Probabilistic Surfel Fusion for Dense LiDAR Mapping

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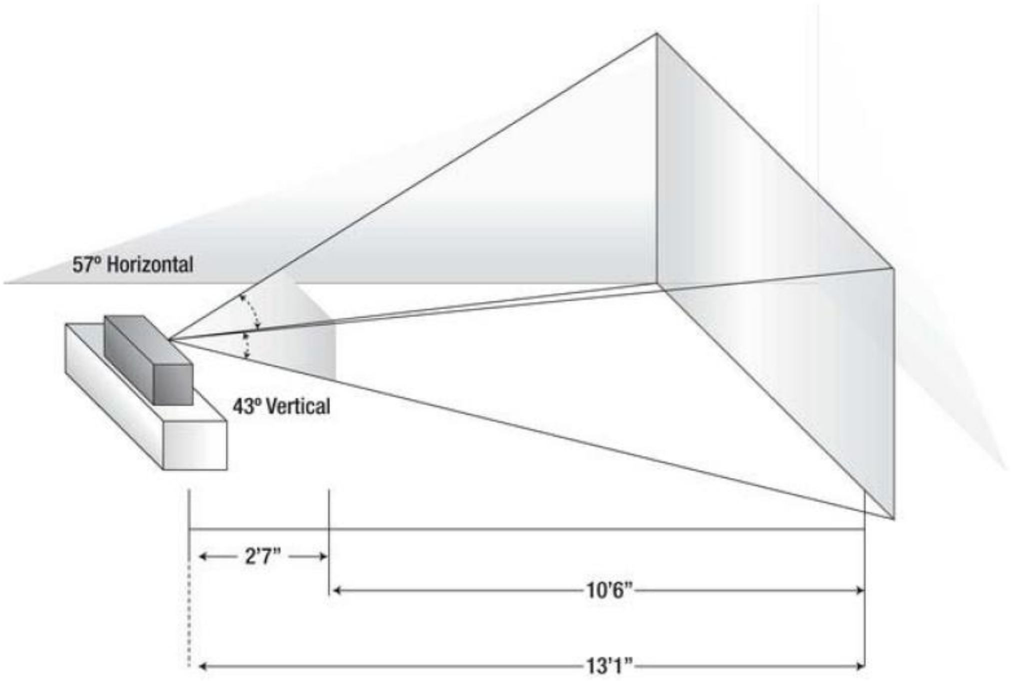
ICCV workshop 2017

Introduction

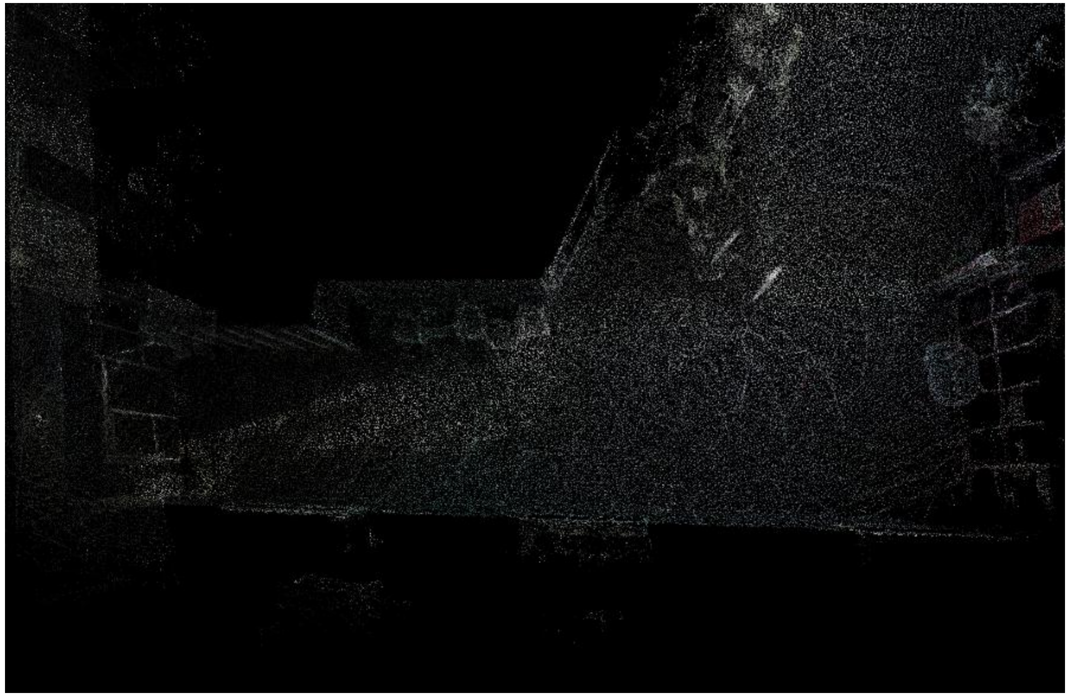


Narrow FoV
Short sensing range
Sensitive to ambient light

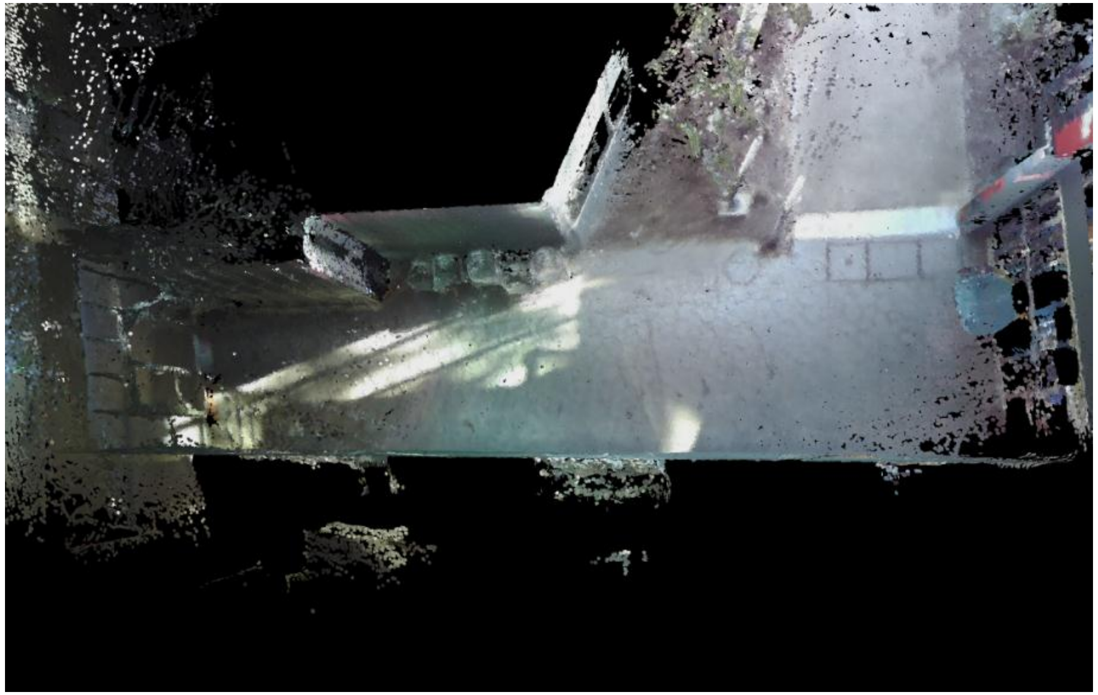
This work covers the map fusion for LiDAR

Introduction

What is a surfel? Surface + Element



Points Cloud map

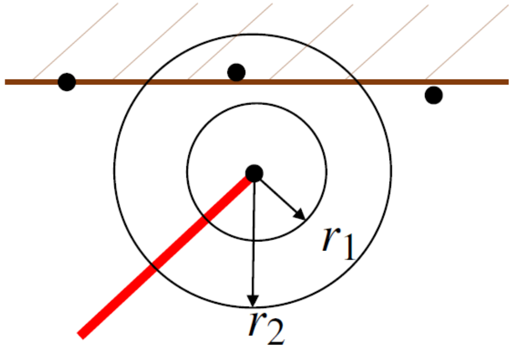


Surfels map

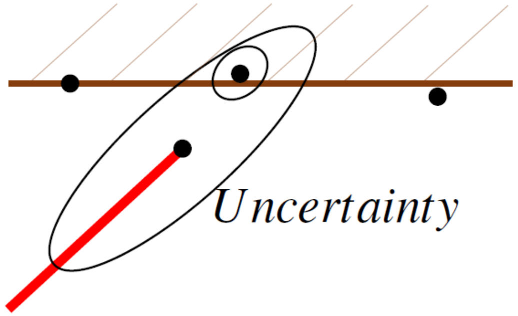
Introduction

What make it difficult to introduce surfel fusion in LiDAR-based SLAM

- Absence of projective data association



Radius search

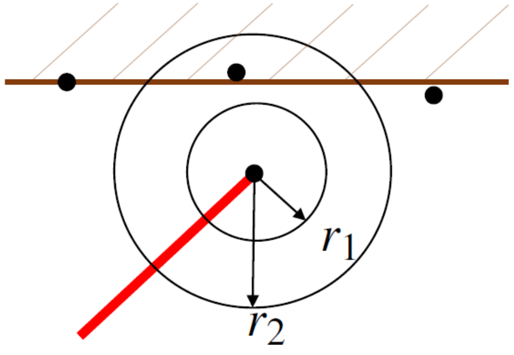


Uncertainty based search

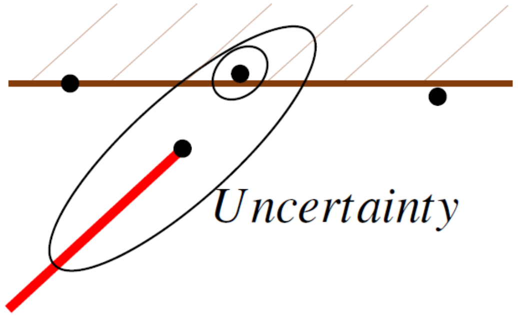
Introduction

What make it difficult to introduce surfel fusion in LiDAR-based SLAM

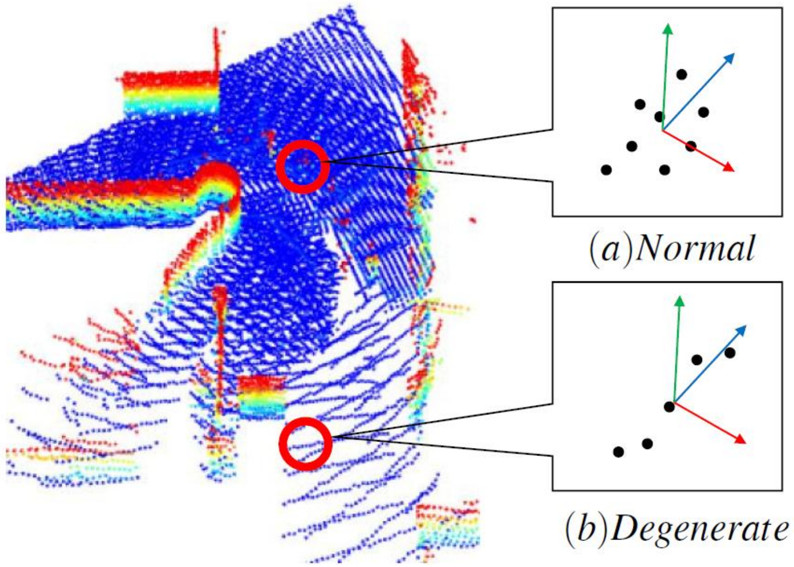
- Absence of projective data association
- Existence of the surfel degeneracy



Radius search

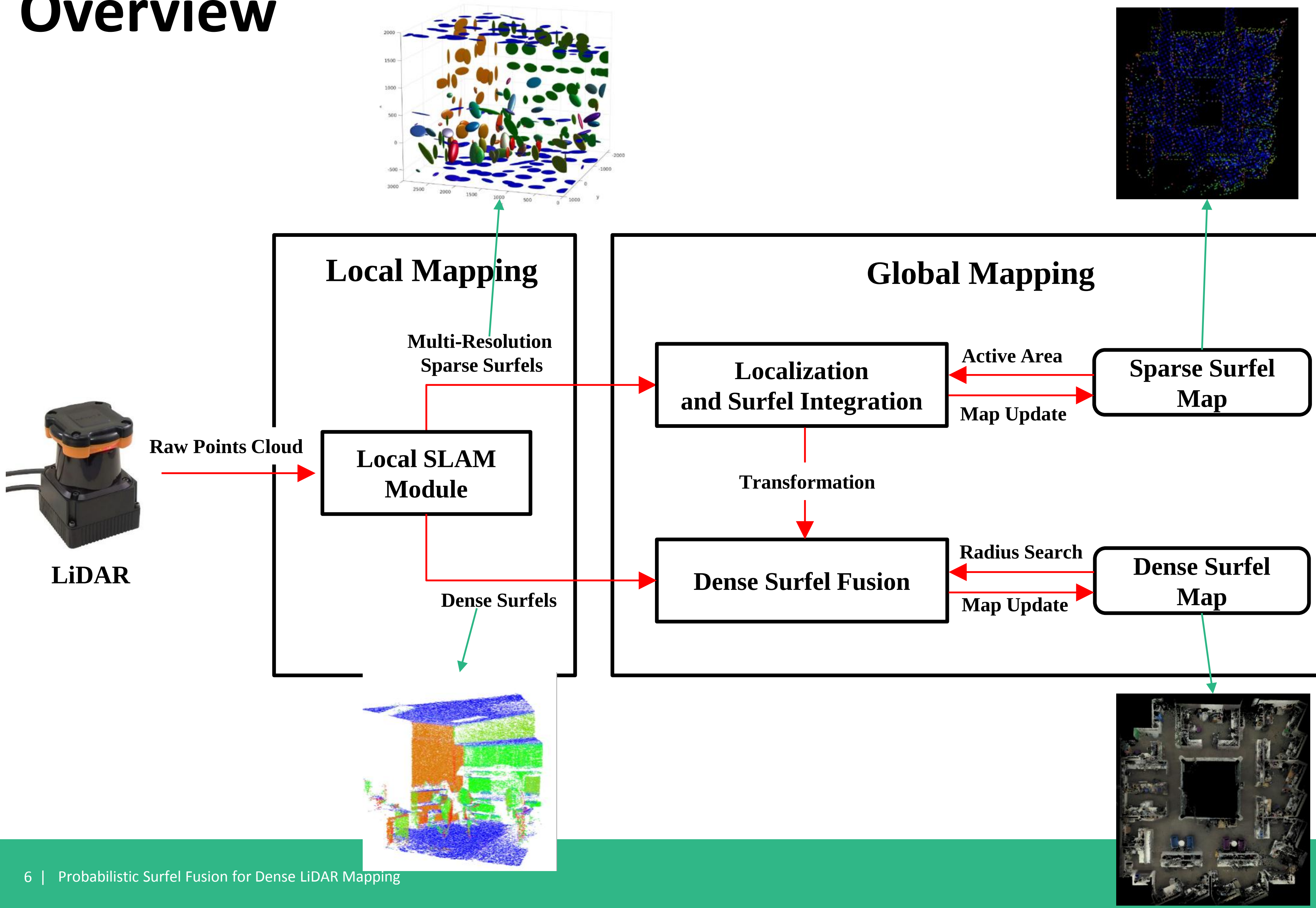


Uncertainty based search



Unstable normal direction

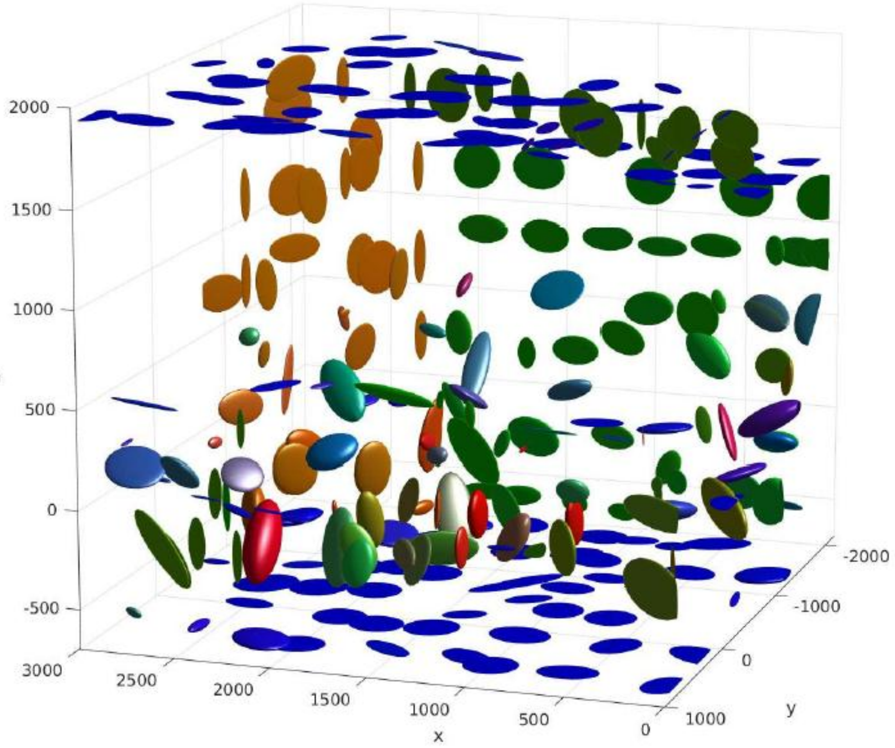
Overview


Local Mapping
Multi-Resolution Sparse Surfels
Raw Points Cloud
Local SLAM Module
LiDAR
Dense Surfels
Global Mapping
Localization and Surfel Integration
Active Area
Map Update
Sparse Surfel Map
Transformation
Dense Surfel Fusion
Radius Search
Map Update
Dense Surfel Map

Dual Map Representation

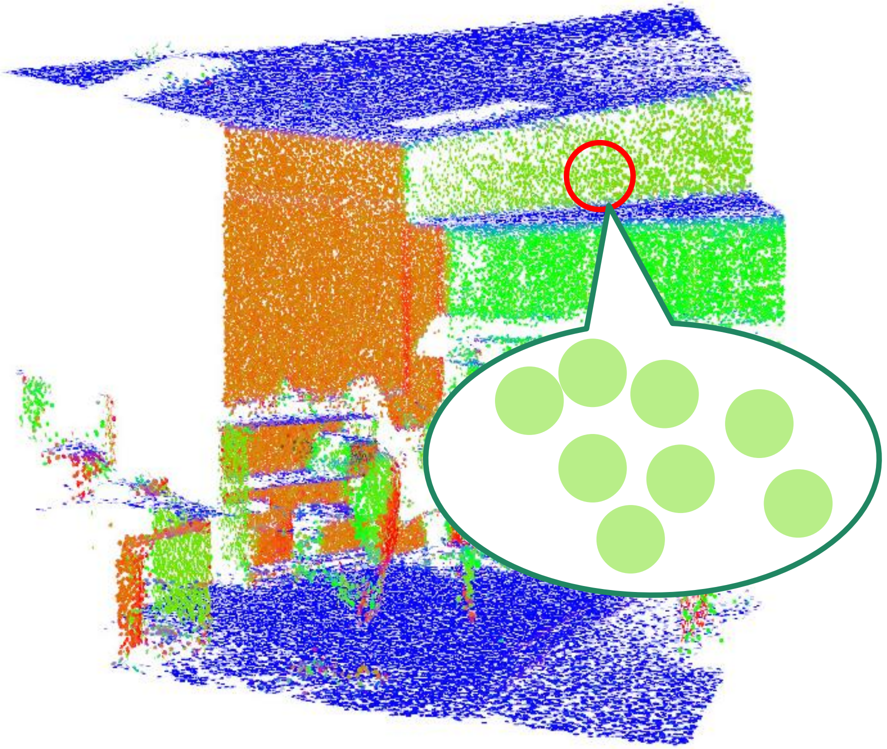
Robust ICP
Fast

Too sparse



3D Ellipsoidal Surfel Map

from Multi-resolutional Voxel Hassing



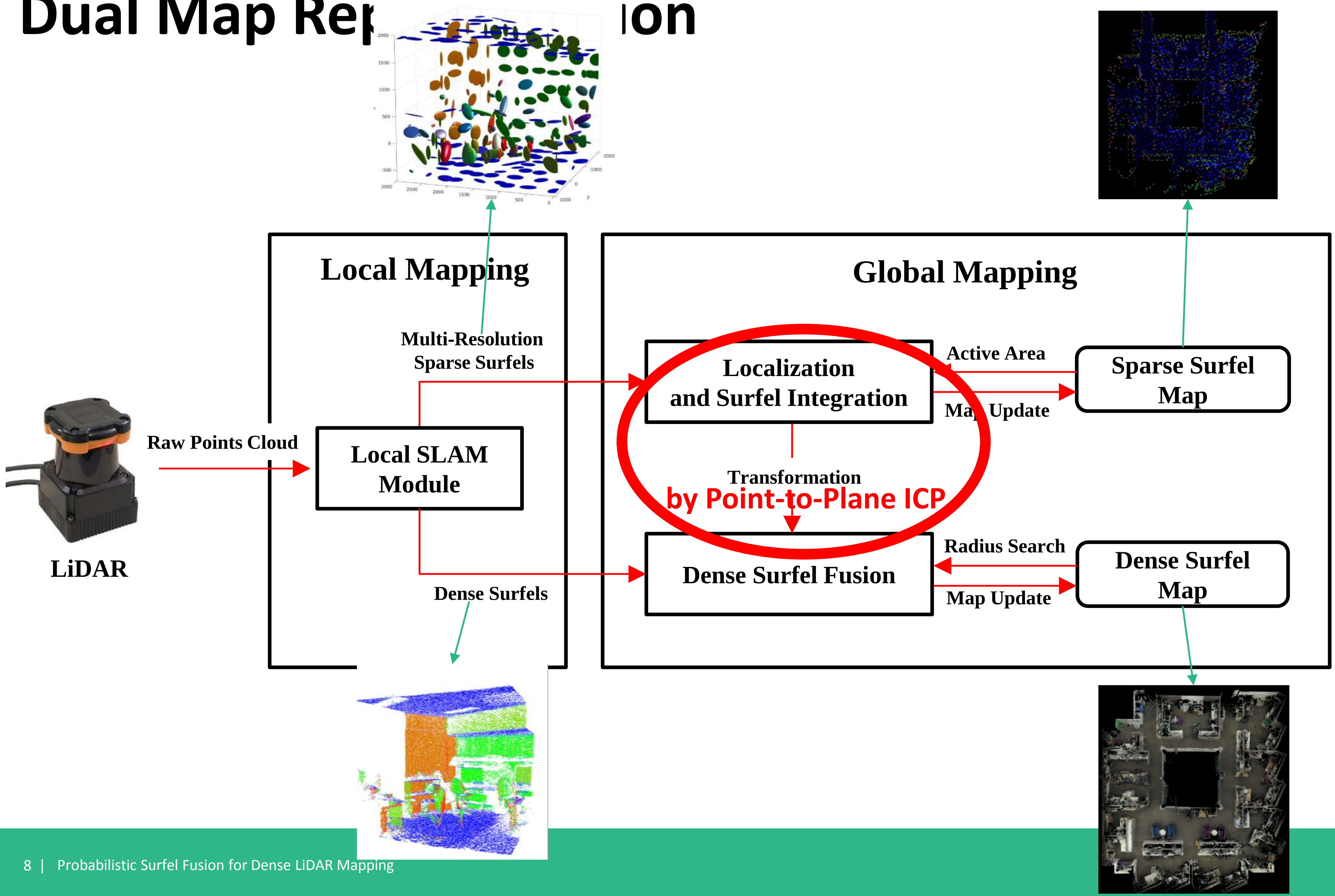
Visualization

2D Disk Surfel Map

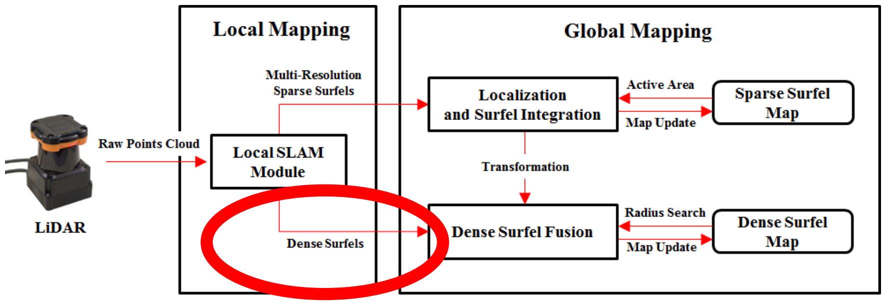
from Nearest Neighbor Searching

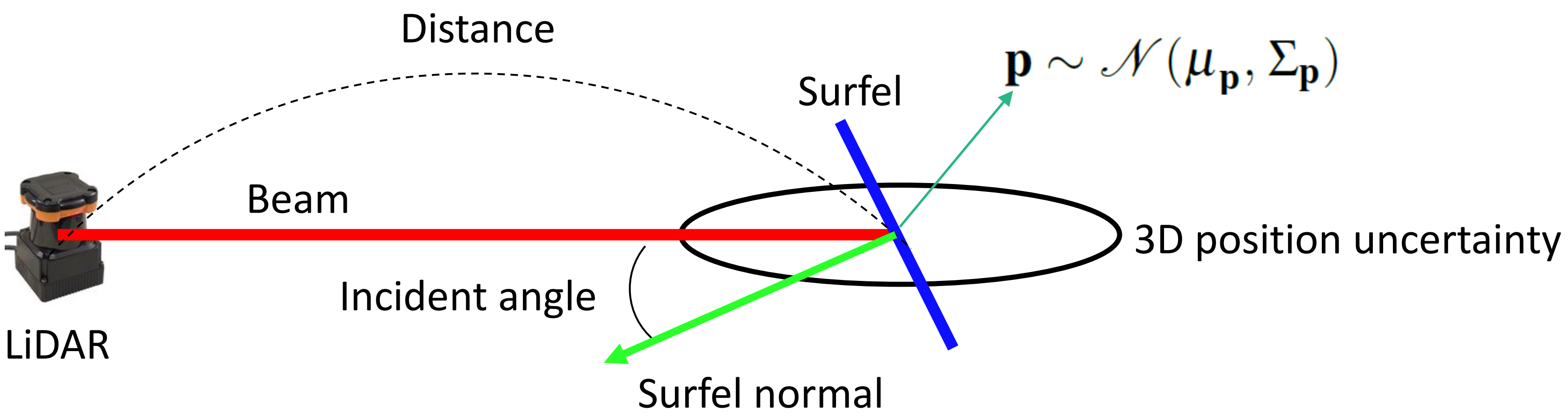
*Color is coded with normal direction

Dual Map Rep… ion



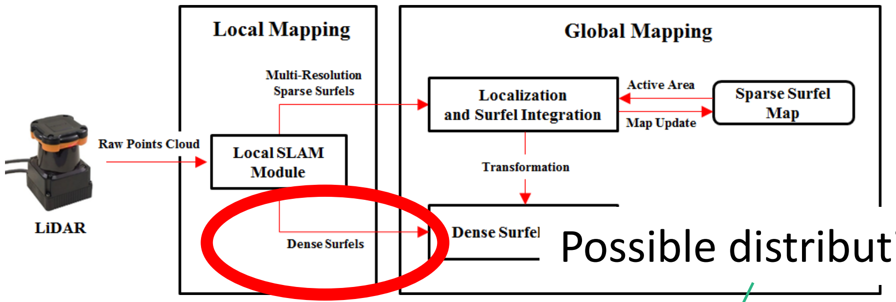
Noise Modelling



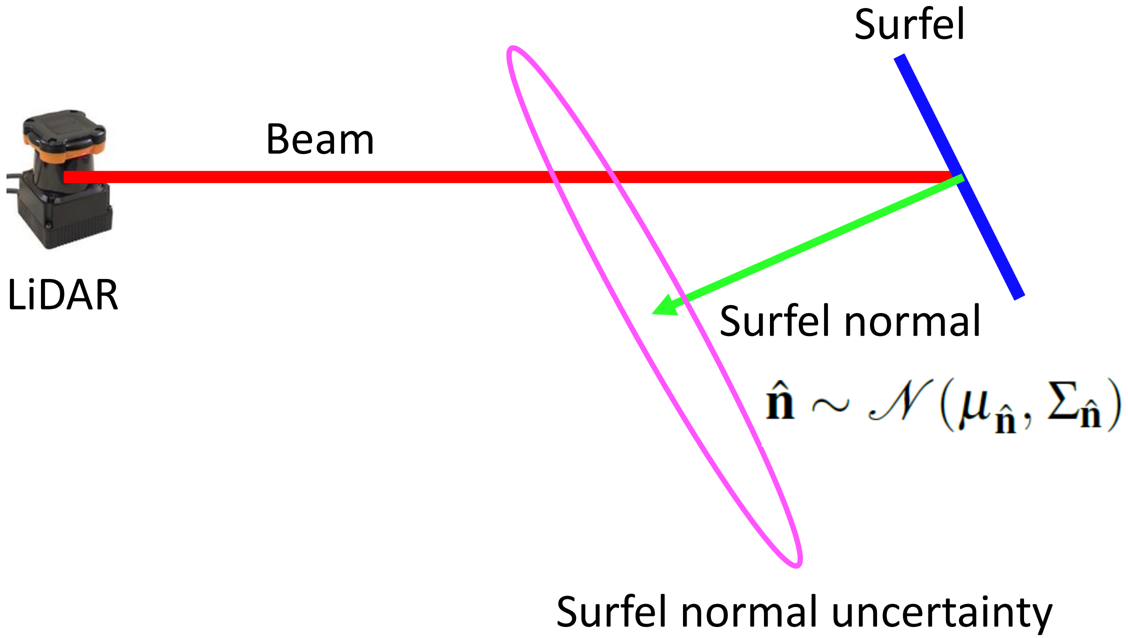


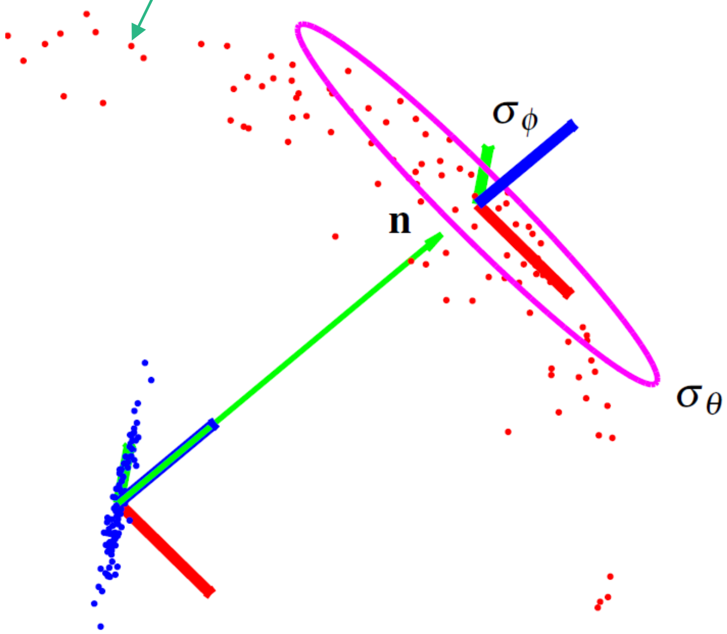
Surfel position uncertainty modeling

Noise Modelling



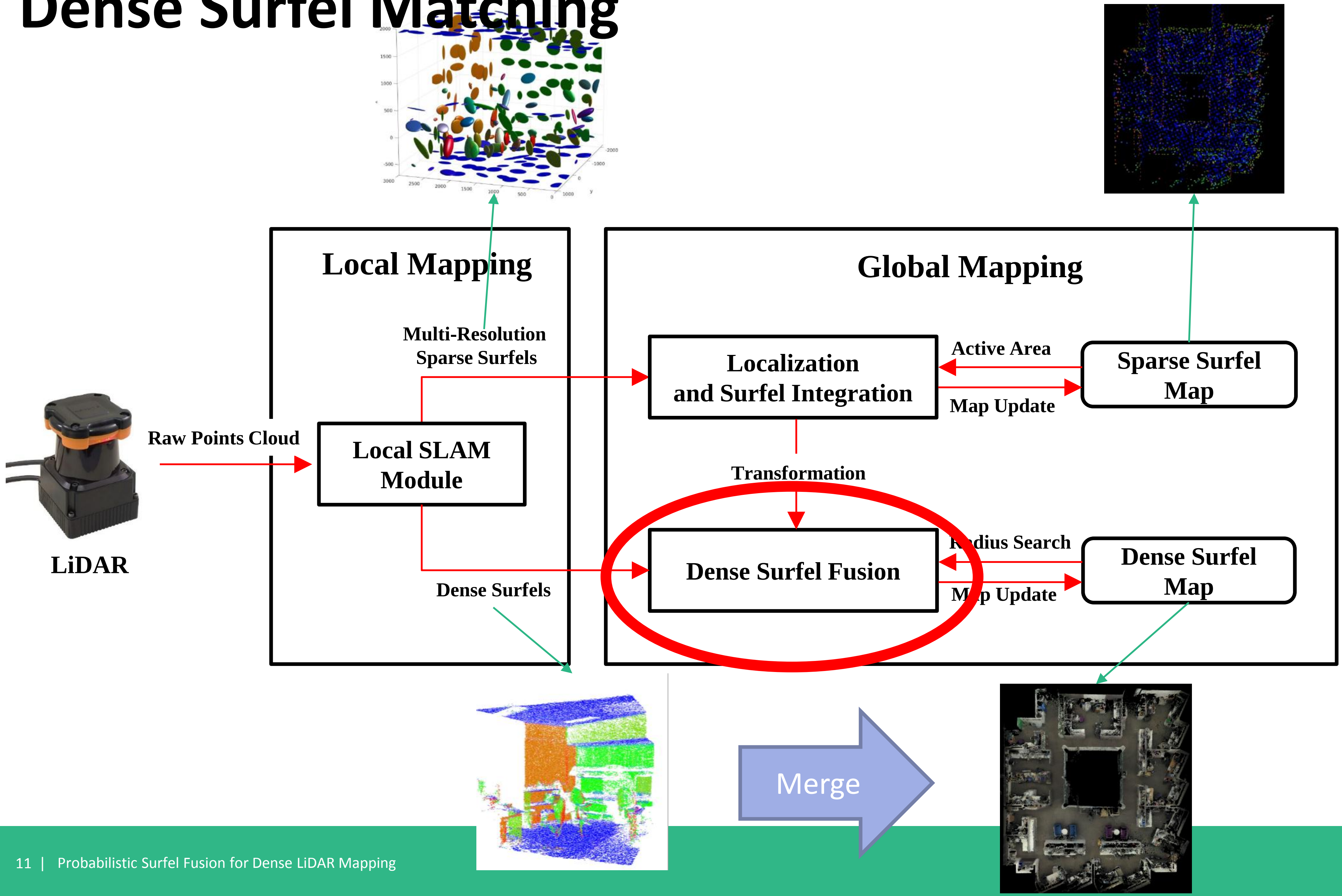
Possible distribution of normal vector



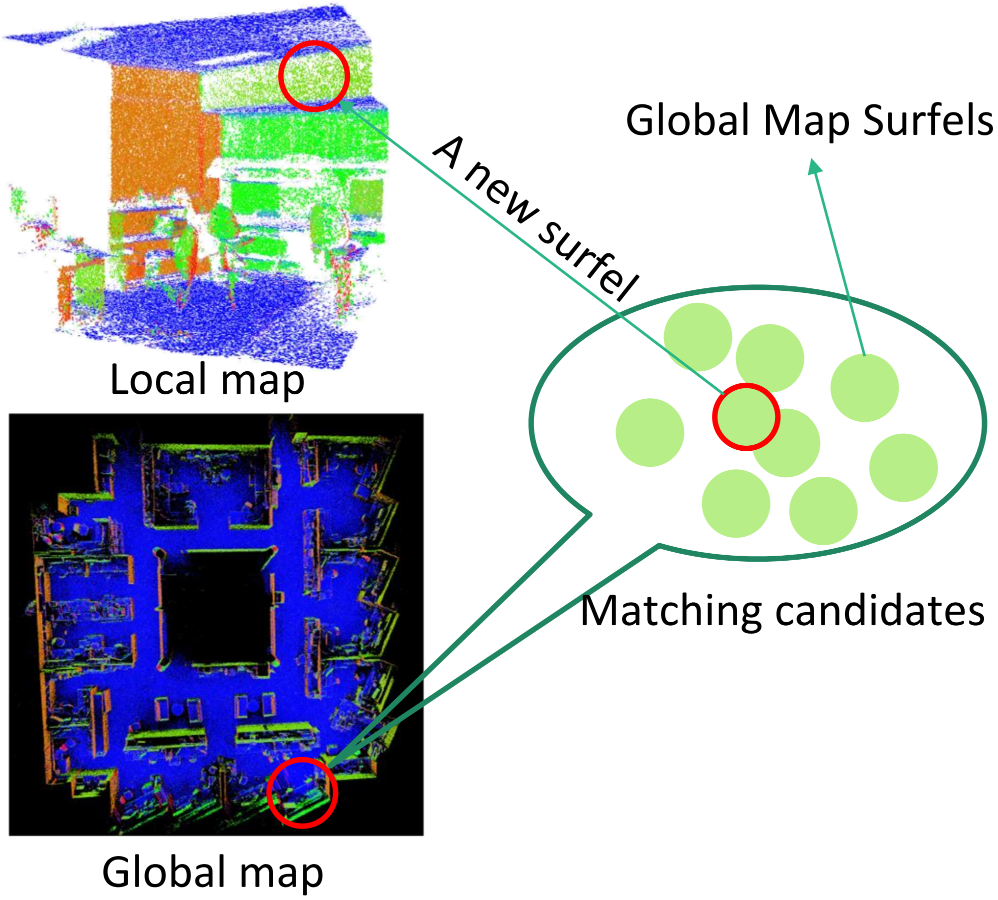


Surfel normal direction uncertainty modeling

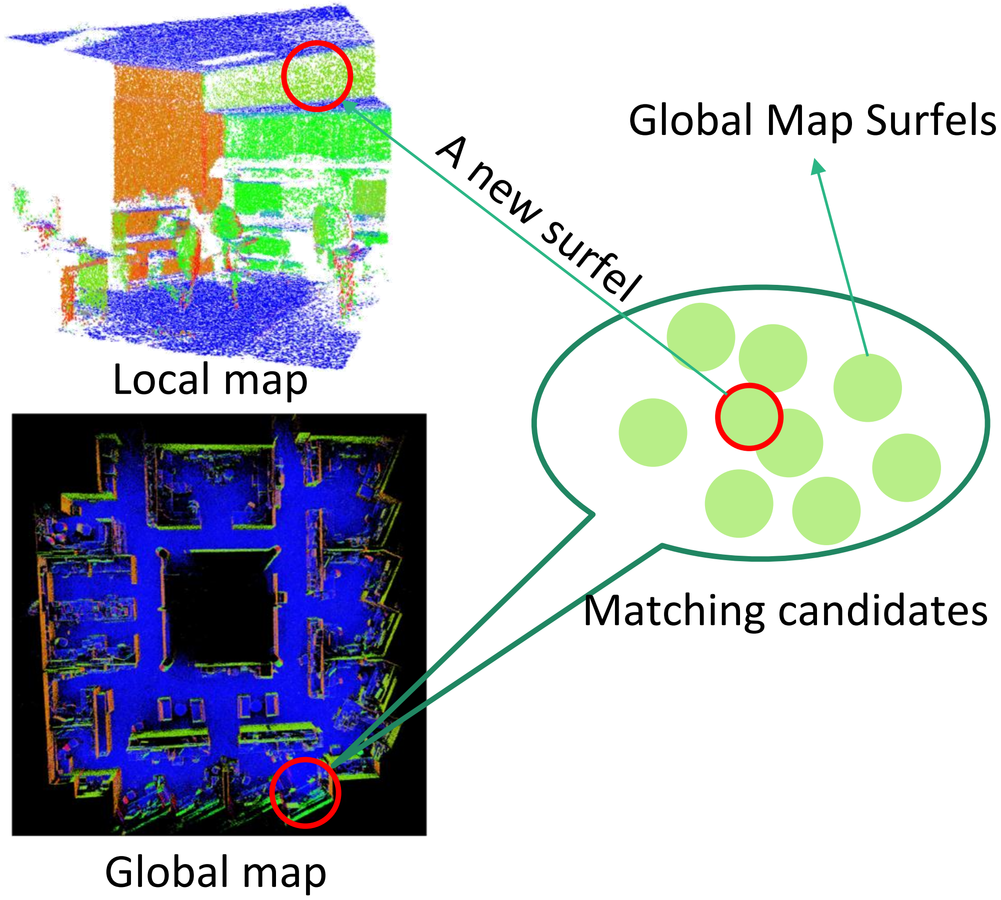
Dense Surfel Matching



Dense Surfel Matching

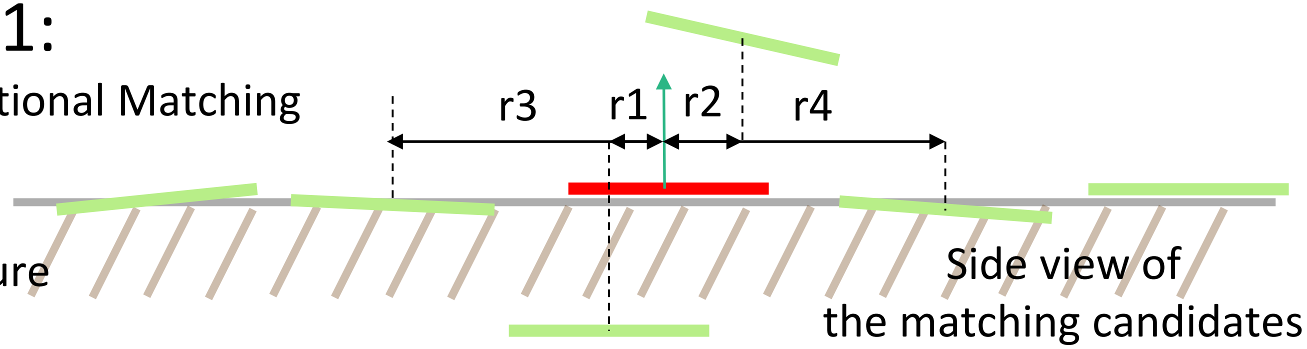


Dense Surfel Matching

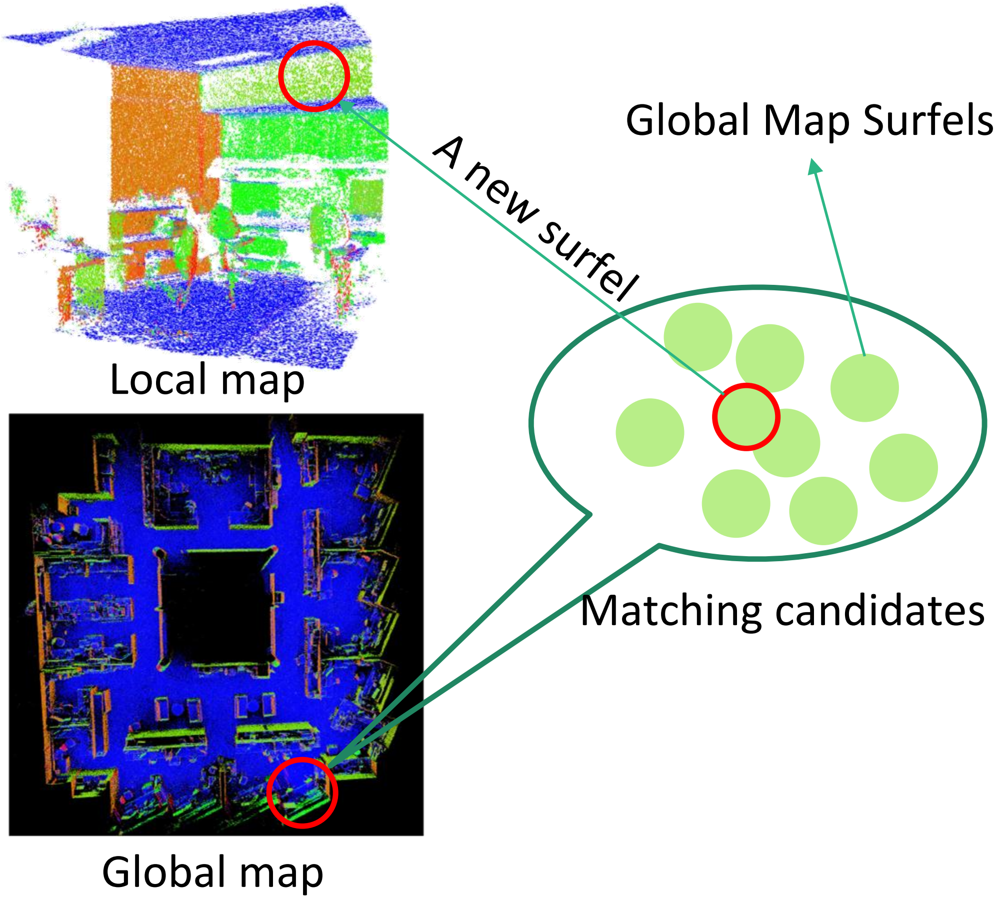


Step1:

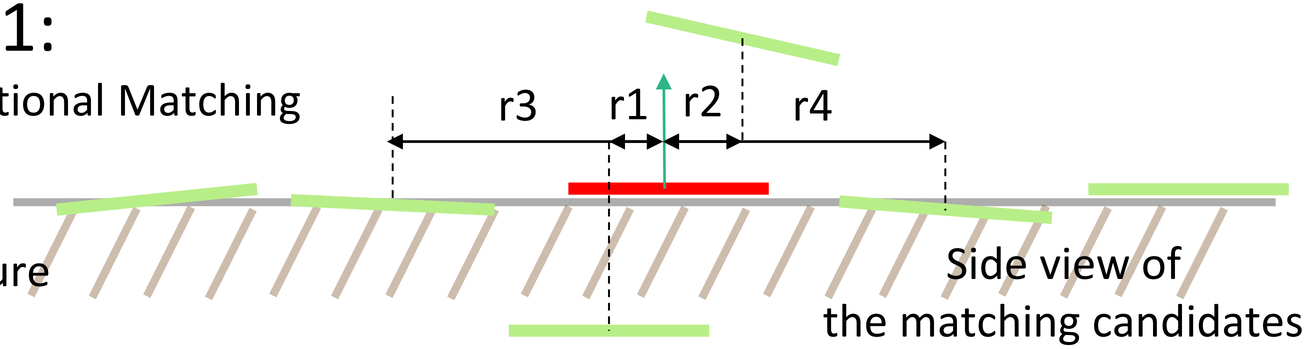
Resolutional Matching



Dense Surfel Matching



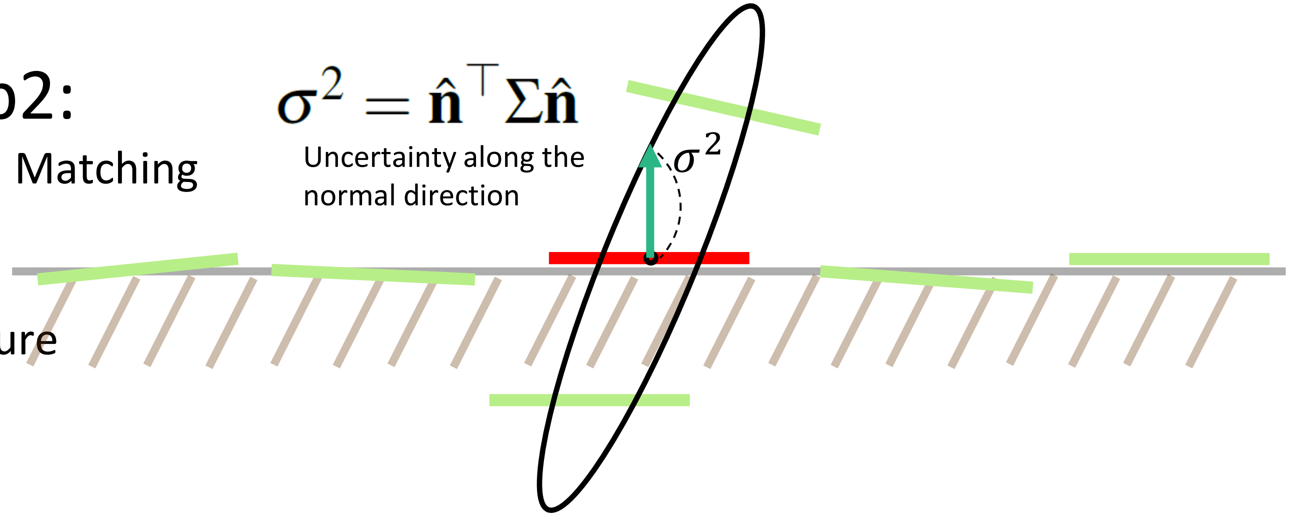
Step1:
Resolutional Matching



Step2:
Depth Matching

$$\sigma^2 = \hat{\mathbf{n}}^\top \Sigma \hat{\mathbf{n}}$$

Uncertainty along the normal direction



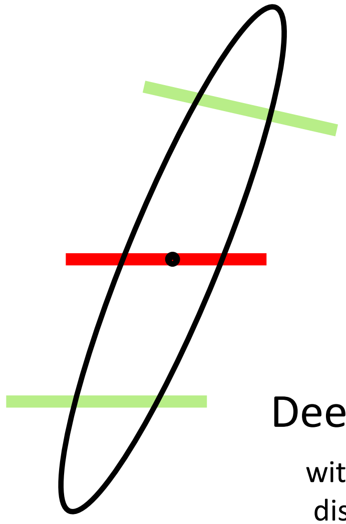
Dense Surfel Matching

Benefits of this approach

1. Easy control of the surface resolution
    - Space digitization is not required
2. It searches more in the laser beam direction
    - Better noise handling

Higher Resolution

with a Euclidian distance threshold



Deeper searching

with a Mahalanobis distance threshold

Dense Surfel Fusion

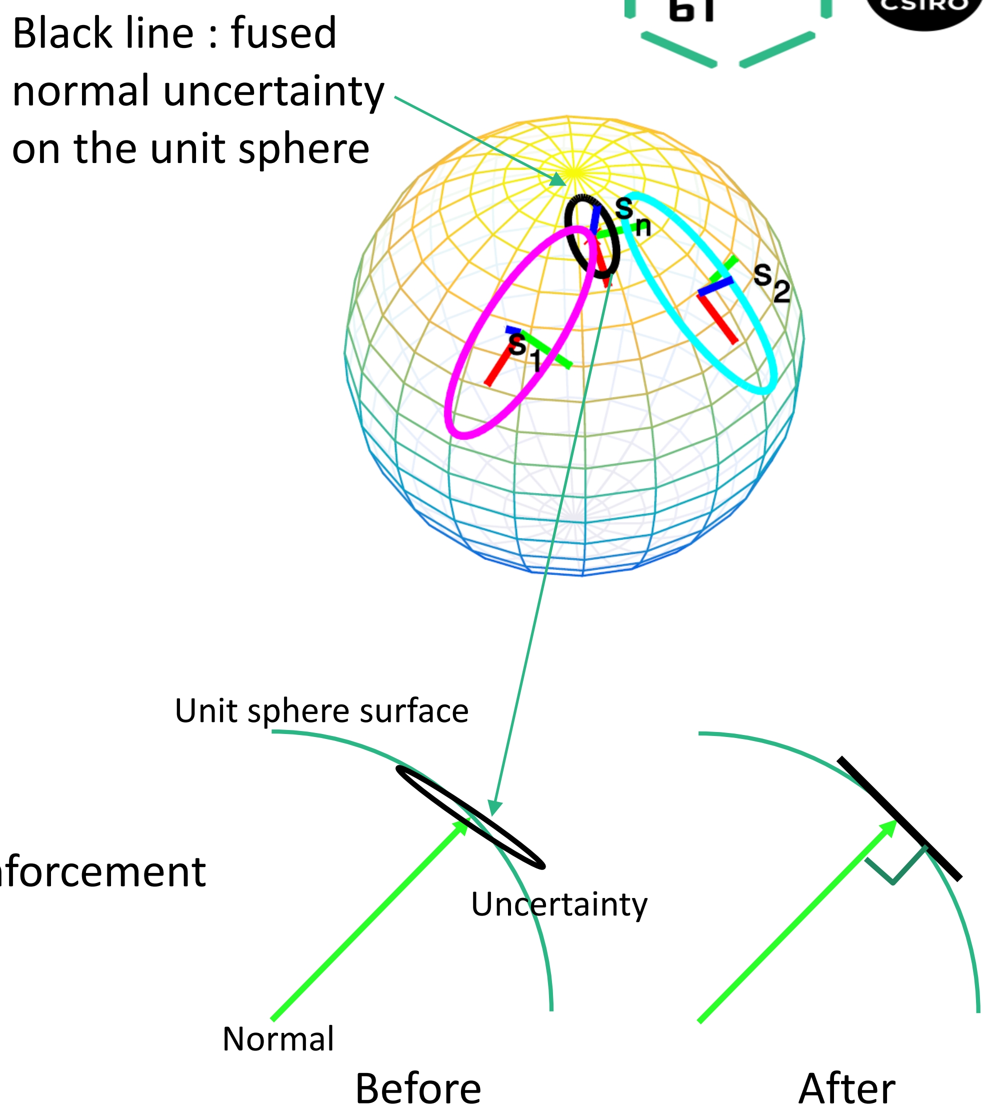
Centroid Fusion:

$$\left.\begin{aligned}\Sigma_d &\leftarrow (\Sigma_s^{-1} + \Sigma_d^{-1} + \Sigma_s^{-1})^{-1} \\ \mathbf{p}_d &\leftarrow (\Sigma_s^{-1} + \Sigma_d^{-1})^{-1}(\Sigma_d^{-1}\mathbf{p}_d + \Sigma_s^{-1}\mathbf{p}_s)\end{aligned}\right\} \text{Fusion}$$

Normal Direction Fusion:

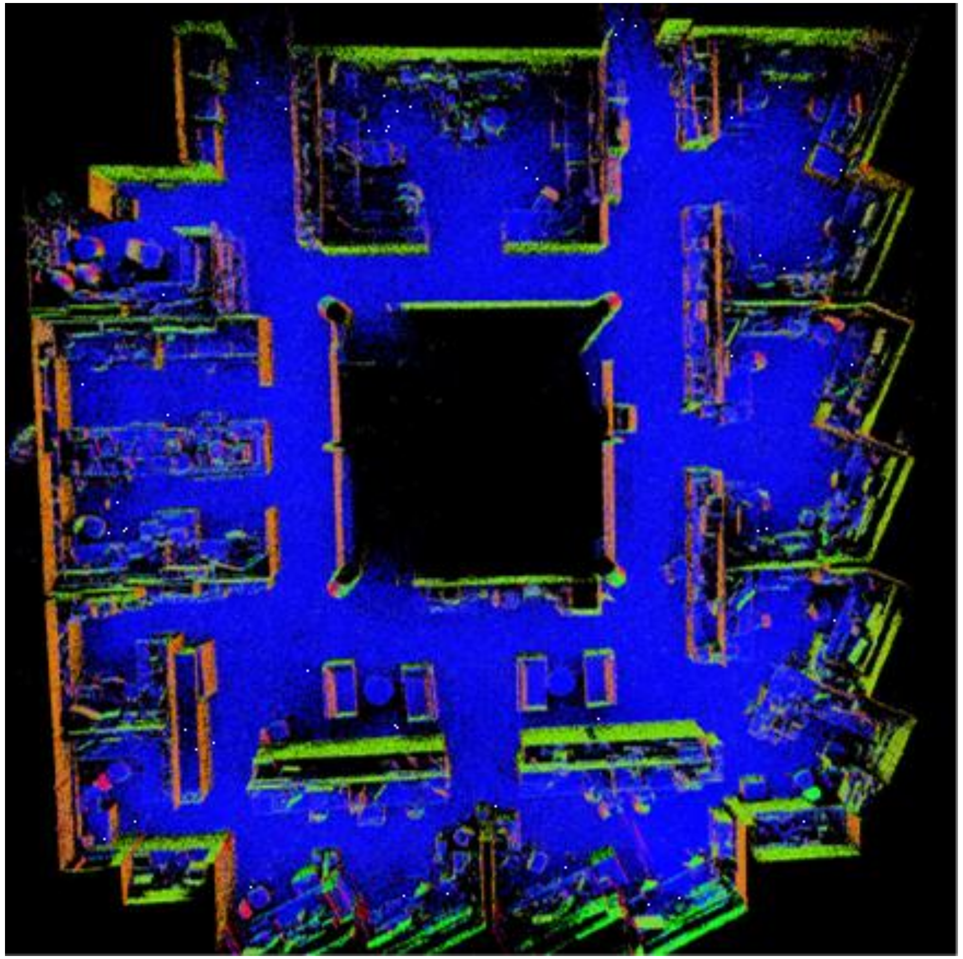
$$\left.\begin{aligned}\Sigma'_{\mathbf{n}_d} &\leftarrow (\Sigma_{\mathbf{n}_s}^{-1} + \Sigma_{\mathbf{n}_d}^{-1})^{-1} \\ \mathbf{n}'_d &\leftarrow \Sigma'_{\mathbf{n}_d}(\Sigma_{\mathbf{n}_s}^{-1}\mathbf{n}_s + \Sigma_{\mathbf{n}_d}^{-1}\mathbf{n}_d)\end{aligned}\right\} \text{Fusion}$$

$$\left.\begin{aligned}[\,\lambda \;\; \mathbf{v}\,] &\leftarrow SVD(\Sigma'_{\mathbf{n}_d}) \\ \Sigma_{new} &\leftarrow \lambda + diag(\sigma_\theta^s, \sigma_\phi^s, -\lambda_3) \\ \mathbf{R} &\leftarrow [u_1 \times \mathbf{n}'_d \quad (u_1 \times \mathbf{n}'_d) \times \mathbf{n}'_d \quad \mathbf{n}'_d] \\ \Sigma'_{\mathbf{n}_d} &\leftarrow \mathbf{R}\Sigma_{new}\mathbf{R}^T\end{aligned}\right\} \text{Tangentiality reinforcement}$$

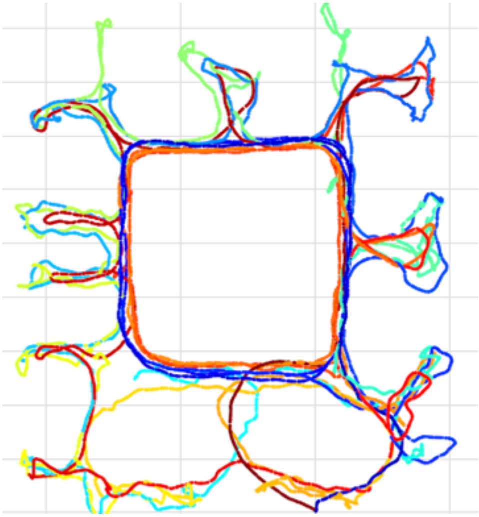


Experiment Results

Real Data Experiment



Surfel map with normal direction color coded

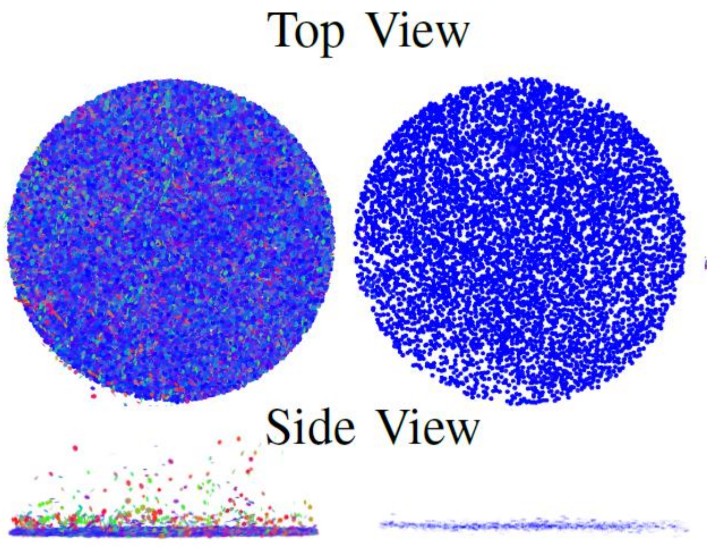


Trajectory

Color fused surfel map

Utilized scanning system

Real Data Experiment



CT-SLAM Proposed

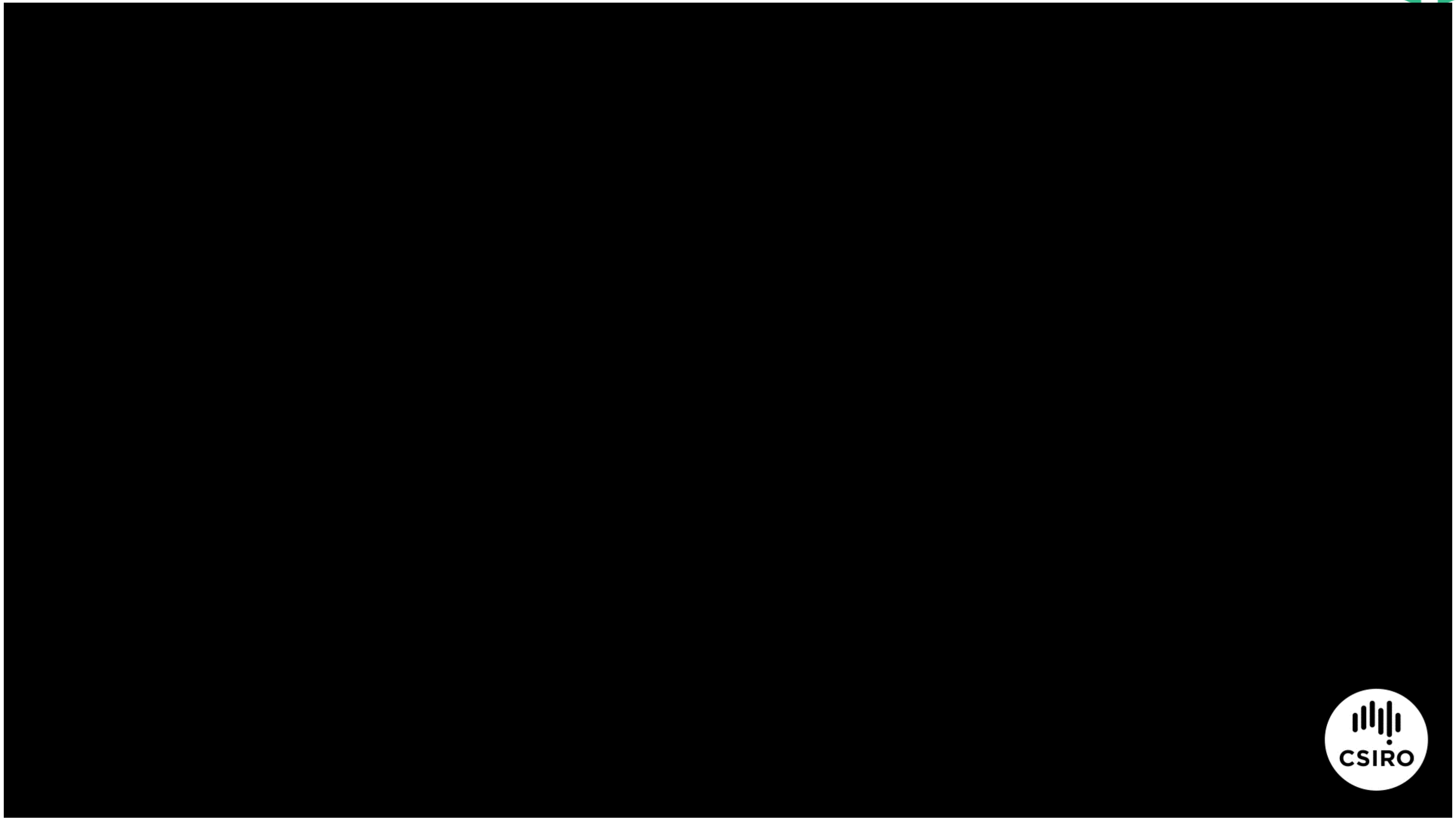
0.7m patch extracted from the maps

Patch No.	CT-SLAM				Proposed method			
	Position Err.		Normal Err.		Position Err.		Normal Err.	
	mean	std.	mean	std.	mean	std.	mean	std.
a	8.2	14.8	5.8	4.7	**3.4**	**4.7**	**4.0**	**4.3**
b	9.3	16.8	6.9	6.7	**3.2**	**4.4**	**4.9**	**4.4**
c	8.9	17.3	5.3	6.9	**3.4**	**6.2**	**4.4**	**4.7**
d	9.4	17.0	4.9	5.7	**3.9**	**5.3**	**4.5**	**4.6**
f	8.0	13.7	5.5	5.0	**3.4**	**4.7**	**4.8**	**4.6**
g	9.1	16.0	6.1	6.6	**4.5**	**6.5**	**4.5**	**4.7**

Table 2. Comparison by wellknown structures.

*Position error is in mm. Normal error is in degree.

Real Data Experiment



Summary

1. Probabilistic dense surfel fusion for LiDAR is proposed
2. Our method shows denser but lesser noise level
3. An advantage on long-term SLAM applications

Questions ?..

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