. *Left:* Mean ($\bar{x}$) subtract the grand mean (GM) of translations in the x-y plane for US calibration. *Right:* 3D point cloud

4. DISCUSSION

For the pivot calibrations, the greatest standard deviation occurs in the x-translations. This is inferred to have happened due to bending in the needle when pivoting. A potential solution to this is using a thicker needle when possible.

For the US calibrations, the greatest standard deviation is seen in the y-translations. This is inferred to have happened due to the US beam width. All US calibrations were performed freehand, each of the calibrations were not all done at the focal point. A potential solution to this is to calibrate the US probe at the same depth each time. When using freehand calibrations, a potential solution is to utilize the method proposed in Thomas Chen's thesis.[4] He proposed a beam widthweighed calibration framework.[4] This framework decreases variability in calibrations and provides quality control for freehand calibrations.[4] It goes this by incorporating slice thickness into the computation.[4]

There are potential limitations that occurred during our study. A potential limitation that occurred is metal interacting with the field generator and causing field distortion.[5] This field distortion occurs when the tracker is placed near magnetic or conducting materials, such as metal on tables.[5] A potential solution to this is to dynamically map the field distortion such that the error can be accounted for.[5]

When collecting pivot calibrations, we found that the resulting calibration coordinate transforms varied considerably depending on the user (Figure 7). User 1 computer calibrations for clip 1, user 2 computed calibrations for clip 2 and user 3 computer calibrations for clips 3-5. These variations were inferred to have happened due to differences in how individuals hold the needle when calibrating. This influenced our decision to use only one user for the data used in our results section.

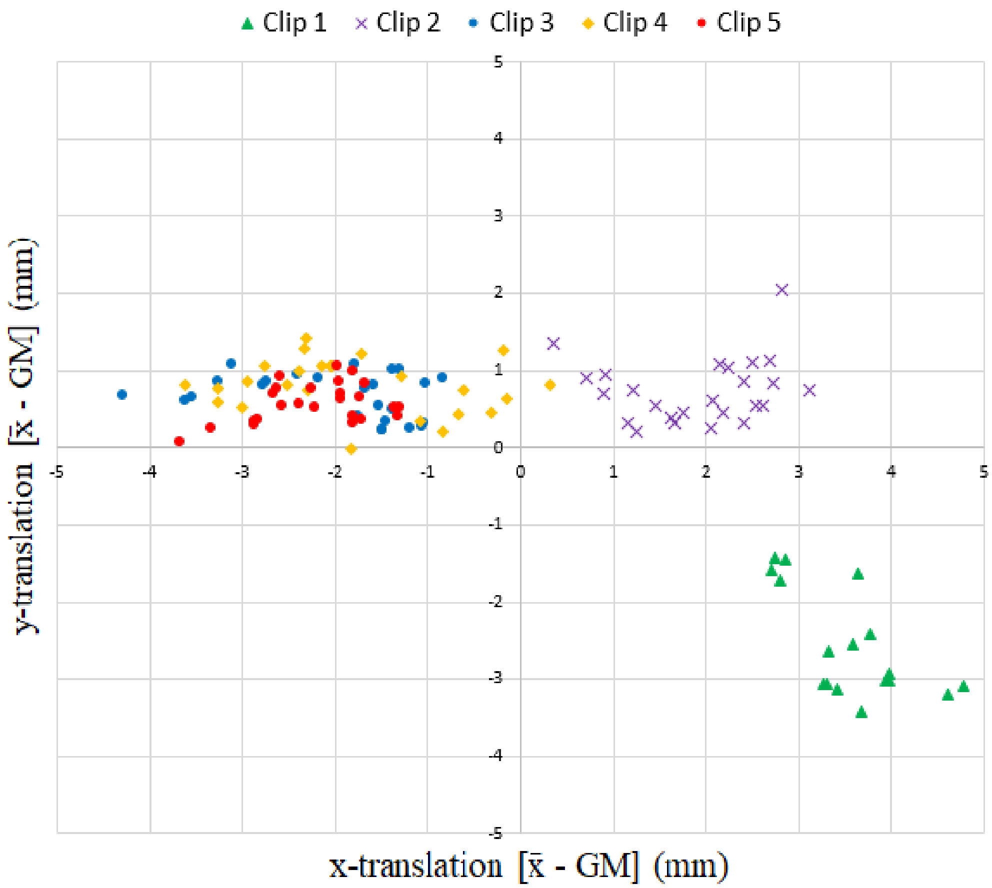

Figure 7. Mean (x̄) subtract the grand mean (GM) of translations in the x-y plane for needle calibration. In this diagram, clip 1 calibrations were computed by user 1, clip 2 by user 2 and clips 3-5 by user 3.

There are potential next steps that can be further explored after this study. One of our next steps is to explore the difference between the calibration reproducibility of open source (3D-printed) tracking clips and commercially available general purpose tracking clips. The rationale behind this is that commercially available tracking clips may have undergone additional quality control compared to 3D printed clips within the lab.

5. CONCLUSION

In our experience with tracking clips designed for PLUS, needle and US calibrations are reproducible when exchanging and re-clipping the tracking clips. Our results have shown that needle and US calibrations do not need to be recalibrated on a frequent basis. Instead, more care should be taken to minimize confounding variables such as needle bending and US beam width and the focal point when calibrating to ensure reproducibility between calibrations. Consistency may change across different types of tracking clips than those used in our experiments.

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