Assessing Accuracy and Precision of 3D Augmented Reality Holographic models derived from DICOM data

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Technical Note

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Abstract

Objective: Assess accuracy and precision of measurements on 3D Augmented reality (AR) models derived from CT DICOM data, and compare AR model measurements with PACS measurements.

Materials/Methods: 5 individual 3D hologram models were produced using a CT phantom with fiducial markers set at varying distances. DICOM files were translated into 3D AR models using open source software. AR models were adapted for display on the Microsoft HoloLens using a novel application. AR models were projected and distances between the projected fiducial markers were measured. Finally, 5 measurements each were obtained of the holographic projected distances between fiducials in the x1, y1, and z1 labeled planes respectively for precision assessment. Mann-Whitney U test was performed to compare measured distances on AGFA-PACS, AR models, and actual measured distances on phantom models. Results: No significant difference was found between gold standard measurements and either PACS measurements (p=0.9124) or AR measurements (p=0.8966). AR model measurements had a standard error of 0.24mm, 0.24mm, and 0.38mm in the x,y, and z planes respectively. Furthermore, measurements on AR models demonstrated a high degree of accuracy in comparison to gold standard measurements.

Conclusion: Current AR technology is can produce reliable 3D AR models from CT DICOM data

Introduction

Augmented reality applications are being increasingly utilized in a number of fields including military, industry, and sports [1-3] with emerging potential applications in medical imaging[4-7]. Recent advances in technology have allowed for increased portability of augmented reality hardware, making more widespread utilization possible [8,9]. While preliminary investigation of accuracy and precision of augmented reality models has been described with large, projection based equipment [10], only limited data exists for accuracy and precision of head mounted display (HMD)-based conversion of Digital Imaging and Communications in Medicine (DICOM) medical imaging information into augmented reality models [6,11-16]. This technique holds promise for clinical applications in pre-surgical planning and in medical education [12,16]. The aim of this study was to assess the accuracy and precision of the DICOM-derived 3D holographic models data in the Microsoft HoloLens (Microsoft Corporation, Redmond, WA USA) HMD using a proprietary C# programming language-based software application and to determine if any statistically significant differences exist between gold-standard physical measurements, Picture Archiving and Communication System (PACS)-based measurements, and Augmented Reality holographic measurements.

Methods

Five unique 3D models were produced using a CT quality control phantom (model 137856101, GE Healthcare, Waukesha WI USA) with fiducial markers (CT/MRI 2 mm center hole Multi-modality marker,

MM3002, Izi Medical Products, Owings Mills, MD USA) set at various known distances — the distances were measured using electronic digital calipers (model 01407A, Neiko Tools, Henan, China) FIGURES 1, 2. A total of six measurements between fiducial markers were made for each model CT phantom: two in the x-direction, two in the y-direction and two in the z-direction. These measurements were set as the gold standard (GS). CT scans of the phantom were obtained using the Head CT quality control phantom settings (0.625mm slice thickness, 134mAs, 22.7cm DFOV, 0.516:1 pitch) on a GE Lightspeed CT scanner (GE Healthcare, Waukesha WI USA) and stored as DICOM files within our AGFA Picture Archiving and Communication System (PACS), (AGFA, Mortsel, Belgium).

The DICOM files obtained were converted into a 3D phantom models, and measurements were made on the AGFA-PACS using ruler tool to trace the distances between the fiducial markers--approximately from the nearest edges of the markers FIGURE 3.

Open-source software programs Horos (Purview, Annapolis, MD USA) and Blender (Stichting Blender Foundation, Amsterdam, Netherlands) were used to translate DICOM files into a 3D image. The 3D images were adapted and loaded onto the Microsoft HoloLens platform using a C# programming language based code on the Unity Platform (Unity Technologies, San Francisco, CA USA) called RadHA (Radiology with Holographic Augmentation), an investigational tool developed at our institution. FIGURE 4 demonstrates a side-by-side comparison of the CT phantom and its hologram. The 3D models were projected as holograms and the distances between the projected fiducial markers were measured. Using the built-in Hololens capabilities, the hologram was pinned to a table where the calipers could be laid flatly to make the measurements, FIGURE 5. These measurements are known as Holo measurements. A non-parametric statistical analysis (Mann-Whitney U test) was performed to compare GS vs. Holo and GS vs. PACS measurements.

Measurements were obtained for precision assessment between fiducial markers in the x1, y1, and z1 labeled planes. Percent error was calculated for the measurements made on the hologram model. The relative standard deviation (RSD) for percent error was obtained for Holo precision.

Results

All measurements taken for each CT phantom trial on GS, PACS, and Hologram are found in **Table 1**.

TABLE 1. Model Measurements on Gold Standard, PACS, and Hologram.

Model Measurements (mm)				
Model	Measurement	GOLD	PACS	Hologram
1 (A)	x1	39.72	38.5	38.17
	x2	74.3	75	73.46
	y1	36.59	36.5	36.35
	y2	18.4	18	17.88
	z1	58.09	58.6	57.56
	z2	18.81	19.5	18.39
2 (B)	x1	20.58	20.5	20.3
	x2	55.64	56.1	56.96
	y1	40.66	41.1	39.98
	y2	36.47	36.5	36.76
	z1	19	18.5	19.12
	z2	46.92	47.3	47.43
3 (C)	x1	19.98	20.5	21.01
	x2	10.4	11.3	10.8
	y1	32.73	32.4	32.15
	y2	52.5	52.9	51.58
	z1	56.36	56.5	55.69
	z2	15.14	16.4	15.55
4 (D)	x1	49.35	49.5	48.98
	x2	45.45	46.3	45.8
	y1	25.71	25.2	25.04
	y2	32.54	33.4	32.45
	z1	18.08	19.5	17.91
	z2	38.89	40.1	39.22
5 (E)	x1	27.71	26.7	26.79
	x2	44.6	44.7	44.8
	y1	27.62	27.3	25.58

y2	58.04	58.1	57.83
z1	54.05	54.5	54.14
z2	87.84	88.4	87

The GS distances measurements are summarized as follows: min=10.4mm, Q1=21.9mm, Q2=37.7mm, Q3=51.7mm, max=87.8mm and mean=38.7mm. For PACS, the measurement values obtained were: min=11.3mm, Q1=21.7mm, Q2=37.5mm, Q3=52.1mm, max=88.4mm and mean=39.0mm. Holo measurement values were: min=10.8mm, Q1=22.0mm, Q2=37.5mm, Q3=50.9mm, max=87mm and mean=34.5mm.

Mann-Whitney U test was performed for comparison between GS measurements and PACS measurements and resulted in no statistically significant difference (p=0.9124). PACS measurements yielded an average percent error of 2.51% and a standard deviation of 0.38. GS compared to Hologram measurements also resulted in no statistically significant difference (p=0.89656) with an average percent error of 2.19% with a standard deviation of 0.44. The Holo precision assessment yielded an RSD of 1.08%.

Discussion

For both PACS and Holo measurements, the average percent error was 2.5% or less, approximately less than 1.25 mm. The Holo measurement average percent error was less than PACS average percent error; Holo measurements are comprable in accuracy to PACS, the current accepted standard in medical imaging. Moreover, the Holo precision assessment obtained was an RSD of 1.08%, approximately an error of about 0.5mm.

Currently, there is little existing literature assessing the accuracy of the 3D hologram derived from DICOM data. A 2017 study evaluated the utility of AR in endovascular interventions using the Hololens. CT data was utilized to reproduce a hologram of vasculature superimposed on a phantom, and a two-step calibration employing a tracked catheter demonstrated the plausibility of visualizing endovascular procedures without the use of x-ray. Their accuracy assessment pertained to the first calibration step and demonstrated a root-mean-square error of 4.357 mm in 20 trials of 4 landmarks. Though there is no distinction on the error and its dimensionality, our data suggest a smaller degree of error possibly due to the scale of our phantom.

A limitation faced while obtaining measurements on the Holo models was that distances were made by visually estimating distances between markers. On the other hand, GS measurement on the physical model had tactile-feedback to establish edges, while the Holo models were reliant on the observer's best estimation of depth and distance between markers. Moreover, these measurements were obtained by one

observer. There was no assessment for variability between HMD users and no consideration for user experience which may impact accuracy and precision of measurements.

Ultimately, this study demonstrates the utility and reliability of Hololens AR technology and other similar devices for rendering accurate holographic models. The advantage of holographic models is the visualization of a 3D internal anatomical structures and the ability to superimpose the image on real environment[17]. The AR holographic models have potential to transform fields of medicine such as radiology, surgery and medical education [12,18−20]. Perhaps in the near future as AR becomes readily available across platforms including smartphones, adoption of this technology will be made in classroom, clinical, and hospital settings. The hope is that this study has set the groundwork for future research into AR's emerging applications in medicine.

Declarations

- Ethics approval and consent to participate

Study was approved by our institutional review board.

- Consent for publication

Not applicable

- Availability of data and material

The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

- Competing interests

JU: Jesus Uribe -Nothing to disclose

LV: Lan Vu, MD -Nothing to disclose

BL: Benjamin Laguna, MD -Founder, Sira Medical, pre-revenue Augmented Reality startup, not

discussed in this manuscript

JC: Jesse Courtier, MD - Founder, Sira Medical, pre-revenue Augmented Reality startup, not

discussed in this manuscript

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- Authors' contributions

Author Contributions

1. Guarantor of the integrity of the entire study: JC
2. Study concepts and design: JC
3. Literature research: JU, BL
4. Clinical Studies: n/a
5. Experimental studies/data analysis: JU, JC
6. Statistical analysis: LV
7. Manuscript preparation: JU, LV, BL
8. Manuscript editing: JU, LV, BL, JC

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Figures
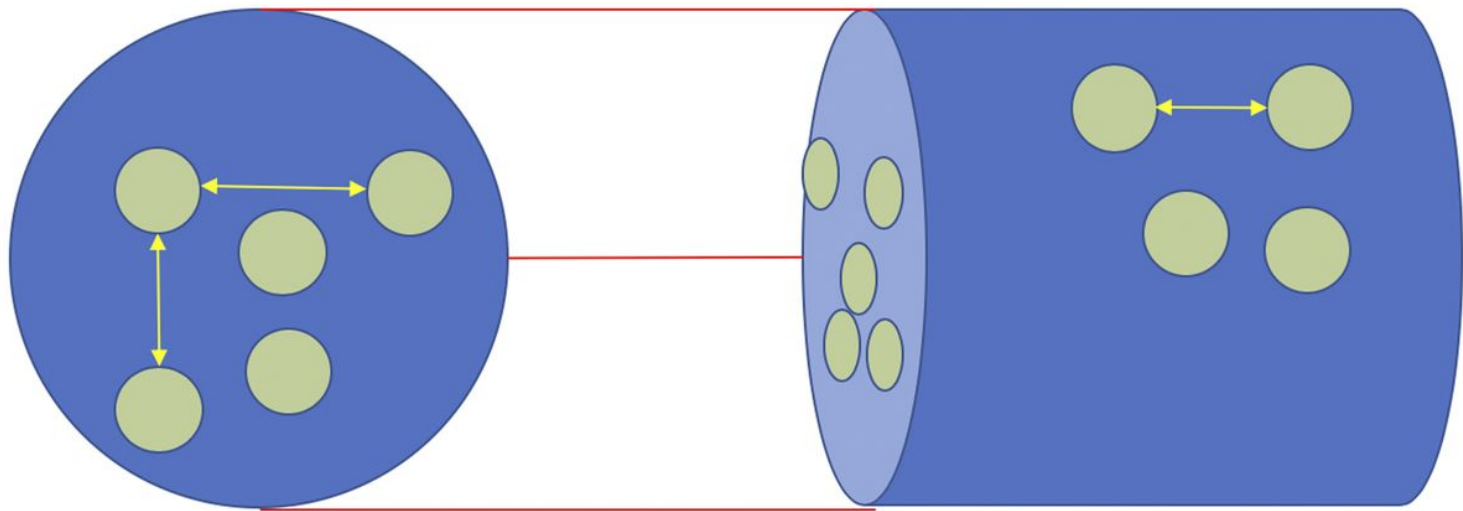
Figure 1

A representation of a trial demonstrating fiducial marker placement (green circles) on the front (A) and side (B) of the CT quality control phantom.
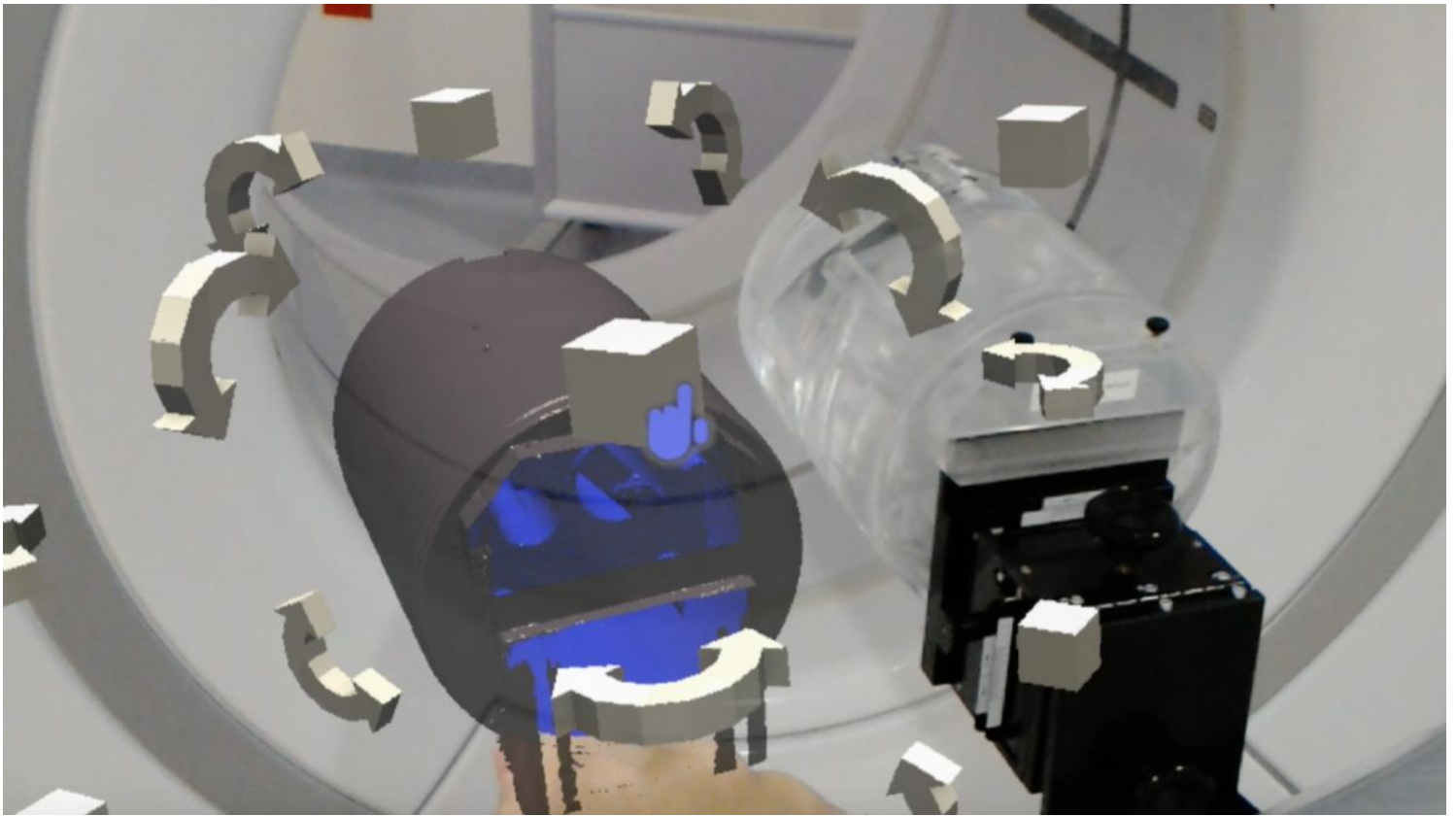
Figure 2

Photograph illustrating scientific caliper measuring distance between fiducial markers.
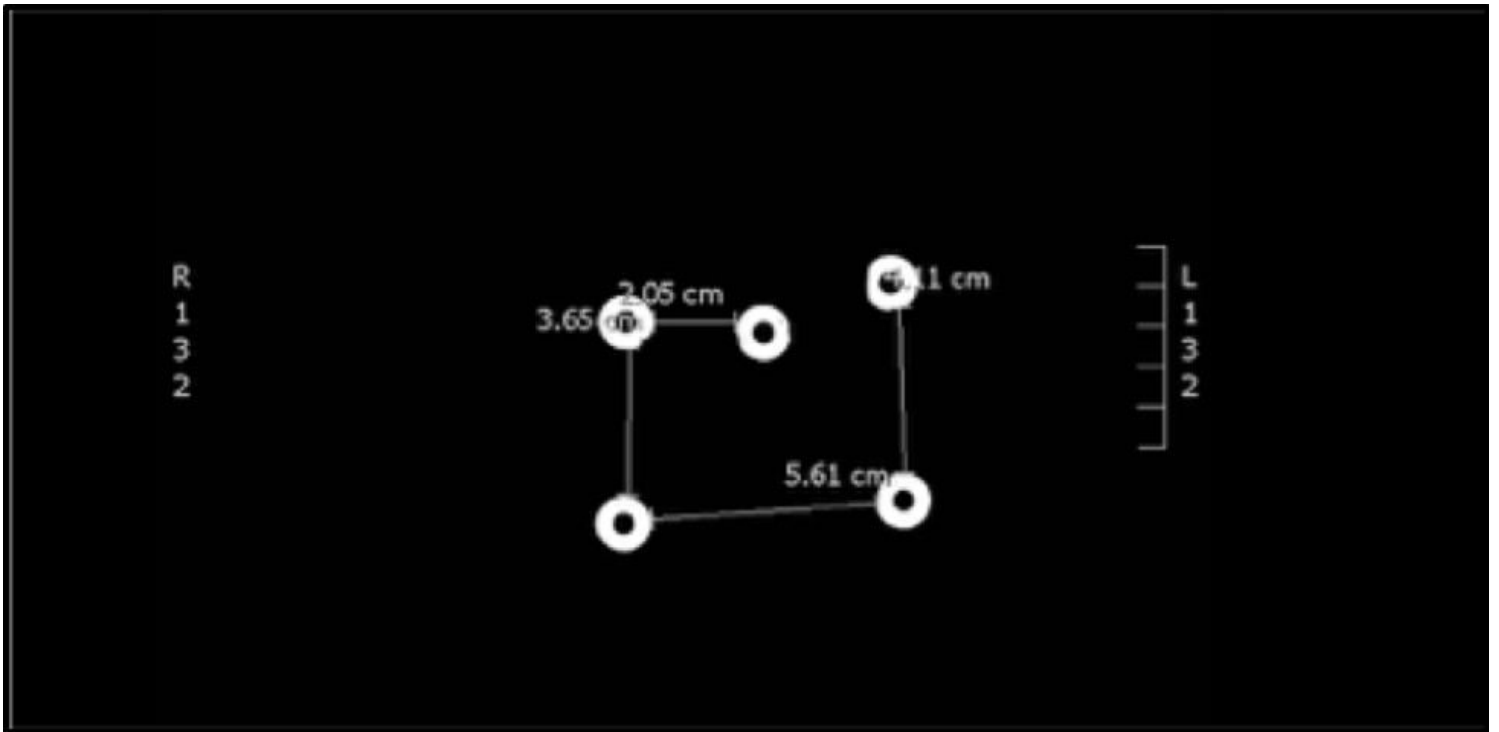
Figure 3

PACS ruler tool measuring distances between markers on DICOM image of scanned quality control phantom.
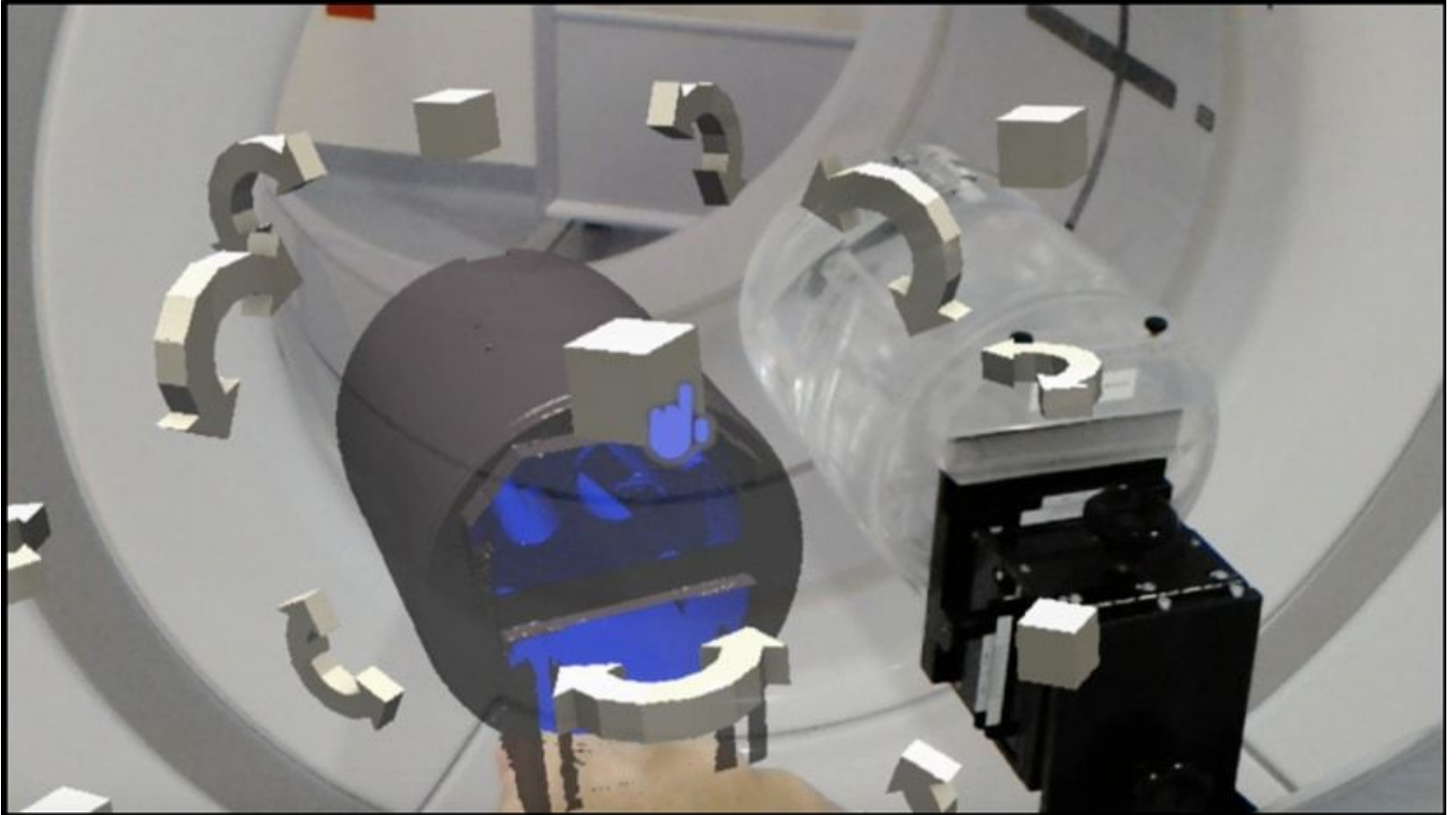
Figure 4

Side-by-side comparison of CT phantom and the resulting Augmented Reality hologram.
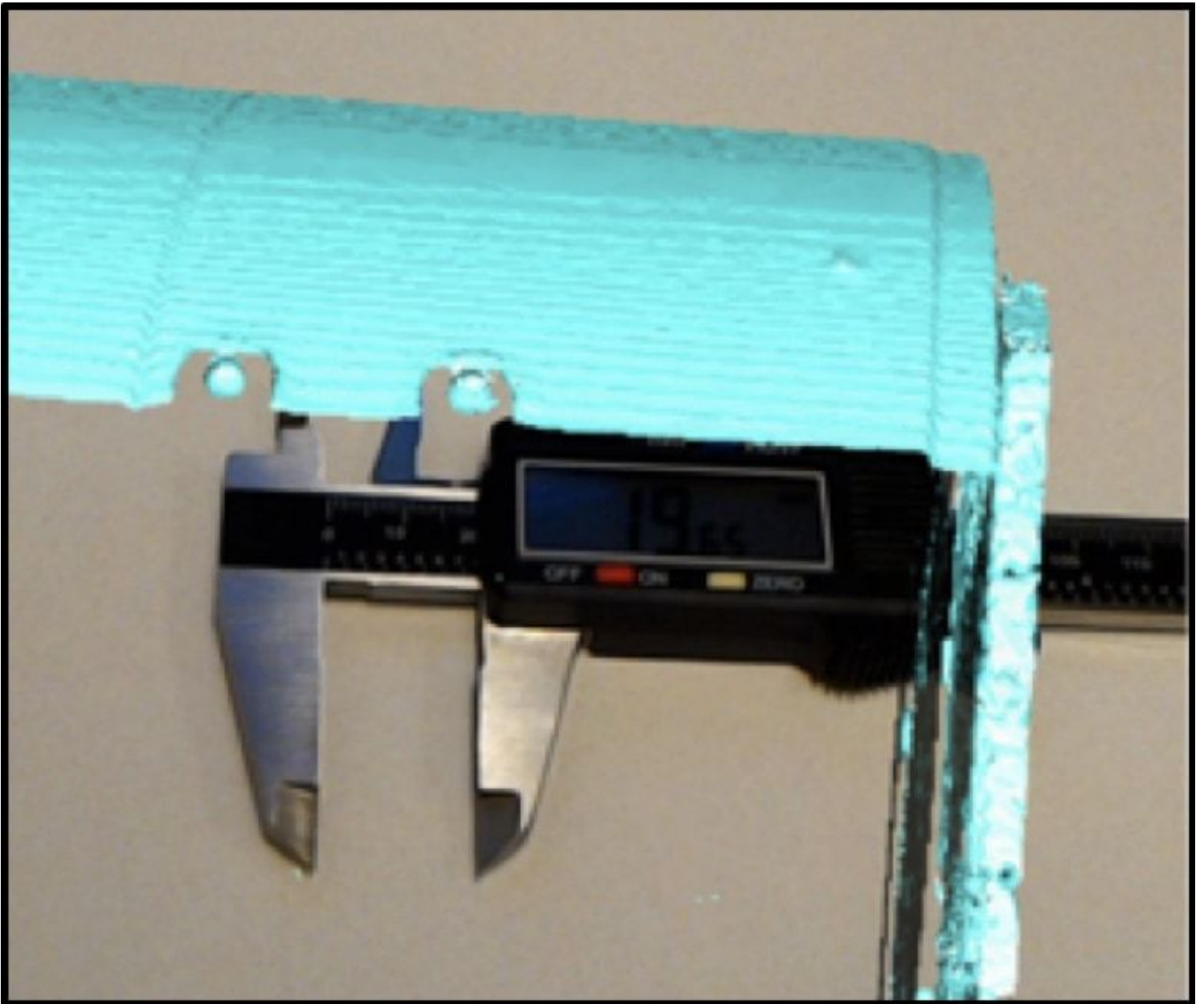
Figure 5

Photograph taken through screen capture of the hologram measurement with calipers.