Kinect-based 3D Mapping of Indoor Environment
基于Kinect的室内三维环境建图

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Background

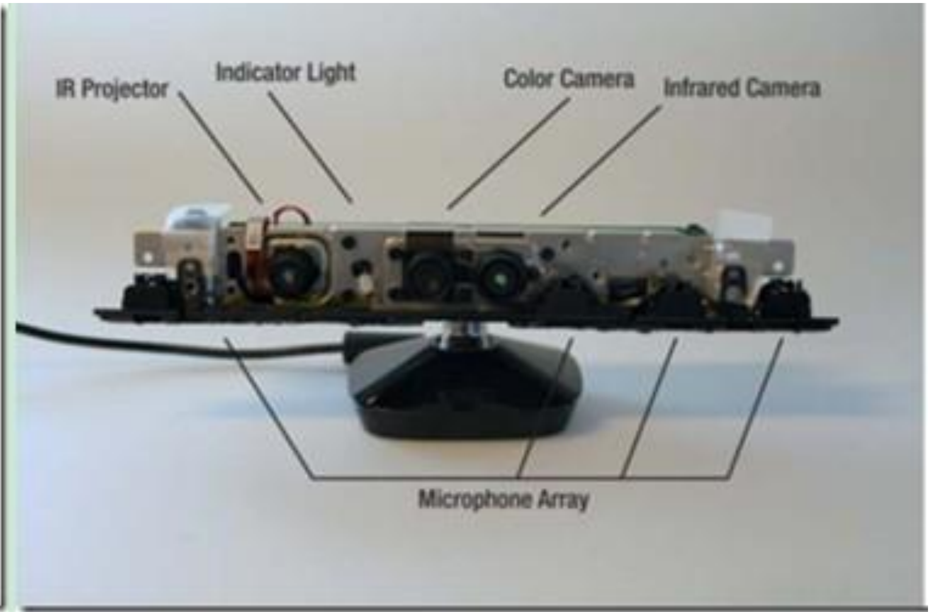
- Robots are going into families, e.g. home service robot

- For a home service robot:
- When it explores the unknown indoor environment, it needs to know:
  - Where it is? → Localization
  - How the environment around it like? → Mapping

- SLAM – Simultaneous Localization and Mapping

Background

- A brief introduction of Kinect
  - Kinect was primarily designed for natural interaction in a computer game.
  - The Kinect sensor captures depth and color images simultaneously at a frame rate of about 30 fps.
  - This characteristics of the data captured by Kinect have used in mapping and 3d modelling.



Previous Work

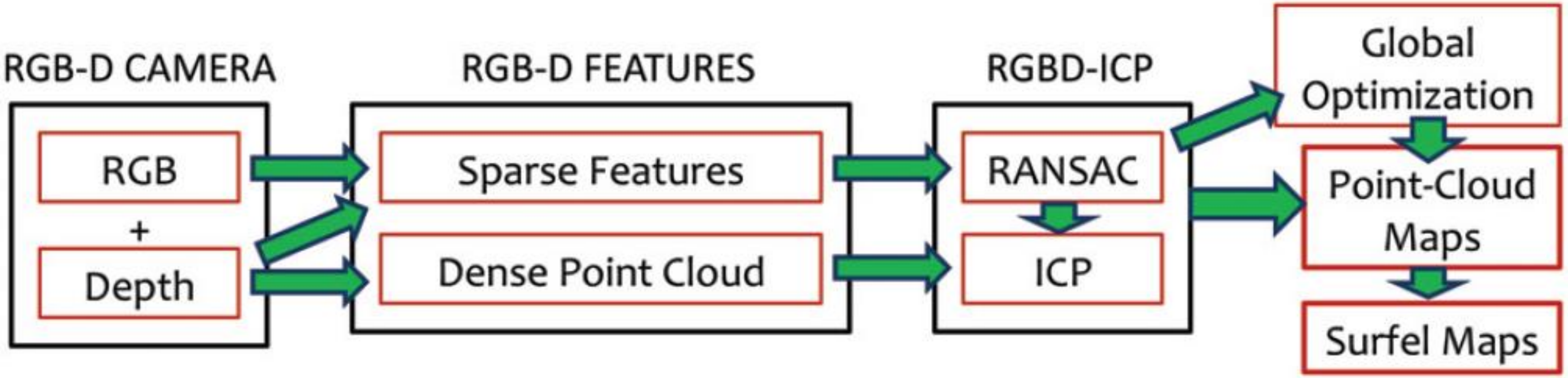


Fig.2 Overview of 3D mapping[1]

- Shortcomings:
  - Ignore the sensor(Kinect) noise
  - Error accumulating

[1] RGB-D mapping: Using Kinect-style depth cameras for dense 3D modeling of indoor environments Peter Henry, The International Journal of Robotics Research, 2012

Main work

- Analysis of the depth accuracy of Kinect
- Grid-based downsample as pre-processing

Some common ways of data pre-processing in 3D mapping

- Uniform downsampling
- Lowpass filter
- Removal of the outliers

- All of the above are mainly used to reduce computation and avoid the disturbance of the wrong measurement, regardless of the characteristics of sensor noise or structure information of the original point cloud.

Analysis of the depth accuracy of Kinect

- Disparity to depth

$$Z_k = \frac{Z_o}{1 + \frac{Z_o}{fb} d}$$

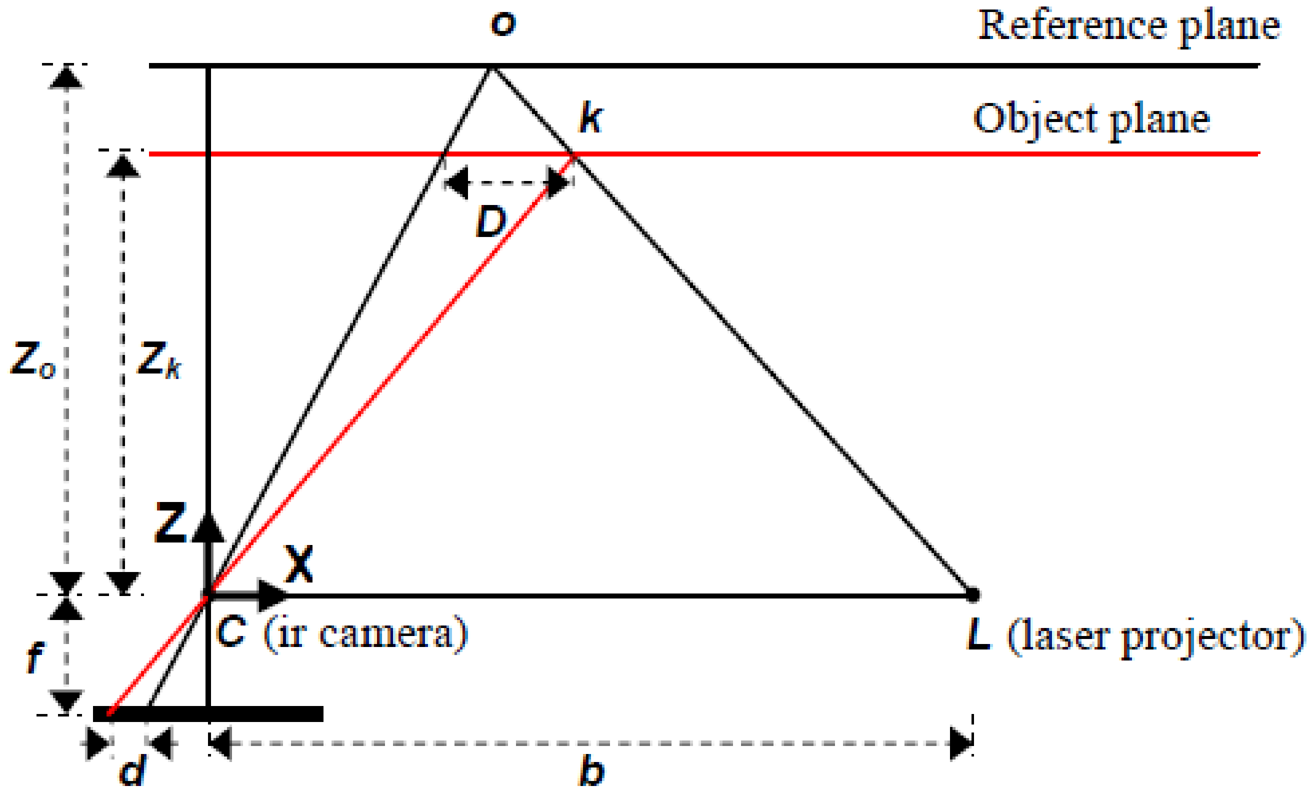


Fig. 4 illustration of disparity to depth

Analysis of the depth accuracy of Kinect

- Assume that d is a random variable with a normal distribution.
- Propagate the variance of the disparity measurement and obtain the variance of the depth measurement

$$\sigma_{Z_k} = \left(\frac{m}{fb}\right) Z_k^{\ 2} \, \sigma_{d'}$$

- Z_0, f and b are all camera parameters which can be determined by calibration

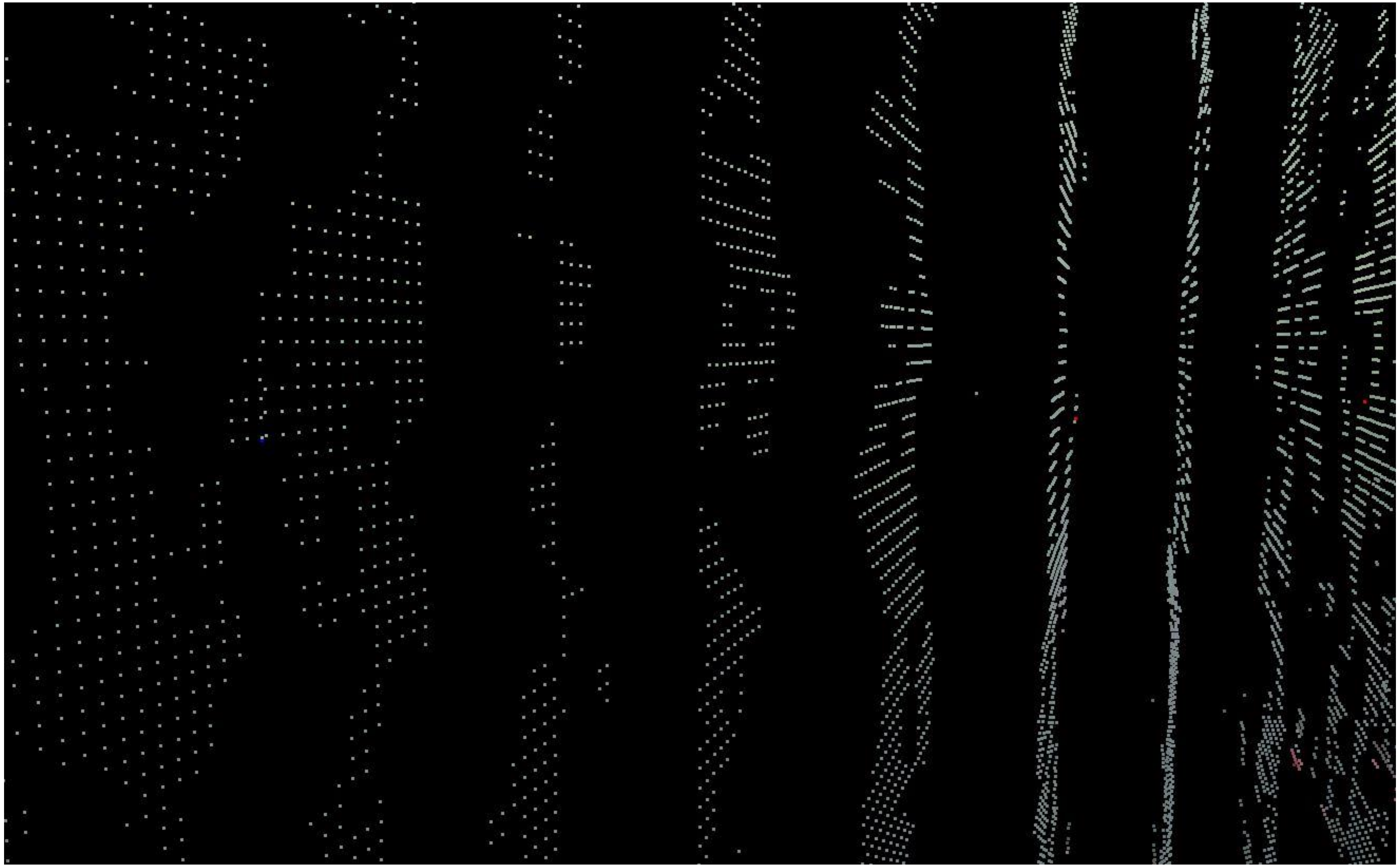
Kinect点云数据精度对法向量计算的影响

- 25个点局部领域的拟合结果

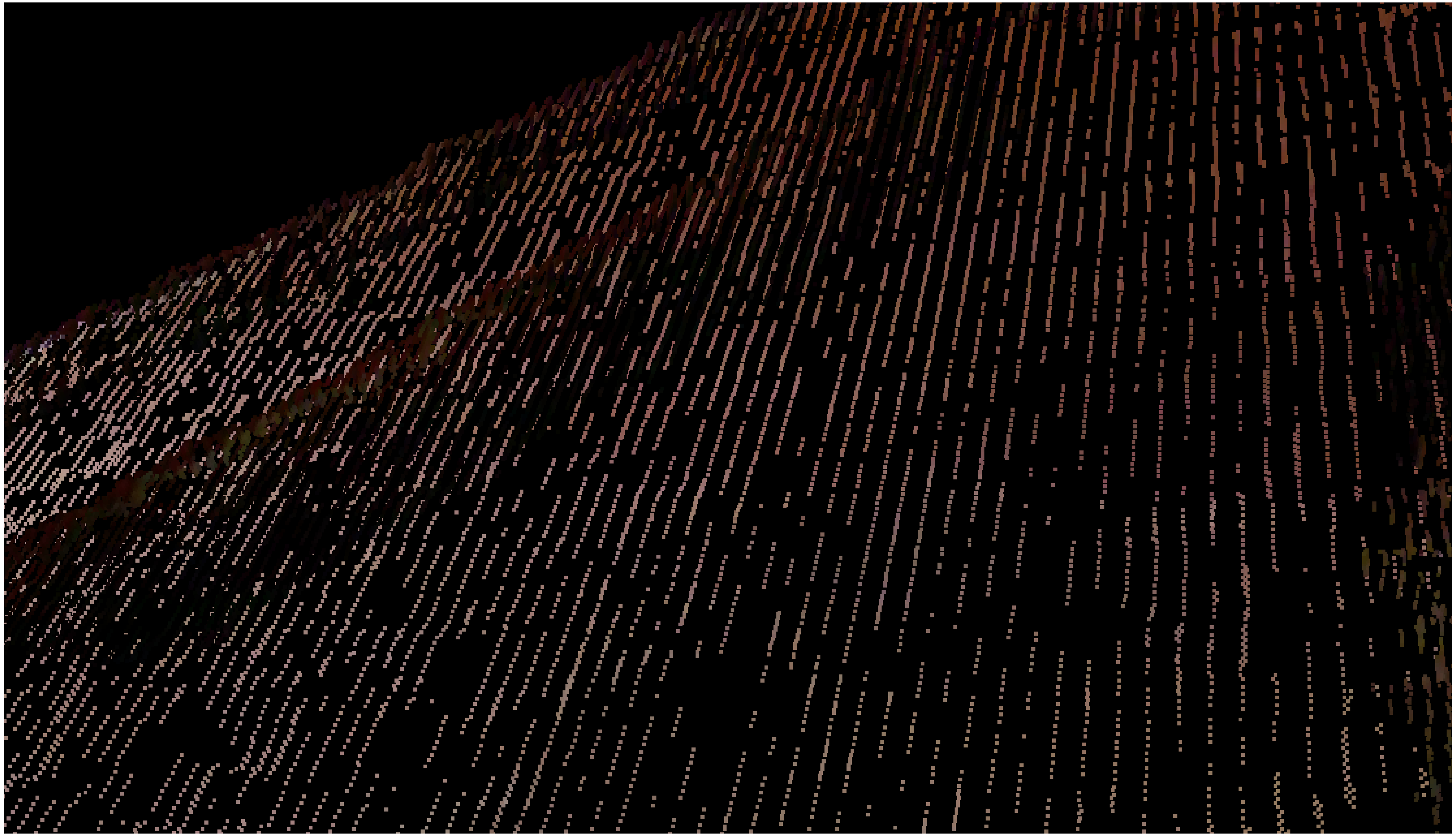
区域一：depth=~4m

区域二：depth=~2m

区域一：depth=~4m



区域二：depth=~2m



Grid-based downsample

- A uniform grid in image plane is constructed and projected into the 3D space to partition the point cloud.
- For every grid:
  - Compute covariance matrix of 3d coordinates of the points inside:
    - The largest eigenvalue: whether the points are from the same surface.
    - Eigenvector corresponding to the smallest eigenvalue : normal vector of the fitted plane from the points inside.
  - Construct a binary tree
    - Based on point set partition.
    - Hierarchical representation.

Covariance of 3d coordinates

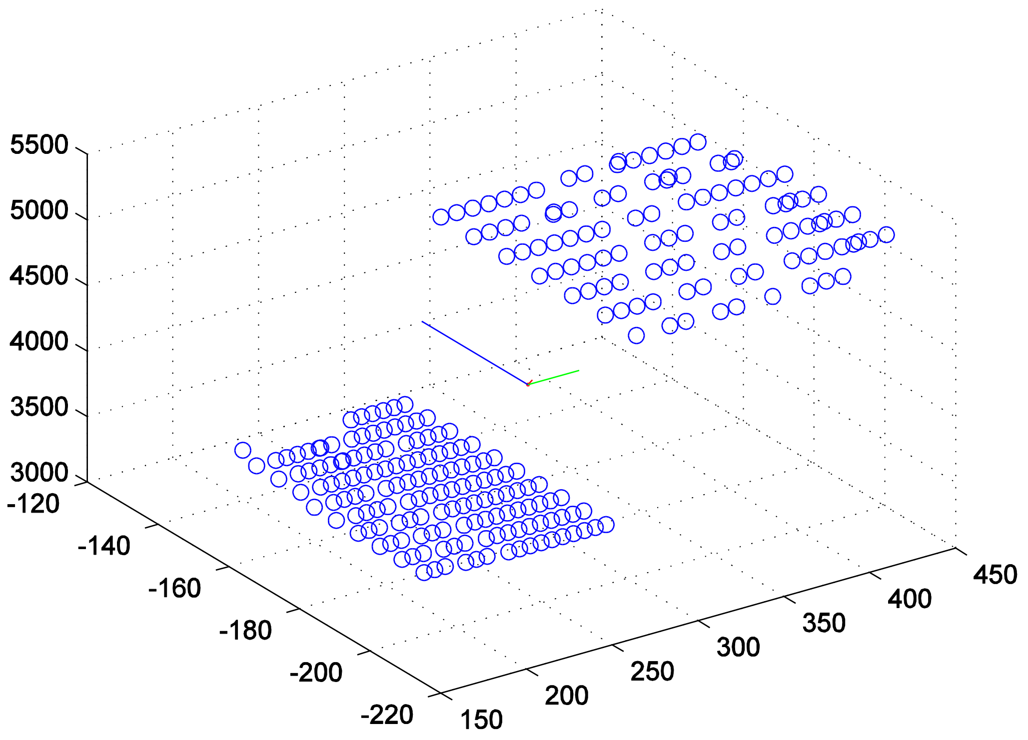


Fig. 5 large covariance

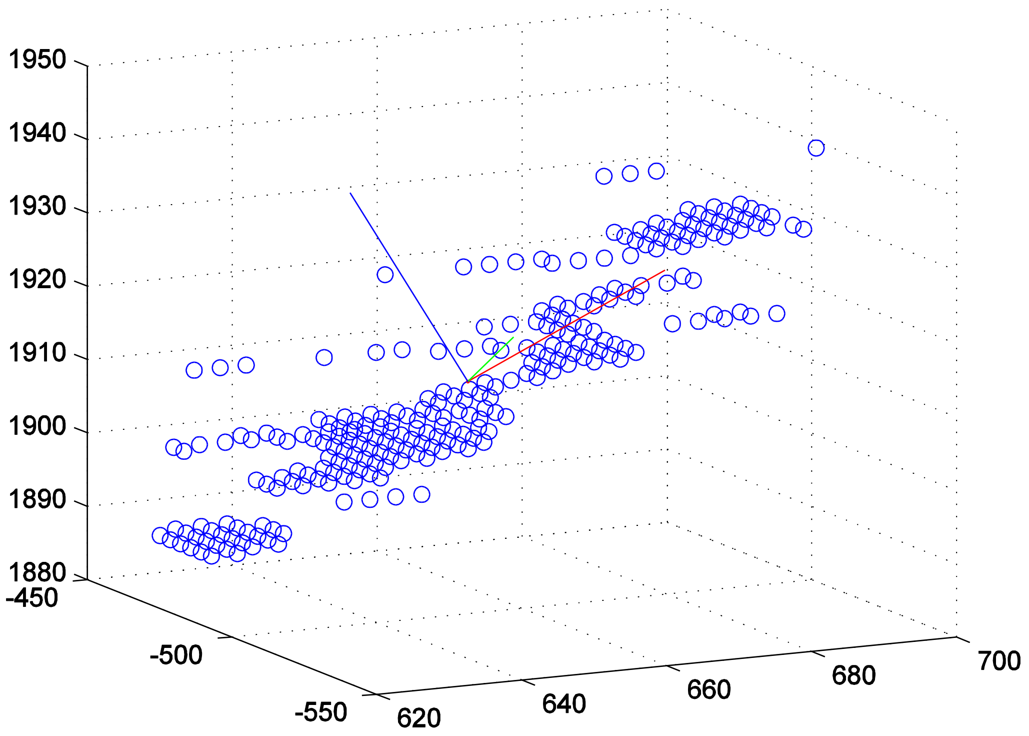


Fig. 6 small covariance

Binary tree construction

- Root node: all the points in one grid.
- A parent node in the tree can be split into two child nodes, each representing a certain partition of the points in the parent node.
- Partition is based on the eigenvector corresponding to the largest eigenvalue of the covariance matrix.
- For every level of the tree, the partition process is stopped when certain criterion is satisfied.

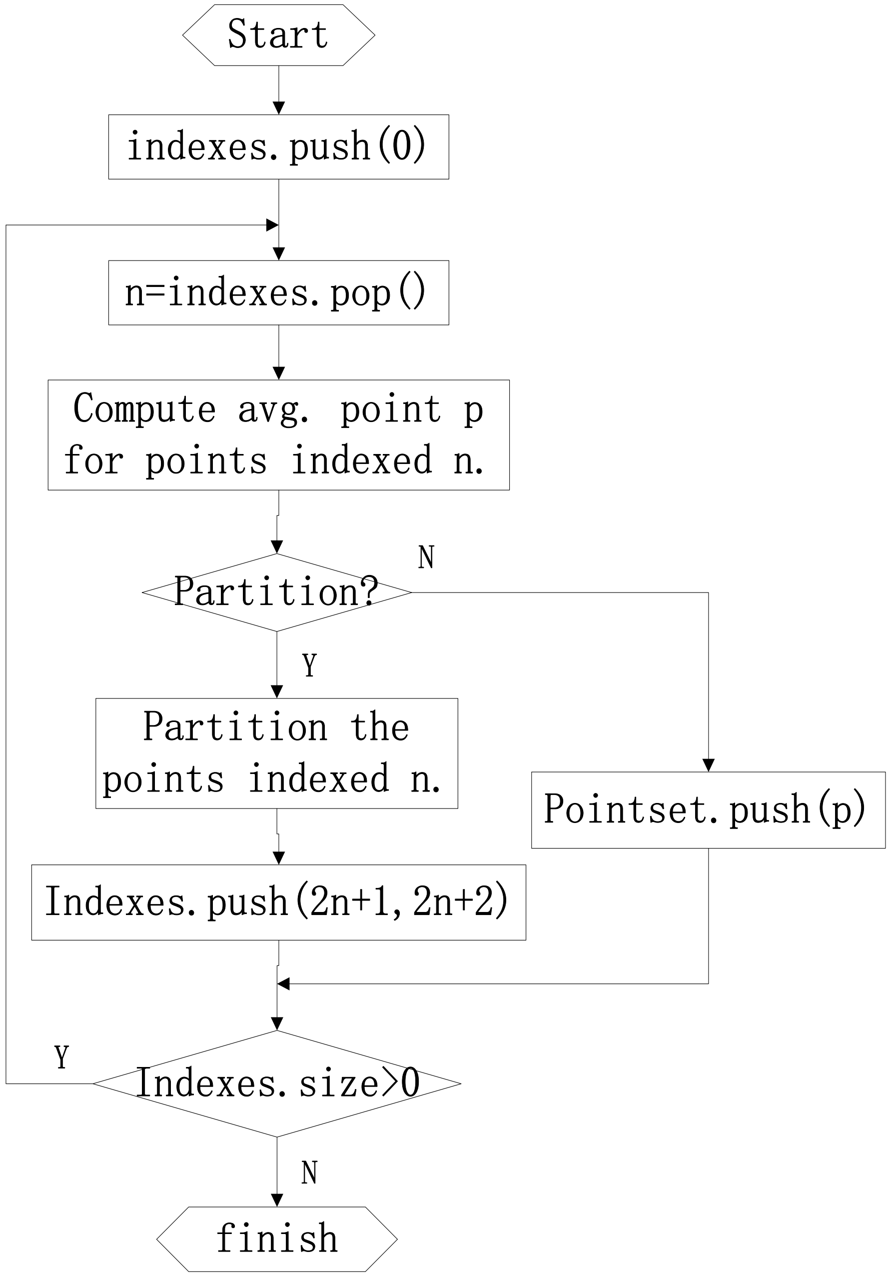


Fig. 9 binary tree construction

Binary tree construction

- Criterion to stop partition:
- Using the points in certain level of the tree to fit a plane $ax+by+cz=d$
- (a,b,c) is the normal vector.
- Define fitting rate

$$\alpha = \frac{N_{number\ of\ points\ when\ |ax+by+cz-d|<th}}{N_{number\ of\ all\ the\ points}}$$

- And set a threshold for the fitting rate to complete the partition.

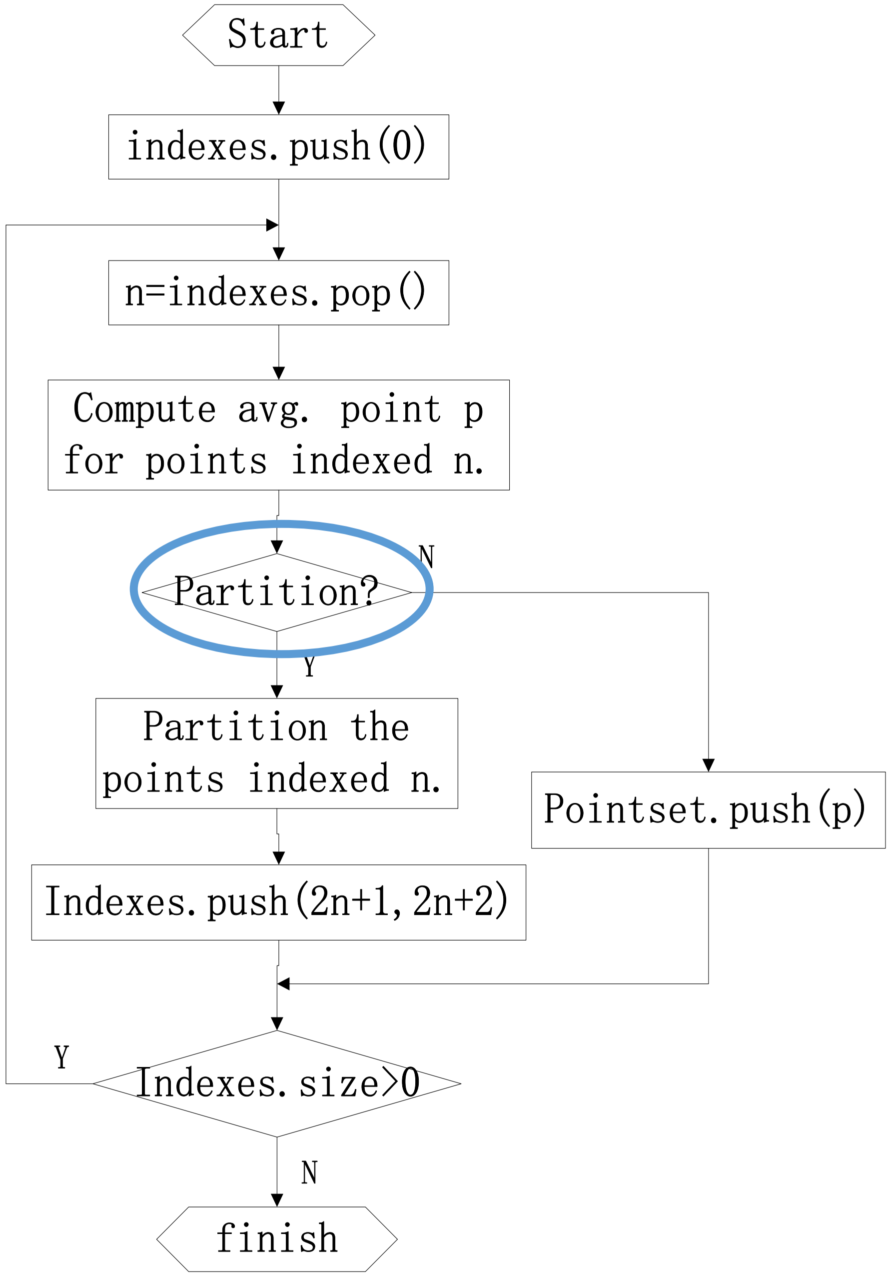


Fig. 9 binary tree construction

Binary tree construction

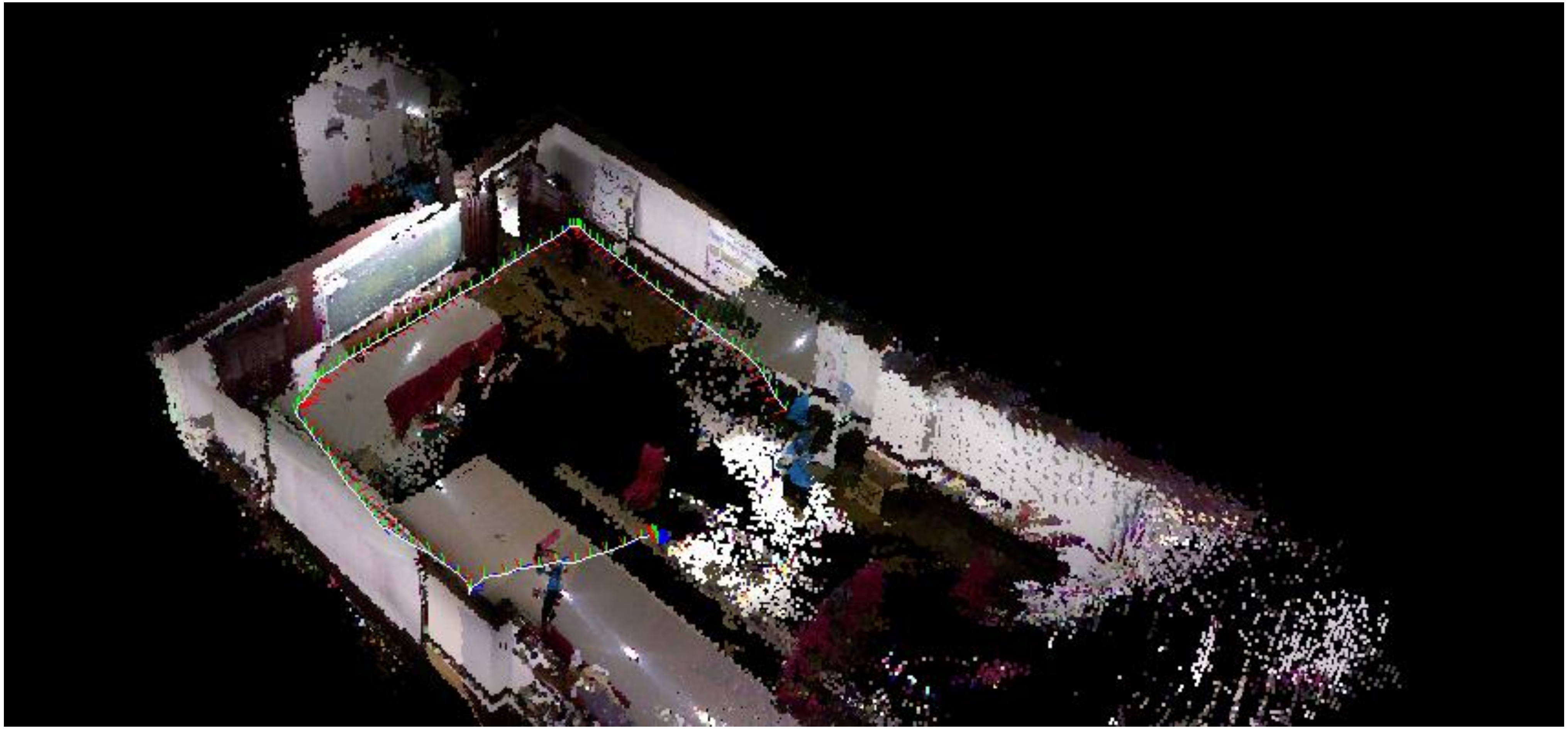
- The accuracy of the depth is inversely proportional to the square of depth value.

$$\sigma_{Z_k} = (\frac{m}{fb}) {Z_k}^2 \sigma_{d'}$$

- So the threshold for the fitting rate will be weighted by the square of depth.

$$th_\alpha = \mu Z_k^2$$

Experiments



Future work

- Apply the grid-based method in scan matching
- Global optimization in real time

Thank you !