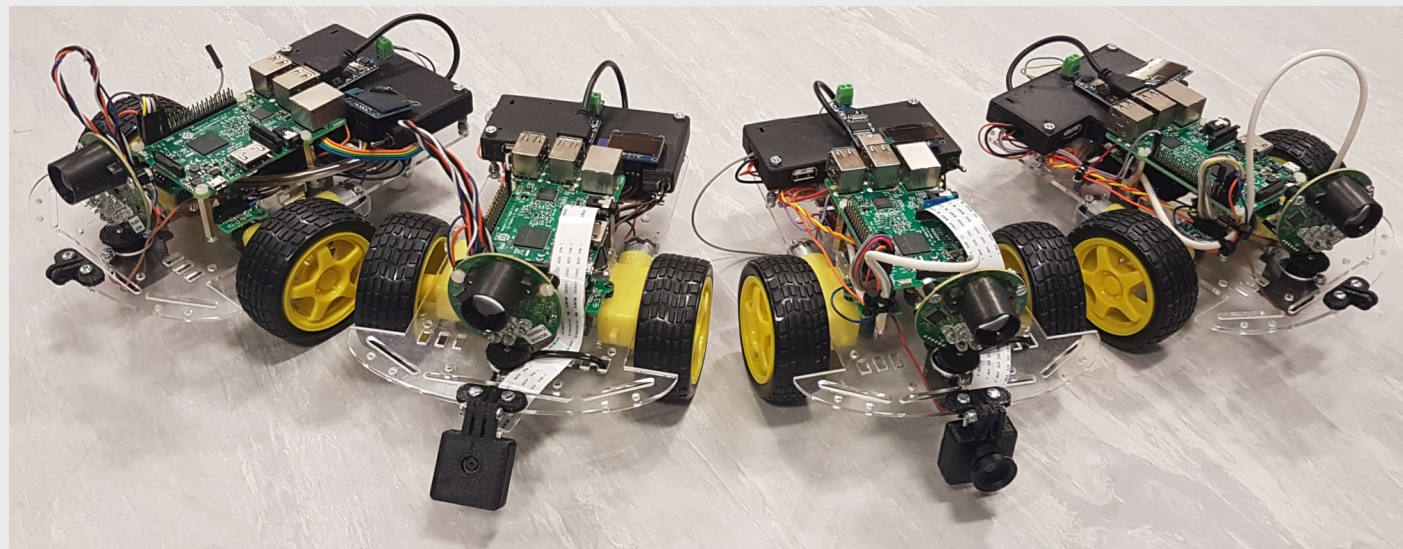


1 - Abstract

Our work aims to develop **autonomous 3D reconstruction & pathplanning** techniques that can leverage **multiple robotic agents**.

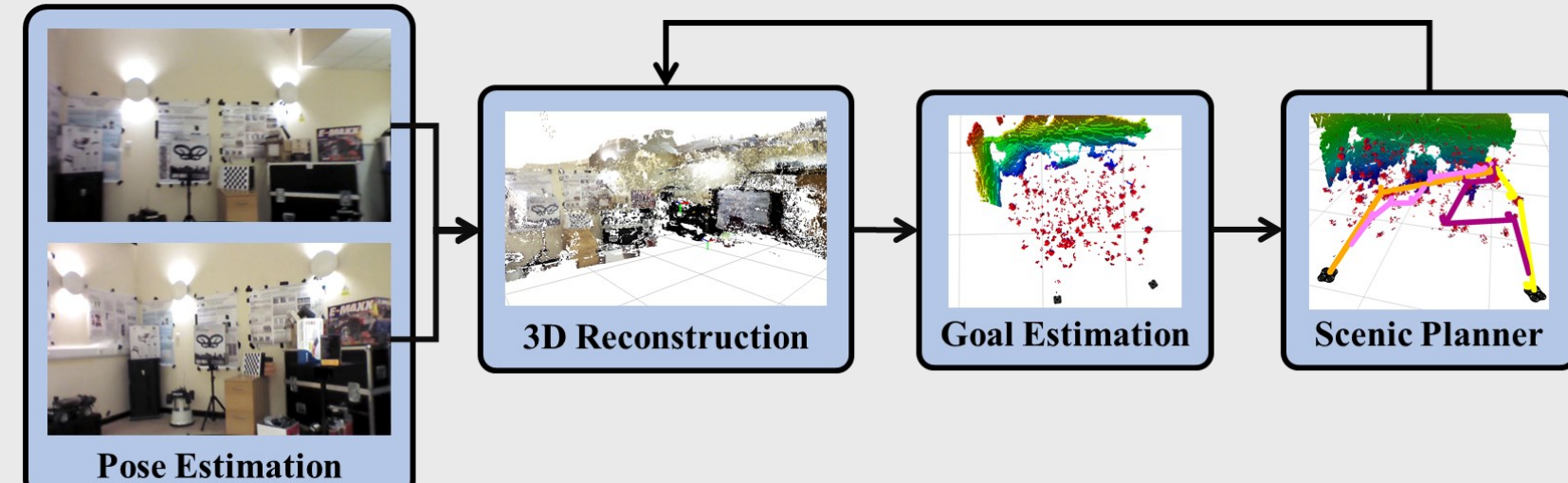


Unlike previous work, the **agents' collaborative behaviour** is based up on their **shared reconstruction** of the world.



Roaches: Purpose-Built, Low-Cost, Collaborative Robotic platforms for autonomous reconstruction.

2 - Overview



System Overview

1. Online Pose Estimation

- PTAM, Sensor Fusion, Coordinate Frame Registration.

2. Dense Reconstruction

- Deep Matching, Triangulation, Octree Encoding.

3. NBV Goal Estimation

- Sequential Monte-Carlo (SMC) on SE3 manifold using pose-only costs.

4. Scenic Route Pathplanner

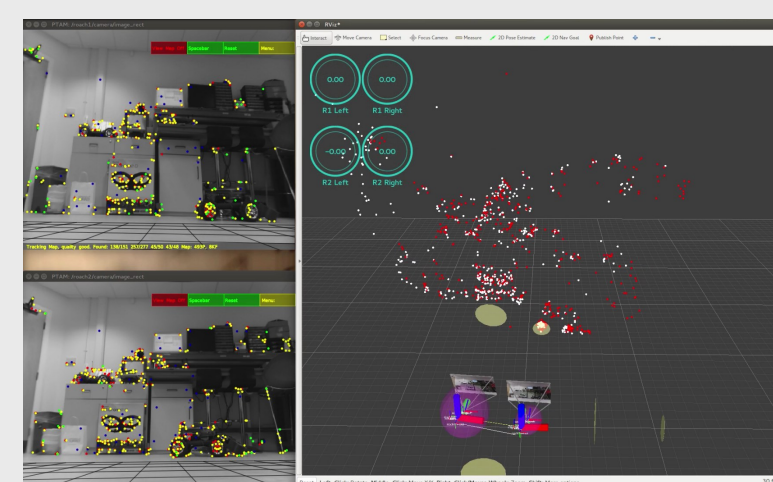
- Estimates path to NBV, optimises Information Gain.

5. Opportunistic Collaboration Framework

- Pairwise collaboration only when convenient (Agents can act as dynamic stereo pair or independent SfM sensor.)

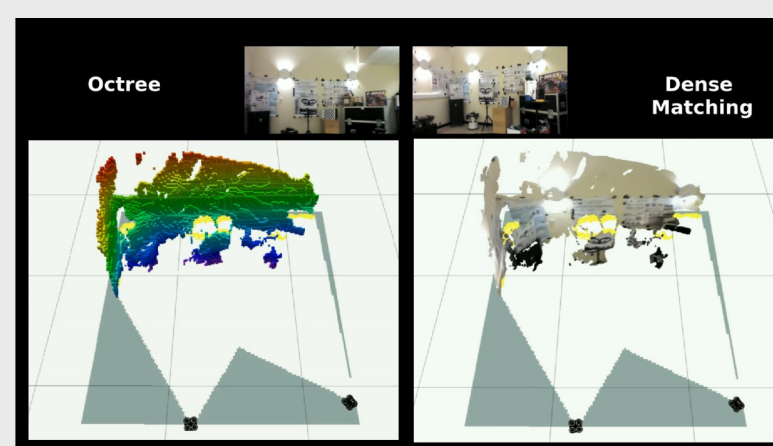
3 - Pose Estimation

- PTAM** as local **SLAM**.
- Sensor Fusion:**
Fuse wheel odometry, IMU and PTAM.
- Coordinate Frame Registration:**
Register each PTAM into a common CF.

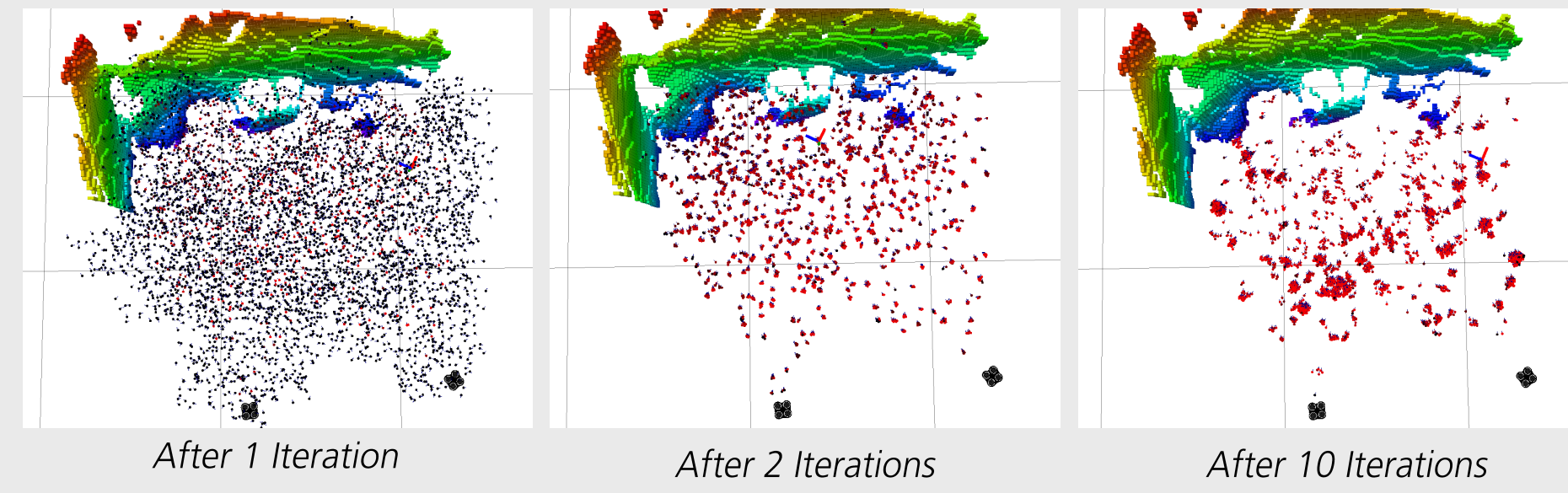


3 - Reconstruction

- Deep Matching:**
Bi-Directional DeepFlow.
- Triangulation:**
Iterative LS and Reprojection Error Filtering.
- Data Association:**
Octree-based coarse filtering, Mahalanobis-Space Nearest Neighbour, Kalman Update.



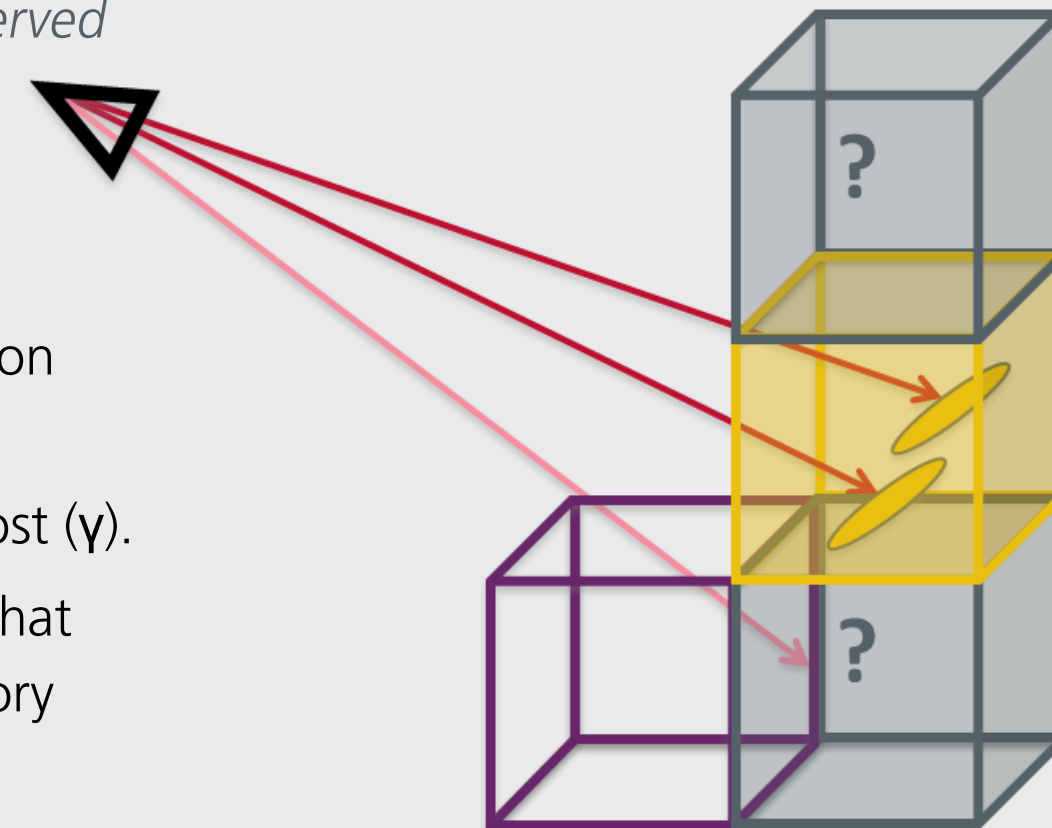
4 - NBV Goal Estimation



- We sample a 4-Dof manifold of SE3
- Each **sample** casts S_r rays
- Raycasting** based on **Octree** :

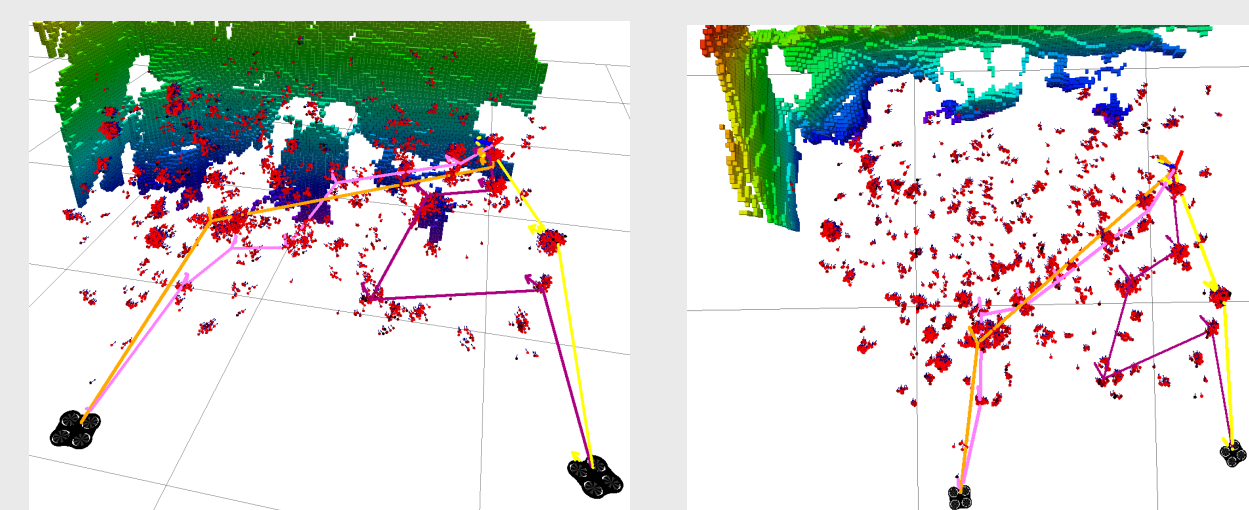
$$\frac{1}{|S_r|} \sum_{r \in S_r} \begin{cases} \frac{1}{|P_v|} \sum_{p \in P_v} e^{-|\lambda_p e_p \times r|} \\ \gamma \in [0, 1] \end{cases}$$

- Pass:** *Empty Voxels*
- Intersect:** *Occupied, Unobserved*
- Each **ray** has an associated cost based the **voxel** it **intersects**.
- Occupied** voxels' cost depends on its reconstructed points.
- Unobserved** voxels get a flat cost (γ).
- Gamma** (γ) is a free parameter that determines the robots' exploratory behaviour.



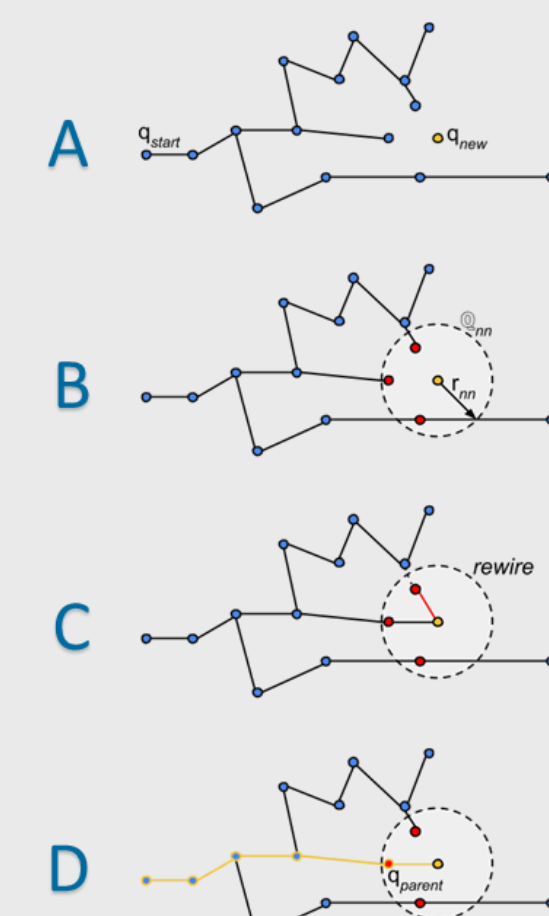
SMC-Cost Visualisation

5 - Scenic Pathplanning & Collaboration

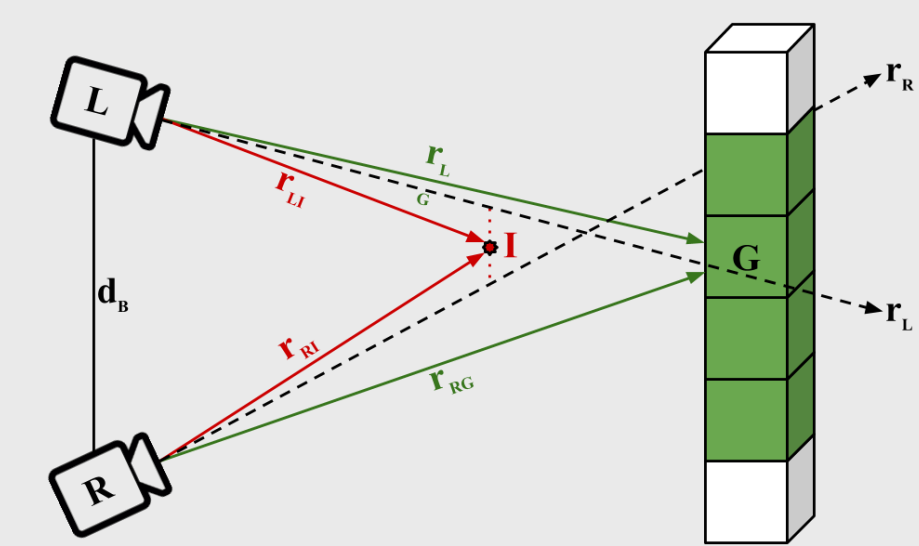


Collision-free Path Estimation through high-information areas.

- We use an **RRT*-like** planning approach.
- A **tree** is **grown** by sampling **SE3**.
- Tree-Growth** is **biased** towards **SMC particle clusters** (areas rich in **good views!**).
- Path **optimises** stereo configuration.
- Estimate **Stereo** (collaborative) and **SfM** (independent) paths for each agent.
- Choose best path: **Opportunistic Collaboration!**



RRT* Tree Growing

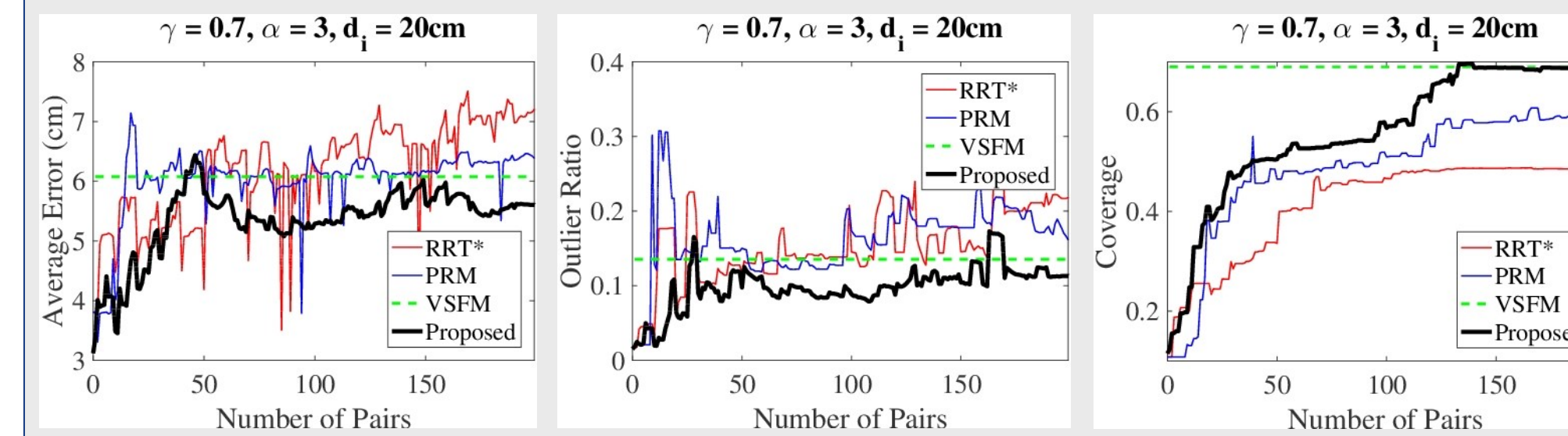


Stereo/SfM Pair Cost

6 - Offline Reconstruction Results

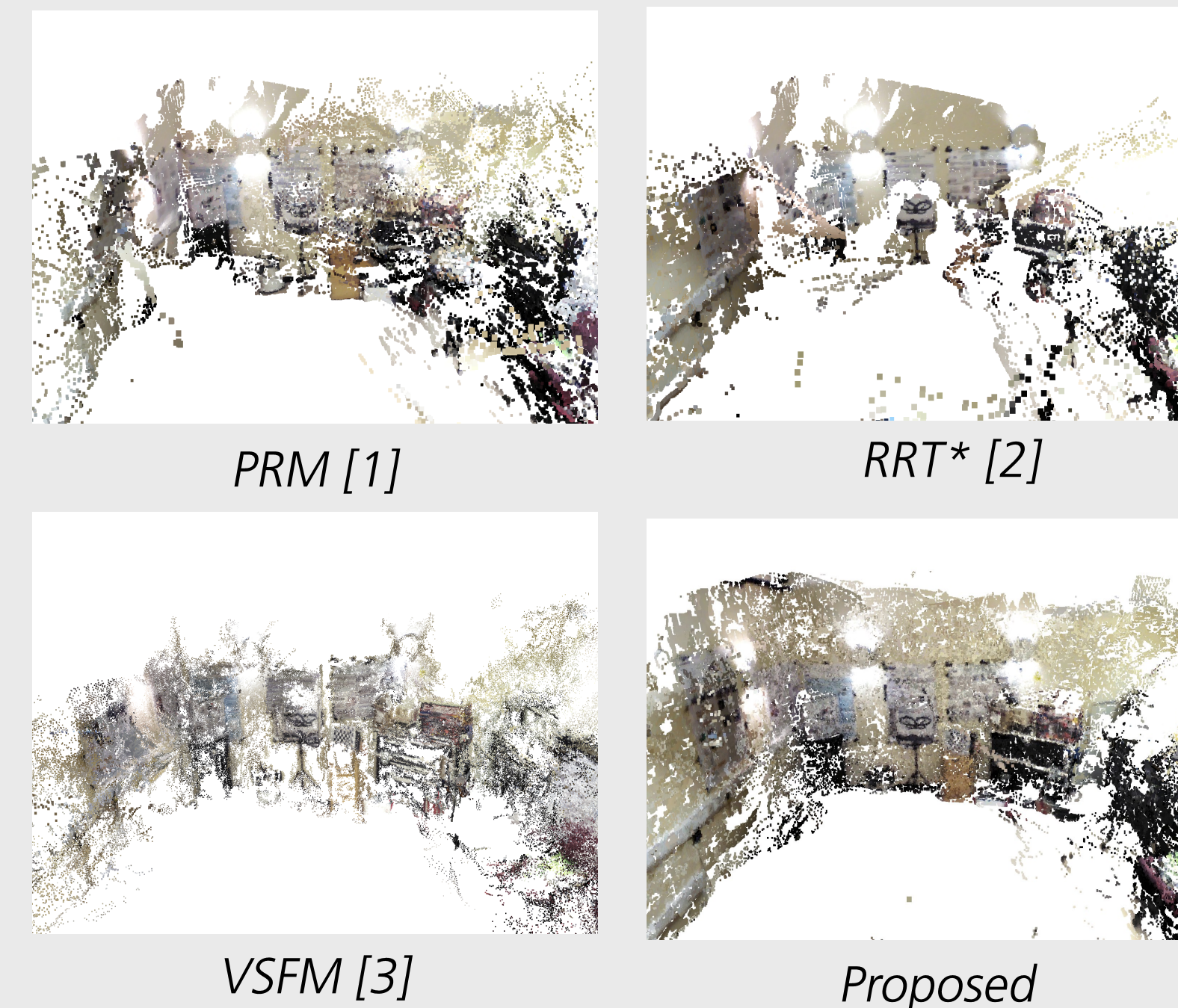
- Offline **Aerial (SE3)** Dataset
- ~8500 images** (72250000 possible stereo pairs!)
- RGB-D Ground Truth

6.1 - Quantitative



- NBV** given to **competing pathplanners** (as a goal).
- Our approach **outperforms** 2 state-of-the art pathplanning algorithms (**PRM** [1] and **RRT*** [2]).
- We **outperform** a batch method [3] which uses all ~8500 views.
- Our approach uses only **0.0000027%** of **possible stereo pairs** (3% of the views).

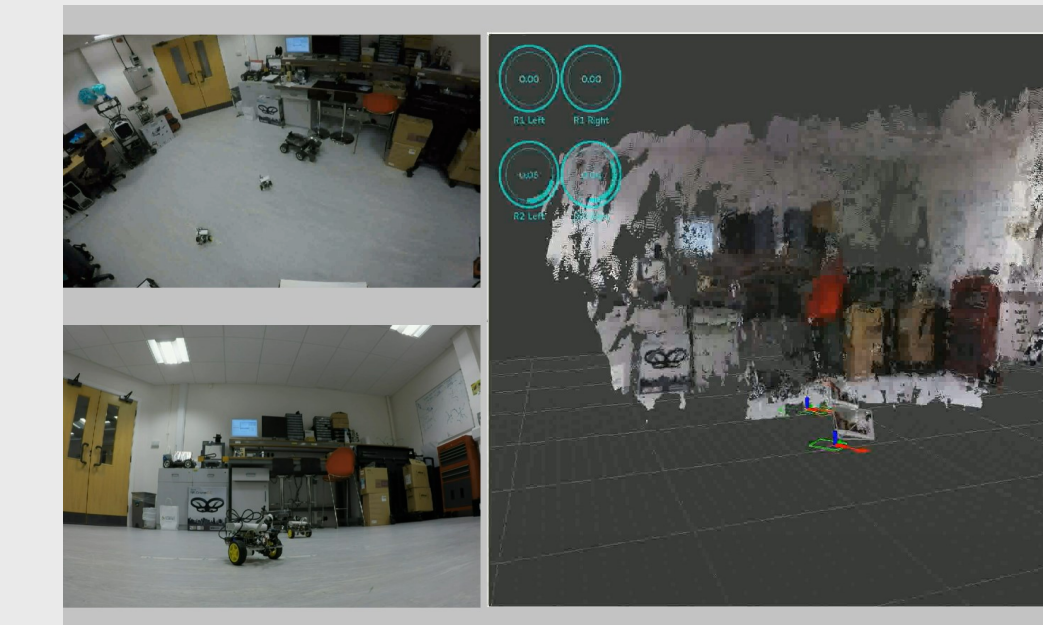
6.2 - Qualitative



- Cleaner, more complete** reconstruction than competing **pathplanners** and **batch approach**.

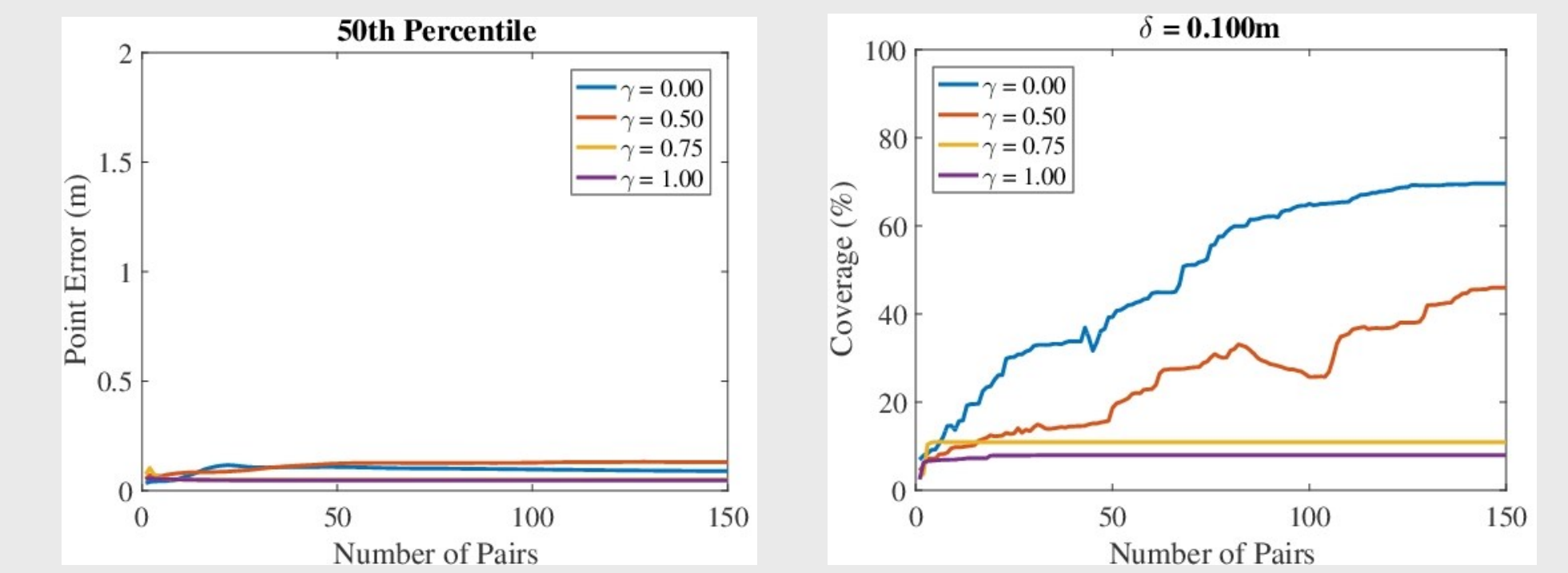
7 - Online Reconstruction Results

- Fully **online, autonomous 3D reconstruction**.
- Ground-Based** (SE2) Robots.
- Robots perform **automatic initialisation**.
- Fully **Collaborative**.
- RGB-D Ground Truth.



7 - Online Reconstruction Results (Cont.)

7.1 - Quantitative



- Robots achieve **high-coverage** with **low error**.
- Different Values of **Gamma** control exploration.
- Agents **opportunistically collaborate** during reconstruction.

7.2 - Qualitative



RGB-D [4]

Proposed

- Qualitatively, **reconstruction** is **dense** and **comparable** to **RGB-D approaches**.

8 - Conclusions

- NBV** estimation does **not** require **image** data, **only pose**.
- Scenic Pathplanning** enables higher-level constraints on navigation problems.
- High-Quality** dense **reconstructions** with a fraction (3%) of the data.
- Emergent **collaborative behaviours** result from **vision-based pathplanning**.

References

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