3D scene reconstruction using a Time-Of-Flight camera

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Outline

- Introduction
- Camera Time-Of-Flight
- Data filtering
- Camera motion estimation and 3D map
- Meshes generation from points cloud
- Conclusion & perspectives

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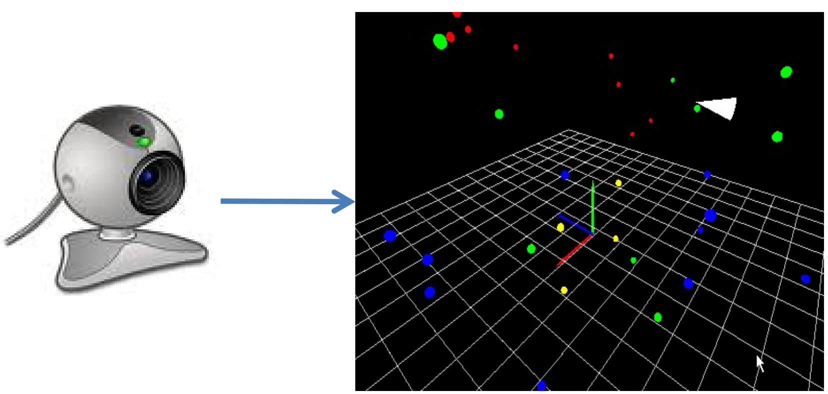
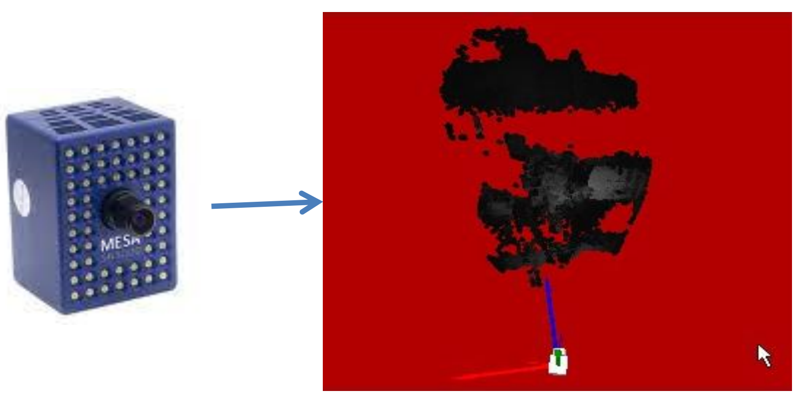
Introduction

- Goal: perform a 3D reconstruction of the surrounding environnement using a Time-of-flight (TOF) camera
- Context: static scene and moving camera (Simultaneous Localization And Mapping problem: SLAM)
- Previous works:
    - SLAM using monocular camera
    - Limitations: sparse reconstructed map
- New method: based on Time-Of-Flight sensor (dense reconstruction)



Webcam SLAM



TOF SLAM

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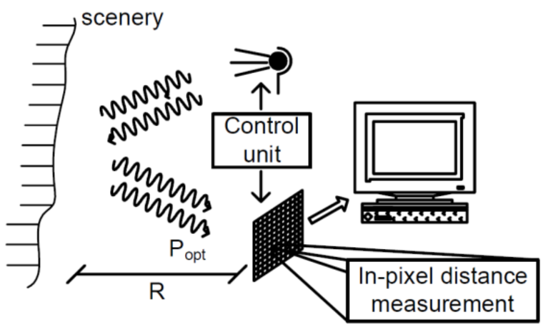
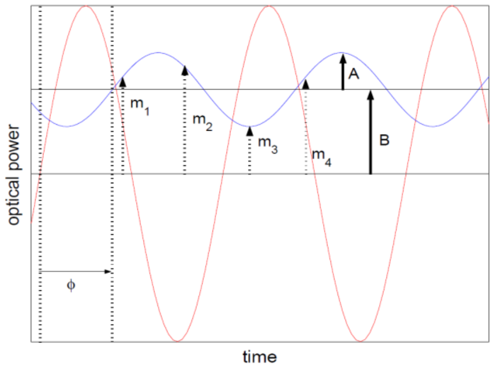
TOF camera (introduction)





- Camera Time-of-flight (TOF) is an active range finder:
  - Emits light (LEDs) and Measures TOF (CCD sensor)

- Reconstructed signal (4 measurements each period) characterized by
  - ➢ Offset B: Mean of the total light incident on the sensor: background plus modulated signal
  - ➢ Amplitude: Object reflectivity and object distance
  - ➢ Phase shift: Distance

- The distance accuracy of the measurement depends on the acquired amplitude A and offset B

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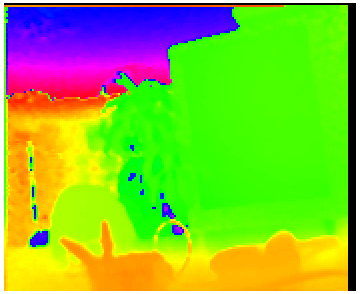
TOF camera (pros and cons)

- Swissranger SR3000
  - Number of LEDs: 55
  - Resolution: 176x144
  - Output: amplitude + distance
  - Frame rate: 30 fps

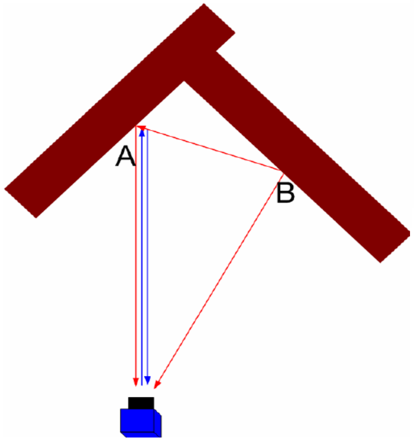
Amplitude



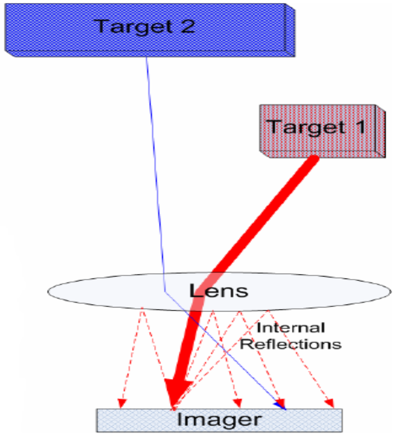
Depth

- Advantages:
  - ➢ Easy to extract range information
  - ➢ High frame rate
  - ➢ Not suffer from missing texture in the scene or bad lighting conditions
  - ➢ Compactness of the sensor

- Disadvantages:
  - ➢ Multiple reflections
  - ➢ Light scattering
  - ➢ Low resolution (176x144)
  - ➢ Camera network

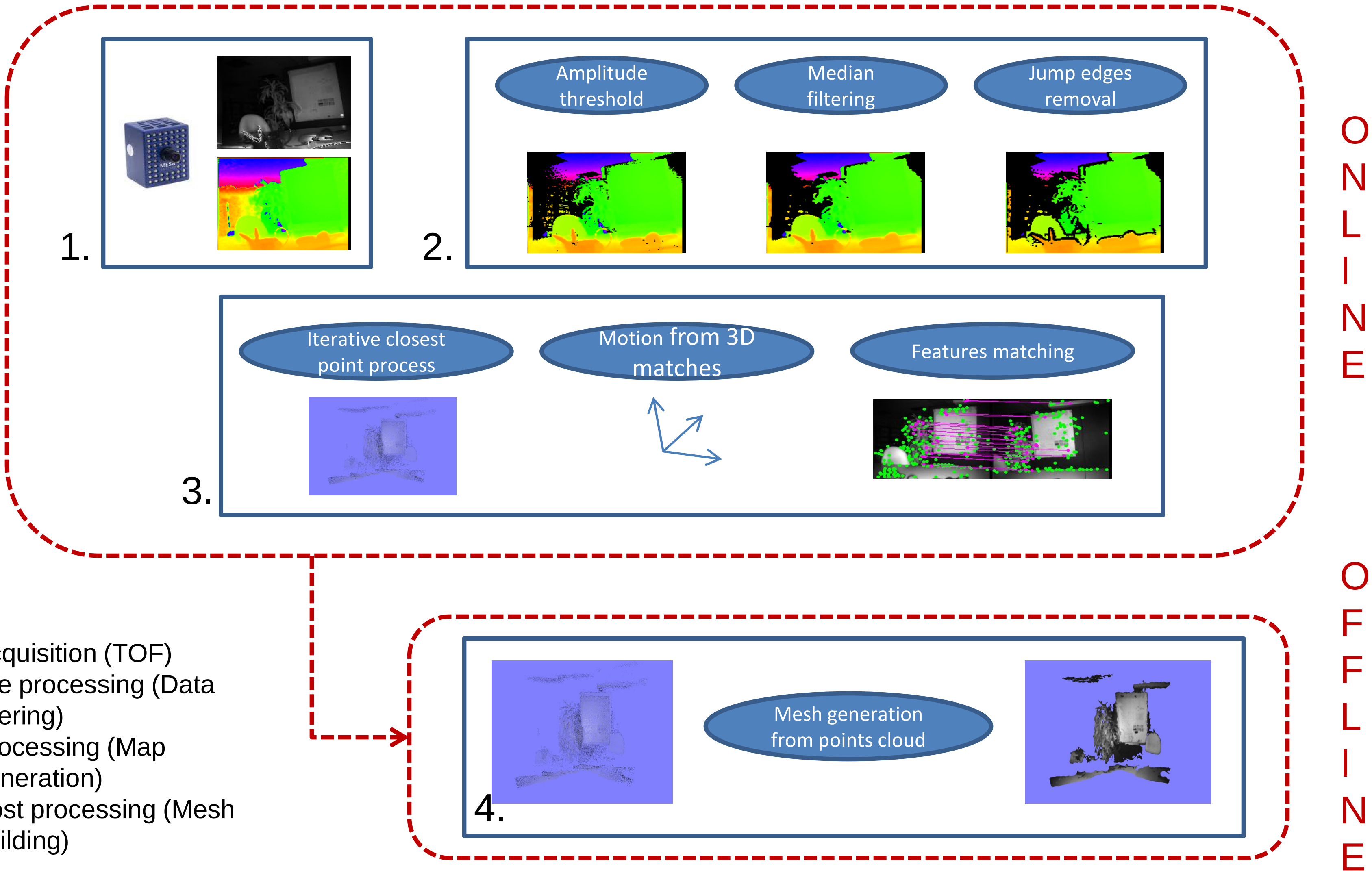


Multiple reflections



Light scattering

Whole process overview



1. Acquisition (TOF)
2. Pre processing (Data filtering)
3. Processing (Map generation)
4. Post processing (Mesh building)

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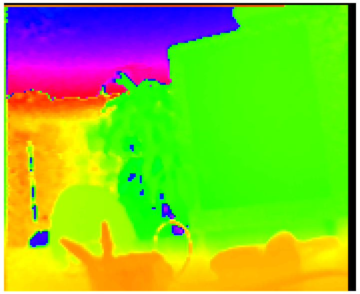
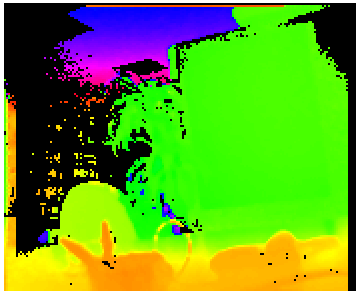
Preprocessing: filtering



Raw distance

Raw amplitude

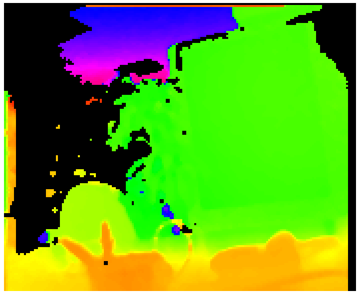
- Raw data provided by TOF camera are very noisy
- Necessary to clean it



Amplitude threshold

- Depth accuracy depend on amplitude value
  - Lower is the amplitude, lower is the accuracy
    - Far objects
    - Low reflectivity

→ Threshold based on amplitude



Median filtering

- Pepper and salt noise is very important due to
  - Sensor noise as light scattering
  - Amplitude thresholding

→ Median filtering

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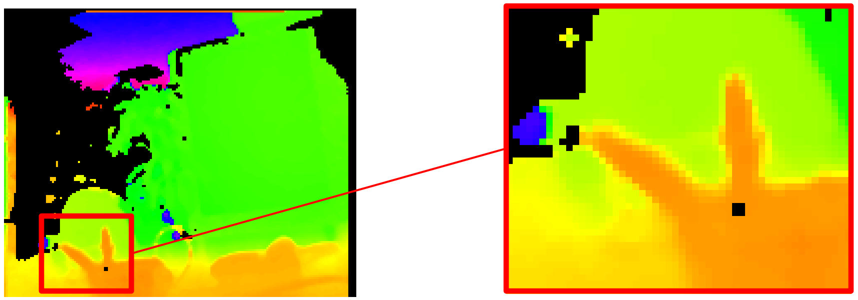
Jump edge filtering

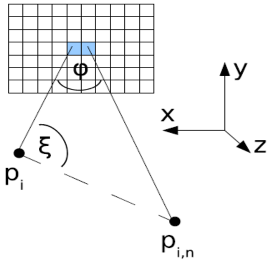
- Problems on abrupt distance transitions
  - TOF camera smooth abrupt depth transitions
  - A small measurement error provide an important error on distance value

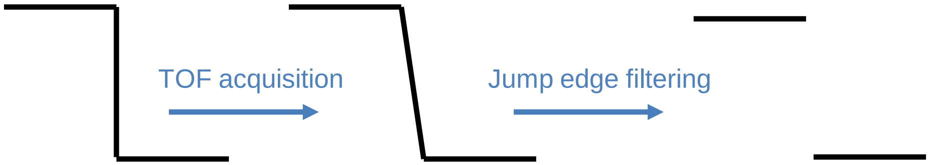


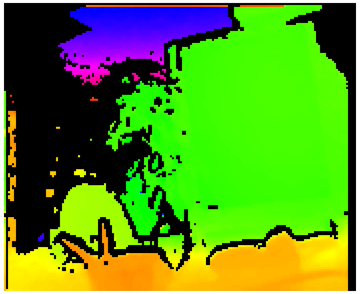
- Green: chair
- Orange: pencils
- Yellow: Noise (smooth transition)

-> JUMP EDGE FILTERING

- Higher is the $\xi_{i,n}$ angle value, higher is the depth transition
- Knowing camera intrinsic parameters, compute $\xi_{i,n}$ (from φ and 3D points)
- Remove pixels with at least 2 neighbors with an angle $\xi_{i,n} > s$

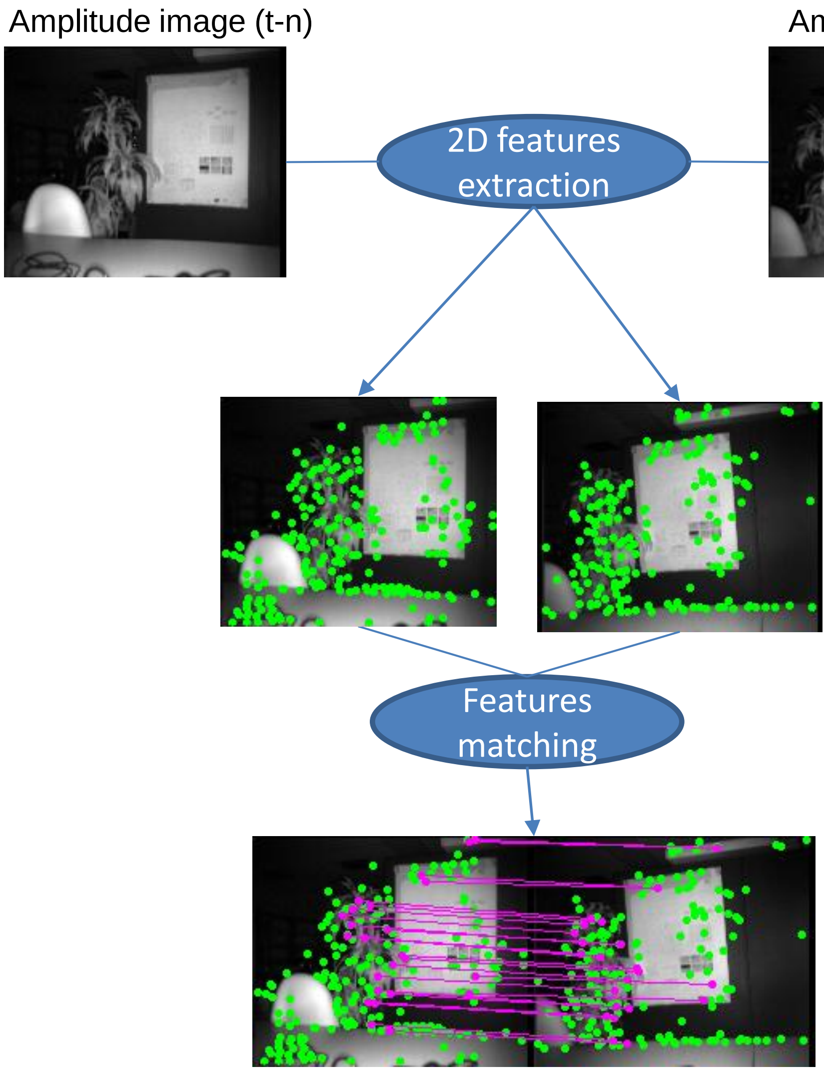






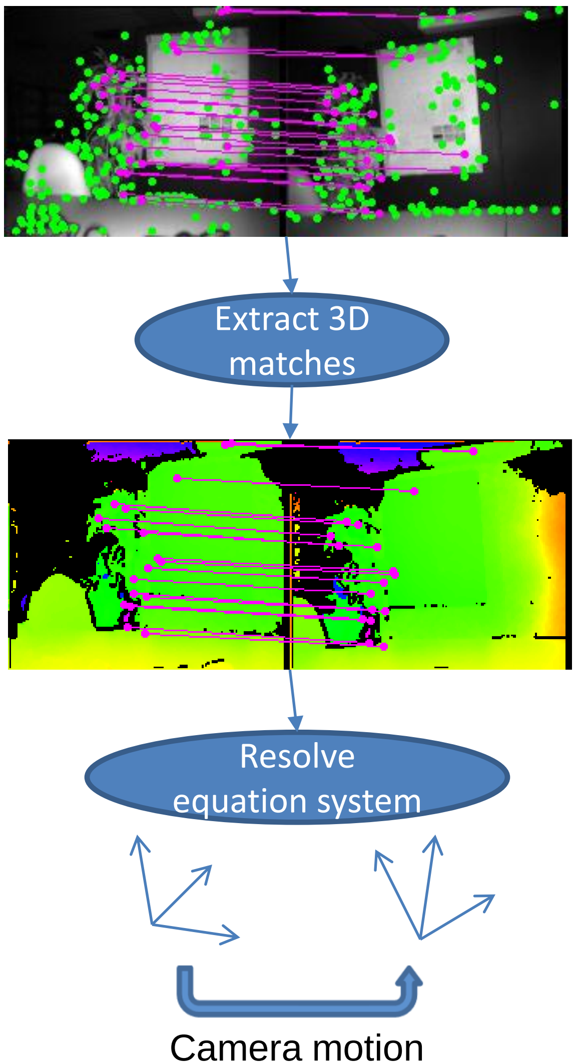
Jump edges filtering

Processing: 2D matching



- Use Amplitude image (2D information) to make matches between 2 images
  - ➢ Detect SIFT features into the current frame
  - ➢ Match features using SIFT descriptors between the last reference frame and the current one

Processing: 3D matching



- For each match $p1 = Rp2 + t$

- Rotation matrix is represented as a quaternion
  - Reduce number of parameters to estimate
  - Maintain constraints (matrix normalization)

$$\mathbf{q} = (w, x, y, z) \mapsto \mathbf{R} = \begin{bmatrix} w^2 + x^2 - y^2 - z^2 & 2xy - 2wz & 2xz + 2wy \\ 2xy + 2wz & w^2 - x^2 + y^2 - z^2 & 2yz - 2wx \\ 2xz - 2wy & 2yz + 2wx & w^2 - x^2 - y^2 + z^2 \end{bmatrix}$$

- Estimate q from 3D matches (rotation)
  - Linear equation system (SVD)

- Apply rotation found to the first point set
- Compute centroids of each point set
- Extract t from point centroids (translation)

Processing: Outliers

- Two kind of outliers
  - Bad matches between 2 SIFT points
  - Bad distance measurement by TOF camera

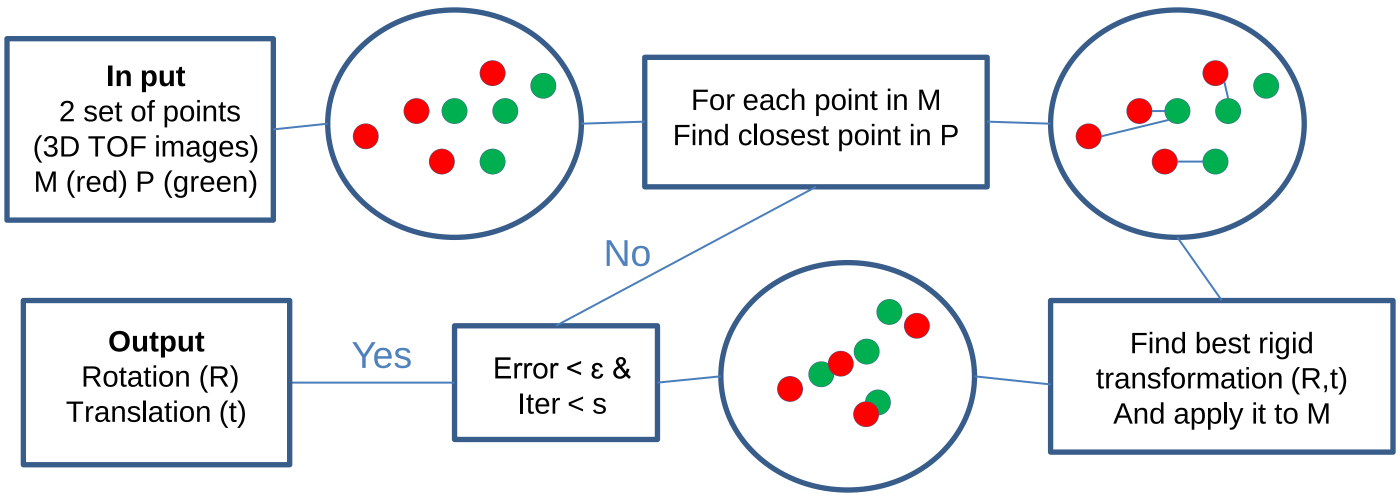
→ RANSAC

- while iterations < **k**
  - Select randomly 3 points into the two 3D point sets S1 and S2
  - Estimate q and t
  - Apply (q,t) to not selected points in S1 (S'1)
  - Compute error between S'1 and corresponding points in S2
  - Extract list of P points with an error < **e** (S''1)
  - If (P>**d**)
    - evaluate (q,t) with all points into (S''1)
    - If (q,t) is the best model, update the best model (q,t)
- Return the best model (q,t)

- If RANSAC finished correctly and estimate motion is higher than a threshold (rotation or translation)
  - ➢ Update camera motion and 3D map
  - ➢ Current image is the next reference image

Processing: ICP

- Estimate the motion using only few matches is not enough
- A global optimization is required to improve preciseness of the motion estimation → Iterative Closest Point (ICP)



- Whole distance maps are used to estimate transformation
- The output motion is validated if error is small (not based on iter) and motion is lower than a threshold

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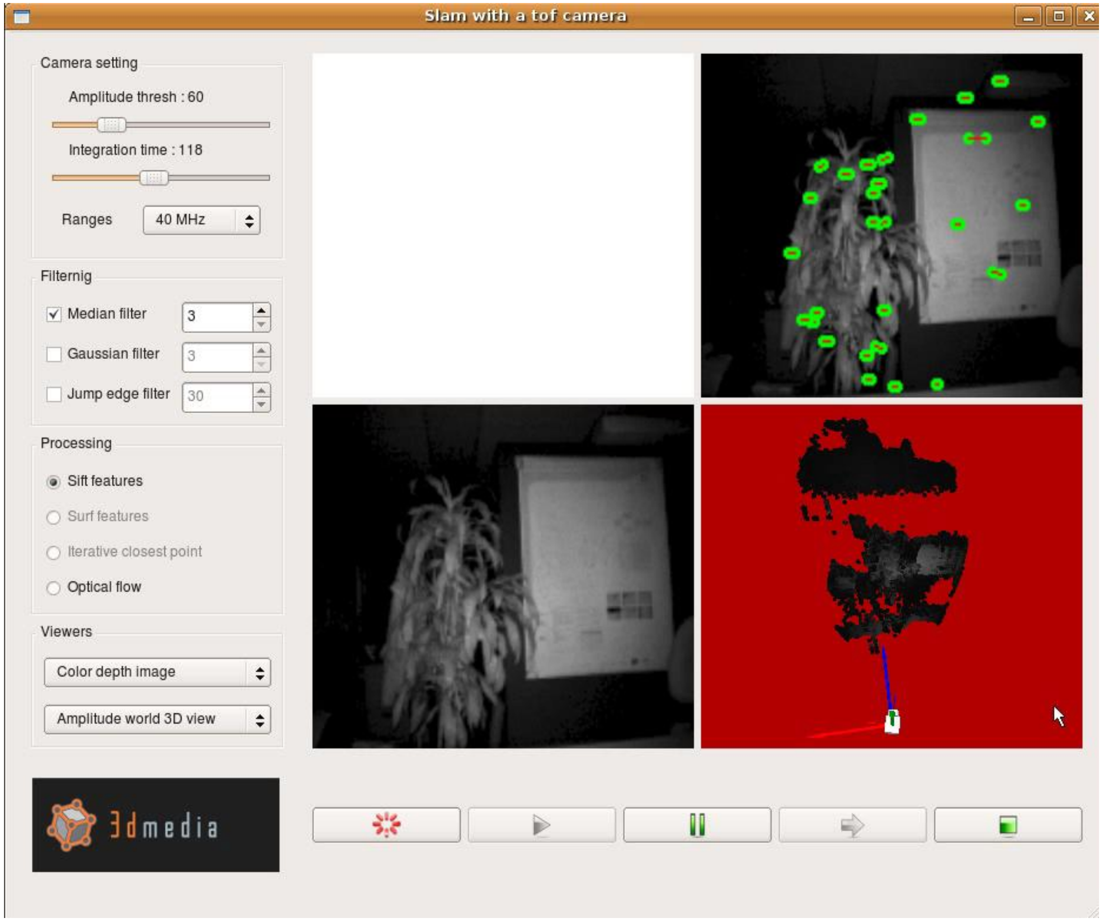
Processing: Demo



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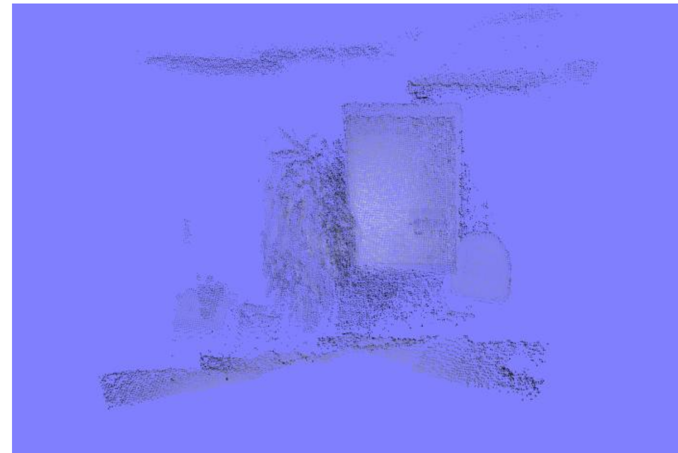
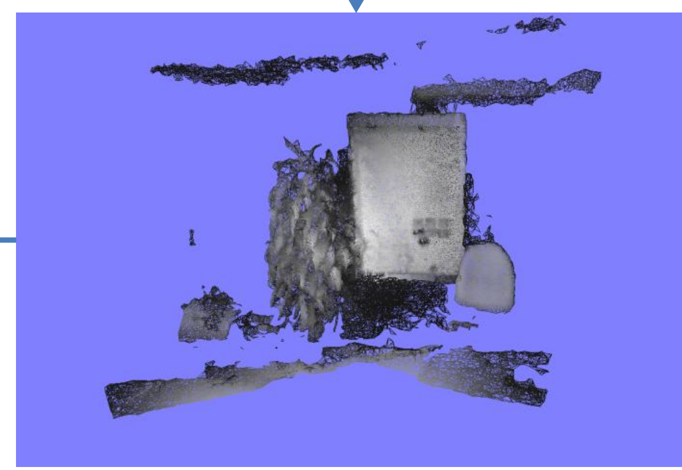
Postprocessing: 3D meshes

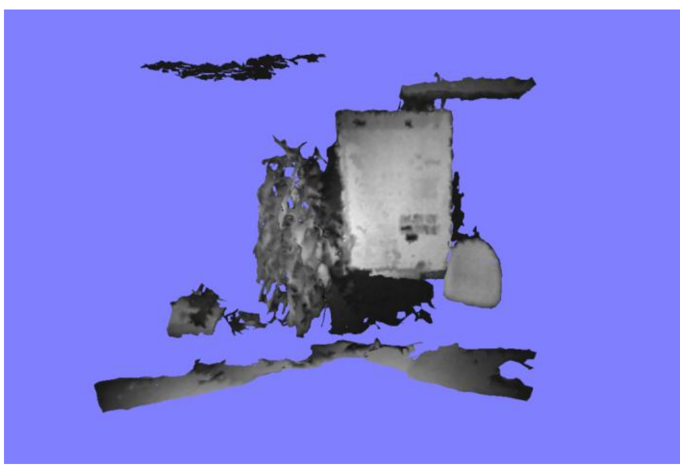
- Generate a mesh from 3D point cloud (meshlab library)
  - ➢ **Ball pivoting**, marching cubes Poisson's reconstruction
- Filter mesh
  - **Based on objects size**
  - Subdivision algorithms
  - **Hole filling**
  - **Laplacian smoothing, …**



Surface reconstruction



Filtering



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Conclusion & Perspectives

- Conclusion
  - ➢ SLAM using TOF camera
  - ➢ Dense 3D map reconstruction of the scene
  - ➢ Map represented by meshes

- Perspectives
  - ➢ Investigate different versions of ICP algorithm (Trimmed ICP, …)
  - ➢ Calibration of the depth map (relative to amplitude image, …)
  - ➢ Use a temporal motion estimation model (Extended Kalman Filtering, Particle Filtering)

Thank you for your attention

Questions?