Seminar Presentation: Display Calibration for Holographic OST-HMD

Group 15: Yiwei Jiang

Mentors: Ehsan Azimi, Dr. Peter Kazanzides

Reviewed Paper

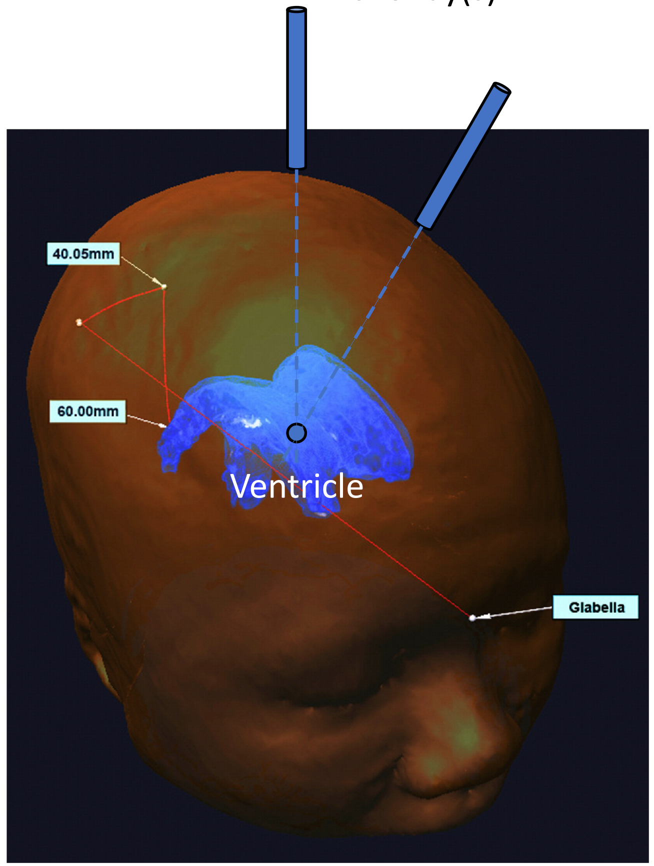
Qian, Long, et al. "Comprehensive tracker based display calibration for holographic optical see-through head-mounted display." *arXiv preprint arXiv:1703.05834* (2017).

Our Project

HMD-Based Navigation for Ventriculostomy

- The goal is to introduce image guidance via augmented reality on HoloLens

- The image guidance is AR overlay of ventricle model from MRI image and catheter guide overlay.



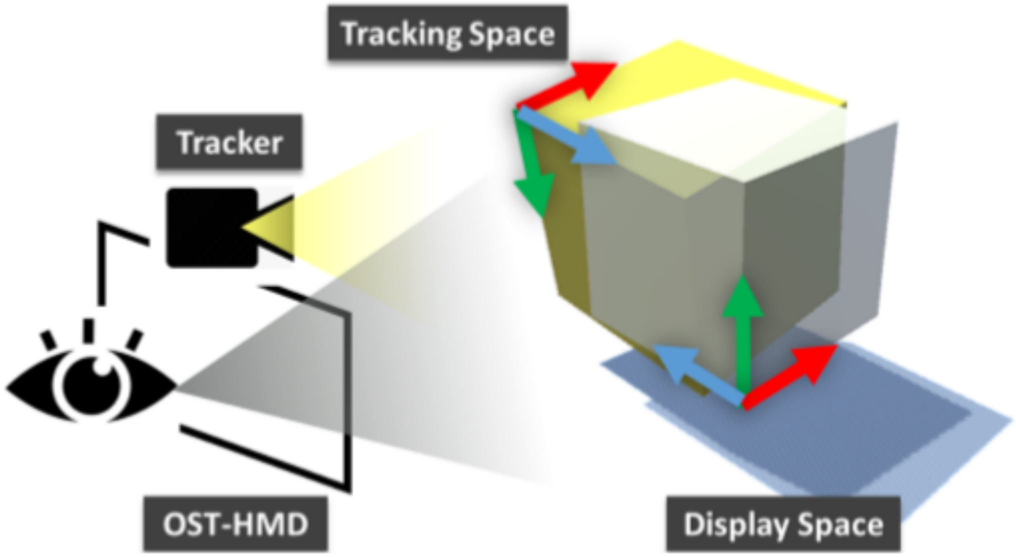
Azimi, E., et al.: Can mixed-reality improve the training of medical procedures? In: IEEE Engineering in Medicine and Biology Conference (EMBC), pp. 112–116, July 2018

Relevancy

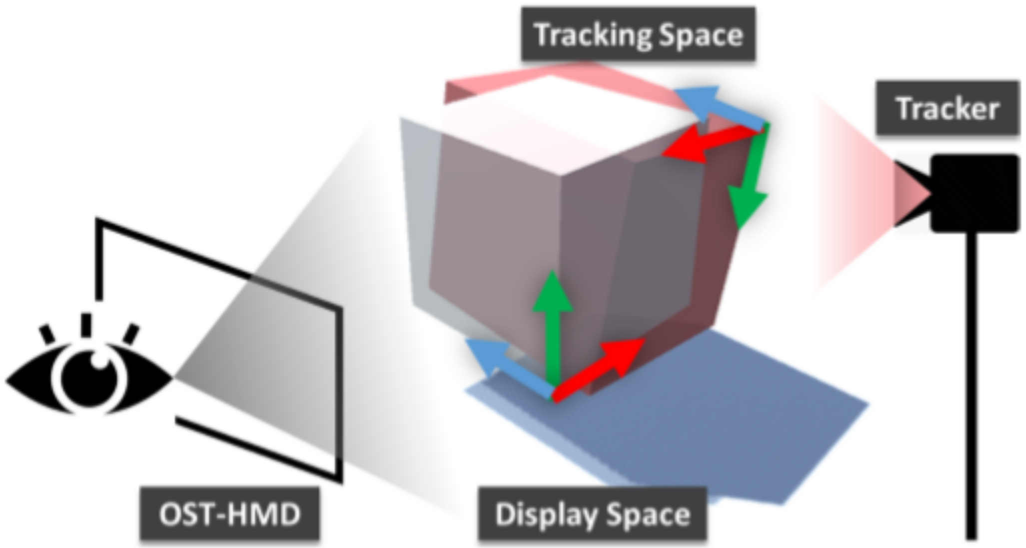
- The accuracy of overlaying a virtual object model to its true counterpart will directly affect the correctness of the guidance it provides.
- Our situation is quite similar to their head-mounted tracker case, one thing different is that for this case they used the embedded camera on HoloLens rather than we use an external ZED camera mounted to HoloLens.
- This blackbox approach enables non-experts to use this application on any HMD without worrying about the technical details of each individual system.

Summary of problem

Misalignment between the tracker space and 3D virtual scene



(a) Example with head-anchored tracking system



(b) Example with world-anchored tracking system

Technical approach

The goal of a calibration process is to find a transform T (·) which maps 3D points from the world coordinates to a 3D virtual holographic environment.

$$p_i = T(q_i) \quad i = 1, \cdots, n.$$

i) Perspective Transformation:

$$\hat{p}_i = [T_P]_{4\times 4} \cdot \hat{q}_i, \quad T_P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix}$$

ii) Affine Transformation:

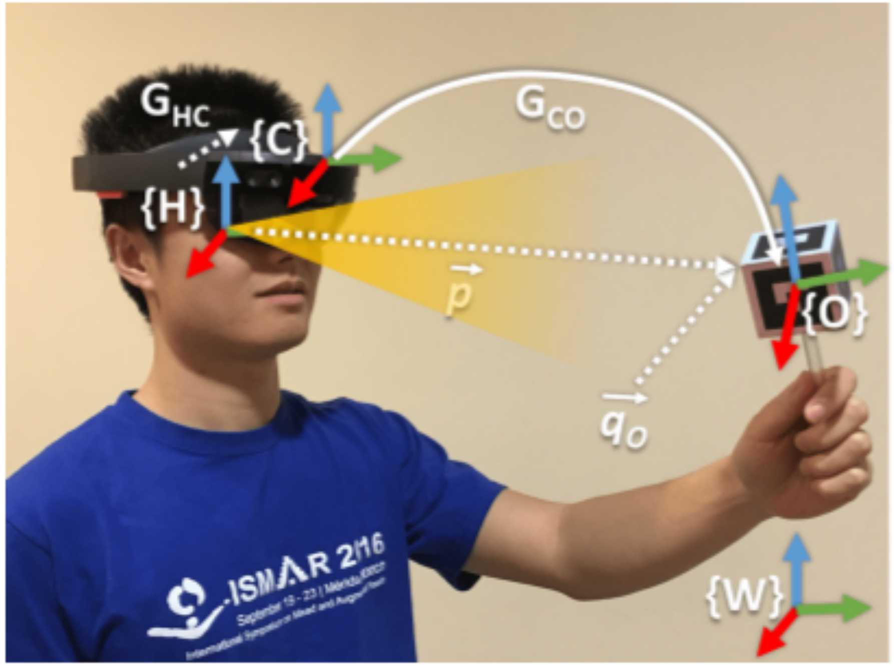
$$\hat{p}_i = [T_A]_{4\times 4} \cdot \hat{q}_i, \quad T_A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

iii) Isometric Transformation:

$$\hat{p}_i = [T_I]_{4\times 4} \cdot \hat{q}_i, \quad T_I = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Technical approach

Calibration with Head-Anchored Tracking System



Given: $\overrightarrow{p_H}$ (Pre-Defined)

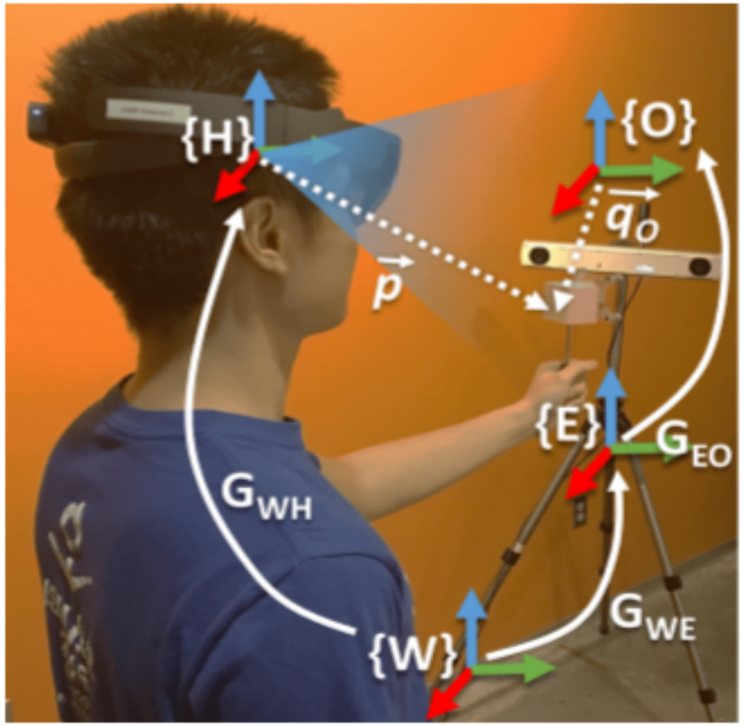
G_{CO}(AR Tracking) => $\overrightarrow{q_C} = G_{CO} * \overrightarrow{q_o}$

$\overrightarrow{p_H} = G_{HC} * \overrightarrow{q_C}$

Find: G_{HC}

Technical approach

Calibration with World-Anchored Tracking System



Given: $\overrightarrow{p_H}$ (Pre-Defined)

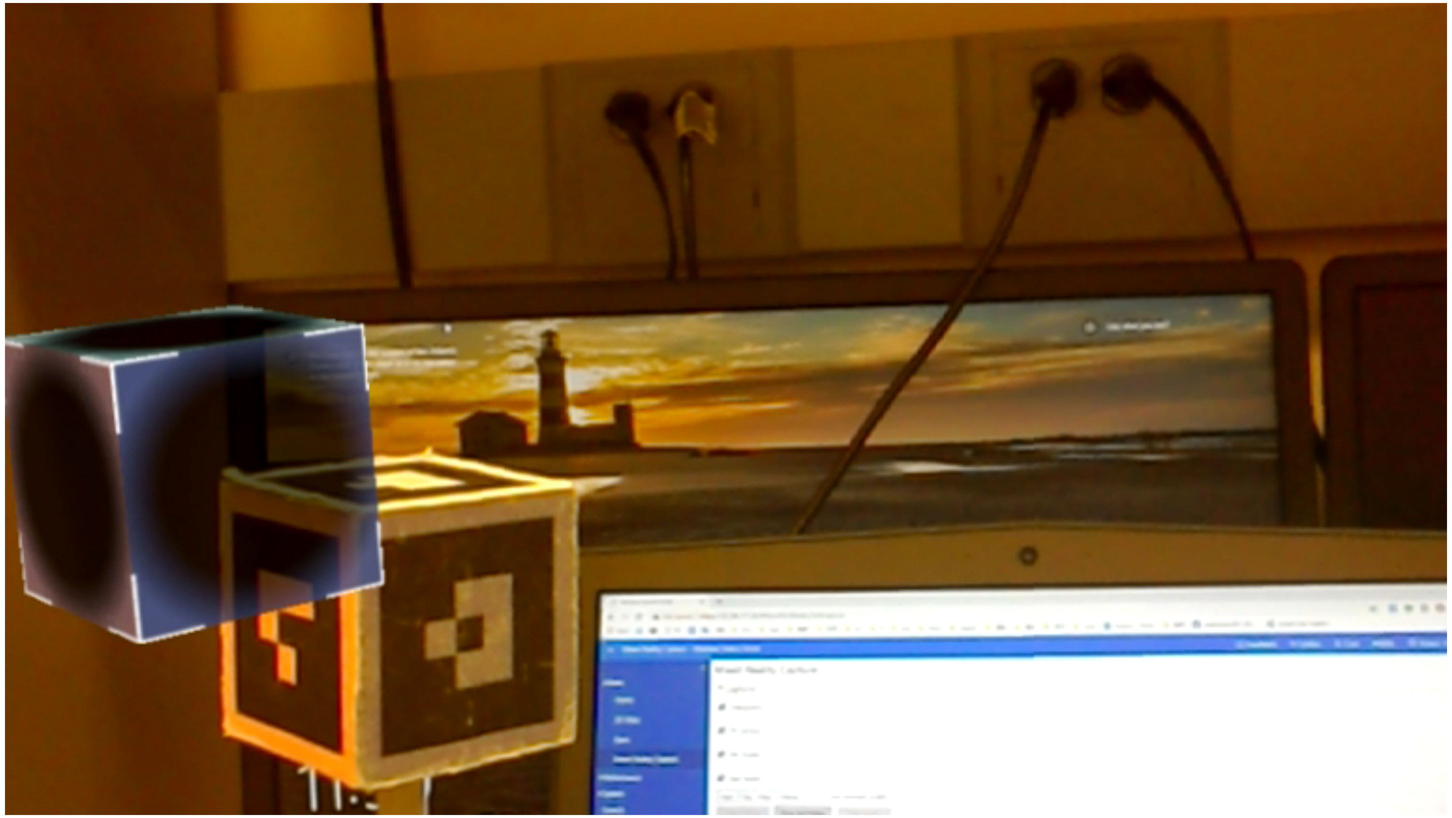
G_{WH}(SLAM-based spatial mapping), G_{WE}, G_{EO}(Tracking)

$\overrightarrow{q_E} = G_{EO} * \overrightarrow{q_O}$ $\quad G_{HE} = G_{WH}^{-1} * G_{WE}$

$\overrightarrow{p_H} = G_{HE} * \overrightarrow{q_E}$

Find: G_{HE}

Experiments



Recorded through Portal, not as same as what the user seeing behind the HoloLens

Evaluation

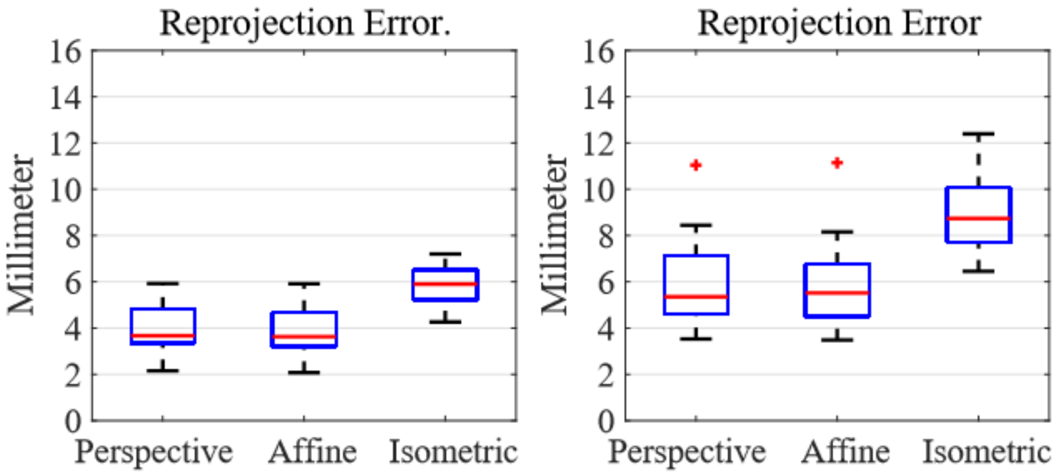
Only the user wearing it can observe the superimposed objects that resulted from the calibration

1, Train-and-Test: Collect 8 additional samples, and are tested against the calibration calculated with the training data sets consisting of the 20 alignments.

2, Double-Cube-Match: A second cube marker is used as an auxiliary reference. A virtual cube is displayed with a predetermined offset with respect to the first marker cube at four different equidistant positions. The user is asked to align the second real marker cube with the displayed virtual cube.

Key Results

Overall, the calibration process was able to superimpose the holographic cube in the correct pose with regard to its real tracked counterpart.



(a) Calib. with head-anchored tracker (b) Calib. with world-anchored tracker

Train-and-Test with head-anchored tracker and world-anchored tracker

Perspective (4.04±1.04mm)	Perspective (5.88±1.81mm)
Affine (3.96±1.06mm)	Affine (5.83±1.78mm)
Isometric (5.86±0.81mm)	Isometric (8.92±1.60mm)

Key Results

Table 1: Reprojection error along different axes for the calibration with head-anchored tracking system

Model	Axis X (mm) mean	std	Axis Y (mm) mean	std	Axis Z (mm) 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

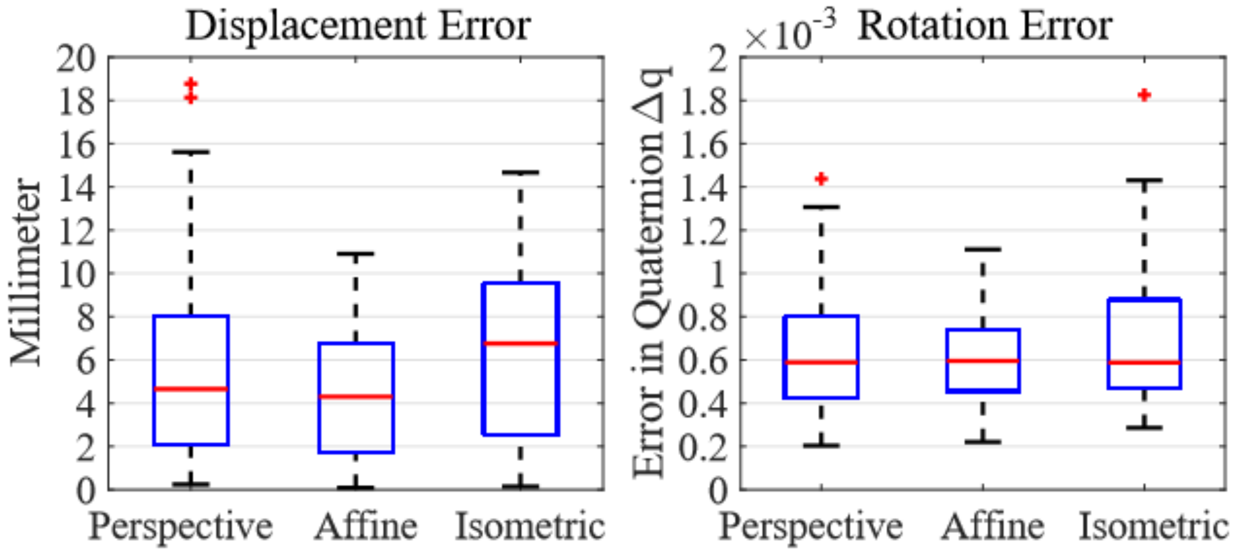
The x-y plane is perpendicular to the user's view, and the z axis is parallel with the user's line of sight, indicating the depth of alignment.

Table 2: Reprojection error along different axes for the calibration with world-anchored tracking system

Model	Axis X (mm) mean	std	Axis Y (mm) mean	std	Axis Z (mm) 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

The x, y, and z axis are parallel to the world coordinate system {W}. The user is able to move around and make alignments from different viewing perspectives. Therefore, no axis is associated with the depth direction in this case.

Key Results



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

Double-Cube-Match for the calibration with world-anchored tracker

Perspective (5.47±4.26mm)
Affine (4.45±3.00mm)
Isometric (6.44±4.15mm)

Perspective (0.999, 0.001, 0.001, 0.001)
Affine (0.999, 0.005, 0.002, 0.007)
Isometric (0.999, 0.009, 0.002, 0.003)

Strength and Limitation

JOHNS HOPKINS UNIVERSITY

Pros:

1. A blackbox approach for solving the transformation, regardless of the internal features of a specific HMD.
2. Two mathematic model are studied, make this method more general and widely compatible.
3. Designed two approaches which can eliminate the subjectivity to some degree.
4. Accuracy around 4mm is good for most applications.

Cons:

1. Only used three of the five markers, and the poses of corners are almost the same.
2. These experiments were performed by two experienced HoloLens users. The results would be more convinced if they did the tests among non-experts.
3. The symmetry of the cube is unfriendly to color blind, an asymmetrical object can be used to improve this.
4. Assumption of linear transformation. Maybe the transformation is somewhat related to the position.

Future Work

JOHNS HOPKINS
UNIVERSITY

1. Integrate head-anchored and world-anchored tracking systems in the holographic OST-HMD using sensor fusion, thereby overcoming issues such as occlusion or limited field of view.

2. This calibration method depends on an external object with markers attached to it. It would be better if the process can be markerless, it would be great if application could detect an object that is there, and then let user move that in different locations for calibrate.

3. Use a stereo camera instead of human behind the HMD, perform the alignments automatically.

Reference

[1] C. B. Owen, J. Zhou, A. Tang, and F. Xiao. Display-relative calibration for optical see-through head-mounted displays. In Third IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR), pages 70–78. IEEE, 2004.

[2] M. Tuceryan, Y. Genc, and N. Navab. Single-point active alignment method (SPAAM) for optical see-through HMD calibration for augmented reality. Presence: Teleoperators and Virtual Environments, 11(3):259–276, 2002.

[3] E. Azimi, L. Qian, P. Kazanzides, and N. Navab. Robust optical seethrough head-mounted display calibration: Taking anisotropic nature of user interaction errors into account. In Virtual Reality (VR). IEEE, 2017.

[4] S. Reichelt, A. Schwerdtner, G. Futterer, H. Stolle, N. Leister, and R. Haussler. Holographic 3-D displays-electro-holography within the grasp of commercialization. INTECH Open Access Publisher, 2010.

[5] Lee, C. K., Tay, L. L., Ng, W. H., Ng, I., & Ang, B. T. Optimization of ventricular catheter placement via posterior approaches: a virtual reality simulation study. Surgical neurology, 70(3), 274-277.2008

Question ?