Institution : **ECN** (Ecole Centrale de Nantes)

Doctoral school: **STIM** (Sciences et Technologies de l'Information et Mathématiques)

Laboratory: **LS2N** (Laboratoire des Sciences du Numérique de Nantes)

Team : **ARMEN** (Autonomie des Robots et Maîtrise des interactions avec l'ENvironnement)

Collaborative Mapping for Outdoor Environments

Contreras, Luis
e-mail : *Luis.Contreras@ls2n.fr*

Co-supervisor: *Kermorgant, Olivier*
Supervisor: *Martinet, Philippe*

1. Introduction

Challenge: Develop applications of human driven multi-robot systems to build large 3D maps of outdoor environments with restrictions of:

- -accuracy
- -reasonable amount of time
- -efficient usage of resources.

2. Proposed Approach

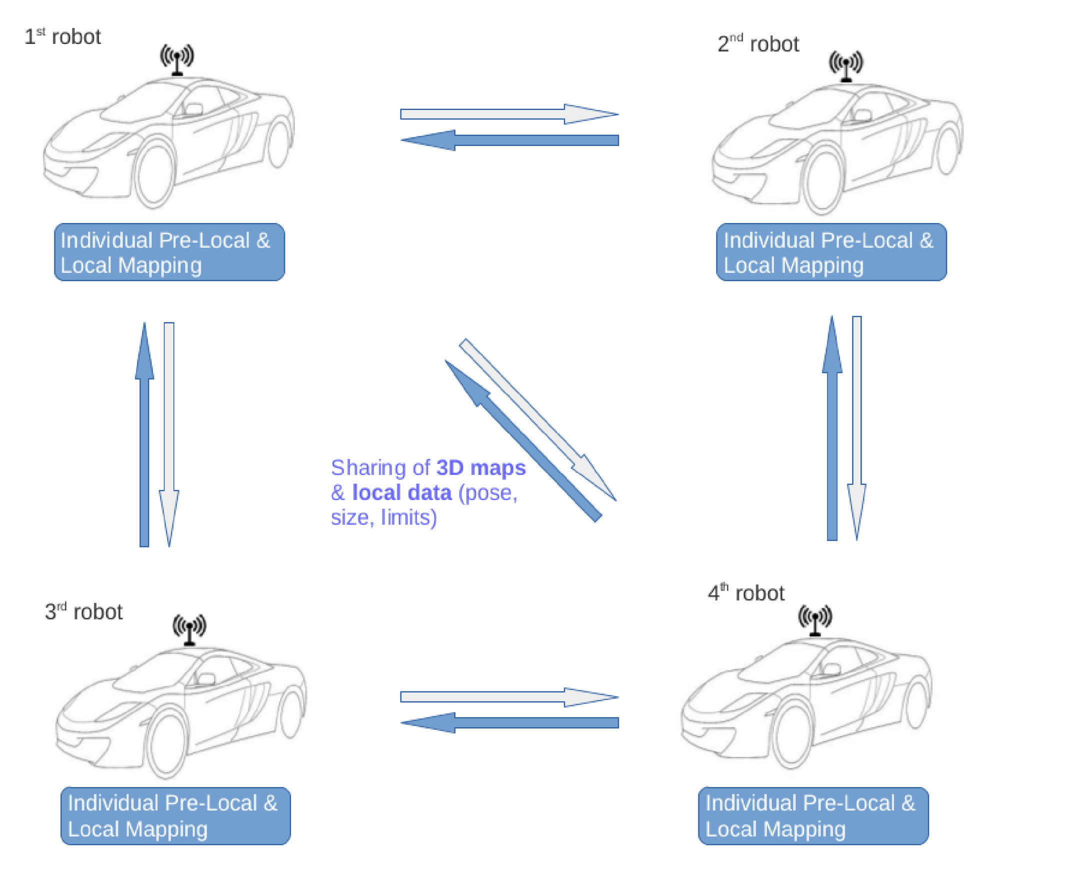


Fig. 1. Architecture of our Collaborative Decentralized Mapping System

Our system (see Fig.1) is divided in 3 stages:

a) *Pre-Local Mapping Stage*: based on [1]

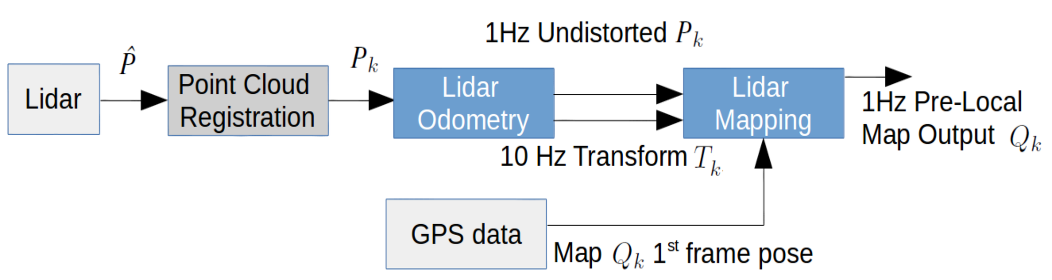


Fig. 2. Architecture of Pre-Local Mapping Stage

b) *Map Sharing Stage*: proposed method to exchange maps between robots

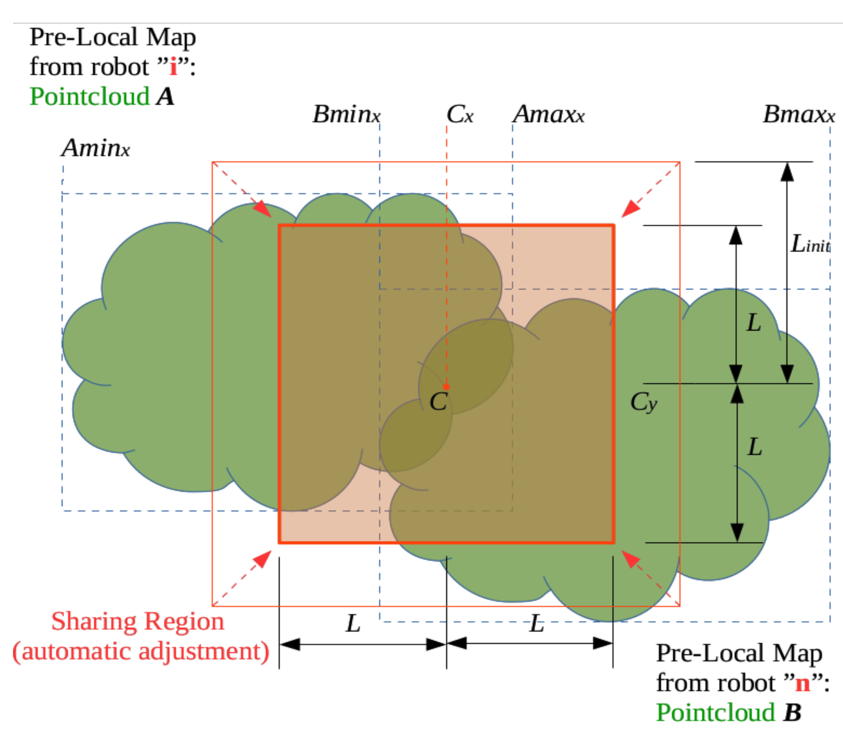


Fig. 3. Graphical representation of the Map Sharing Stage

Data: Point Cloud A, Vectors A_{min}, A_{max}, B_{min} and B_{max}, Scalars L_{init}, L_{step}, Np_{max}
Result: Point Cloud A_{sel}

```
begin
  A_sel ← ∅;
  C_x = 0; C_y = 0; C_z = 0;
  (V2_x, V3_x) = GetValues(Amin_x, Amax_x, Bmin_x, Bmax_x);
  (V2_y, V3_y) = GetValues(Amin_y, Amax_y, Bmin_y, Bmax_y);
  (V2_z, V3_z) = GetValues(Amin_z, Amax_z, Bmin_z, Bmax_z);
  C_x = (V2_x + V3_x)/2;
  C_y = (V2_y + V3_y)/2;
  C_z = (V2_z + V3_z)/2;
  Np = PointSize(A);
  for (L=L_init ; Np > Np_max ; L = L - L_step) do
    Smin_x = C_x − L ; Smax_x = C_x + L;
    Smin_y = C_y − L ; Smax_y = C_y + L;
    Smin_z = C_z − L ; Smax_z = C_z + L;
    foreach a ∈ A do ;
    if Smin_x < a_x < Smax_x and Smin_y < a_y < Smax_y and Smin_z < a_z < Smax_z then
      A_sel = A_sel + a;
    end
    Np = PointSize(A_sel);
  end
end
```

Algorithm 1: Pseudo-code of Sharing technique

c) *Local Mapping Stage*: An intersection method from maps [2] and a relative ICP [3] refinement are performed in each robot. Registration is computed by minimizing the mean squared distance *E* for corresponding point pairs (***b'***,***a'***):

$$E(R,\boldsymbol{t}) = \frac{1}{Np_{b'}} \sum_{i=1}^{Np_{b'}} \| \boldsymbol{a'}_i - (R\,\boldsymbol{b'}_i + \boldsymbol{t}) \|^2$$

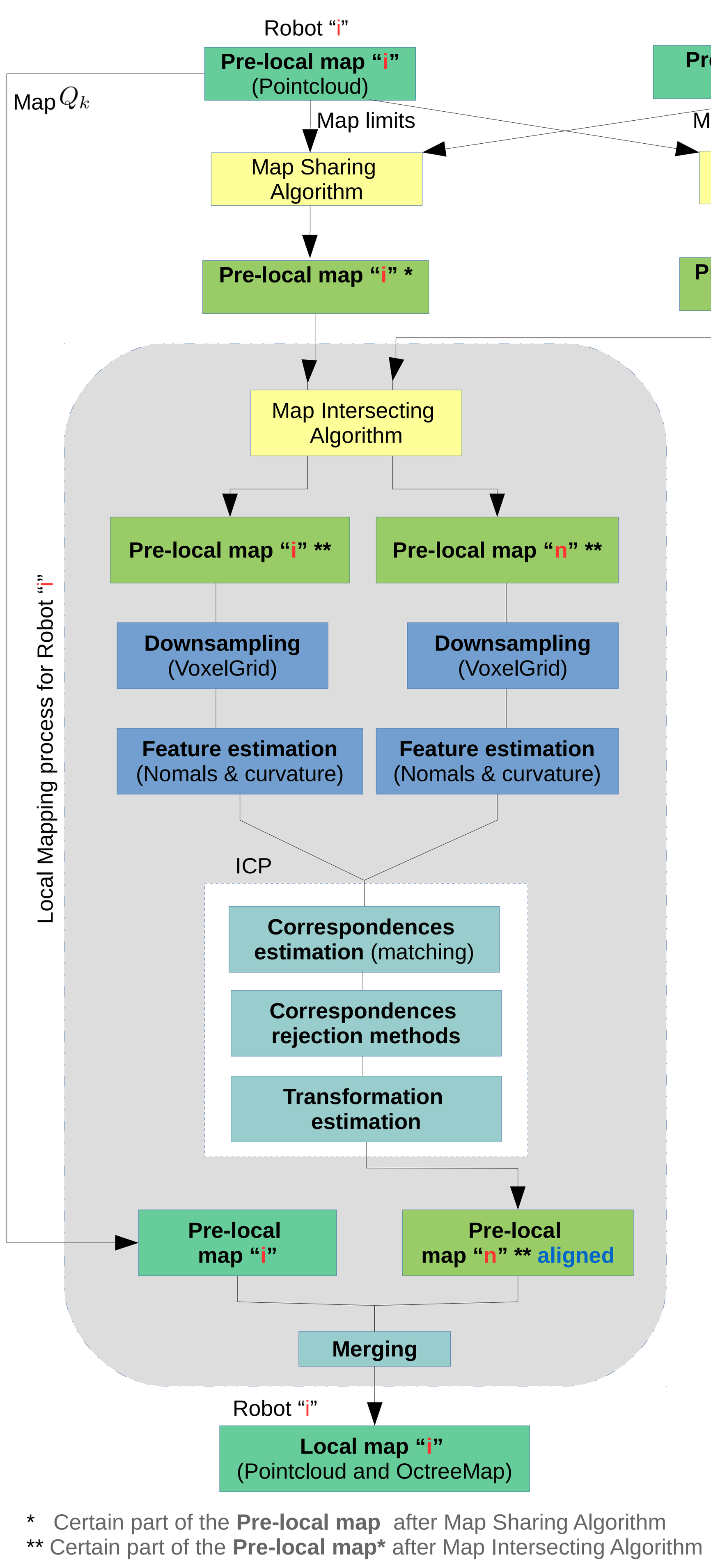


Fig. 4. Architecture of Local Mapping Stage

3. Results

The experiments were performed using two vehicles, a Renault Fluence and a Renault Zoe customized and equipped with:

- a Velodyne realtime 3D lidar sensor VLP-16, with 360° horizontal field of view and a 30° vertical field of view (± 15° up and down)

- two laptops with Core-i5 processor running the real-time mapping process independently on each vehicle.

Fig. 5. Vehicles used during tests

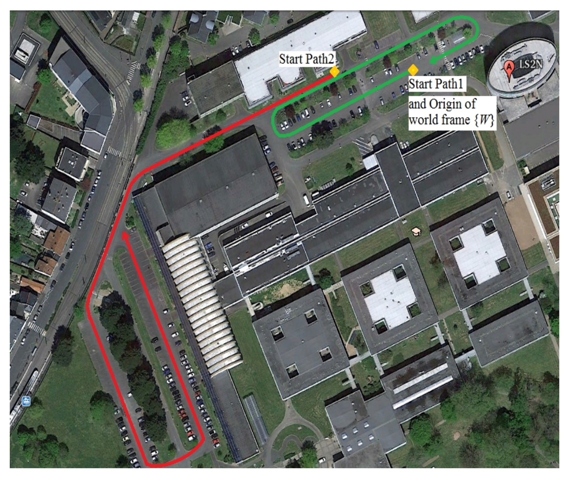


Fig. 6. Travel paths (top view). The experiments were conducted in the outdoor environment from ECN campus in an area of approximately 290m x 170m.

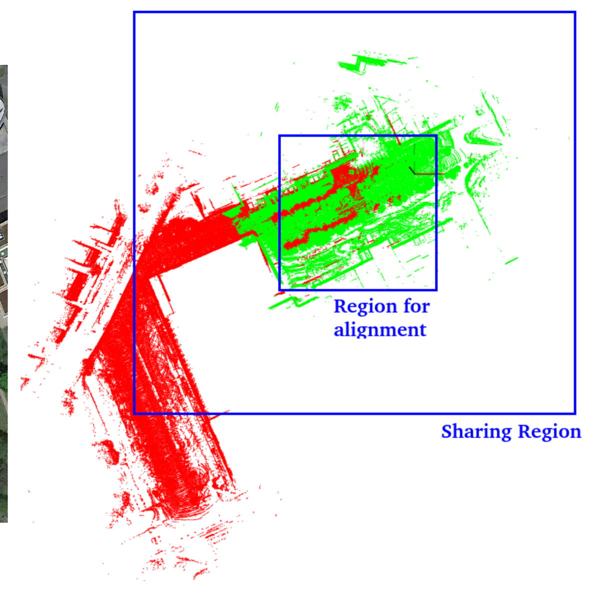
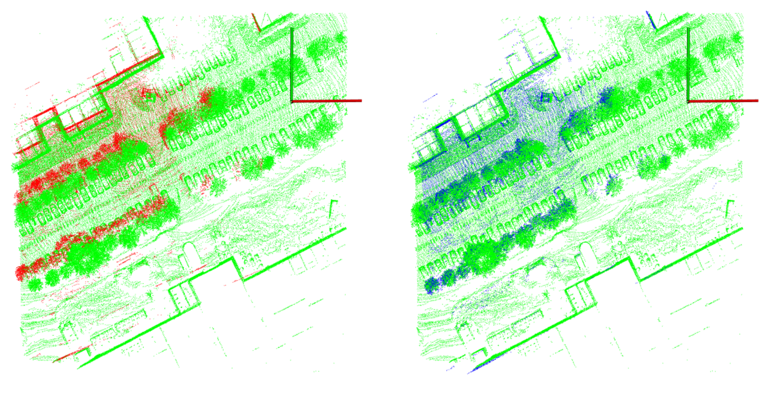


Fig. 7. Pre-Local Maps for both robots projected in the common coordinates system prior ICP refinement (top view). Sharing and Alignment region in 2nd robot.

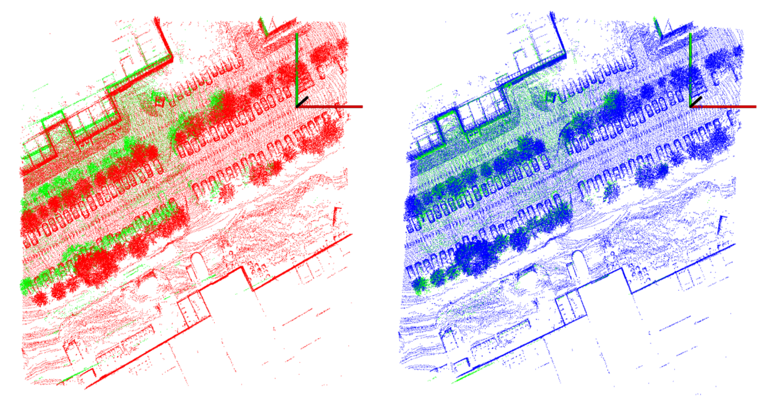
Relative Alignment in robots

Fig. 8. Alignment of maps with ICP refinement in 1st robot. (a) Green and red maps represent the target and source clouds pre ICP, top view. (b) Green and blue maps represent the target and aligned source clouds post ICP, top view.



(a) (b)

Fig. 9. Alignment of maps with ICP refinement in 2nd robot. (a) Green and red maps represent the target and source clouds pre ICP, top view. (b) Green and blue maps represent the target and aligned source clouds post ICP, top view.



(a) (b)

1st Robot	2nd Robot
Rotation-matrix (T_{ICP}) : $\begin{bmatrix} 0.997 & -0.065 & 0.036 \\ 0.065 & 0.998 & 0.007 \\ -0.037 & -0.005 & 0.999 \end{bmatrix}$	Rotation-matrix (T_{ICP}) : $\begin{bmatrix} 0.996 & 0.068 & -0.049 \\ -0.068 & 0.998 & 0.005 \\ 0.049 & -0.002 & 0.999 \end{bmatrix}$
Translation-vector (T_{ICP}) : $[0.693 \quad 1.572 \quad -2.149]$	Translation-vector (T_{ICP}) : $[-1.110 \quad -1.557 \quad 2.510]$
(a)	(b)

Table 1. Refinement transformation matrix for both robots.

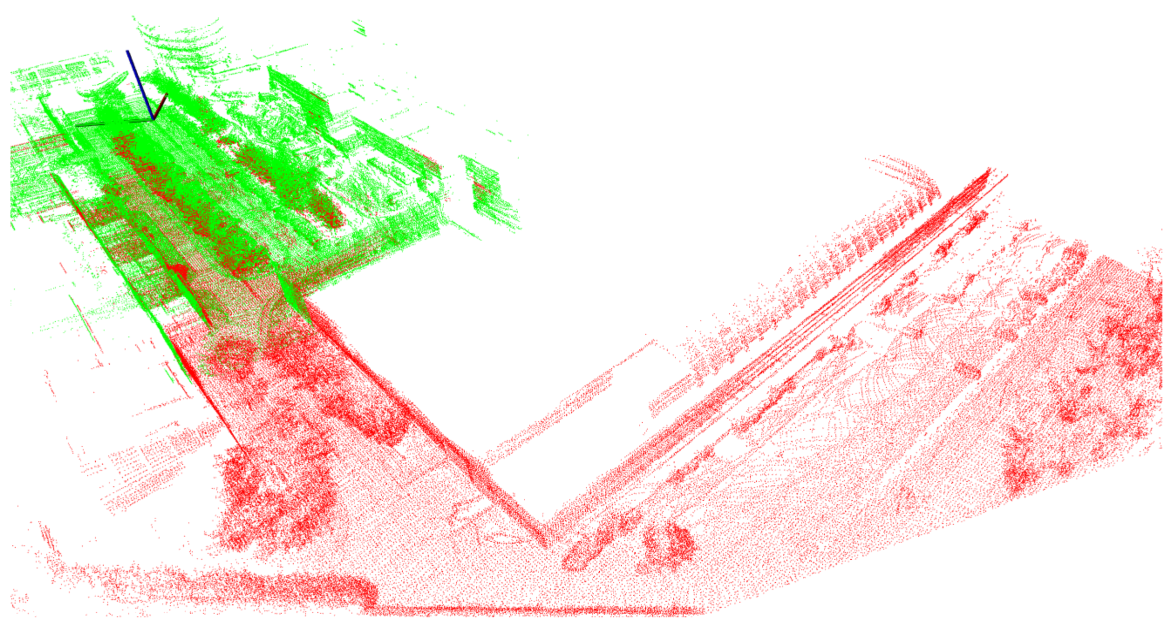


Fig. 10. 3D-Map merging result in 1st Robot (different view)

Main contributions:

1) The proposal of a multi-robot architecture for performing a decentralized mapping to outdoor environments.
2) The validation of an efficient merging of 3D maps from real experimental data, including sharing and intersecting techniques between point-clouds from robots for individual registration processes, using previously low-cost GPS data for the generation of the Pre-Local maps.

REFERENCES:

[1] JI ZHANG AND SANJIV SINGH, "LOAM: Lidar Odometry and Mapping in Real-time ," Robotics: Science and Systems Conference, July, 2014.
[2] J. Jessup, S. N. Givigi, and A. Beaulieu, "Robust and efficient multirobot 3-D mapping merging with octree-based occupancy grids," IEEE Systems Journal, vol. PP, no. 99, pp. 1–10, 2015.
[3] S. Rusinkiewicz and M. Levoy, "Efficient variants of the ICP algorithm," in Third International Conference on 3D Digital Imaging and Modeling (3DIM), June 2001.