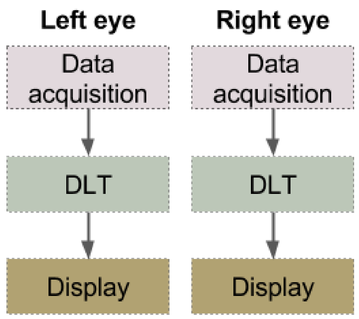
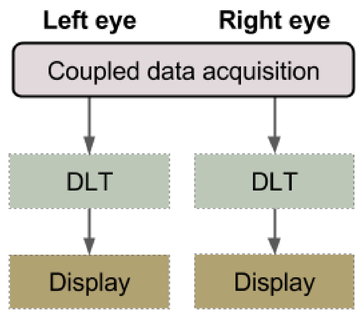
Modeling Physical Structure as Additional Constraints for Stereoscopic Optical See-Through Head-Mounted Display Calibration

Long Qian, Alexander Winkler, Bernhard Fuerst, Peter Kazanzides, Nassir Navab

Existing Methods for Stereo OST-HMD Calibration



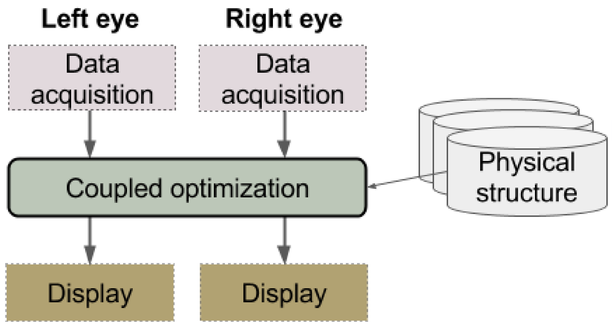
- Treat two eyes separately
- No coupling is considered



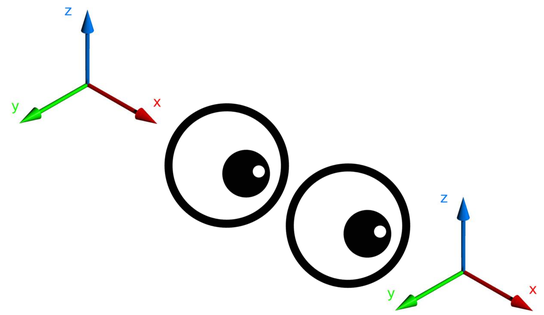
- Make stereo alignment
- Uncoupled optimization

Decomposition results do not satisfy physical constraints.

Coupled Optimization



- Consider physical structure as additional constraints.



Assumed physical constraints:

1. Same aspect ratio in x and y axis on the screen
2. Same aspect ratio on the two virtual cameras
3. No skew in user perceived image
4. Same viewing direction for both eyes
5. Rectified stereo vision
6. Fixed, given interpupillary distance

Projection matrix decomposition:

$$\begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & 1 \end{bmatrix} = \begin{bmatrix} \alpha_x & s & d_x \\ 0 & \alpha_y & d_y \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} R & T \end{bmatrix}$$

Parameter space: (Modeled explicitly)

$$\Psi = \{\alpha_x^l, \alpha_y^l, s^l, d_x^l, d_y^l, q_x^l, q_y^l, q_z^l, q_w^l, t_x^l, t_y^l, t_z^l,$$
$$\alpha_x^r, \alpha_y^r, s^r, d_x^r, d_y^r, q_x^r, q_y^r, q_z^r, q_w^r, t_x^r, t_y^r, t_z^r\}$$

Optimization: $\arg\min_{\theta} F(\theta), \theta \in \Psi$ — Minimize reprojection error directly

$$F(\theta) = \sum_i \left\| I_{Left}^i - \Gamma_L(P_{Left}^i, \theta) \right\| + \sum_j \left\| I_{Right}^j - \Gamma_R(P_{Right}^j, \theta) \right\|$$

Left eye: 2D user input — Right eye: Reprojected 2D location

Observations:

1. There is violation of physical constraints, if two views are calibrated separately.
   - Different aspect ratio $\alpha_x^l = 2637.88,\ \alpha_x^r = 2797.33,\ \alpha_y^l = 2506.21,\ \alpha_y^l = 2608.20$
   - Nonzero skew $s^l = -95.69,\ s^r = 22.39$
   - Non-rectified stereo vision
2. Coupled optimization guarantees the validation of physical constraints.
3. An initial state is needed for the solution of optimization problem. It can come from the DLT method.
4. Coupled optimization is slower because it is iterative, but since the calibration is done once before actual application, the computational cost is not critical.

Acknowledgement:
This work was supported in part by DoD W81XWH-15-C-0156, awarded to Juxtopia LLC

Technische Universität München
Johns Hopkins Whiting School of Engineering