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Improving 3D Scan Matching Time of the Coarse Binary Cubes Method with Fast Spatial Subsampling

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2. **THE COARSE BINARY CUBES (CBC) METHOD**
3. **SUBSAMPLING STRATEGY**
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1. INTRODUCTION

- **3D Point Cloud Matching** is a basic operation in mobile robotics for localization and mapping.
- All scan directions and depths of a scan may contain relevant data. Farther regions have lower sampling densities.
- The search for scene matching is performed around an initial odometric estimation.

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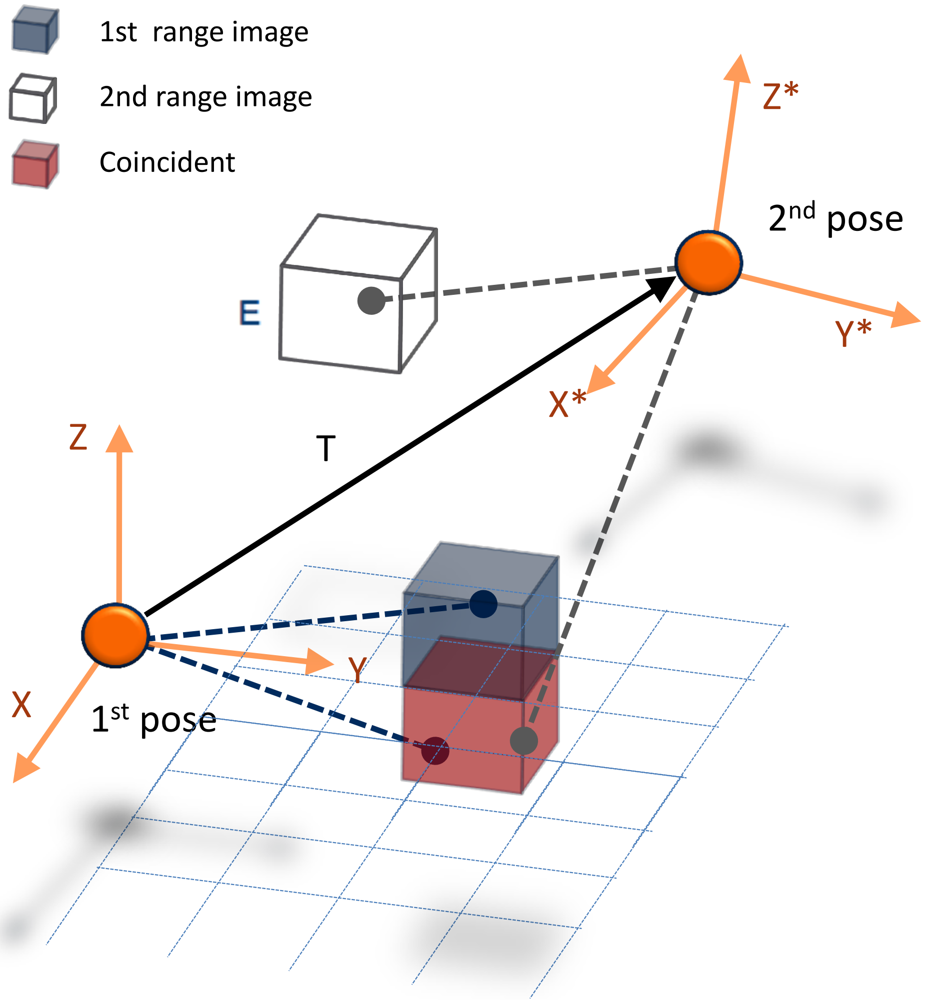
1. INTRODUCTION

- **Aim of this work**: to speed up 3D point cloud matching without loosing accuracy with the Coarse Binary Cubes (CBC) method by applying an effective subsampling procedure.

- **Subsampling methods**: can be broadly classified as *range-independent* when a pre-computed mask is applied to the scan, and *range-dependent* when a representative set of points from the scan is selected (Mandow *et al*., 2010).

2. THE CBC METHOD

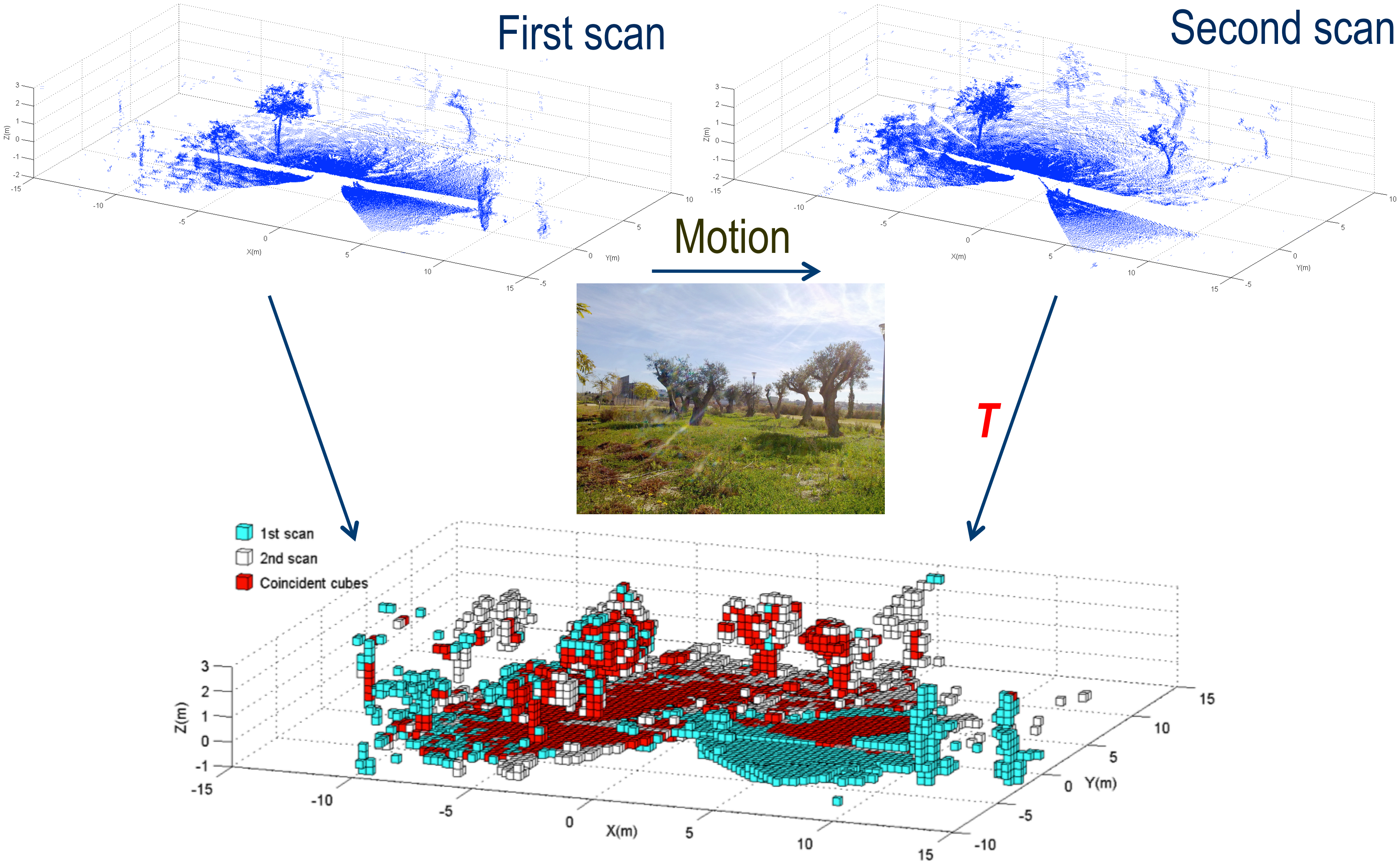


- Which is the spatial transformation

$$\mathbf{T} = [x_0, y_0, z_0, \alpha, \beta, \gamma]$$

to project the second scan into the first scan that maximizes the number *J* of coincident occupied cubes of edge length *E*?

2. THE CBC METHOD



Example of a CBC match with *E*= 0.3 m

2. THE CBC METHOD

- *Objective function J(T)* can be evaluated:
  - without using any 3D data structure,
  - in *O(n)* time, where *n* is the number of points.

- The search for *T* is performed by evaluating different solutions with a variation of the Nelder-Mead method.

- CBC is a compelling alternative to Iterative Closest Points (ICP) and Normal Distribution Transform (NDT) for scene registration (Martínez *et al.*, 2012).

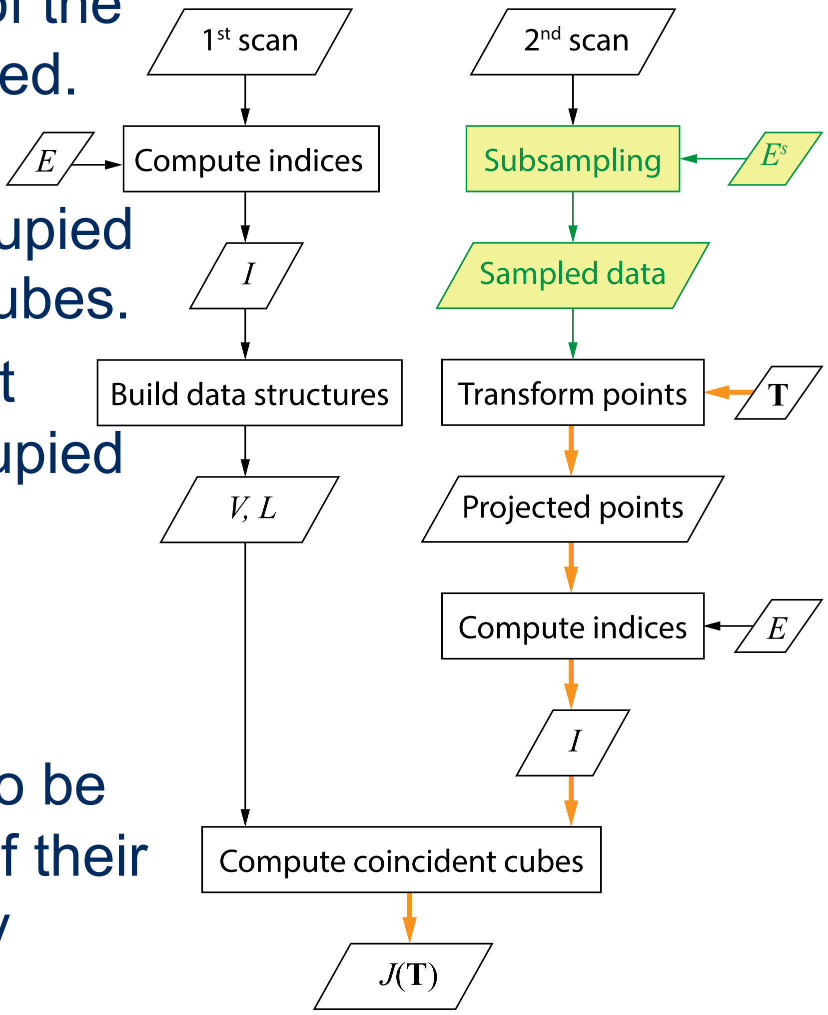
3. SUBSAMPLING STRATEGY

- **Data structures to evaluate *J(T)*:**

  - *I* represents the integer index of the cube where a scan point is located.

  - *V* is a binary vector indexed by *I* whose ones correspond to occupied cubes and its zeroes to empty cubes.

  - *L* is an unsorted integer list that contains the indices *I* of the occupied cubes.

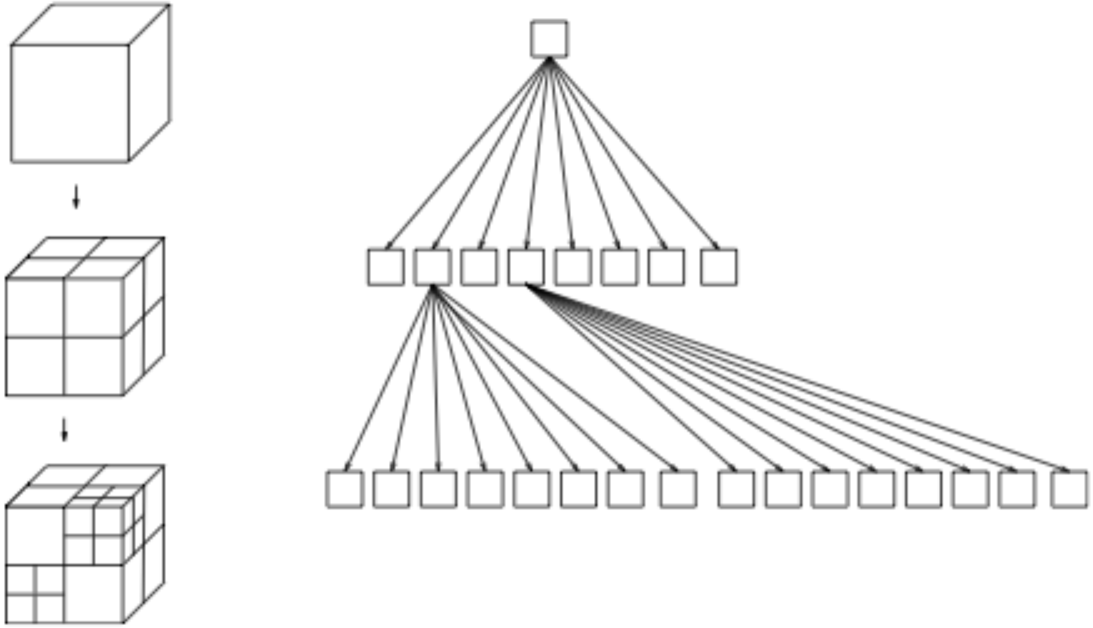


- **New subsampling stage:**

  - reduces the number of points to be projected and the computation of their corresponding indices *I* for every prospective *T*.

3. SUBSAMPLING STRATEGY

- **Octree Cube Centers:** it divides recursively occupied cubes into 8 octants until a minimal octant size E^s is achieved starting from the cube that contains the whole scan (Nüchter, 2009).
  - This is an effective strategy that is closely related with the uniform spatial representation implicitly used by CBC.



3. SUBSAMPLING STRATEGY

- **Implementation with CBC data structures:**

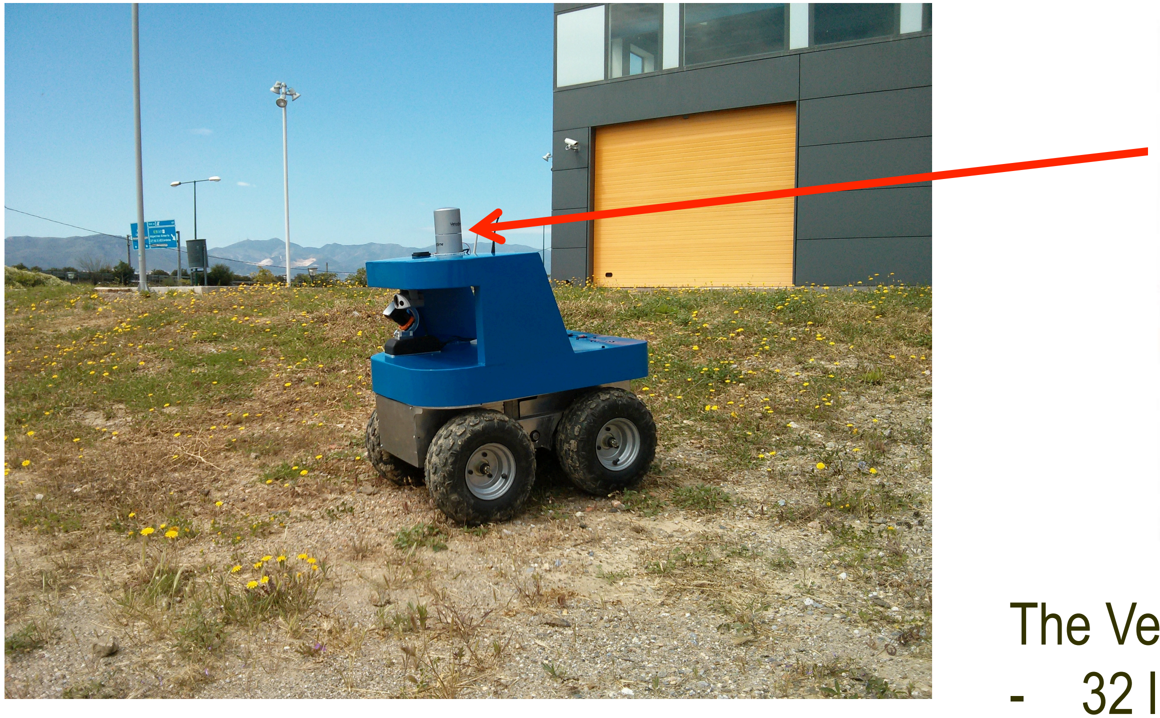
  - V^s is created as a zero binary vector and the list of integers L^s is empty.

  - The integer index I of each point of the second scan is computed.

    - If $V^s(I)$ =0 then $V^s(I)$ is set to 1, and I is inserted into L^s. Otherwise, no action is taken.

  - Finally, the coordinates of the centers of the occupied cubes is extracted from L^s. The subsampled set of points coincides with octree cube centers.

4. EXPERIMENTAL RESULTS



The mobile robot Quadriga:

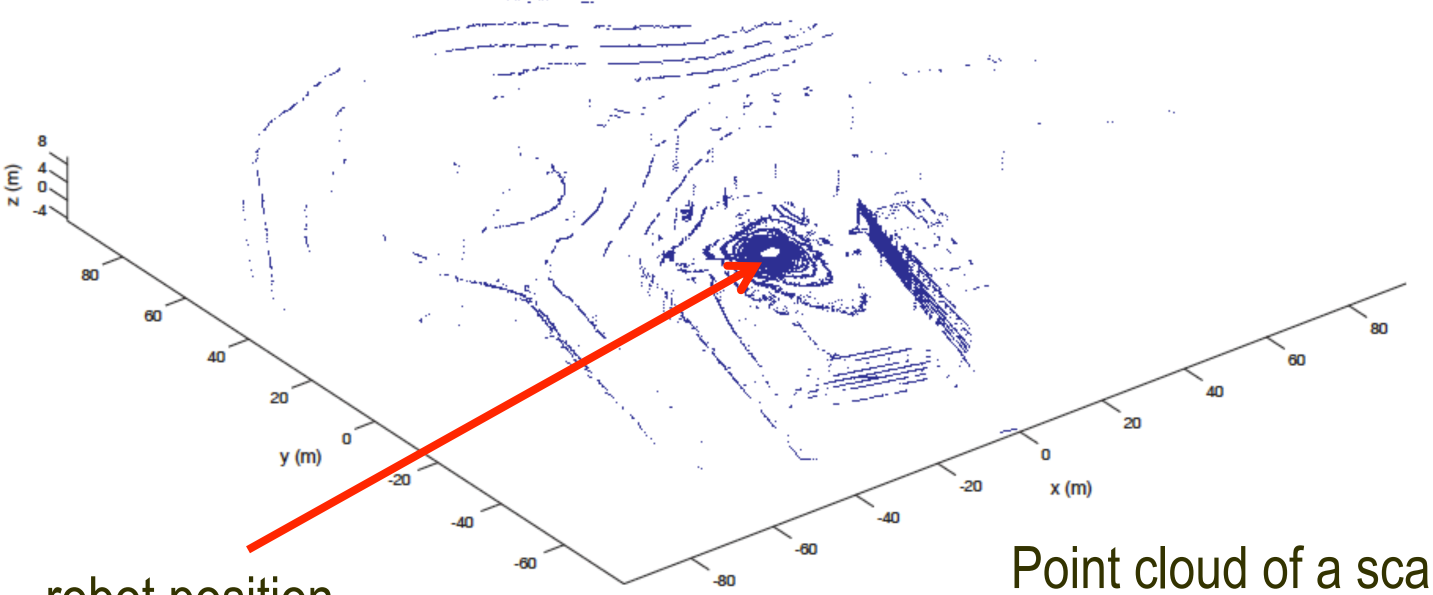
- 4-wheel skid-steer vehicle (Morales *et al.*, 2010),
- 0.82 m height,
- powered with batteries.

The Velodyne HDL-32 device:

- 32 laser beams,
- ranges from 1 m to 100 m,
- scanning time of 0.1 s,
- 360º x 41º field of view,
- 0.16º x 1.33º resolution.

4. EXPERIMENTAL RESULTS

The outdoor environment



robot position

Point cloud of a scan

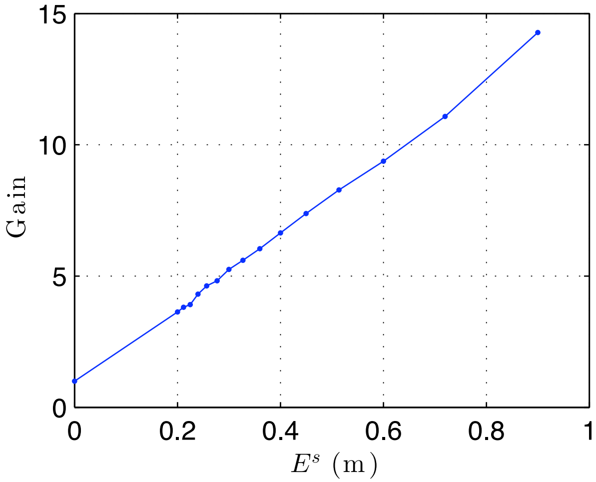
4. EXPERIMENTAL RESULTS

- **Subsampling times:**

E^s	Octree	V^s & L^s
0.9 m	7 ms	4 ms
0.2 m	10 ms	9 ms

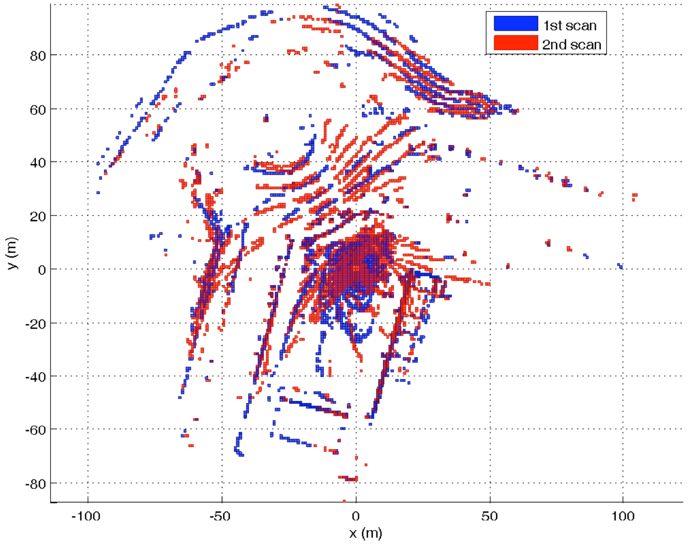
- **Registration times:**

  - The gain with respect to the non-subsampled case increases linearly with E^s.



4. EXPERIMENTAL RESULTS

- **Registration accuracy:**
  - A relation *E/E^s* around *4* provides almost the same number of occupied cubes.
  - Accuracy only degrades when *E/E^s* approaches *1*.
  - A relation *E/E^s* around *3* provides a compromise between accuracy and computation time.



Top view of a CBC alignment
without subsampling

5. CONCLUSIONS

- CBC efficiency has been improved by selecting a subsampling method to obtain a reduced and representative set of points.

- Octree cube centers have been computed with efficient one-dimensional data structures and the relation with the size of the CBC cubes has been studied.

- Experimental results have been obtained with a multi-beam 3D laser scanner mounted on the Quadriga mobile robot.

- Work in progress: to combine subsampling with the parallel execution of CBC via multi-core and multi-threaded processors (Martínez *et al.*, 2013).

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Thank you!

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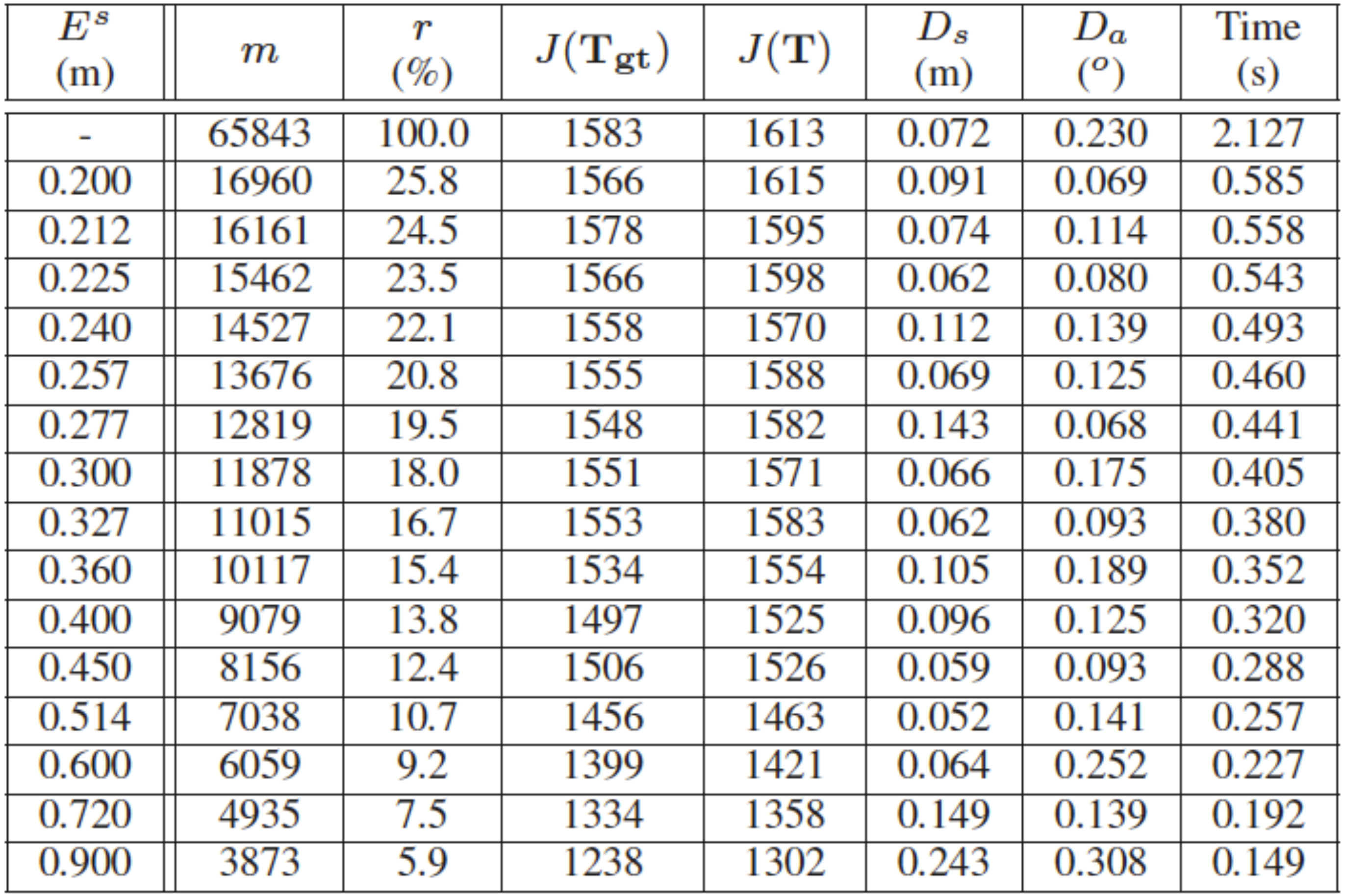
4. EXPERIMENTAL RESULTS

Effect of E^s on registration with E= 0.9 m



E^s (m)	m	r (%)	$J(\mathbf{T}_{\mathbf{gt}})$	$J(\mathbf{T})$	D_s (m)	D_a (^{o})	Time (s)
-	65843	100.0	1583	1613	0.072	0.230	2.127
0.200	16960	25.8	1566	1615	0.091	0.069	0.585
0.212	16161	24.5	1578	1595	0.074	0.114	0.558
0.225	15462	23.5	1566	1598	0.062	0.080	0.543
0.240	14527	22.1	1558	1570	0.112	0.139	0.493
0.257	13676	20.8	1555	1588	0.069	0.125	0.460
0.277	12819	19.5	1548	1582	0.143	0.068	0.441
0.300	11878	18.0	1551	1571	0.066	0.175	0.405
0.327	11015	16.7	1553	1583	0.062	0.093	0.380
0.360	10117	15.4	1534	1554	0.105	0.189	0.352
0.400	9079	13.8	1497	1525	0.096	0.125	0.320
0.450	8156	12.4	1506	1526	0.059	0.093	0.288
0.514	7038	10.7	1456	1463	0.052	0.141	0.257
0.600	6059	9.2	1399	1421	0.064	0.252	0.227
0.720	4935	7.5	1334	1358	0.149	0.139	0.192
0.900	3873	5.9	1238	1302	0.243	0.308	0.149