CIS Seminar Talk Presentation

Paper: Alignment of the Virtual Scene to the Tracking Space of a Mixed Reality Head-Mounted Display

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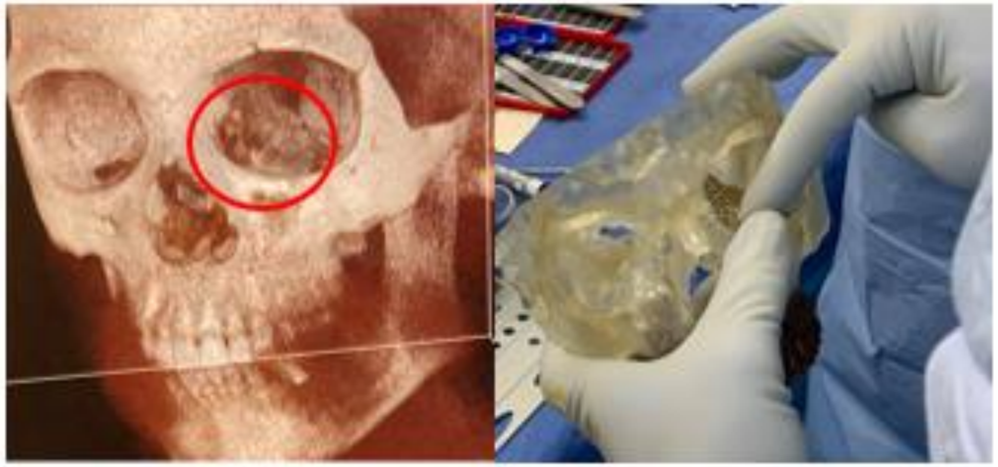
CIS Project Summary

Orbital floor reconstruction**:**

- A concave plate is placed along the wall of the eye socket to prevent tissue from entering fracture cavity.
- Hard to place.
    - Low visibility
- Misplacement can result in injury to sensitive tissue.
- Long operating time.

AR assisted surgery:

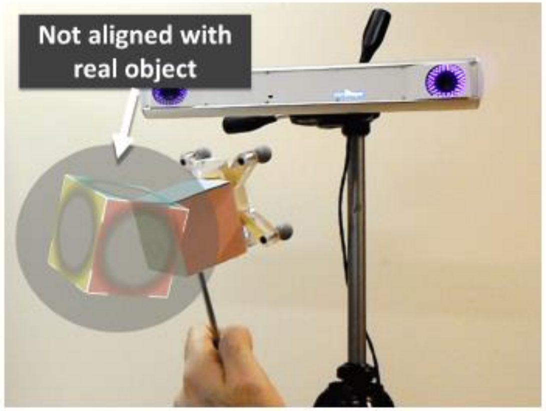
- Registration
- Calibration
- Navigation visualization



Paper Relevance

Registration: Alignment of real objects and rendered graphics in head mounted display (HMD)

Blackbox approach
- Directly computes 3D to 3D projection matrix
- Ignores the intermediate process



(a) See-through view before calibration

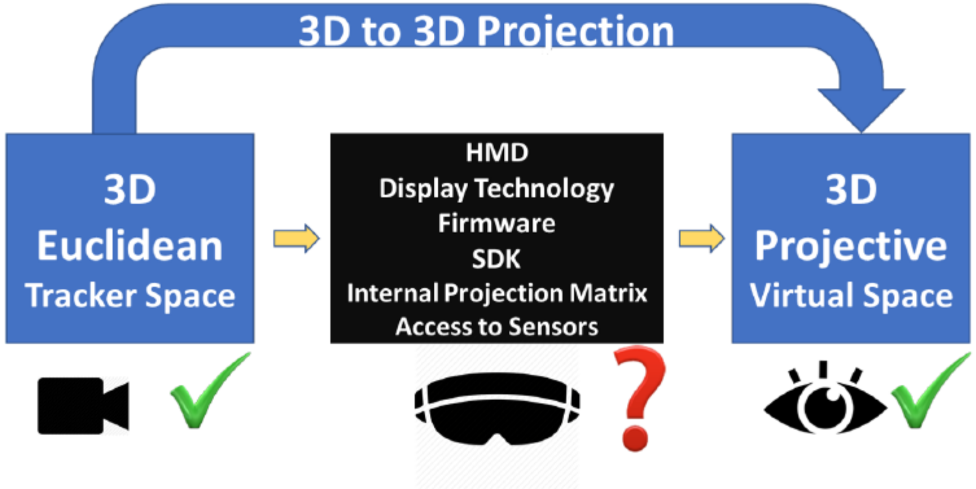


Fig. 2: Conceptual schematic of blackbox approach towards display calibration: regardless of the internal features of an HMD, as long as there is access to the generated 3D scene for the user and the tracking data, the display can be calibrated with the proposed method.

Figures: E. Azimi, L. Qian, N. Navab, and P. Kazanzides. Alignment of the Virtual Scene to the Tracking Space of a Mixed Reality Head-Mounted Display. Retrieved from: https://arxiv.org/pdf/1703.05834.pdf. 2019

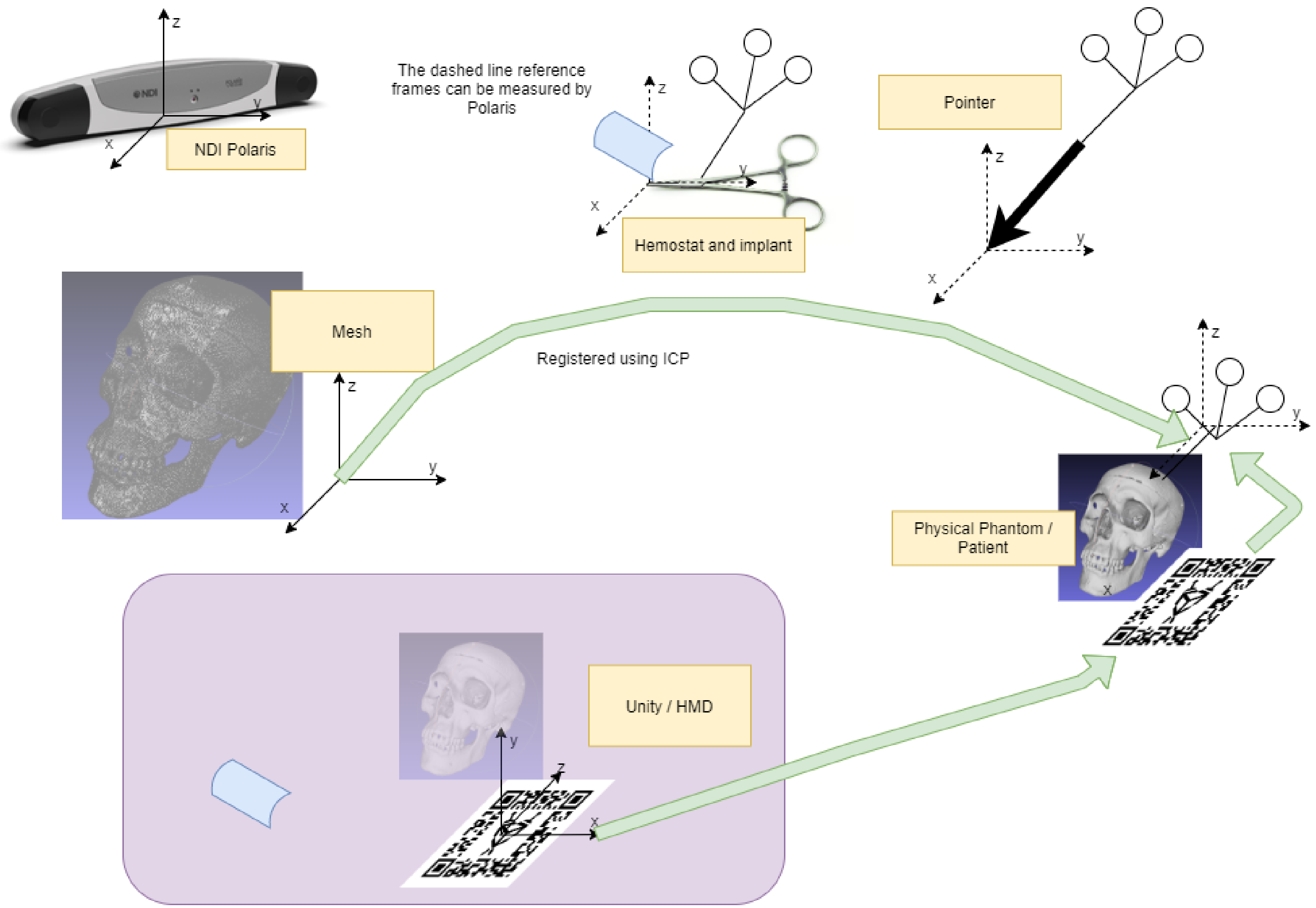
Paper Relevance

Registration

- Alignment of rendered graphics and real objects

Our CIS project approach

- AR tag as the bridge between HMD and real world



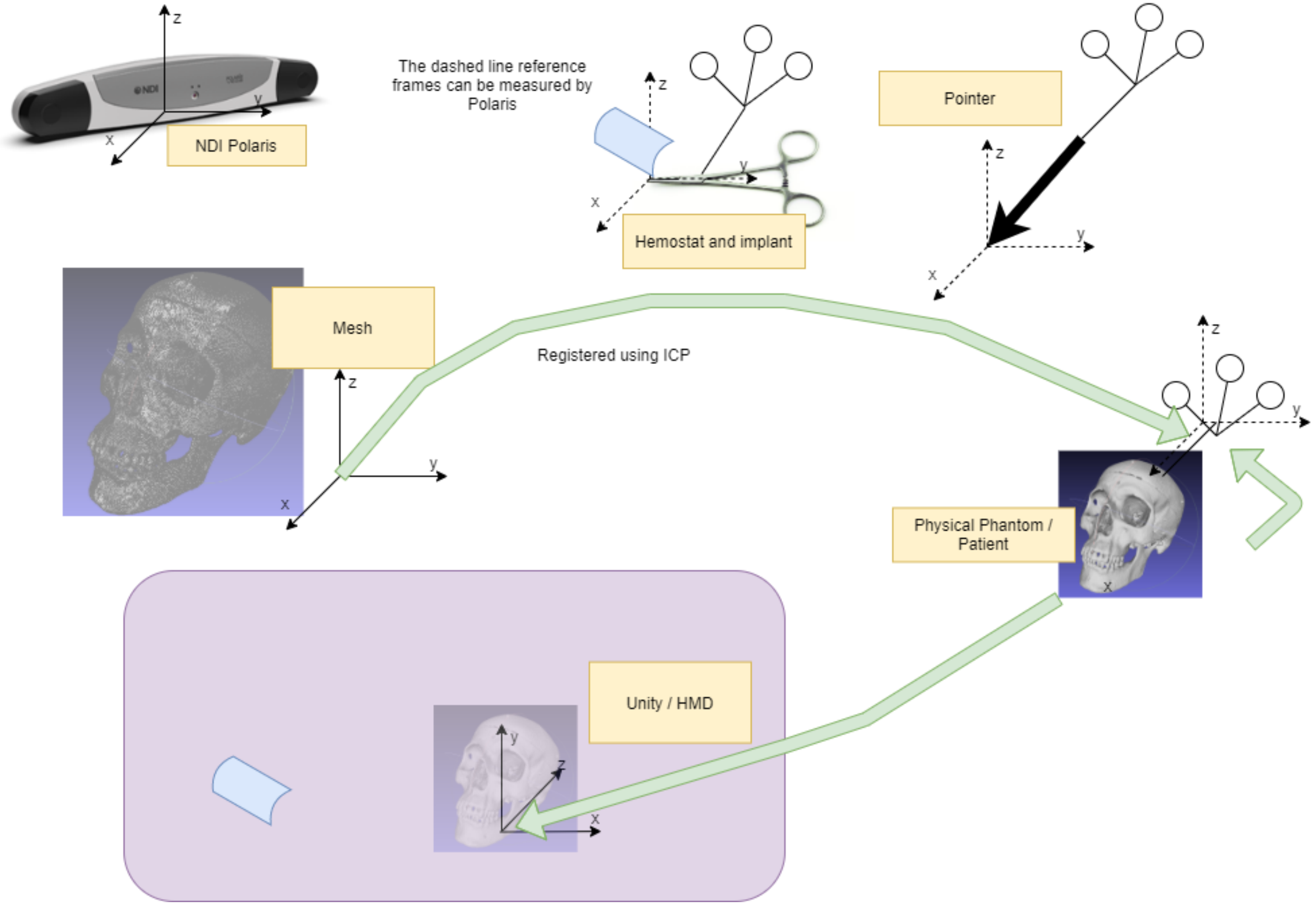
Paper Relevance

Registration

- Alignment of rendered graphics and real objects

If use the paper proposed method

- Calibration to obtain 3D to 3D projection matrix



Background

HMDs:

- Transformation chain – from real 3D object to user’s eye is incomplete
  - Users may not have access to projection matrix
  - Limited to from display to tracking system
  - Cannot provide transformation from the display to eye

- No systematic work has been done for the alignment
  - Vuforia has image-tracking support
    - Does not address the alignment between rendered object and user’s eye

Paper Significance

Contributions:

- An end to end solution to find the 3D to 3D projection (Virtual object to user's eye)
- A faster and easier multipoint alignment
- Robust experimental verification of the methods
    - Different platforms (1. HoloLens, or 2. Moverio BT-300)
    - Different setups (1. inside-out: head-anchored tracking system, or 2. outside-in: world-anchored)
    - Different tracking systems (1. inside-out: HoloLensARToolKit marker tracking, or BT-300 front-facing RGB camera; 2. outside-in: FusionTrack 500 optical tracker)
    - Geometrical models (1. perspective, 2. affine, or 3. isometric)
    - multimodal evaluation procedure.
- A novel evaluation method (Double-cube match)

Theory

World 3D points to virtual 3D points:

- $p_i = T(q_i)$
    - Affine: 12 degrees of freedom, isometric: 6 degrees of freedom, prospective: 15 degrees of freedom
- Optimization problem
    - $\min_{T} E_{reproj}$
    - $E_{reproj} = \frac{\sum_{i=1}^{n} \sqrt{(p_i - T(q_i))^2}}{n}$
    - e.g. Direct Linear Transformation (DLT) algorithm
    - For isometric case -> point-to-point registration

Theory

- HMD: two displays
  - Each display has a projection matrix $P_{3\times4}$ (3D to 2D)

$$[P_{LE}]_{3\times4} = [P_{LD}]_{3\times4} \cdot [T]_{4\times4}$$

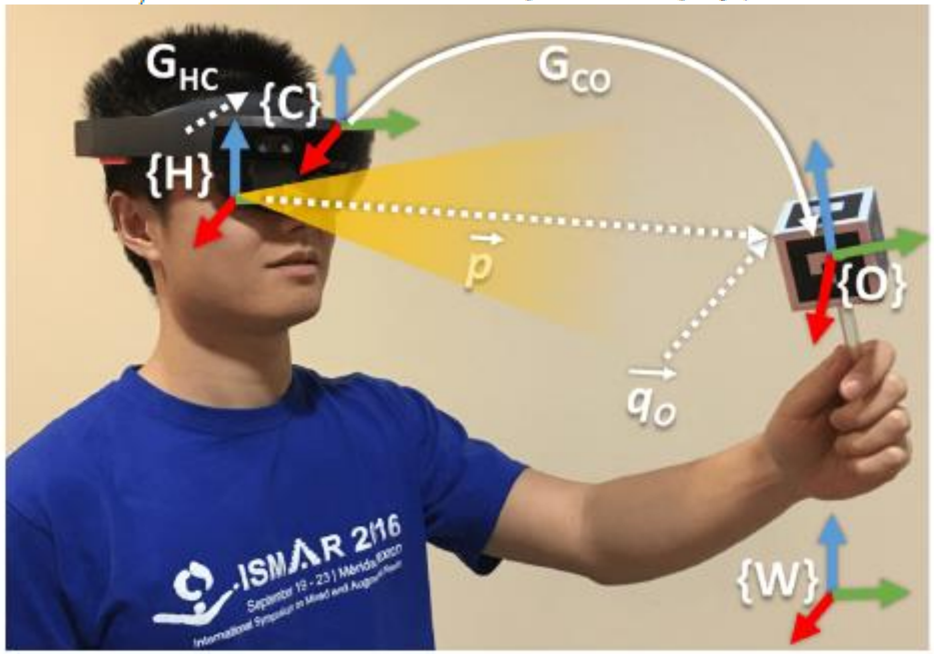
$$[P_{RE}]_{3\times4} = [P_{RD}]_{3\times4} \cdot [T]_{4\times4}$$

  - Will be discussed in the critic section

Experiment

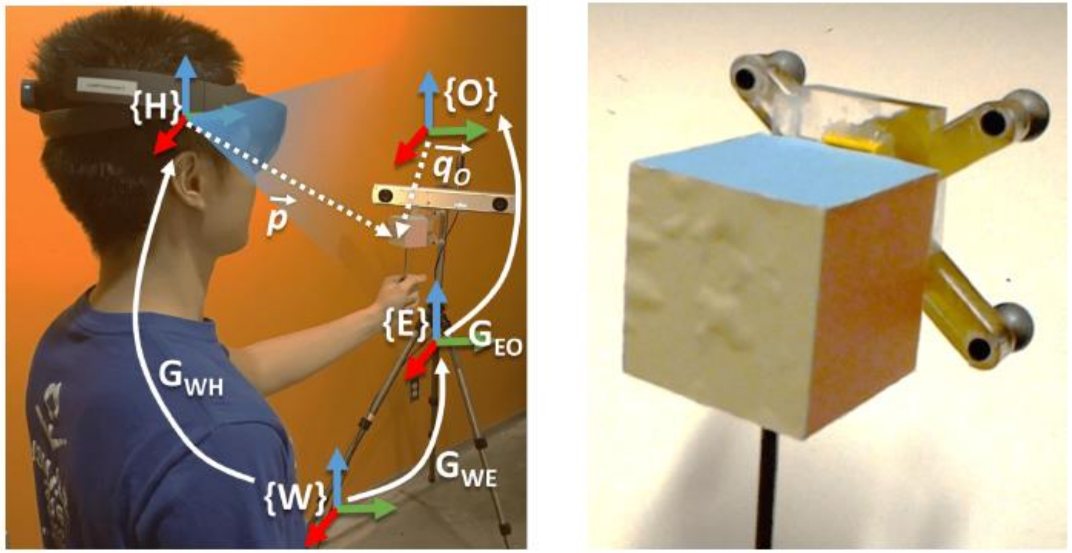
Transformation map

$$\{q \mid q_i = G_{CO,i} \cdot \vec{q}_O, i = 1, \cdots, n\} \text{ and } \{p_i \mid i = 1, \cdots, n\}$$



Head-anchored tracking

Note: G_{CO} is tracked by HoloLensARToolKit



(a) Transformation graph

(b) Tracked object

World-anchored tracking

Note: G_{WH} is tracked by SLAM-based spatial mapping

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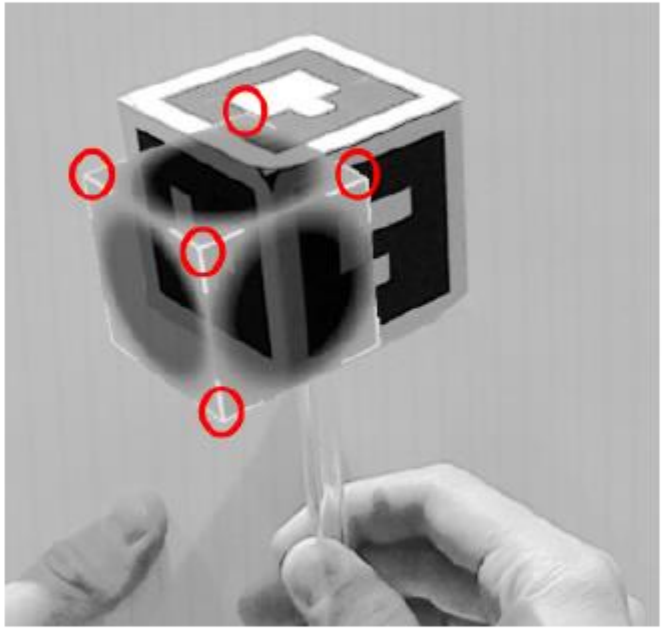
Experiment

Multipoint alignment

- 5 points alignment at a time
- Checkerboard marker can be tracked by camera



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Experiment

Evaluation methods

- Calibrate-and-test
  - Standard approach
  - Collect additional samples to test reprojection error

- Double-cube-match
  - Use a second cube marker
  - Display a virtual cube in virtual scene
    - 150 mm offset from the first cube
    - User align the second marker to the virtual cube
      - Error: Difference between the predetermined pose offset and observed pose – so rotation error is also evaluated

Experiment

Experiment and evaluation workflow

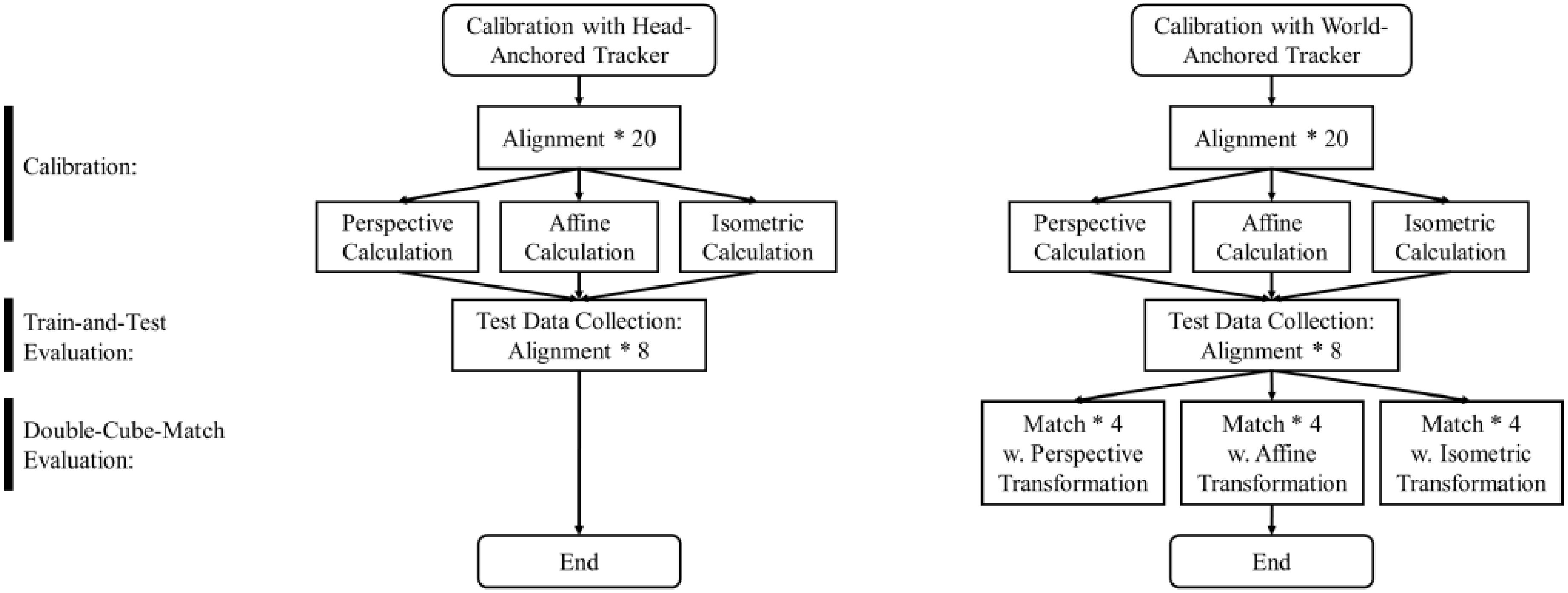

Fig. 6: The workflow of calibration with head-anchored tracker and world-anchored tracker

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Results

Table 1: Reproduction error along different axes for calibration with head-anchored tracking system for HoloLens

Model	Axis X (mm)		Axis Y (mm)		Axis Z (mm)	
	mean	std	mean	std	mean	std
Perspective	1.00	0.81	0.91	0.68	3.55	2.62
Affine	0.94	0.74	0.83	0.63	3.51	2.67
Isometric	1.82	1.08	2.05	1.36	4.58	3.31

Table 2: Reprojection error along different axes for calibration with head-anchored tracking system for Moverio BT-300

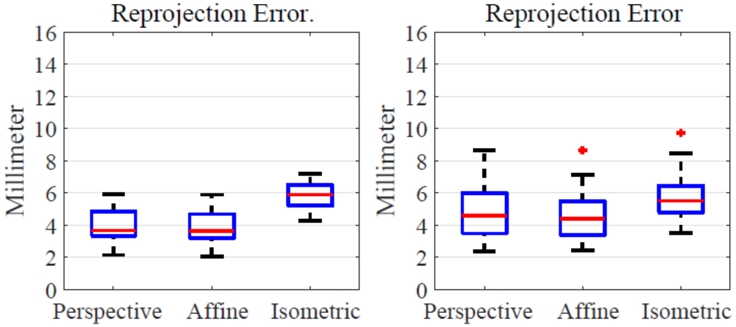
Model	Axis X (mm)		Axis Y (mm)		Axis Z (mm)	
	mean	std	mean	std	mean	std
Perspective	1.11	1.07	1.18	1.13	4.07	3.54
Affine	0.96	0.90	1.07	0.97	4.02	3.49
Isometric	2.30	1.52	1.45	0.98	4.42	3.84

Table 3: Reprojection error along different axes for calibration with world-anchored tracking system for HoloLens

Model	Axis X (mm)		Axis Y (mm)		Axis Z (mm)	
	mean	std	mean	std	mean	std
Perspective	2.47	2.04	3.01	2.49	3.20	3.01
Affine	2.44	1.98	2.98	2.52	3.21	3.01
Isometric	3.64	2.75	6.14	3.88	3.43	2.93

Tables: E. Azimi, L. Qian, N. Navab, and P. Kazanzides. Alignment of the Virtual Scene to the Tracking Space of a Mixed Reality Head-Mounted Display. Retrieved from: https://arxiv.org/pdf/1703.05834.pdf. 2019

Results



(a) HoloLens (b) Moverio BT-300

Fig. 10: Evaluation result of Calibrate-and-Test for the calibration with head-anchored tracker with two different HMDs, based on different geometrical models.

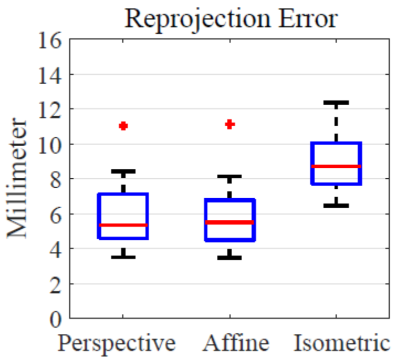
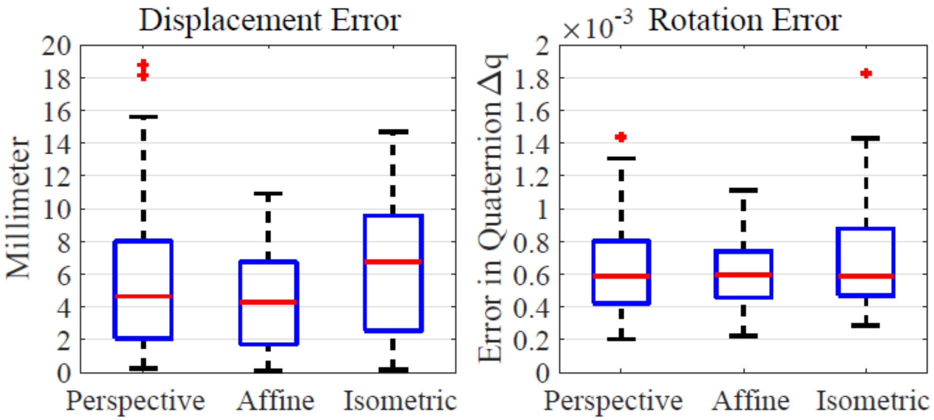


Fig. 11: Evaluation result of Calibrate-and-Test for the calibration with world-anchored tracker using the HoloLens, based on different geometrical models.

Average quaternion error
Affine (0:999; 0:005; 0:002; 0:007)
perspective (0:999; 0:001; 0:001; 0:001)
Isometric (0:999; 0:009; 0:002; 0:003)



(a) Displacement error $E_{\Delta P}$ (b) Rotational error $E_{|\Delta q|}$

Fig. 12: Evaluation result using Double-Cube-Match method, with world-anchored tracker and HoloLens

Results discussion

- Worst accuracy around 4 mm (reprojection error)
- Single corner calibration:
  - perspective and affine models are better than isometric model
- Multipoint calibration:
  - Isometric model performed well
    - The single object preserves the isometric geometric relation
- Double-cube-match:
  - Affine transformation better
    - Transformation between HoloLens and the Atracsys tracker is affine
- Depth has the largest error among three directions in head-anchored tracking
  - World-anchored tracking: user is able to move around and make alignments, so Table 3 errors are consistent in all axis

Future work

- Integrate position tracking system to HMDs using sensor fusion
- Create asymmetric calibration rig (solve the corner ambiguity problem of cubes)
- Conduct user study to investigate fatigue and user-friendliness

Assessment

Pros:

- The calibration method is independent to platform
- Provided alternative evaluation method (double-cube-match) that incorporate rotation error
- End-to-end calibration. Simplified transformation chain

Cons:

- Because the calibration method is an end-to-end method, during the calibration, if the HMD slips, the calibration will no longer be valid
- The description to the effect of the 3D to 2D projection is not very clear
  - From the paper's description, we understand that the calibration is a 3D to 3D process.
    - Confirmed by reprojection error being 3 dimensional
- During calibration, the manual alignment is subjective, while in our project approach (bar code), the measurement is well defined in the systems (optical tracker or Vuforia barcode tracking)

Paper reference

E. Azimi, L. Qian, N. Navab, and P. Kazanzides. Alignment of the Virtual Scene to the Tracking Space of a Mixed Reality Head-Mounted Display. Retrieved from: https://arxiv.org/pdf/1703.05834.pdf. 2019