HoloLens Robot Controller

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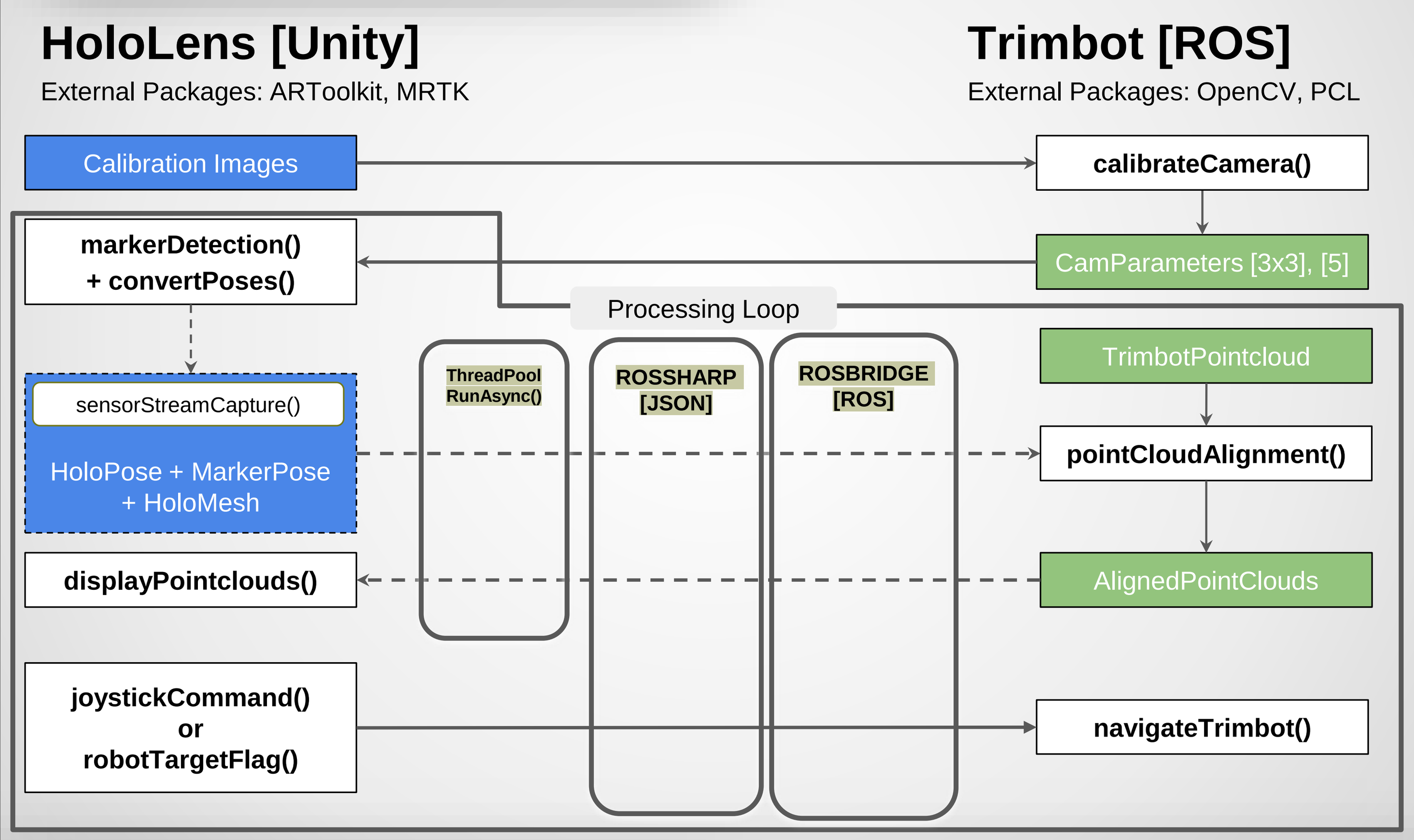
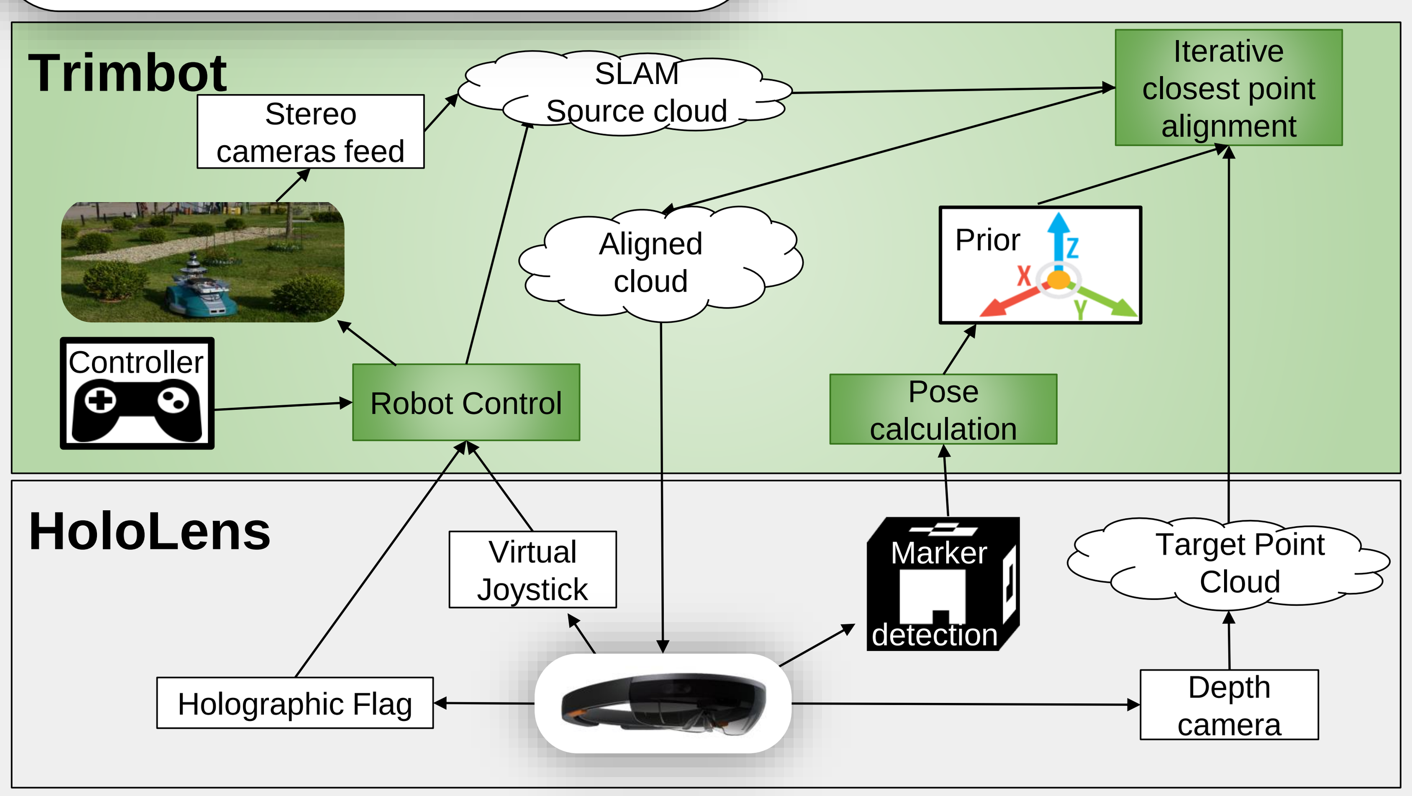
Introduction and Goals

- **An interaction system that displays the Trimbots generated SLAM point cloud as a hologram around the user in the HoloLens and enables him to control the Trimbot via holographic joystick commands or by pointing his fingers on a target location**
- The HoloLens will display the map acquired through robot's visual SLAM system as an overlay which enables user to perceive the state of the robot's visual system.
- For this, it is necessary to establish a communication interface between HoloLens and Trimbot which will be used to exchange map data stored in the respective devices as well as user's control commands.
- Also, the HoloLens needs to detect the robots pose and orientation in order to create the necessary coordinate transformations between the two systems.

Communication



Processing Pipeline



HoloLens App

I) Camera Calibration

- We follow the procedure by Zhang[5] and estimate the **camera calibration matrix** and **distortion coefficients** by taking multiple images of the calibration pattern under different orientations.

Homography between 3D points and the image plane

$$s\,m' = A[R|t]M'$$

$$s\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}f_x & 0 & c_x\\0 & f_y & c_y\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r_{11} & r_{12} & r_{13} & t_1\\r_{21} & r_{22} & r_{23} & t_2\\r_{31} & r_{32} & r_{33} & t_3\end{bmatrix}\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix}$$

X, Y, Z: coordinates of a 3D point in world coordinate space [m]
u, v: image coordinates of the projected point [px]
A: camera matrix with intrinsic camera parameters
cx, cy: principal point at the image center [px]
fx, fy: focal lengths [px]

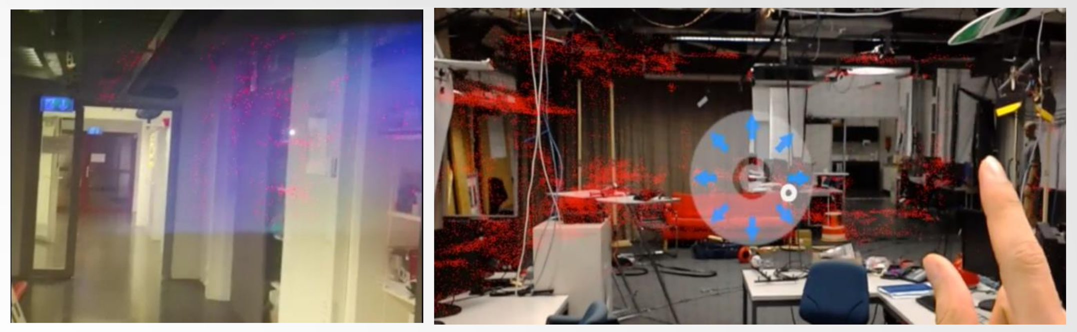
II) Marker Detection and Pose Estimation

Candidate Detection → Multi-Marker Identification → Pose Estimation

- Candidate Detection: Analyze the image (thresholding, contour extraction and selection) for square shapes that could be marker candidates
- Multi-Marker Identification: Apply perspective transformation and thresholding to extract black and white bits and identify markers
- Pose Estimation:
  - 3D transformation (rotation and translation) from marker to camera coordinate system.
  - Infer robot pose and orientation from identified markers

III) Point Cloud Rendering

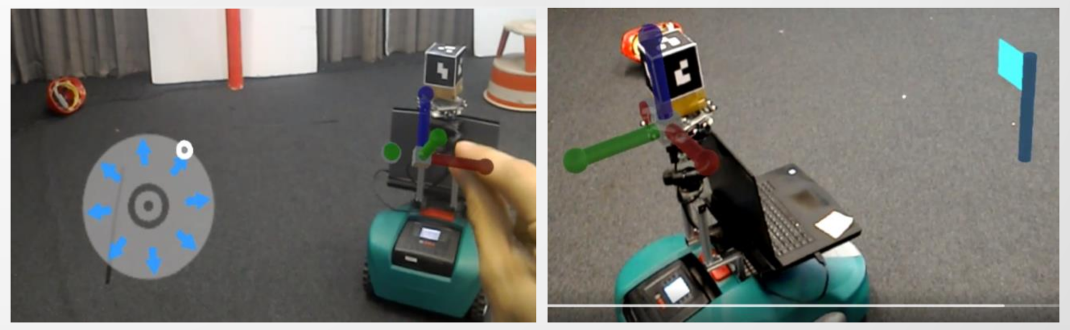
- **Renders** the most recently received **aligned point cloud mesh** published by the Trimbot
- If Trimbot **loses tracking** and **stops publishing** a new point cloud, user is instructed to **use the joystick** to help it **regain orientation**



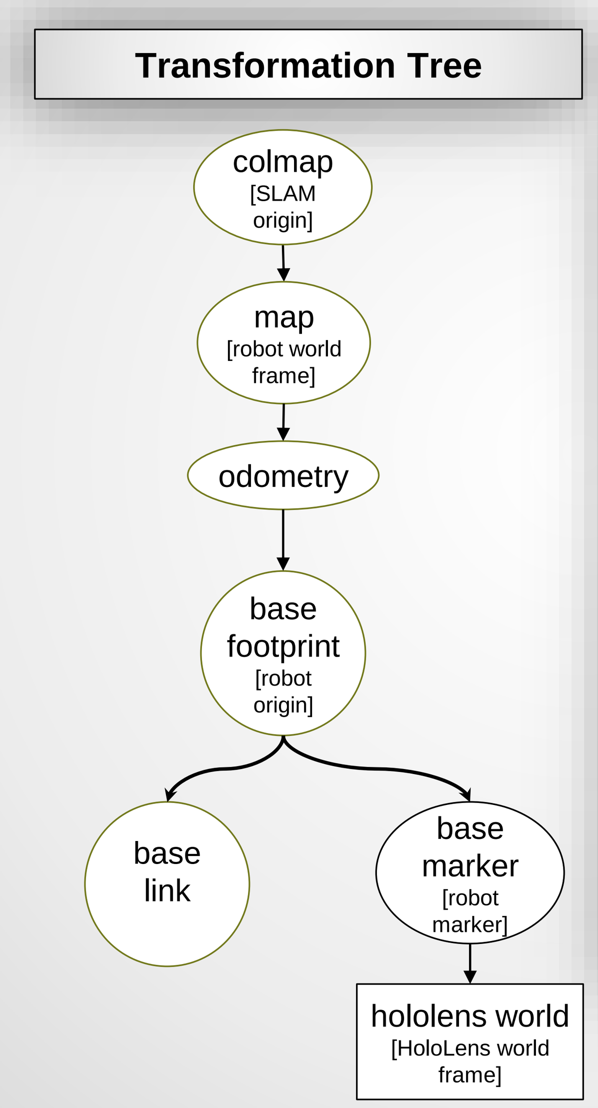
IV) Robot Control Commands

Option A:
- Send **direct control** commands to the Trimbot with a **virtual joystick**

Option B:
- Send **indirect control** commands by tapping at a **desired location** in the real world, which posts a **holographic flag** at that position.
- The **target location** is communicated to the Trimbot, which will **transform** it into its own coordinate system and **navigate autonomously towards the target.**



Transformations



The detected marker pose is used to **update the transformation** between the **robot's marker** and the **HoloLens world frame.**

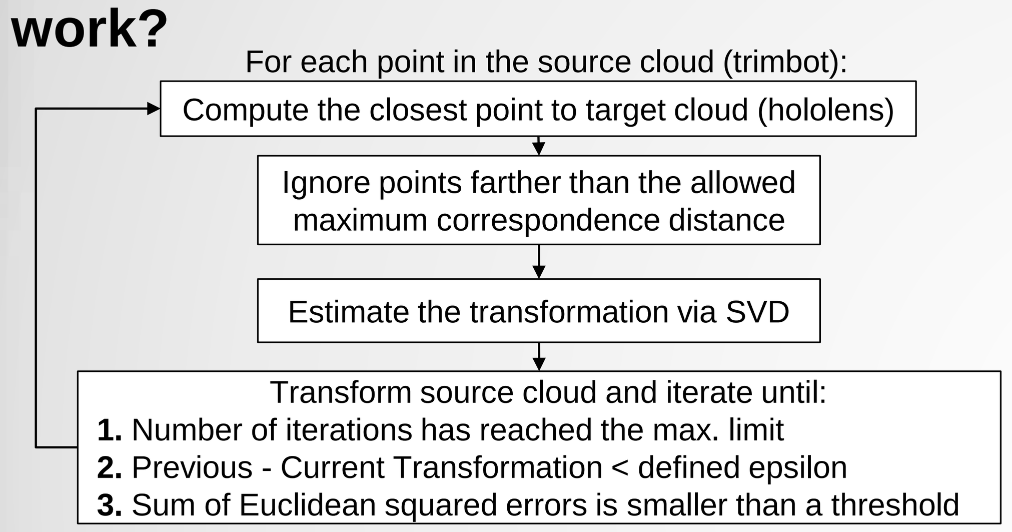
Then, the **overall transformation** is achieved by multiplying all the transformations in the tree from the SLAM origin down to the HoloLens.

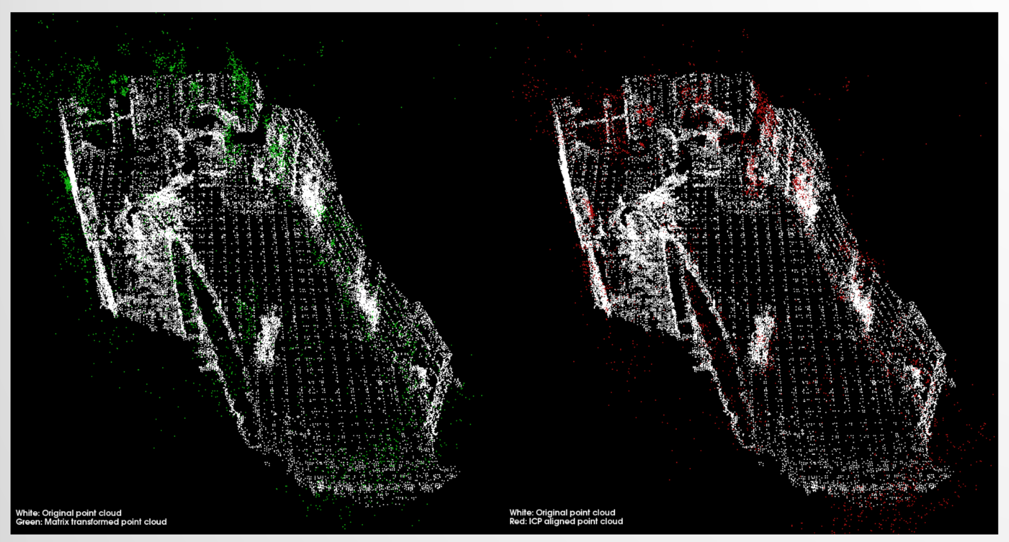
Problem:
If the trimbot **moves** but the marker pose **fails to update**, for example when the markers are not visible to the cameras of the HoloLens, then the transformation becomes invalid.

Solution:
We calculate the transformation only **after updating** the marker pose and **store it externally.**

Alignment

How does Iterative Closest Point (ICP) work?



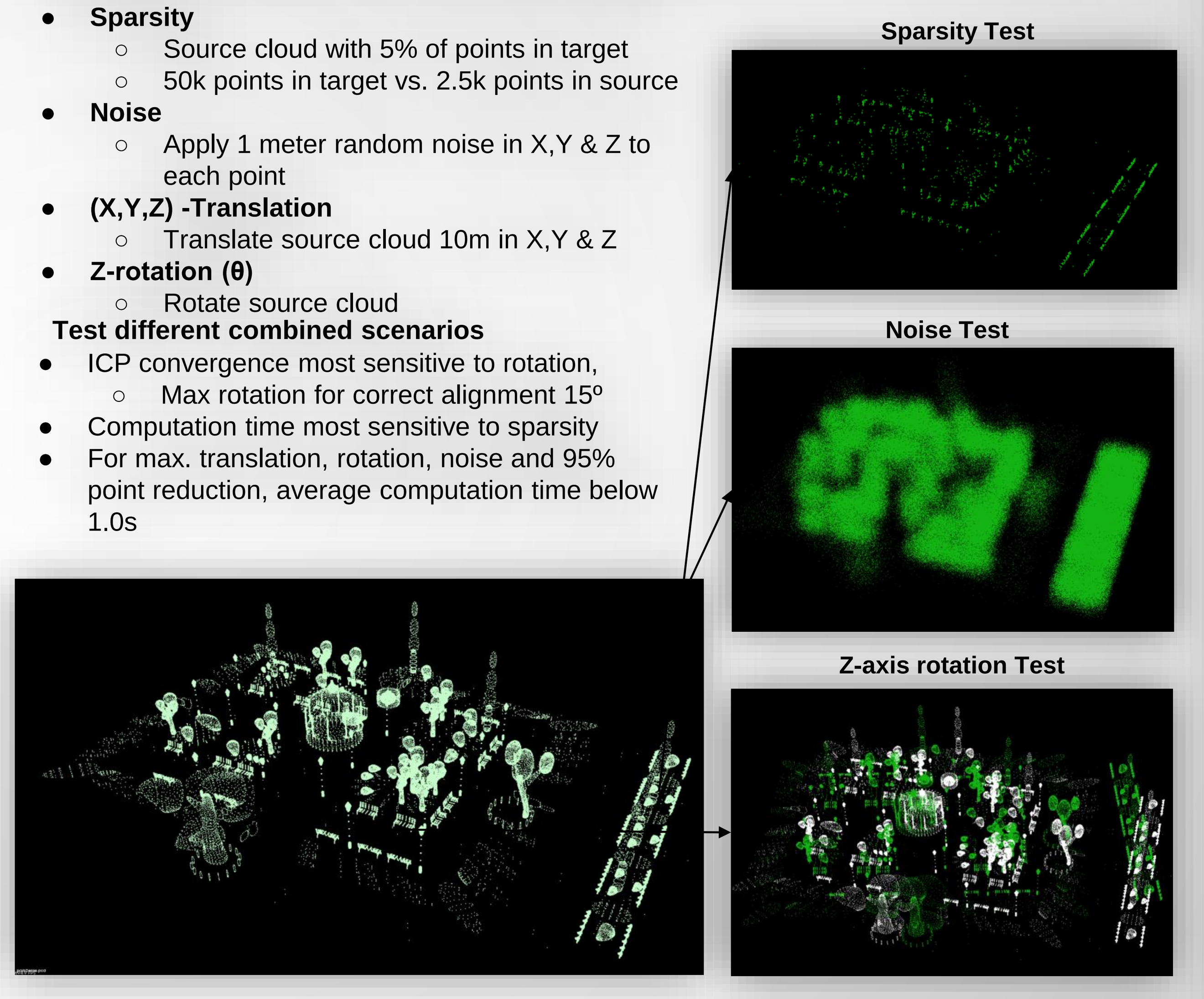


Synthetic data set tests

Without an available dataset to work with, a synthetic point cloud was used to test the limitations of the ICP algorithm. The target cloud was fixed and tested with different scenarios transforming an identical source cloud.

- **Sparsity**
  - Source cloud with 5% of points in target
  - 50k points in target vs. 2.5k points in source
- **Noise**
  - Apply 1 meter random noise in X,Y & Z to each point
- **(X,Y,Z) -Translation**
  - Translate source cloud 10m in X,Y & Z
- **Z-rotation (θ)**
  - Rotate source cloud

Test different combined scenarios
- ICP convergence most sensitive to rotation,
  - Max rotation for correct alignment 15º
- Computation time most sensitive to sparsity
- For max. translation, rotation, noise and 95% point reduction, average computation time below 1.0s



References

[1] J. Yang, H. Li, and Y. Jia. Go-ICP: Solving 3D registration efficiently and globally optimally. In ICCV, 2013
[2] P. J. Besl and N. D. McKay. A method for registration of 3-D shapes. TPAMI, 14(2):239–256, 1992
[3] Point Cloud Library (PCL): Pcl::IterativeClosestPoint< PointSource, PointTarget, Scalar > Class Template Reference, docs.pointclouds.org/trunk/classpcl_1_1_iterative_closest_point.html
[4] The Trimbot2020 project. http://trimbot2020.webhosting.rug.nl/
[5] Zhengyou Zhang. A Flexible New Technique for Camera Calibration, 1998
[6] Microsoft Mixed Reality Toolkit for Unity. https://microsoft.github.io/MixedRealityToolkit-Unity/Documentation/GettingStartedWithTheMRTK.html and https://github.com/microsoft/MixedRealityToolkit-Unity
[7] Microsoft HoloLens (1st gen) and immersive headset tutorials. https://docs.microsoft.com/en-us/windows/mixed-reality/holograms-100
[8] Long Qian. HoloLens ARToolKit:Marker tracking using the front-facing camera of HoloLens and Unity3D, with a wrapper of ARToolKit built for UWP. https://github.com/qian256/HoloLensARToolKit and http://longqian.me/2017/01/20/artoolkit-on-hololens/

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