Projective Alignment of Range and Parallax Data

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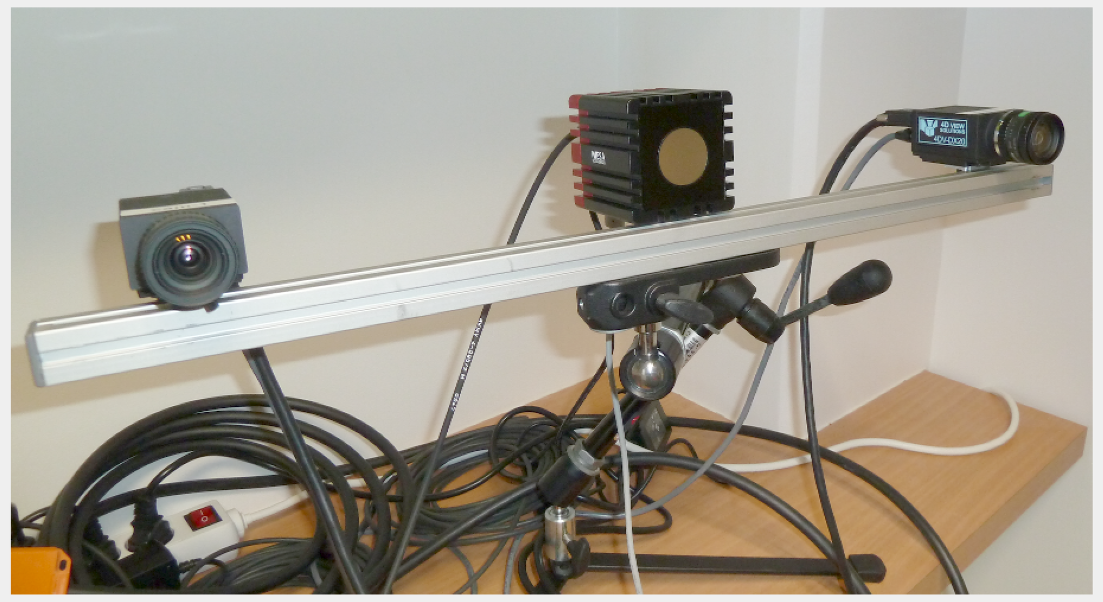
1. Introduction

- The aim is to construct a dense 3D representation, with RGB texture.
- Data is provided by a **time of flight** camera, plus a **stereo** system.



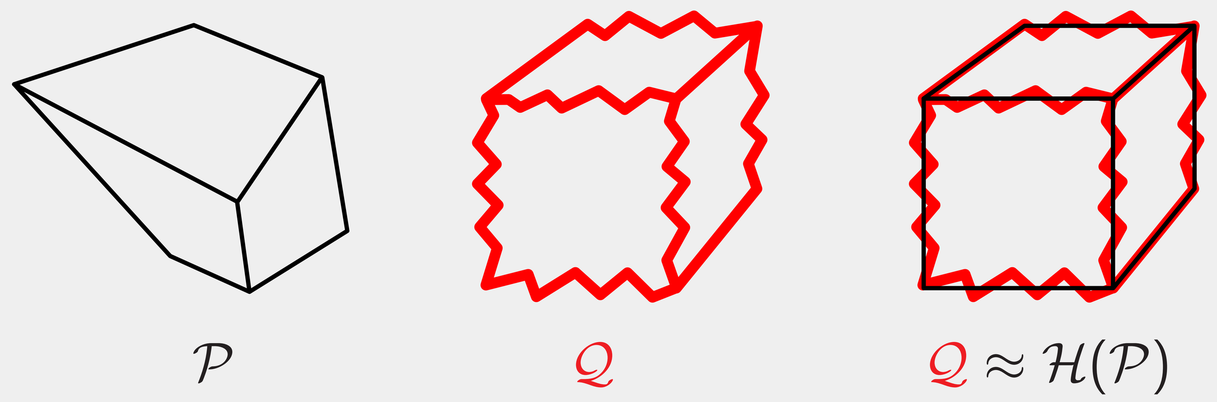
TOF Camera
176× 144 px.
Range 500cm

RGB Cameras
1624×1224 px.
Baseline 60cm

- The range camera provides no colour information.
- The binocular system is uncalibrated, except for lens distortion.

2. Main Idea

- The stereo representation $\mathcal{P}$ is relatively **precise**, but only **projective**.
- The range representation $\mathcal{Q}$ is **noisy**, but essentially **Euclidean**.
- Find the transformation $\mathcal{Q} \approx \mathcal{H}(\mathcal{P})$ between the two representations.



- Let $H_{4\times 4}$ be a projective transformation of 3D space, hence:

$$Q \simeq HP$$

- H is only estimated **once**; it then applies to all points at all times.
- Dense **RGB correspondence** can be initialized by $P \simeq H^{-1}Q$.
- Also applies to **fully calibrated** stereo systems, with $\mathcal{H}$ a rigid motion.

3. Input Data

- Stereo data P_i comes from a projective-invariant triangulation method.
- Planes are **robustly** fitted to the range calibration data.
- Range data Q_i comes from the **intersection** of TOF rays with planes.
- Correspondence $P_i \leftrightarrow Q_i$ is obtained by using a known planar pattern.

4. Estimation

- The homogeneous relation $Q \simeq HP$ is expressed (Förstner '05) as:

$$(Q)_\wedge HP = 0_6, \quad \text{where} \quad \begin{pmatrix} Q_{1:3} \\ q_4 \end{pmatrix}_\wedge = \begin{pmatrix} q_4 I_3 & -Q_{1:3} \\ (Q_{1:3})_\times & 0_3 \end{pmatrix}_{6\times 4}$$

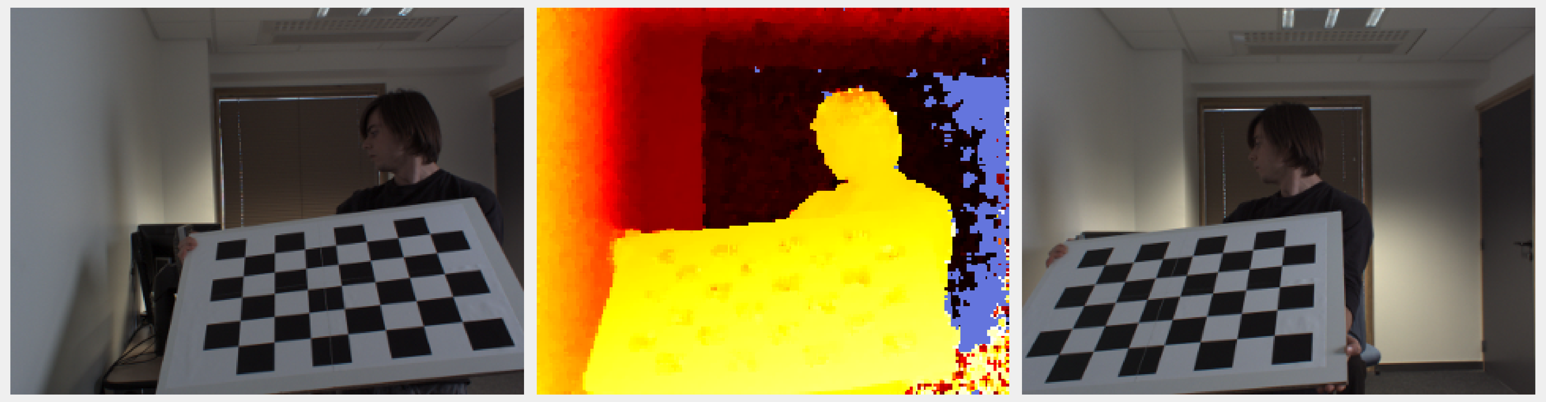
- Let $h_{16} = \text{vec}(H)$, and consider $N \geq 5$ matched points, hence:

$$\left(P^\top \otimes (Q)_\wedge\right) h_{16} = 0_6 \quad \text{and} \quad \begin{pmatrix} P_1^\top \otimes (Q_1)_\wedge \\ \vdots \\ P_N^\top \otimes (Q_N)_\wedge \end{pmatrix} h_{16} = 0_{6N}$$

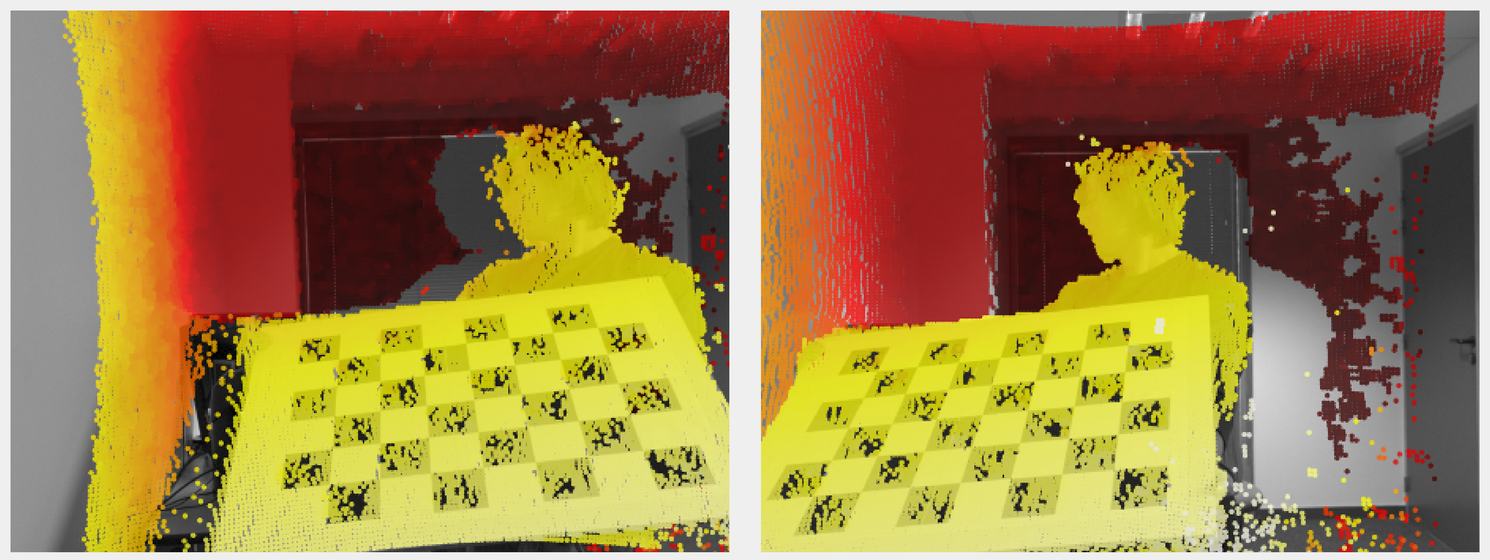
- The solution, obtained by SVD, minimizes an **algebraic error**.

5. Reprojection

- Left and right stereo images, plus colour-coded TOF depth map:



- Reprojection of the 3D range-points, via new cameras C'_L and C'_R:



- Gaps are occluded or undetected surfaces / depth outliers.
- The range data are unreliable for very scattering surfaces, e.g. hair.

6. Transformed Cameras

- The space-homography is used to transform the RGB cameras:

$$C'_L = C_L H^{-1} \qquad \text{and} \qquad C'_R = C_R H^{-1}$$

- New cameras are used to project **all** range points into the RGB views.

7. Plane-Based Method

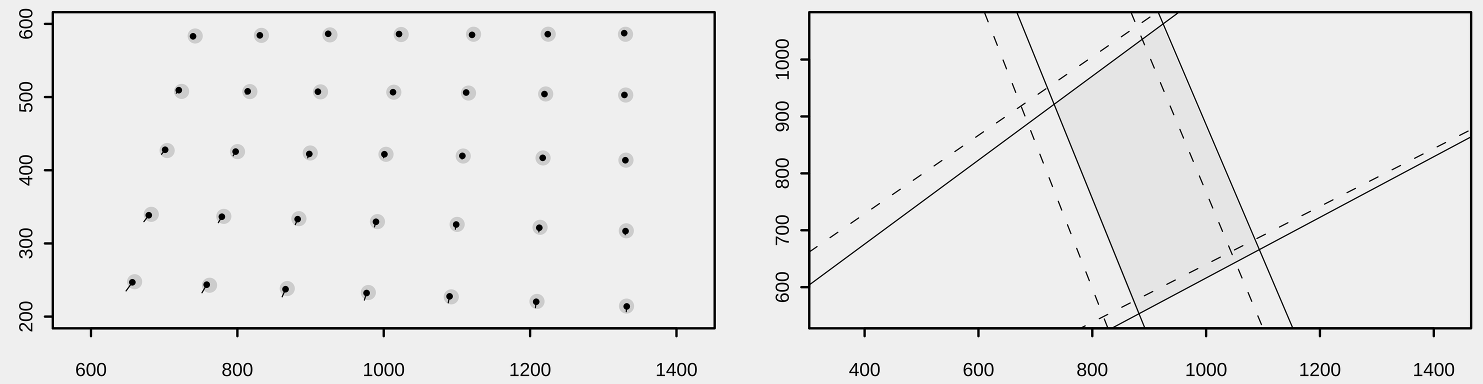
- Detection of calibration-features in the TOF intensity data is difficult.
- It is easier to detect calibration planes directly in the depth data.
- There is a **dual procedure** for mapping between planes:

$$V \simeq H^{-\top} U$$

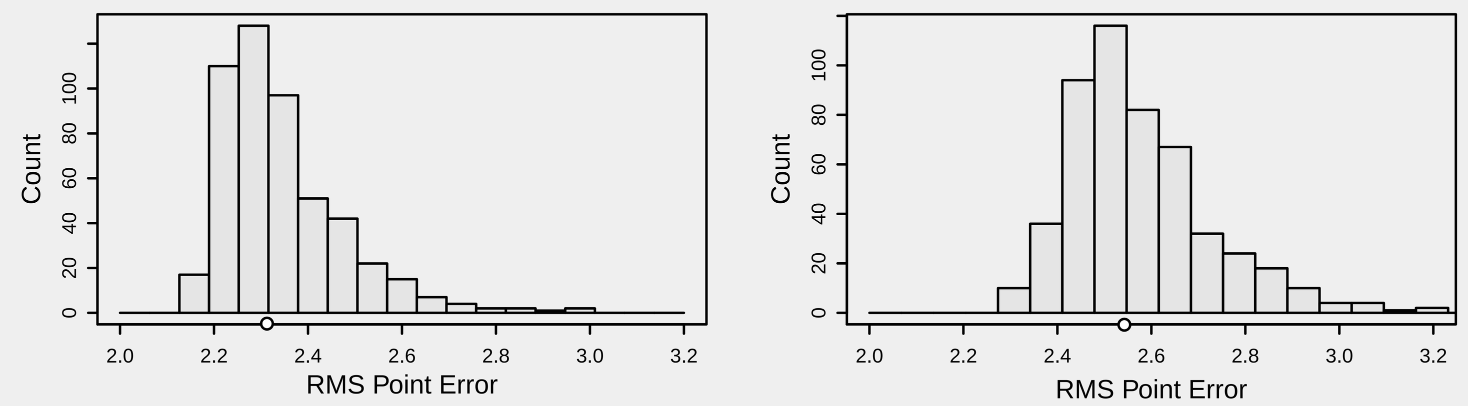
- Extra planes, through the TOF centre, come from straight depth-edges.
- These correspond to **lines** in the TOF image-data.

8. Evaluation

- Initial SVD solution is improved by minimizing **reprojection error**.
- Minimize over H, preserving epipolar geometry, or over C'_L and C'_R.
- Example reprojections of calibration-plane data:



- Grey points / quadrilateral are the true feature locations.
- Black points / solid lines are the optimized projections.
- Point-error is used as the final evaluation metric in both cases:



After point optimization · After line optimization

- Final **RMSE** of ~2.5 pixels in the 1624×1224 images is achievable.

9. Conclusions

- Pinhole-camera **geometry** can be applied to range cameras.
- A projective binocular reconstruction can be **upgraded** to a Euclidean reconstruction, by mapping it onto 3D range data.
- The high-precision reconstruction can be **textured** with RGB data from the colour images.
- Current work involves extending these methods to **multi-TOF** systems.

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