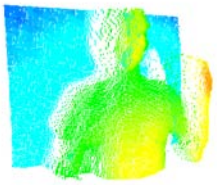
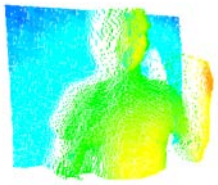


Uwe Hahne and Marc Alexa

Combining Time-of-Flight Depth and Stereo Images without Accurate Extrinsic Calibration

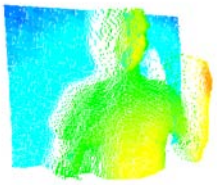


Motivation

- **The human visual system is three-dimensional (3D)!**
- 3D reconstruction of real world objects is widely-used in Science, Web, Games, Movies, TV...
- Upcoming stereoscopic displays are a step towards "3D TV"

[Philips 2007]

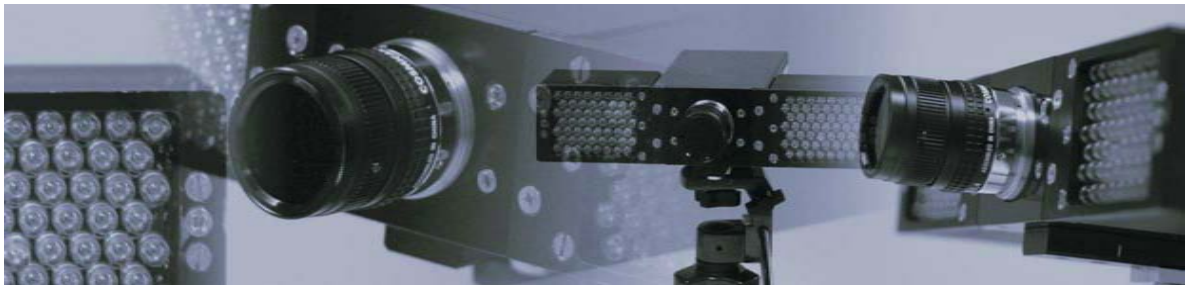
→ Stereo Vision



Motivation

- **However, the stereo problem is still unsolved!**
  - **no features, no matching**
- New 3D camera technologies
  - PMD
  - Zcam

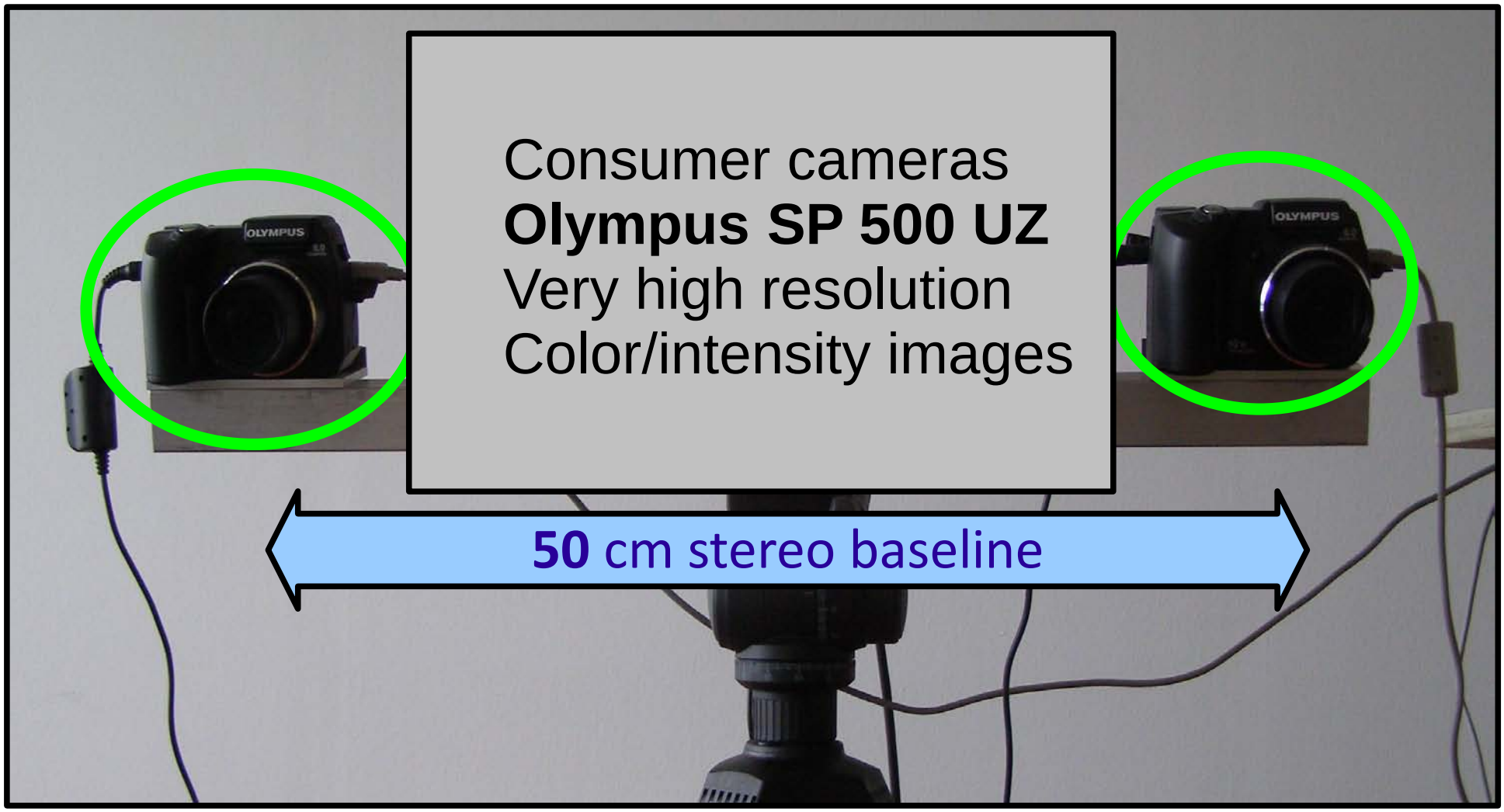
[3DV Systems 2007]



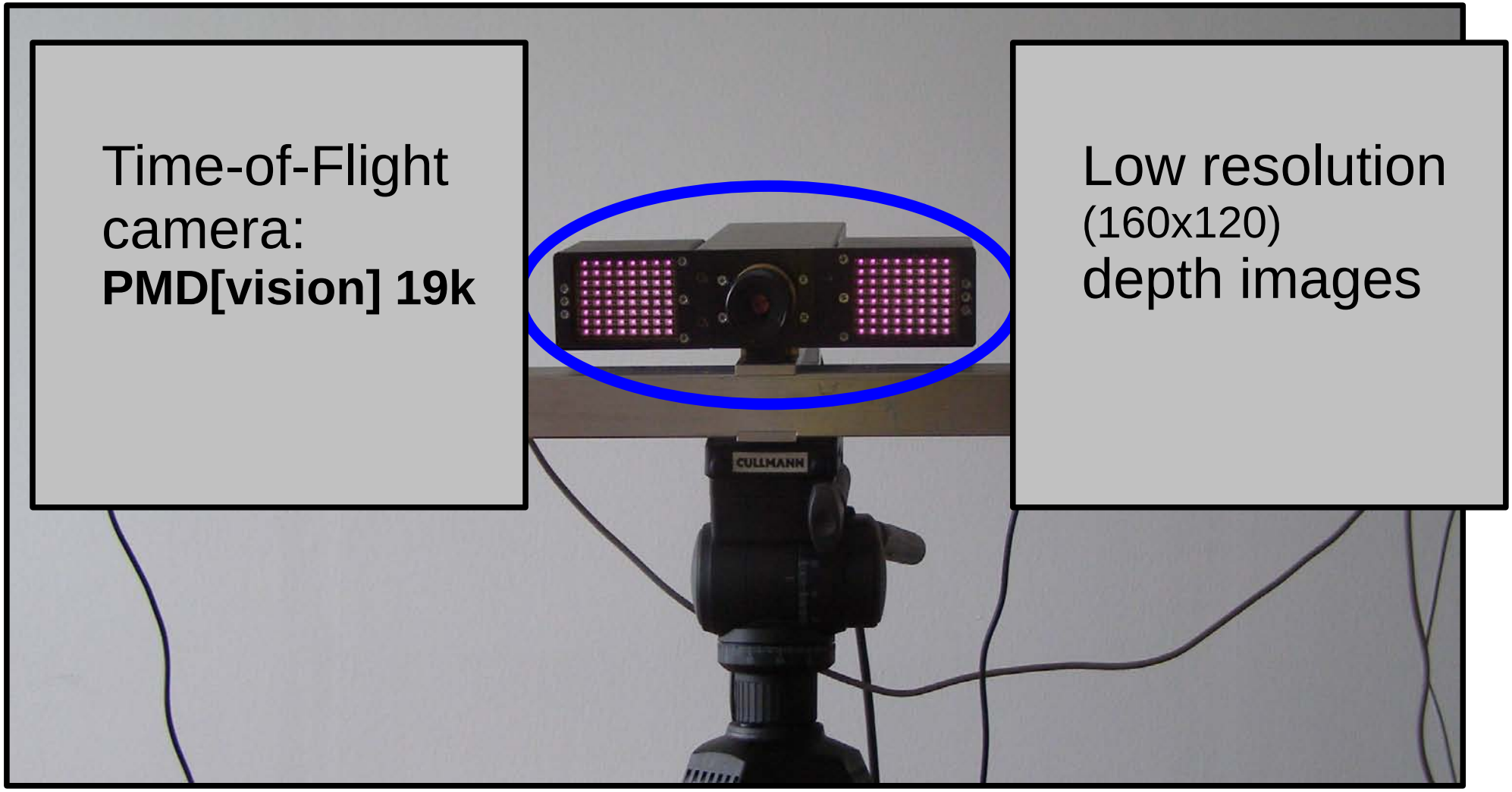
[PMDTec]

→ Use these new technologies to enhance stereo imaging

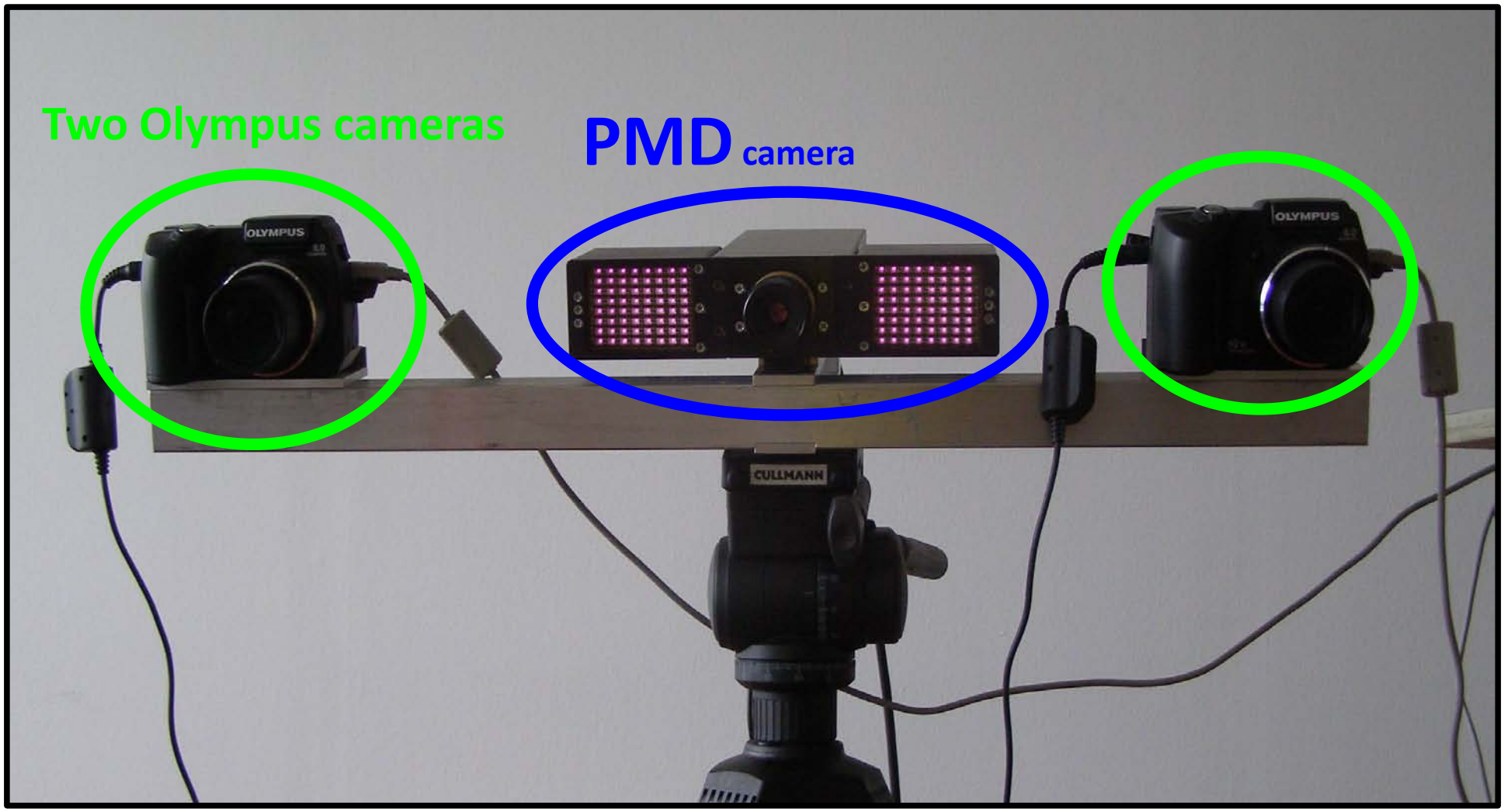
Setup

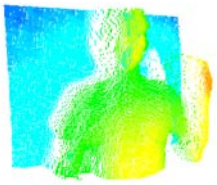

Consumer cameras
Olympus SP 500 UZ
Very high resolution
Color/intensity images
50 cm stereo baseline

Setup


Time-of-Flight camera:
PMD[vision] 19k
Low resolution (160x120) depth images
CULLMANN

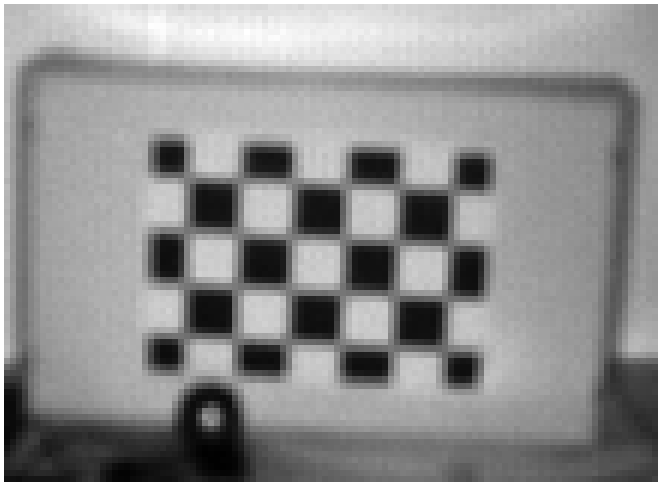
Setup



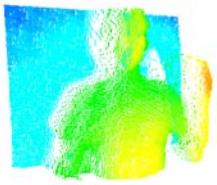


Calibration

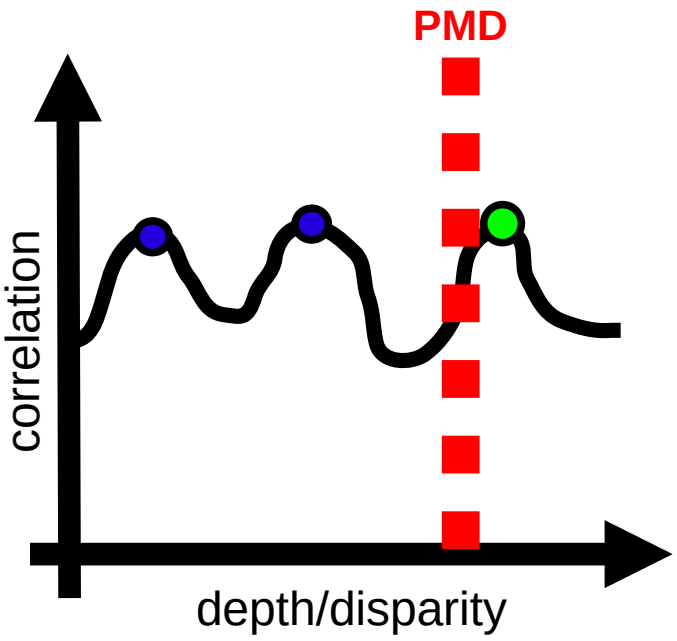
- Register all three images
  - Intrinsic and extrinsic parameters
  - Using OpenCV/Matlab CalibTK
- Problems due to:
  1. Digital **consumer** cameras' mechanics
  2. PMD camera has low resolution and **no real** intensity images
  3. Cameras' views **differ too much** for same extrinsic calibration target

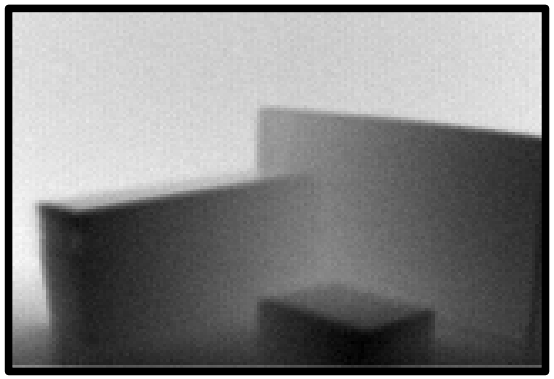


without Accurate Extrinsic Calibration



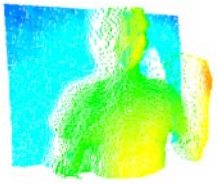
Stereo basics





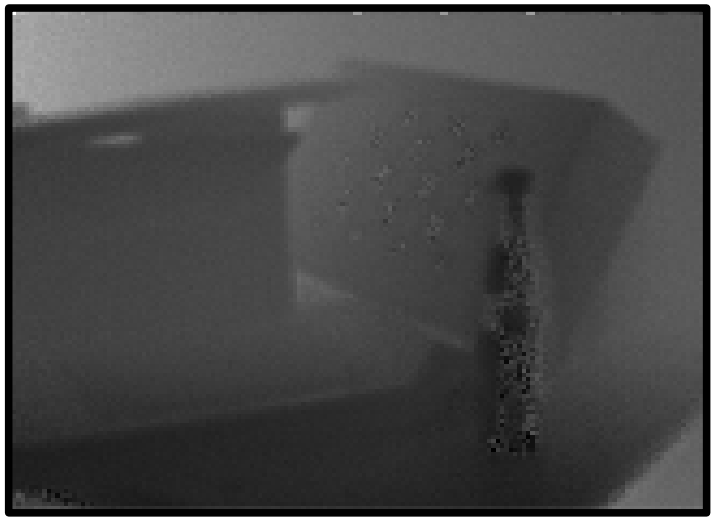
- Stereo algorithms' problems
  - **Ambivalent correspondences**
  - **Depth discontinuities**

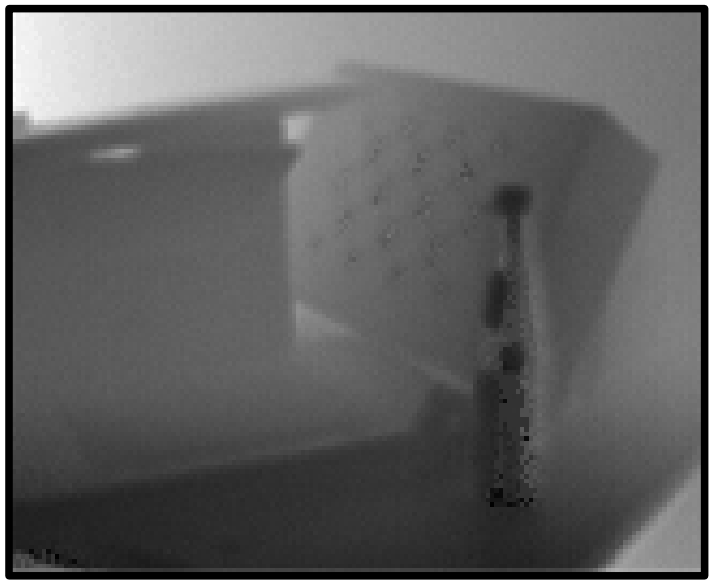
→ PMD data compensates stereo's weakness



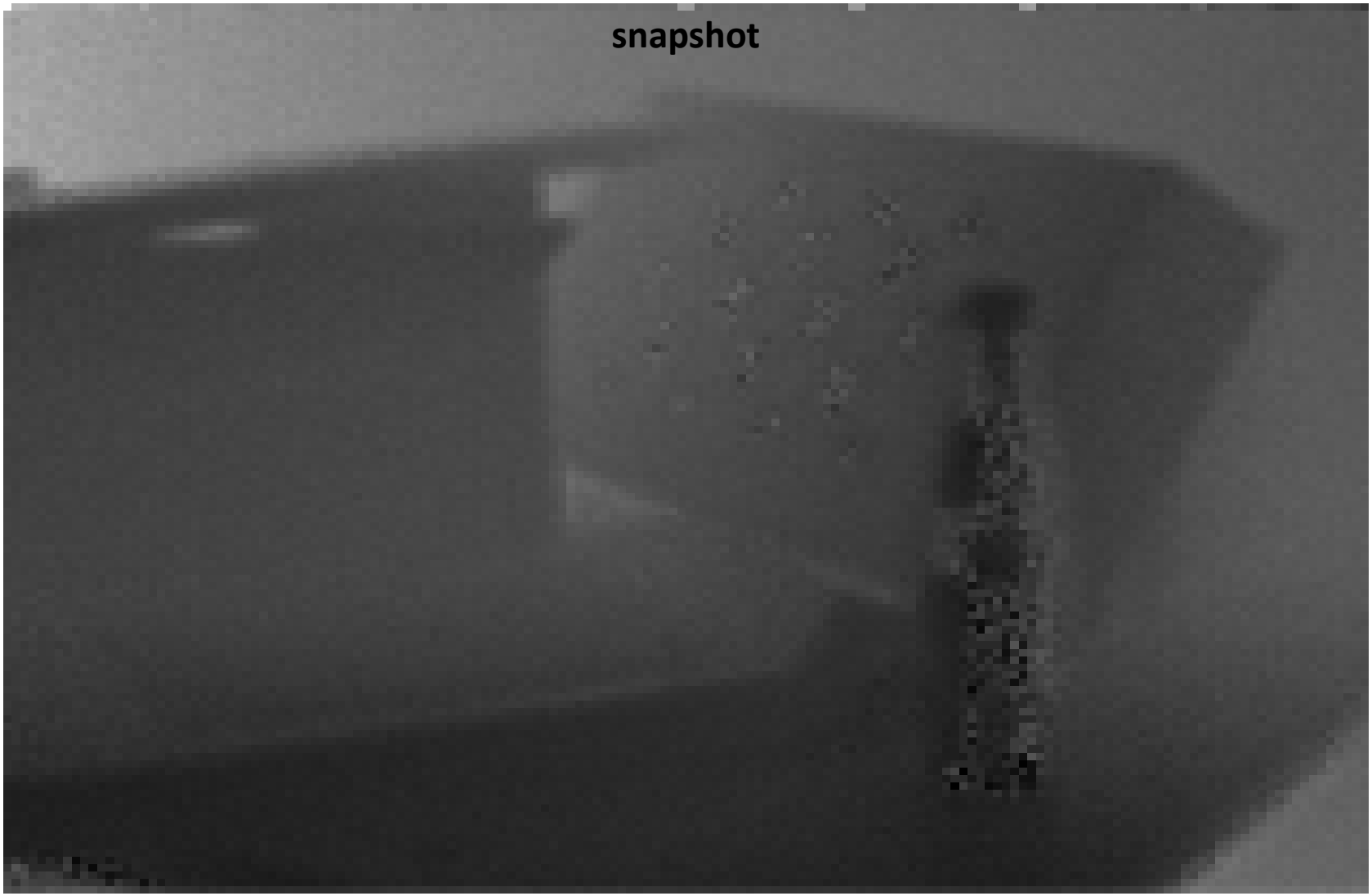
PMD Imaging

- Strong noise in PMD image:
  - Taking 20 images
  - Mean and Median image
  - Variance image
- Enhances image **quality**

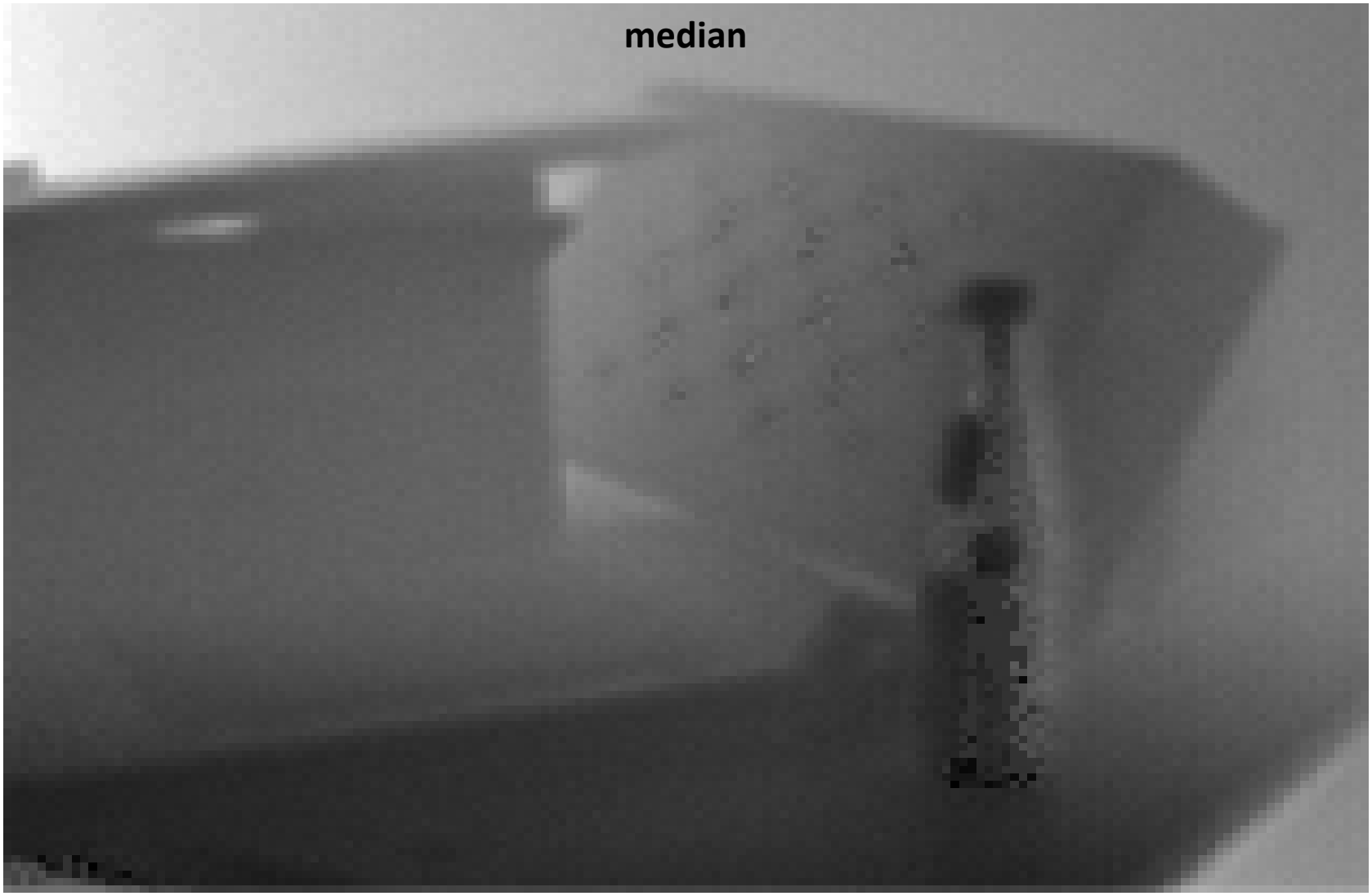


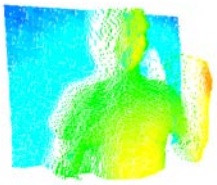


PMD Imaging



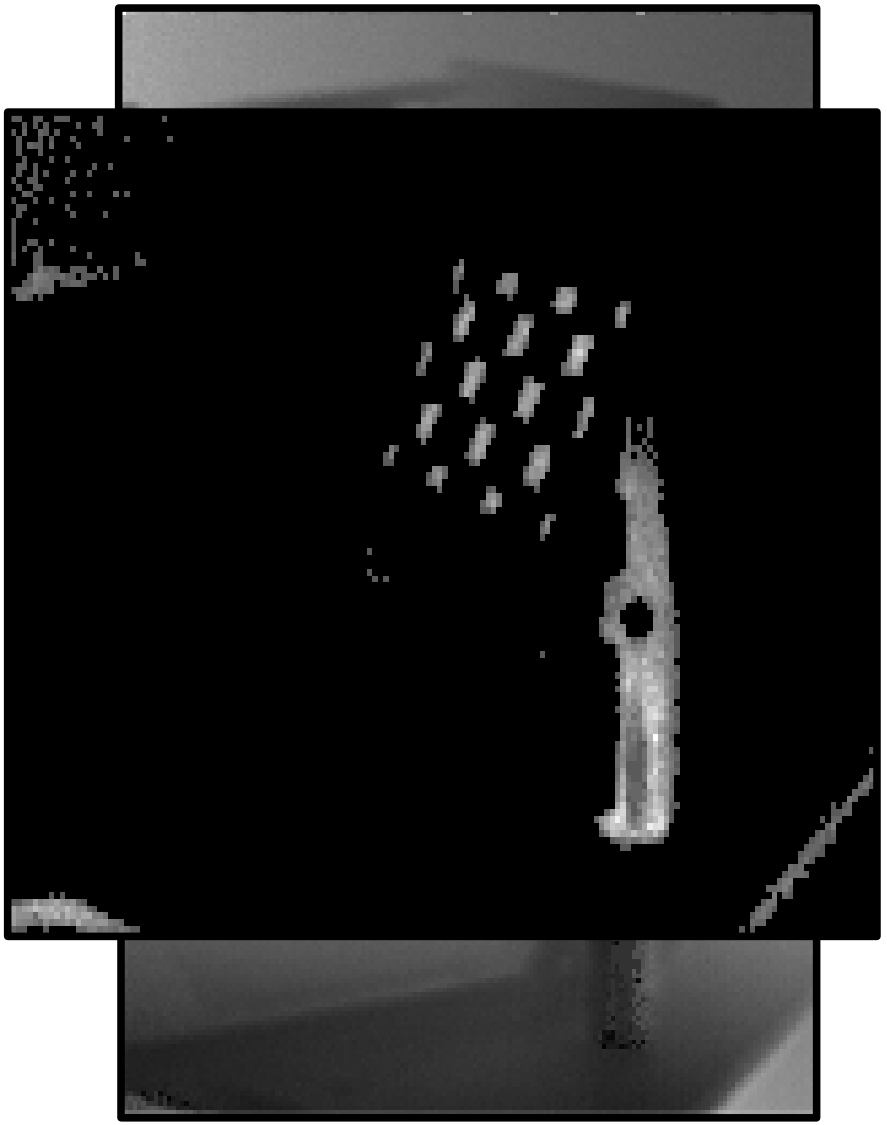
PMD Imaging

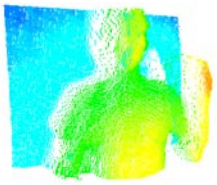




PMD Imaging

- Strong noise in PMD image:
  - Taking 20 images
  - Mean and Median image
  - Variance image
- Enhances image **quality**
- Variance gives information about the **confidence** of the **depth values**





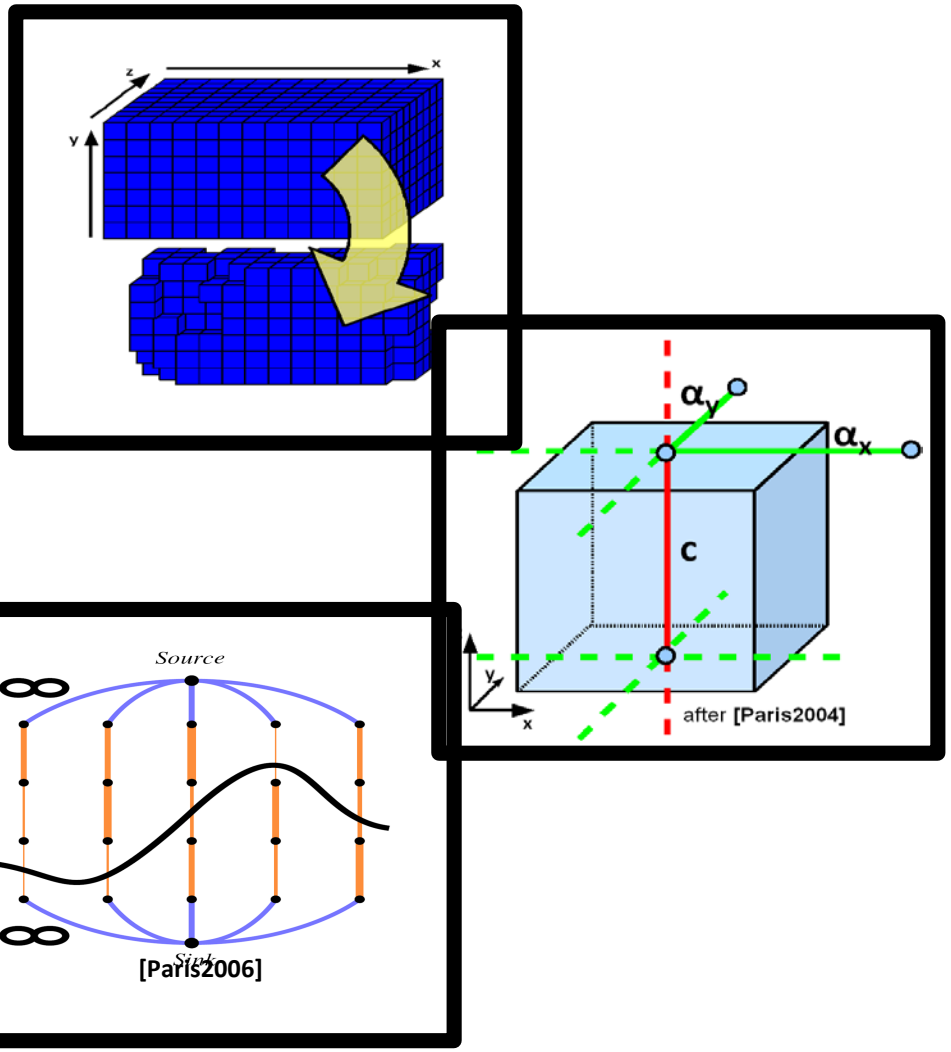
Algorithm

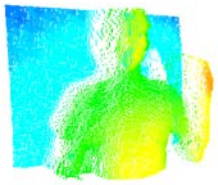
- **"Best formulated as a global problem" [Tomasi2005]**
  - **Dynamic programming**
  - **Max Flow/Min Cut**
  - **Our algorithm is based on Graph Cut formulation [Paris2004]**
- **Idea: Surfaces are diffuse and strong depth discontinuities exist only between objects**
- **Goal: Find a parametric surface S that minimizes an energy functional with two terms:**
  - **Consistency c and Smoothing α**

Graph Cut

Process overview:

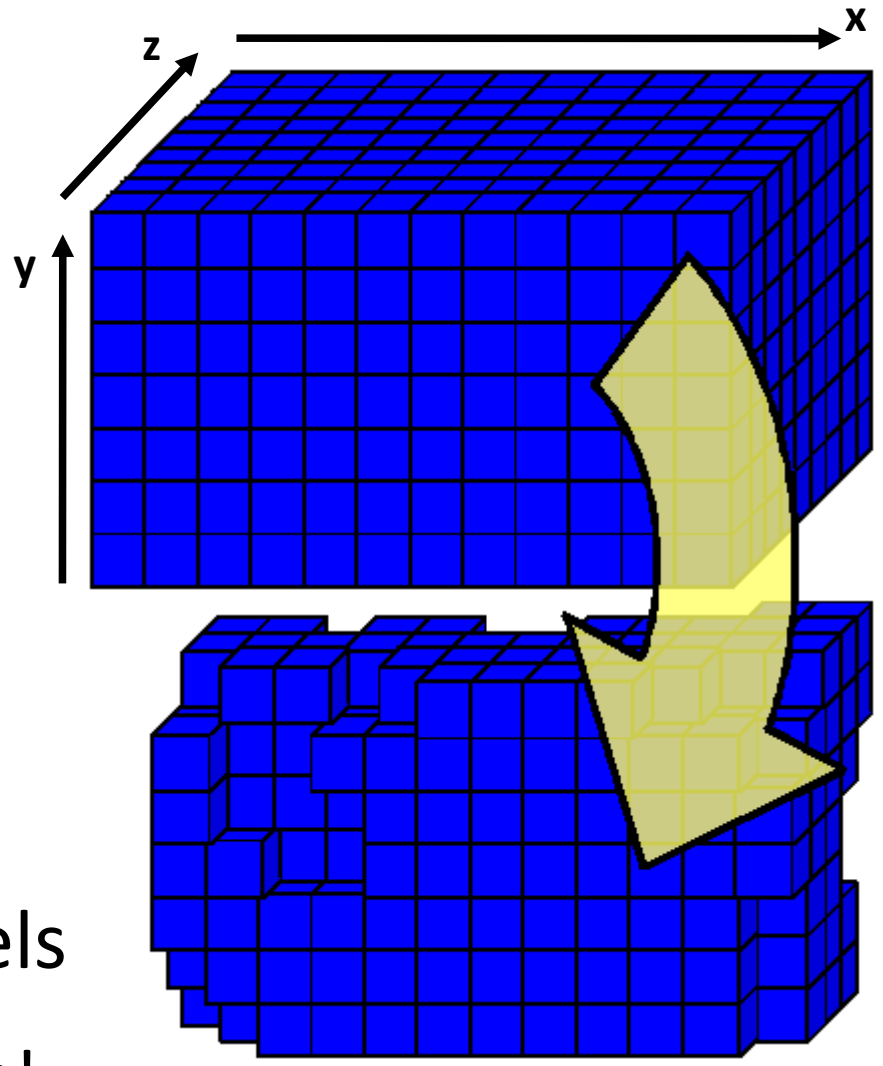
- Build a volume
- Define domain of interest (DOI)
- Construct graph
- Set weights at edges
  - consistency
  - smoothing
- Min cut gives the surface

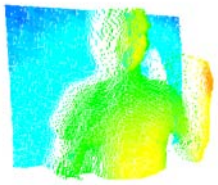




Graph Cut

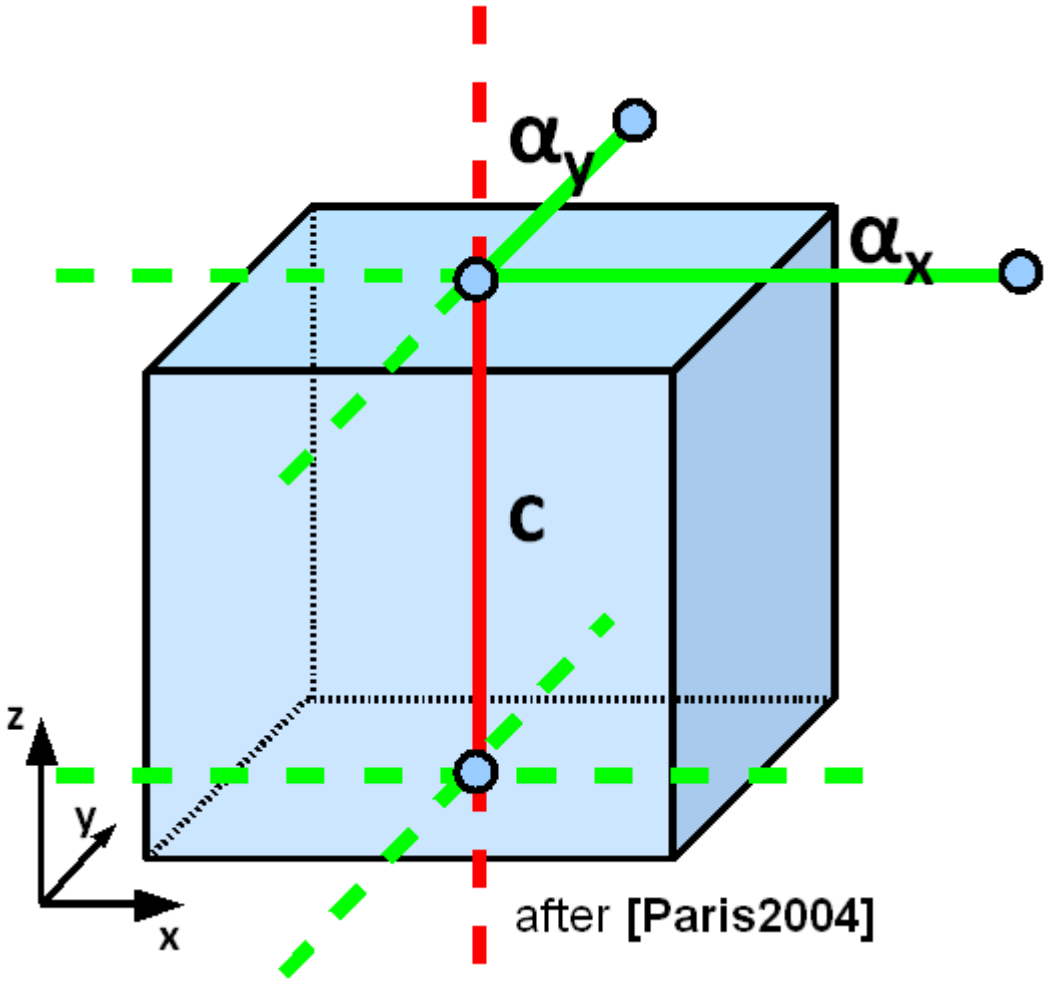
- Volume size 400x300x100 = 12 Mio. voxels
- Define DOI using the **PMD depth image (median and variance)**
- Volume has to remain **6-connected**
- Results in approx. 2 Mio voxels
  - Strongly reduced but still huge!

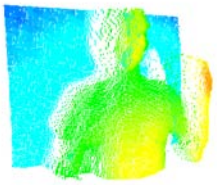




Graph Cut

- Constructing a **graph**:
  - **For each voxel:** one edge for the consistency term **c**
  - **Between each neighbouring voxel:** two edges (for x and y) weighted with smoothing term **α**





Graph Cut

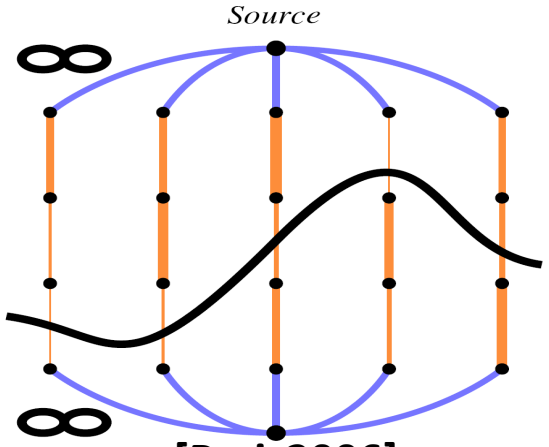
Consistency term:

- **PMD** median image with variance
- **Stereo** consistency with NCC or SSD

Smoothing term:

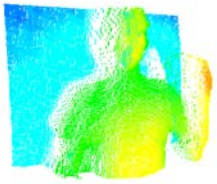
- Depth differences in **PMD** image
- Color differences inside both **stereo** images

- **Add sink and source and connect them with infinitely weighted edges**



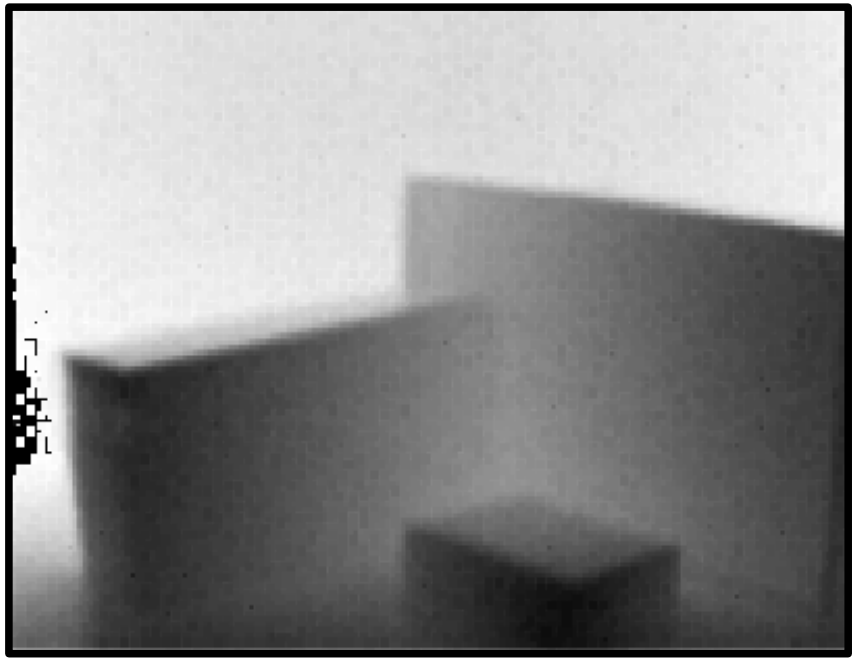
[Paris2006]

Minimal cut gives the surface!

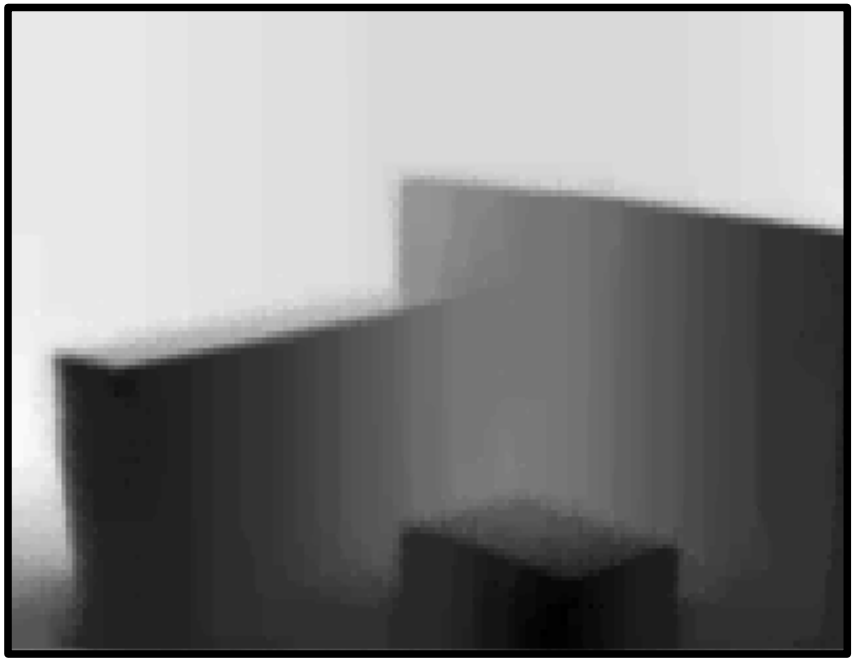


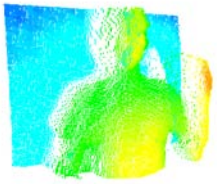
Results

- Stereo (DOI with PMD)



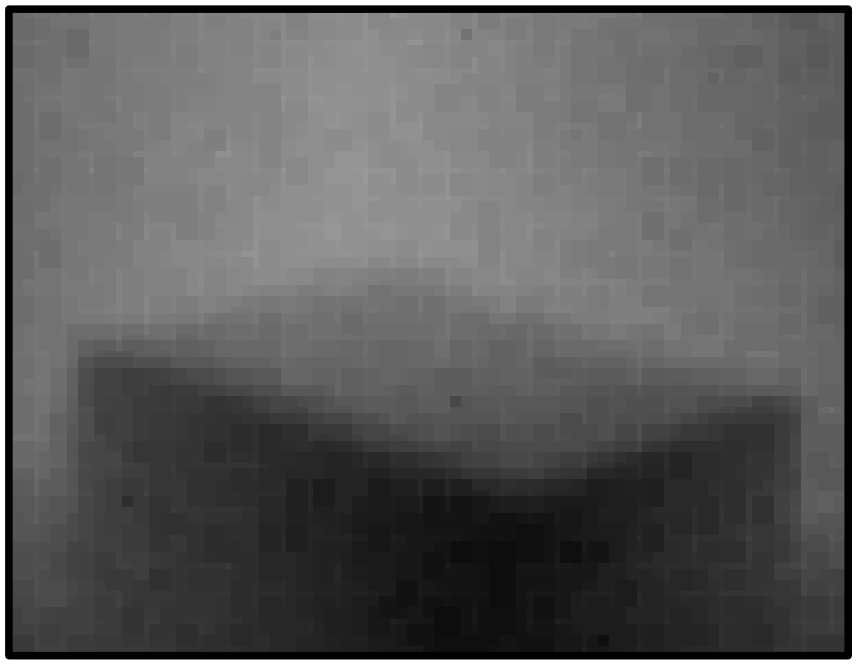
- Our reconstruction



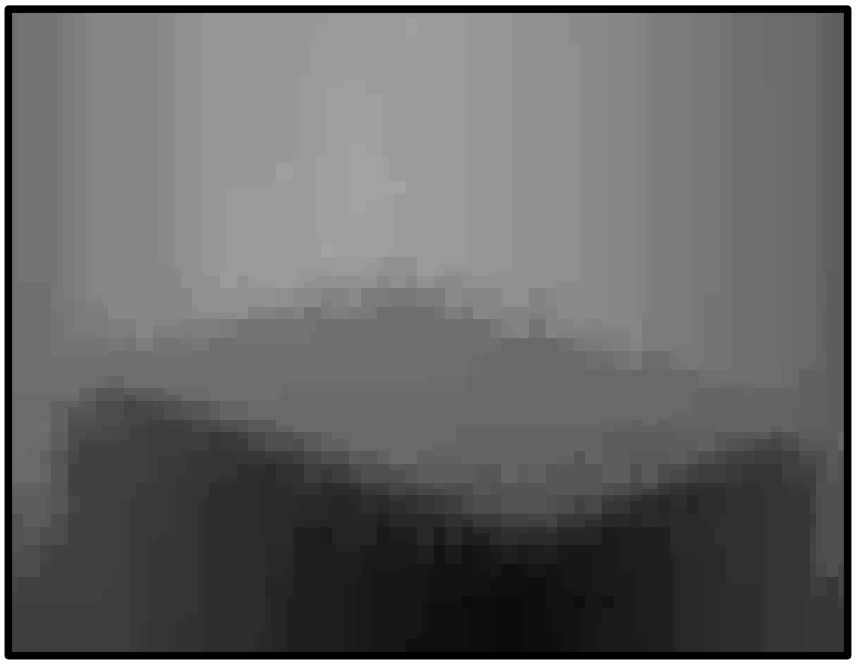


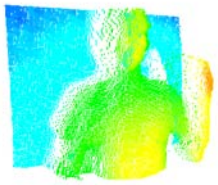
Results

- Stereo (DOI with PMD)



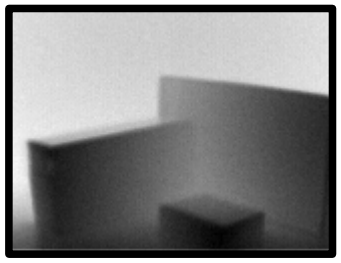
- Our reconstruction





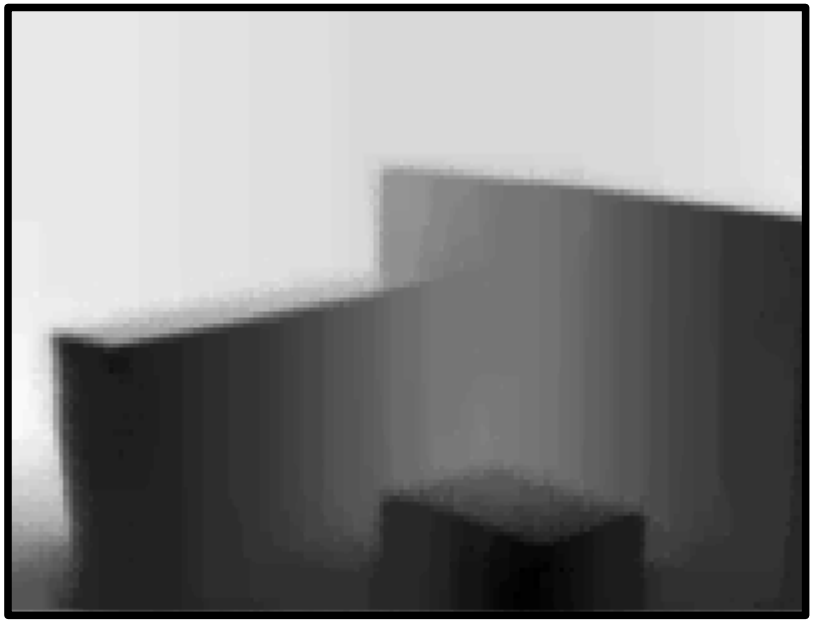
Results

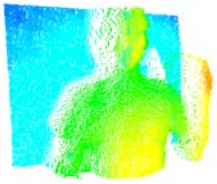
- PMD median image



original resolutions

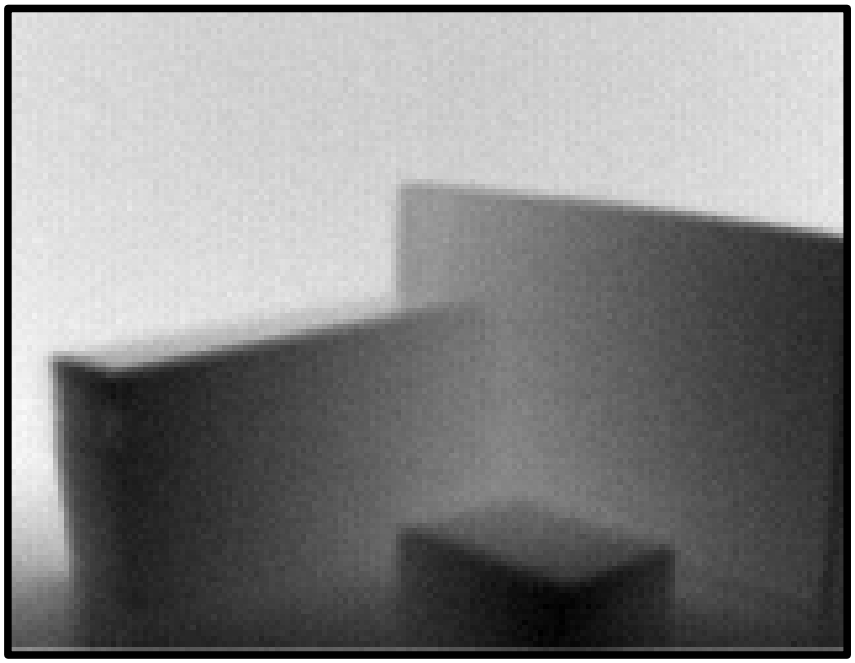
- Our reconstruction



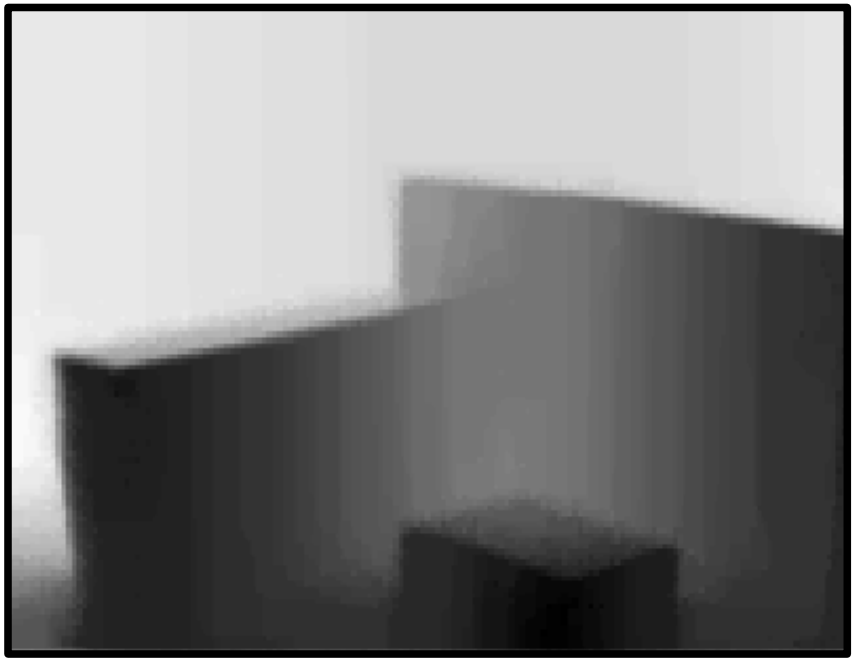


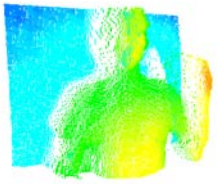
Results

- PMD median image



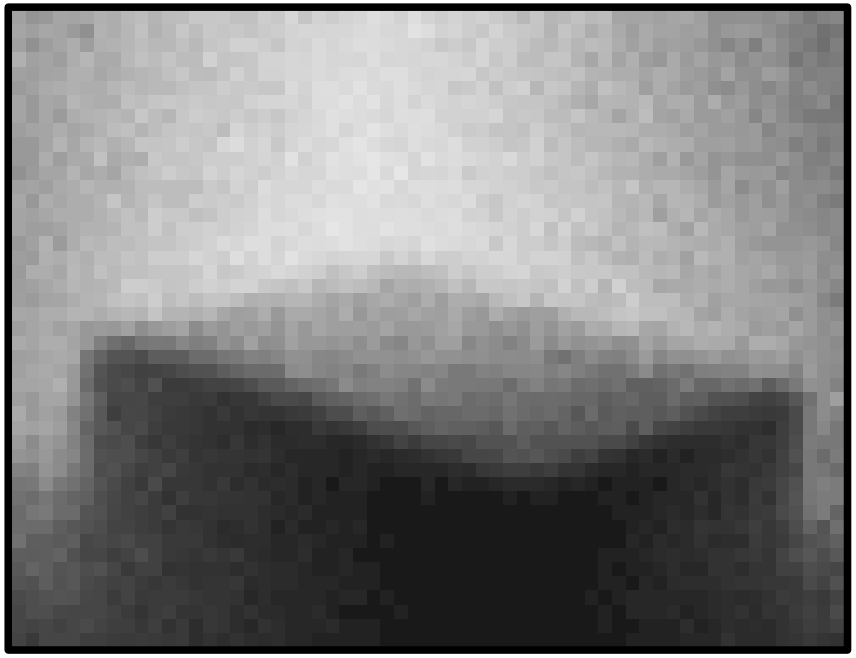
- Our reconstruction



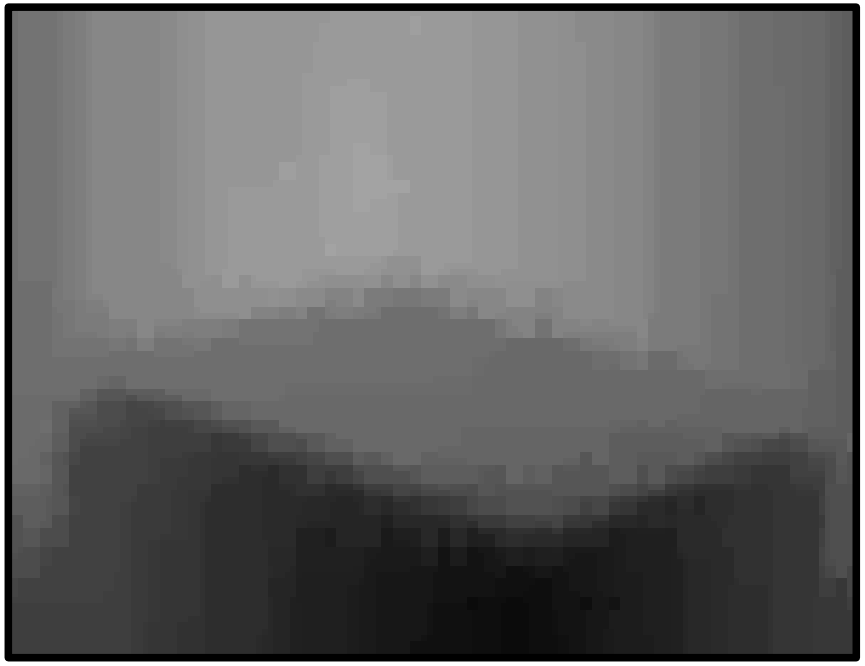


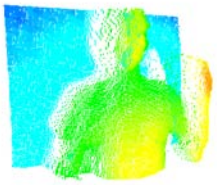
Results

- PMD median image



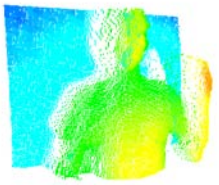
- Our reconstruction





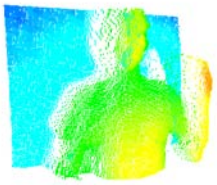
Discussion

- Enhancement of 3D reconstruction without accurate calibration
- Speed up the surface reconstruction using a DOI
  - Computation time are still several minutes
- Higher resolution is limited by algorithm
- Results show only a proof of concept
- Exact evaluation of accuracy is missing



Future work

- For better results, an accurate calibration is **indispensable**
  - **Using other cameras and a more professional setup**
- Computation times will be enhanced
  - Faster stereo algorithms
  - Use PMD data especially for acceleration
- Create Applications
  - AR, VR, Object reconstruction, Motion capturing...



References

- **[Paris2006]** Paris, Sylvain and Sillion, François and Quan, Long - A Surface Reconstruction Method Using Global Graph Cut Optimization, International Journal of Computer Vision, 2006
- **[Paris2004]** Sylvain Paris and François Sillion and Long Quan - A Surface Reconstruction Method Using Global Graph Cut Optimization, Asian Conference of Computer Vision, 2004
- **[Tomasi2005] C. Tomasi - Global Stereo in Polynomial Time, Computational Vision in Neural and Machine Systems, 2005**