A Novel Hybrid Camera System with Depth and Fisheye Cameras

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Motivation

Most consumer **RGB-D cameras** have a **field of view** (FoV) **too small** for certain applications.

On the other hand, there are many cameras (such as **fisheye cameras**) which are able to capture color images with a **large FoV**, but lacking the 3D information.

Proposal

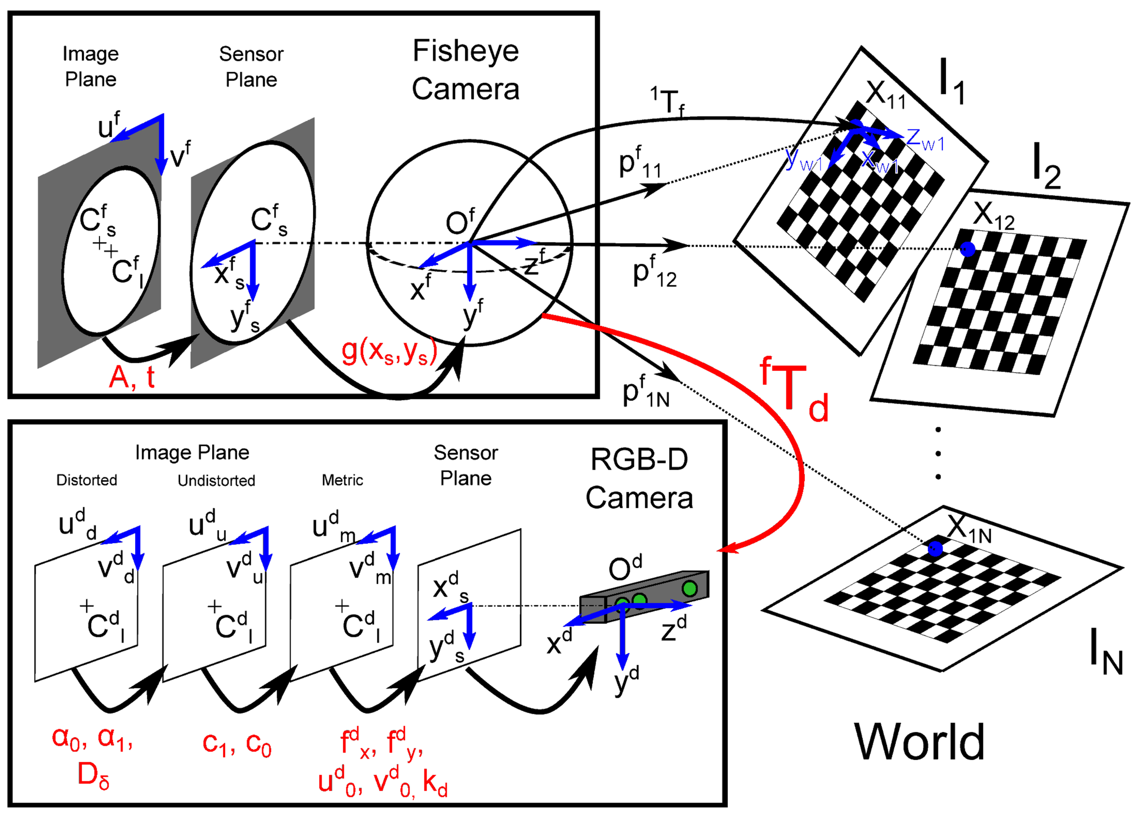
New hybrid system with Fisheye and Depth cameras to overcome the limitations, having:

- Depth certainty and scale
- Wide field of view (>180 deg)

This system needs to be calibrated, but the methods from the literature cannot be used for such complex configuration. In this work, **we present a new method for depth-fisheye calibration**. Experiments show its accuracy with real images.

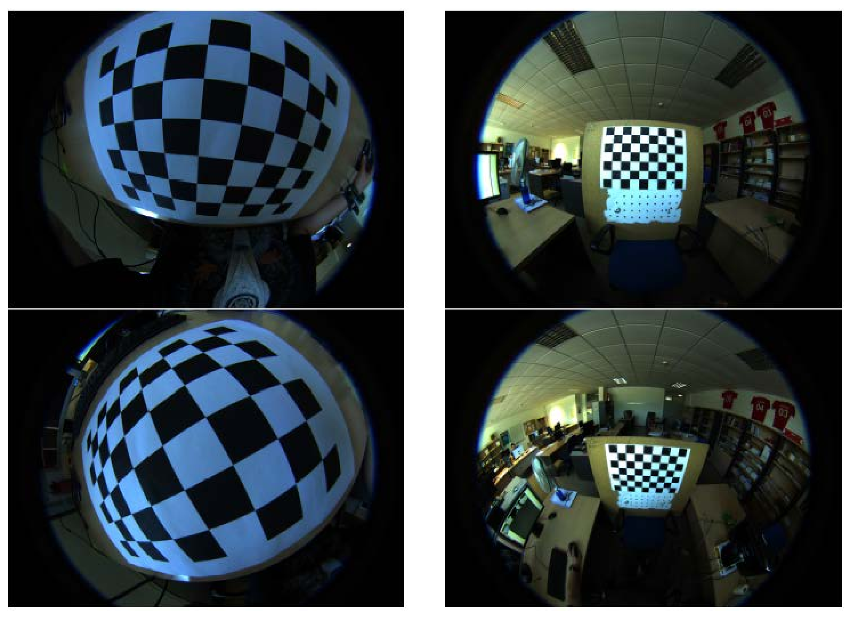
Camera models

- **Scaramuzza's model** for the fisheye camera [1].
  - This makes our method valid for all types of perspective and omnidirectional cameras.
- **Herrera's model** for the depth camera [2].
  - Includes radial and tangential distortion correction and calibrates the conversion to metric measurements.



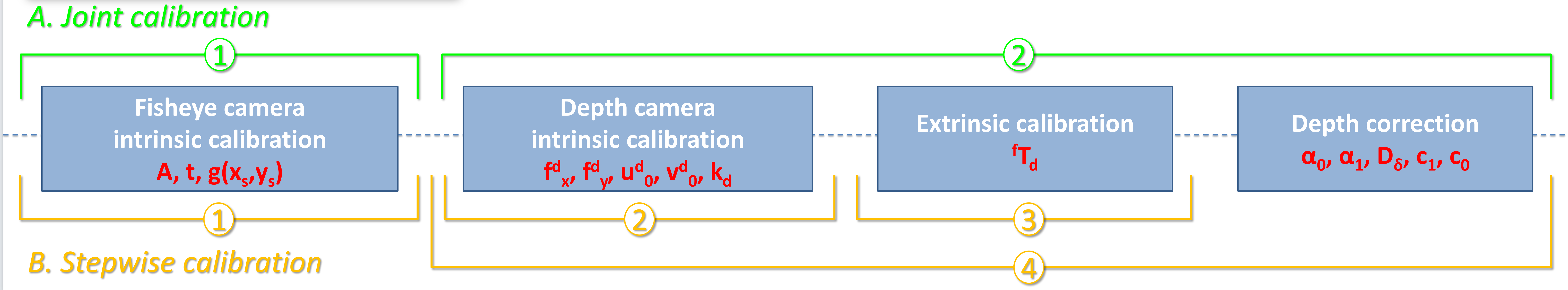
Type of input images

- The calibration pattern must be visible in the fisheye image and its supporting surface in the depth image.
  - To calibrate the fisheye distortion the camera must be close to the pattern.
  - The depth camera is unable to retrieve depth information in close range.



The fisheye needs to be calibrated offline with its own set of images!

Method outline: two alternatives



Computation of each stage

- Fisheye camera intrinsic calibration **A1** **B1**
  - Solved using the method from [1]
- Depth camera intrinsic calibration **B2**
  - Standard camera calibration using IR images
- Extrinsic calibration **B3**
  - Average rotations and translations → Minimize reprojection error

$$^{d}\mathbf{R}_f^{(I_i)} = {}^{I_i}\mathbf{R}_f \cdot {}^{d}\mathbf{R}_{I_i}$$

$$^{d}\mathbf{t}_f^{(I_i)} = {}^{I_i}\mathbf{t}_f - {}^{d}\mathbf{R}_f \cdot {}^{I_i}\mathbf{t}_d$$

$$\arg\min \|\hat{\mathbf{p}}_{ij}^f - \mathbf{p}_{ij}^f\| + \|\hat{\mathbf{p}}_{ij}^d - \mathbf{p}_{ij}^d\|$$

- Global optimization and refinement **A2** **B4**

$$J = \beta \frac{\sum RE_{ij}^f}{\sigma_f^2} + \frac{\sum RE_{ik}^d}{\sigma_d^2}$$

$$RE_{ij}^f = \|\hat{\mathbf{p}}_{ij} - \mathbf{p}_{ij}\|_2$$

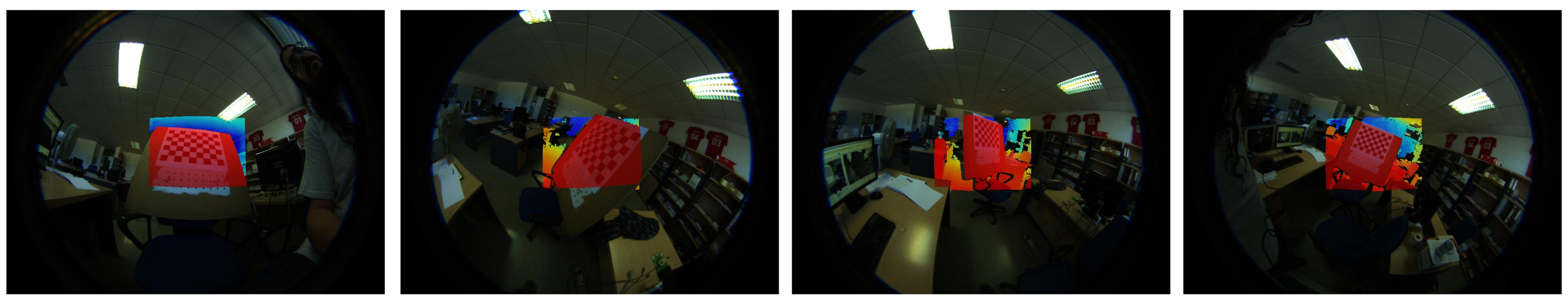
$$RE_{ik}^d = \|\hat{d}_{ik} - d_{ik}\|_2$$

Experiments with real images

Calibration was performed and evaluated with two similar sets of images: Set A (25 images) and Set B (28 images). Mean reprojection error shown in the table.

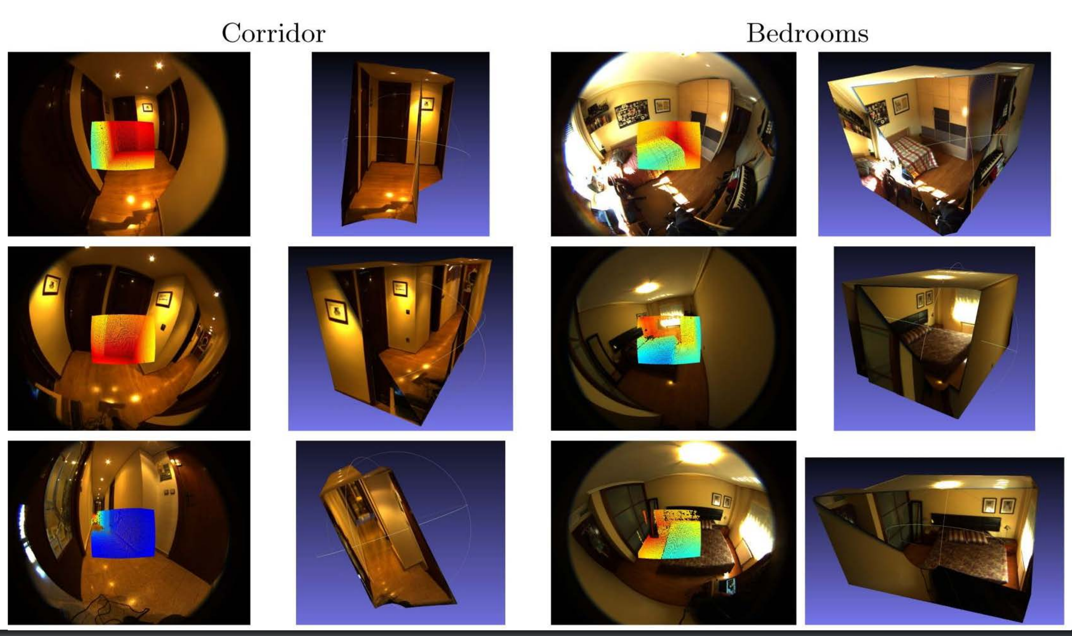
	Evaluated Set A		Evaluated Set B	
	Fisheye (px)	Depth (du)	Fisheye (px)	Depth (du)
1) Joint calib. A	0.185	0.839	0.187	1.477
2) Step calib. A	0.185	0.806	0.187	1.514
3) Joint calib. B	0.165	1.322	0.183	0.856
4) Step calib. B	0.165	1.321	0.182	0.835

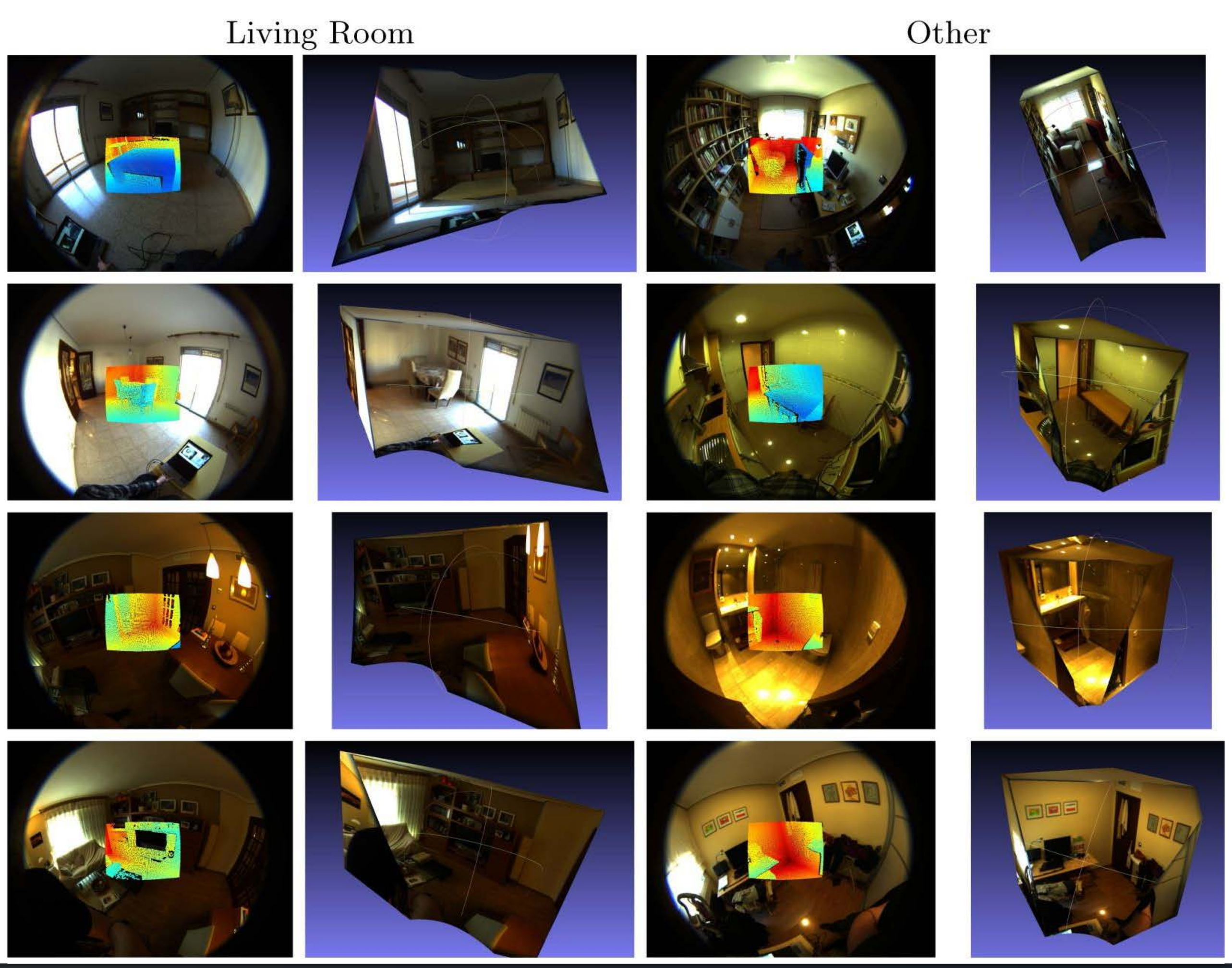
Some examples of depth information mapped to the fisheye image:



Example of application

- We used this hybrid system to perform the **extension of the depth information to the whole field of view of the fisheye** in one single shot [3].
- The estimation of the depth in the periphery is done **via layout extraction**, where the solutions have scale and can be merged with the initial depth information.
- Some results with the final 3D reconstruction:





References

[1] D. Scaramuzza, A. Martinelli, R. Siegwart: A toolbox for easily calibrating omnidirectional cameras. IEEE/RSJ International Conference on Intelligent Robots and Systems (2006)

[2] C. Herrera, J. Kannala, J. Heikkilä: Joint depth and color camera calibration with distortion correction. IEEE Transactions on Pattern Analysis and Machine Inteliligence (2012)

[3] A. Perez-Yus, G. Lopez-Nicolas, J.J. Guerrero: Peripheral expansion of depth information via layout estimation with fisheye camera. European Conference on Computer Vision (2016)

Acknowledgments

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