STIIMA

Sistemi e Tecnologie Industriali Intelligenti
per il Manifatturiero Avanzato
Consiglio Nazionale delle Ricerche

3D stereo reconstruction of train paths for supporting maintenance operations

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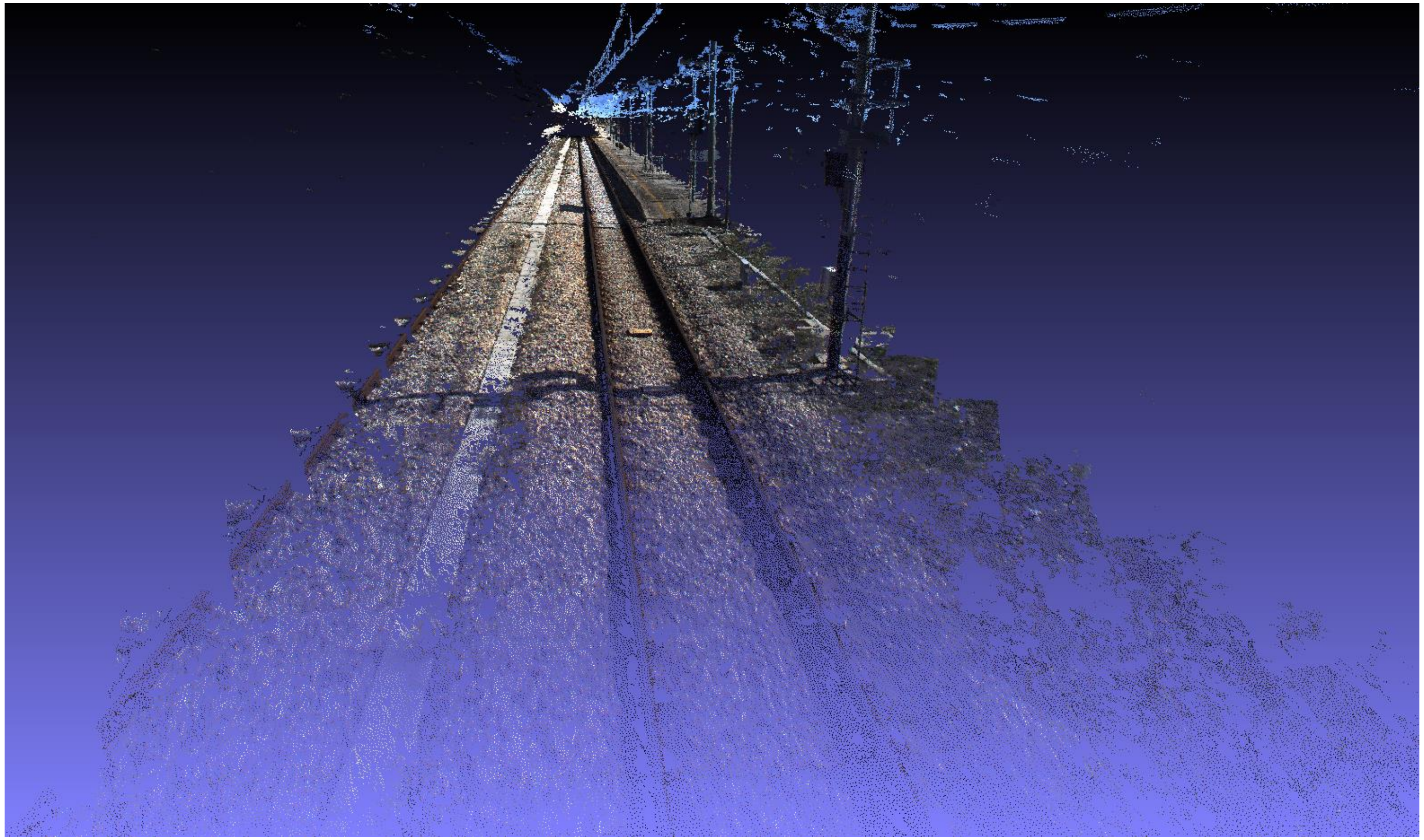
STIIMA – *Bari (Italy)*

EGU2020: Sharing Geoscience Online

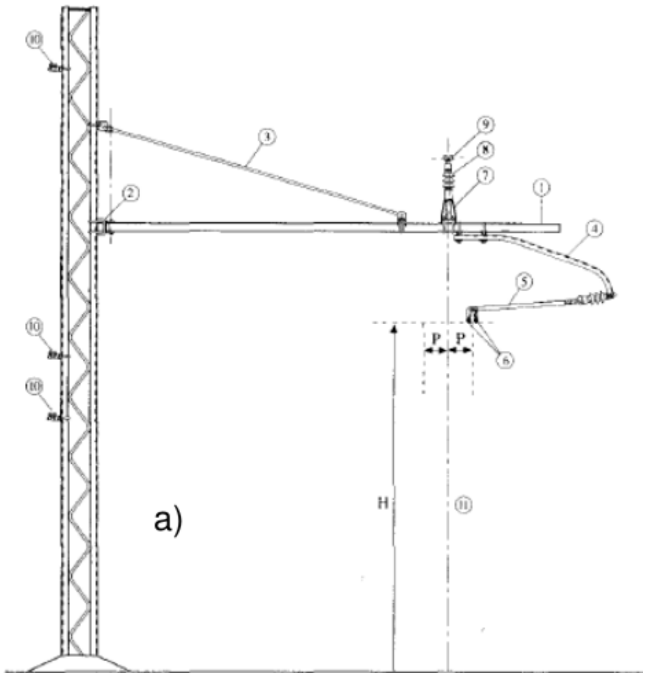
May 4-8, 2020, OnLine



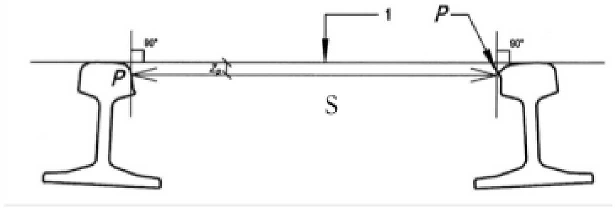
3D stereo reconstruction of train paths for supporting maintenance operations

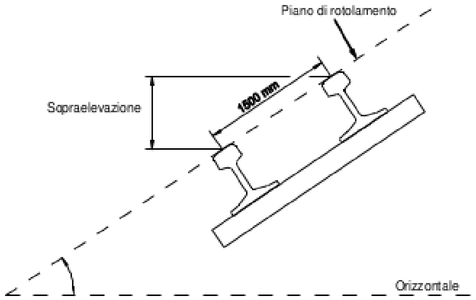
The maintenance of railway infrastructure require **continuous monitoring** of geometric parameter of railway and interaction between train, railway line and catenary.

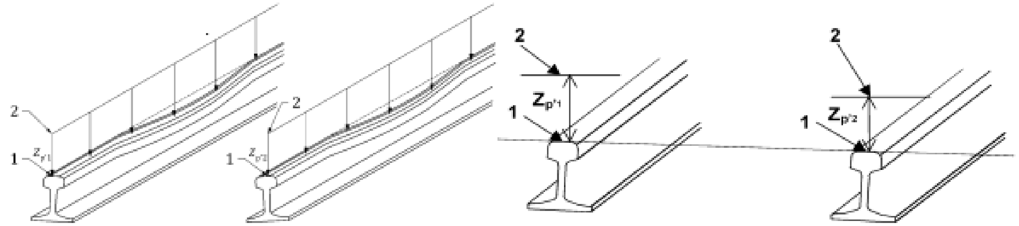
Catenary: wire position (H and P), thickness of wire, contact force, ecc. ecc.

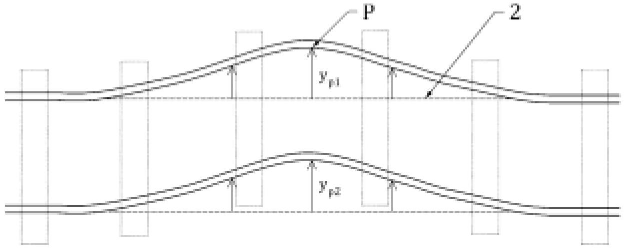


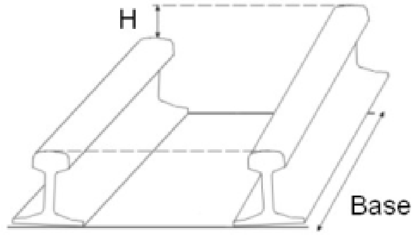
Railway line: Track Gauge, Cross Level / Cant, Twist, Alignment and Longitudinal Level D1, D2, D3 or Mid-Chord Offsets











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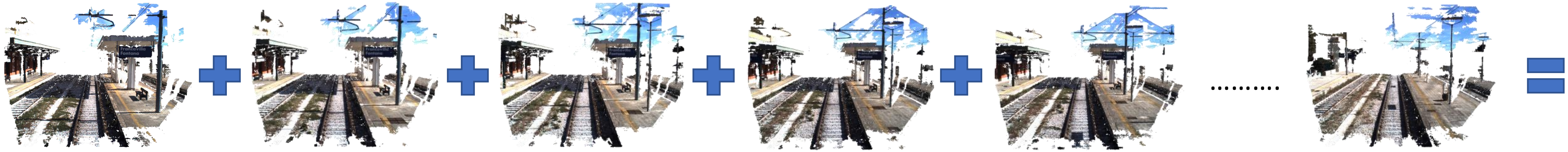
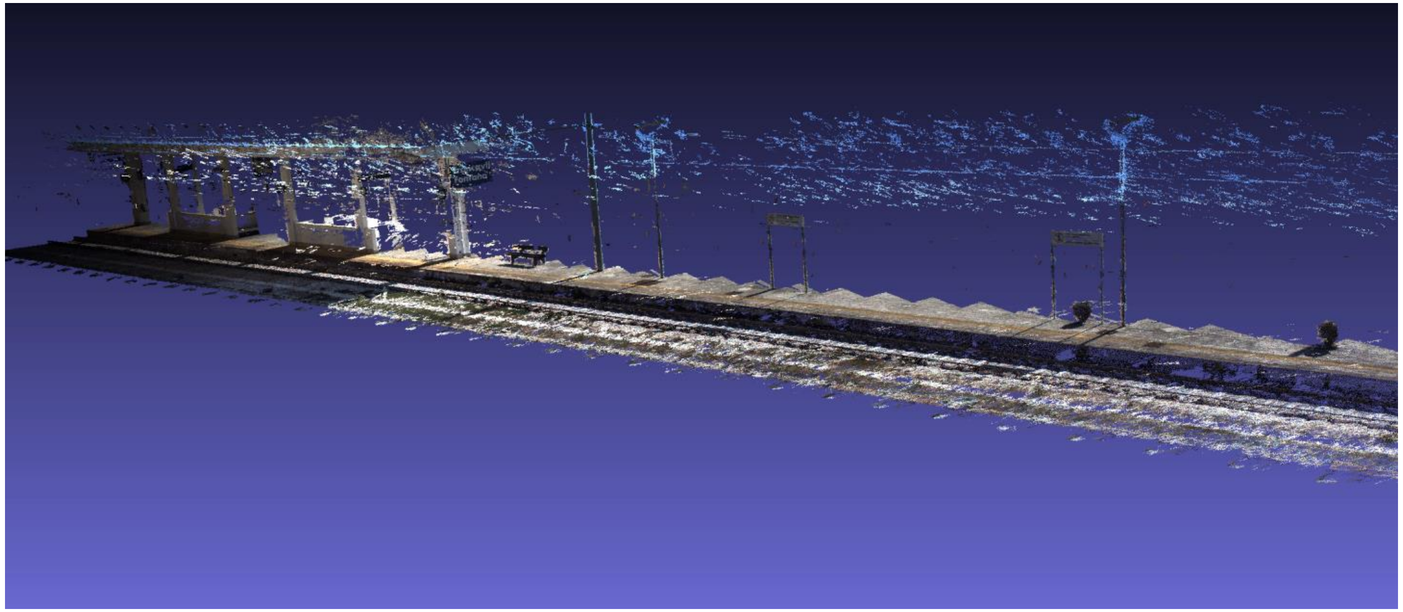
3D stereo reconstruction of train paths for supporting maintenance operations

Purpose of this work is to describe the methods adopted to register a long sequence of 3D map to build a global 3D to be inspected.





The fusion of N Point clouds isn’t simple to do because the train, and so the 3D stereocamera changes the view point respect to the rail. This movements must be compensated to obtain a precise fusion of point cloud. A simple union of point cloud translated of fixed quantity obtained from the odometer is not possible.

3D stereo reconstruction of train paths for supporting maintenance operations

Rectify Left Image

Rectify Right Image

Build Disparity Map
and
3D Point Cloud

Extract KeyPoint2D

Robust Match of KeyPoint2D between two consecutive Point Cloud

Conversion of Robust Match in KeyPoint3D and use RANSAC to estimate R and T

Accumulate R and T to register all slice of PointCloud with small overlap

How to correlate anomalies in the parameter with visual information of track and catenary geometry ?

Railway 3D reconstruction using **Stereo Vision**

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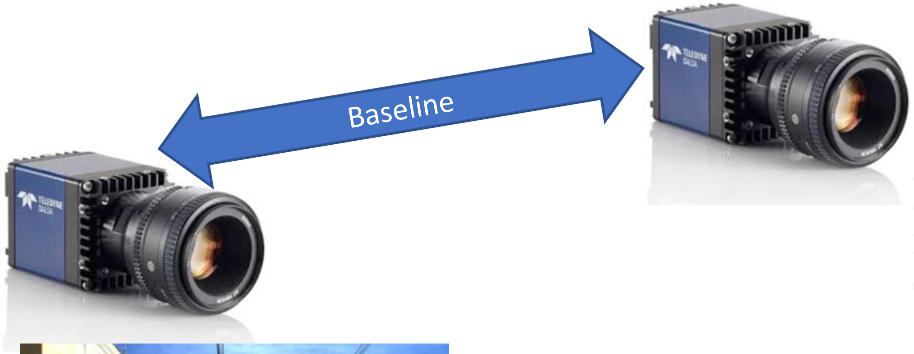
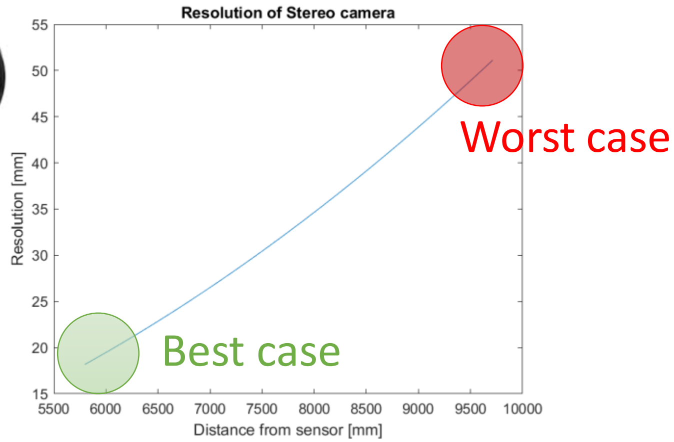
3D stereo reconstruction of train paths for supporting maintenance operations





3D reconstruction with stereovision

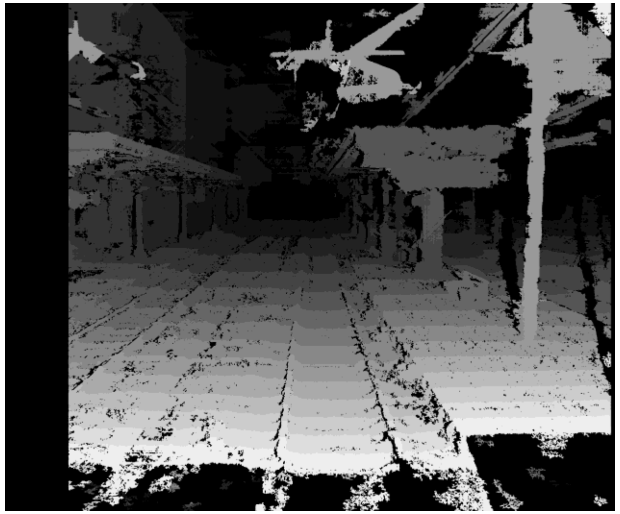
BaseLine 800 mm

Camera resolution:2464x2056

Pixel Size 3,45 µm

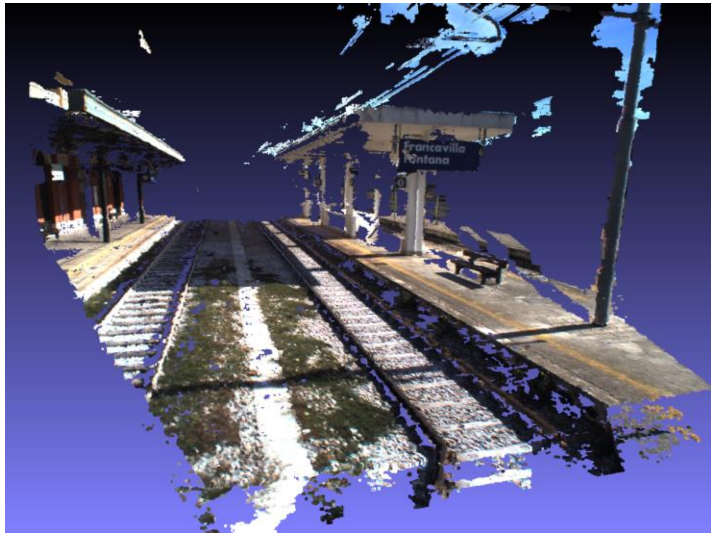
Resolution 20 – 55 mm -> [6 – 10 m]

Semi Blobal Block Matching



Disparity map

3D



3D point cloud

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A precise registration must be done. For each pair of 3D point cloud a Rotation matrix R and Translation T must be calculated to overlap the two point clouds.

$$PointCloud_d = R_d * PointCloud_{d+1} + T_d$$

Where d = position of odometer acquisition system

In general, let be P_d the point clouds at d odometer distance we can write:

$$P_{d_i} = R_{d_i} * P_{d_i+1} * +T_{d_i}$$

where $d_i \; with \; i = 0, .., N$= 0m, 2m, 4m, 6m, and so on.

$$P_{d_0} = R_{d_0} * P_{d_1} + T_{d_0}$$
$$P_{d_1} = R_{d_1} * P_{d_2} + T_{d_1}$$

.

.

$$P_{d_{n-1}} = R_{d_{n-1}} * P_{d_n} + T_{d_{n-1}}$$

Set $Acc_{d_0} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$

$$Acc_{d_1} = \left(R_{d_0} | T_{d_0}\right) * Acc_{d_0}$$

$$Acc_{d_2} = \left(R_{d_1} | T_{d_1}\right) * Acc_{d_1}$$

.

.

.

$$Acc_{d_n} = \left(R_{d_{n-1}} | T_{d_{n-1}}\right) * Acc_{d_{n-1}}$$

$$P = Acc_{d_0} * P_{d_0} + Acc_{d_1} * P_{d_1} + Acc_{d_2} * P_{d_2} + \cdots + Acc_{d_n} * P_{d_n}$$

To estimate R and T for each pair of adjacent Point Clouds we have applied the following method:

For each acquisition the following data is provided:

P_d - Point Cloud

Left camera Rectified Image (2D)

Using a **feature extractor as SURF or SIFT** a set of keypoints and vector of descriptors are extracted from the Left Image.

Let be $KeyPoints_{d_i}$ the set of keypoints and $Descriptor_{d_i}$ the vector of descriptor for each keypoint.

For each $KeyPoint \in KeyPoints_{d_i}$ is associated the 3D position found in the P_{d_i}. We call $KeyPoints3D_{d_i}$ the set 3D points

Algorithm: Estimate R and T for each pair of 3D point Clouds

For each set of $Descriptor_{d_i}$, $Descriptor_{d_{i+1}}$ we extract the best match between the descriptor minimizing a distance function as $Distance^{i}_{h,k} = \left\| Descriptor^{h}_{d_{i+1}} - Descriptor^{k}_{d_i} \right\|$.

A filter applied to the result of matcher assure that each pair of points are unique, e.g.

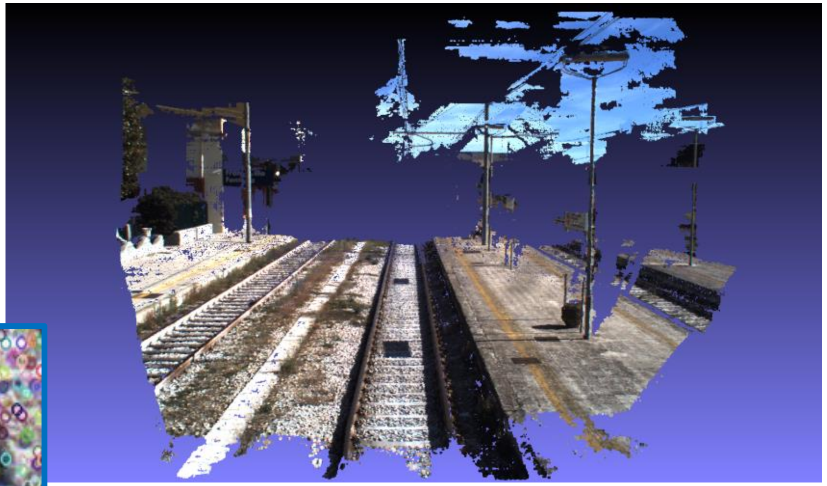
$$\min_{l \in KeyPoint3Ds_{d_i}} Distance^{i}_{h,l} = \min_{K \in KeyPoint3D_{d_{i+1}}} Distance^{i}_{l,k}$$

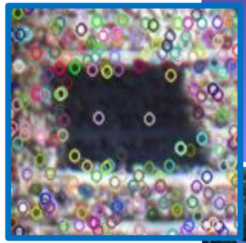
and this equation resolve the unicity of best match.

The solution of problem is to find the best Rotation and Translation that resolve the following equation for all h and k of best batch:

$$KeyPoint3D^{k}_{d_i} = R_{d_i} * KeyPoints3D^{h}_{d_{i+1}} + T_{d_i}$$

The best approach is to use RANSAC method with a simplest rotation and translation calculated using the "Least-Squares Rigid Motion Using SVD" [1]

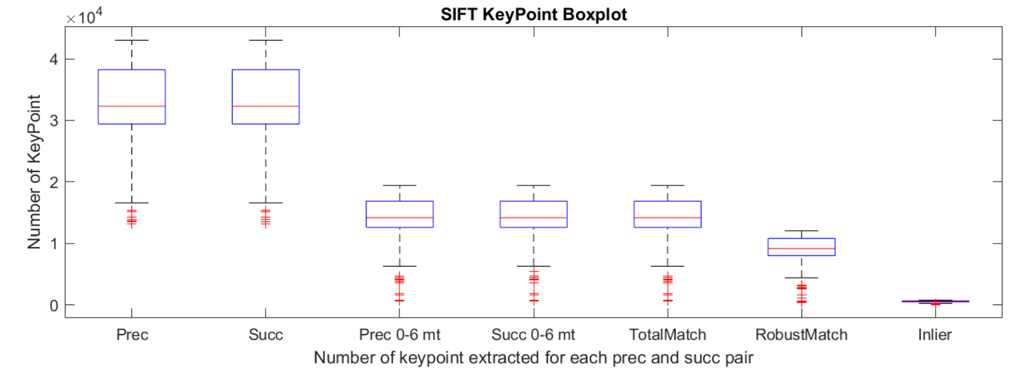


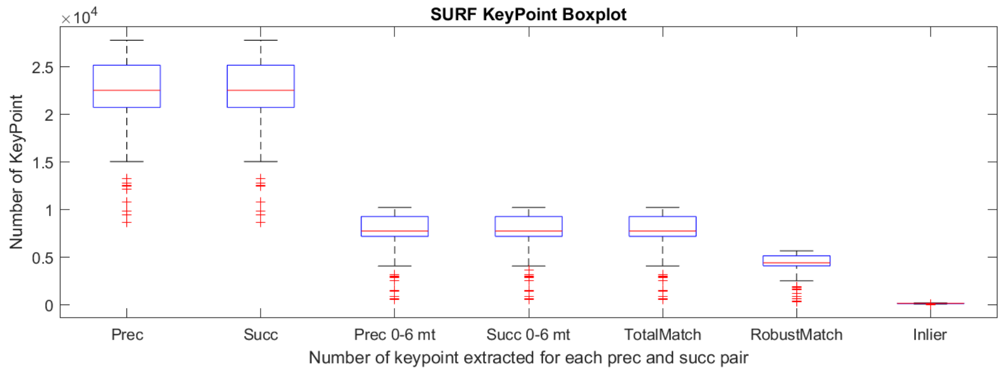


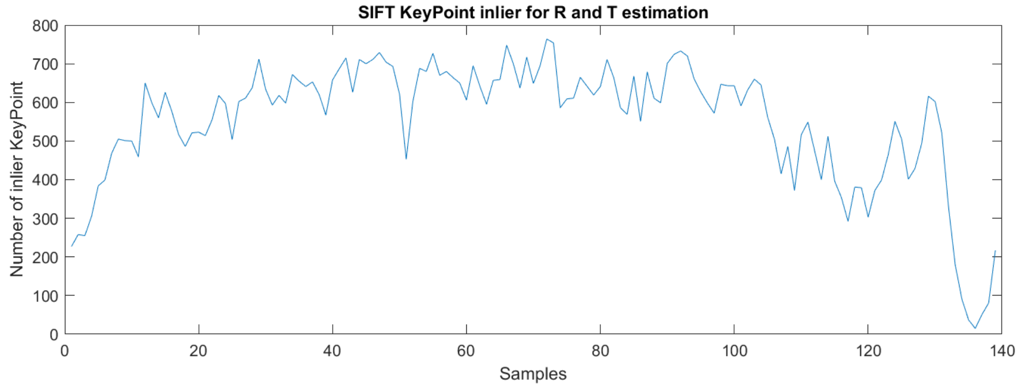
Detail

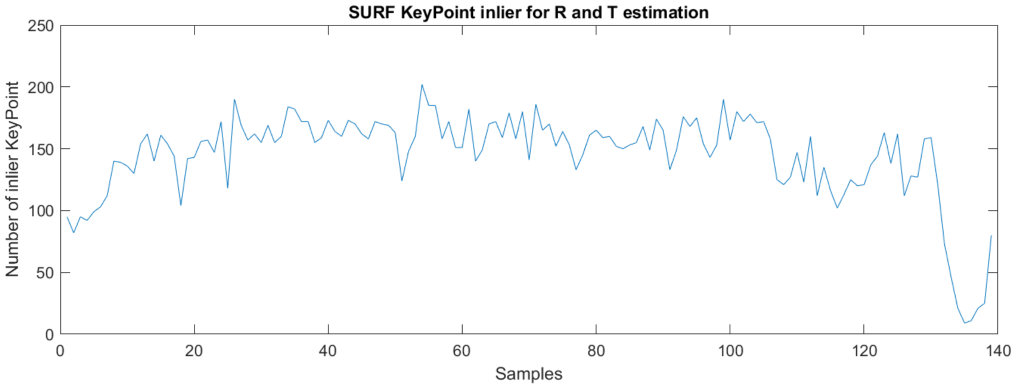
[1] "Least-Squares Rigid Motion Using SVD" Olga Sorkine-Hornung and Michael Rabinovich, Department of Computer Science, ETH Zurich January 16, 2017

Results obtained with Ransac and Least-Squares Rigid Motion Using SVD with minDistance = 0.01 m and p = 0.99









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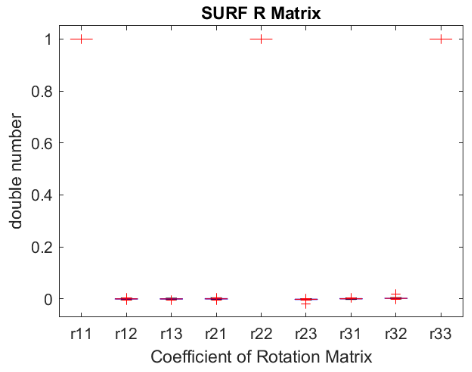
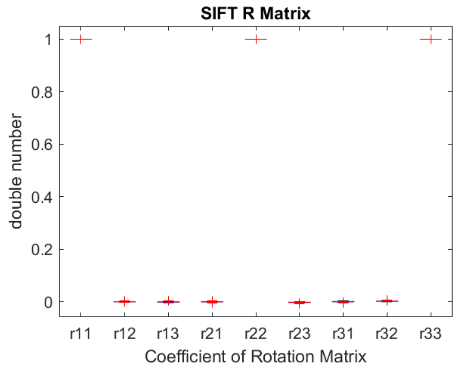
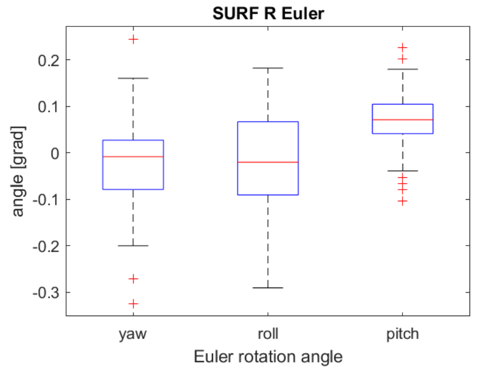
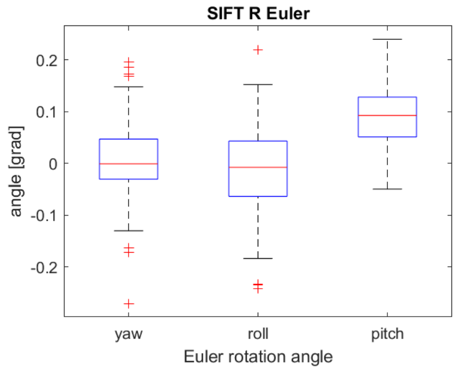
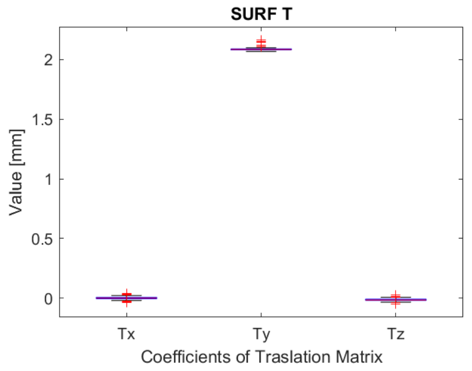
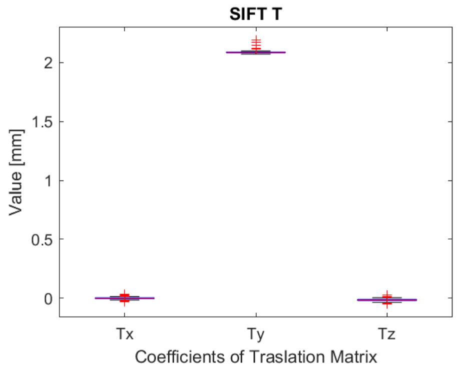


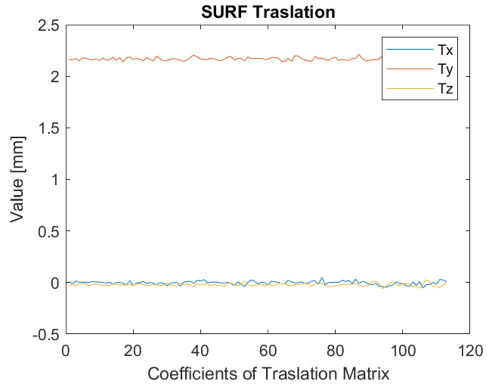


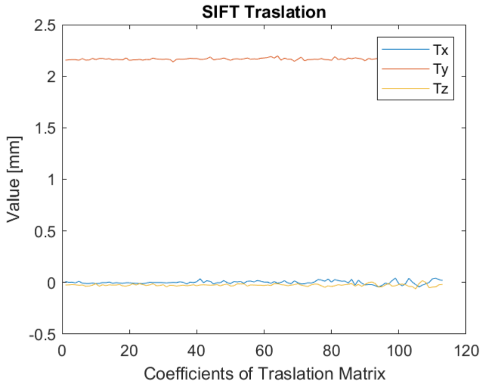












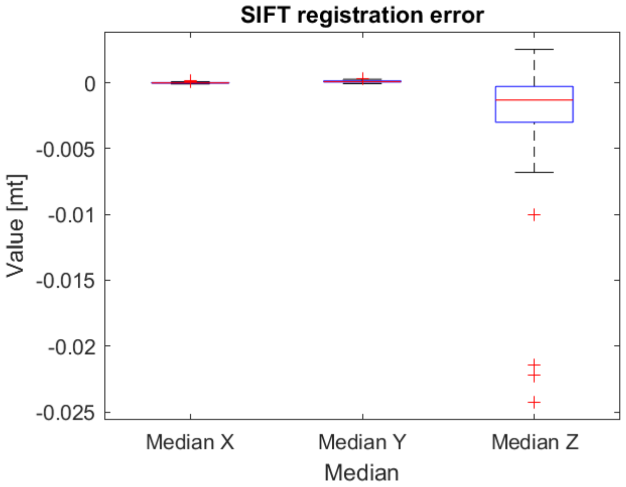
To estimate the performance of registration we have measured the median and mad of min distance measured in each voxel of dimension 5x5 mm in X and Y directions.

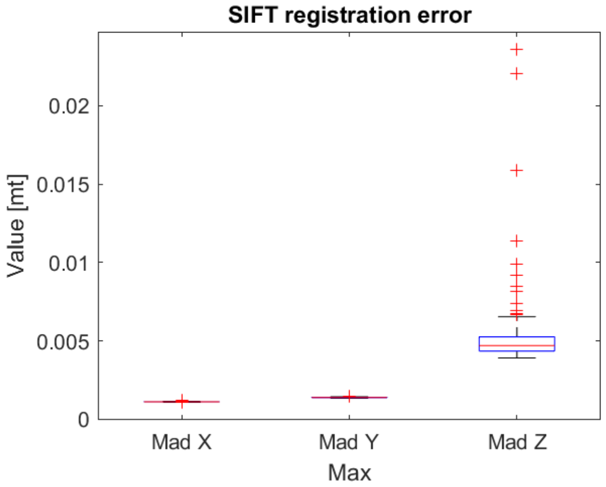
The voxel is contained in the set of

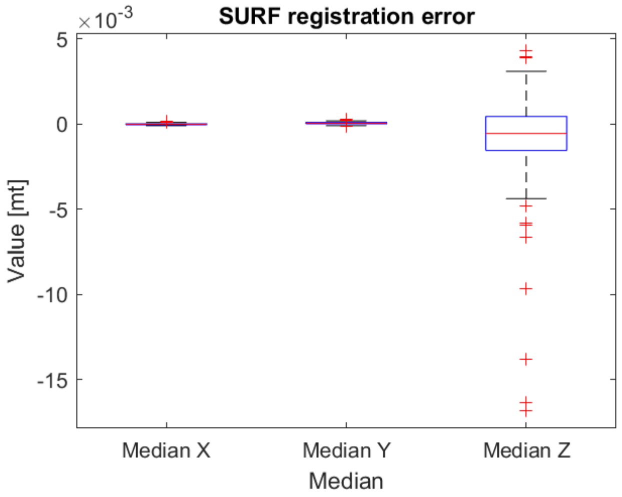
$$\overline{P_{d_i}} \cap R_{d_i}\overline{P_{d_{i+1}}} + T_{d_i}$$

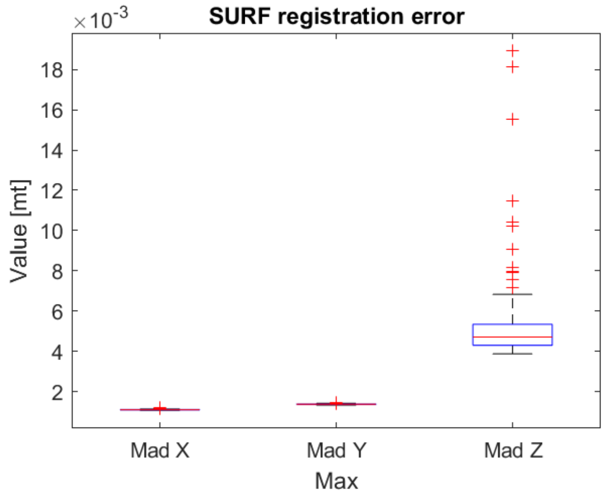
where generally $\overline{P_{d_i}}$ is a ROI of P_{d_i}

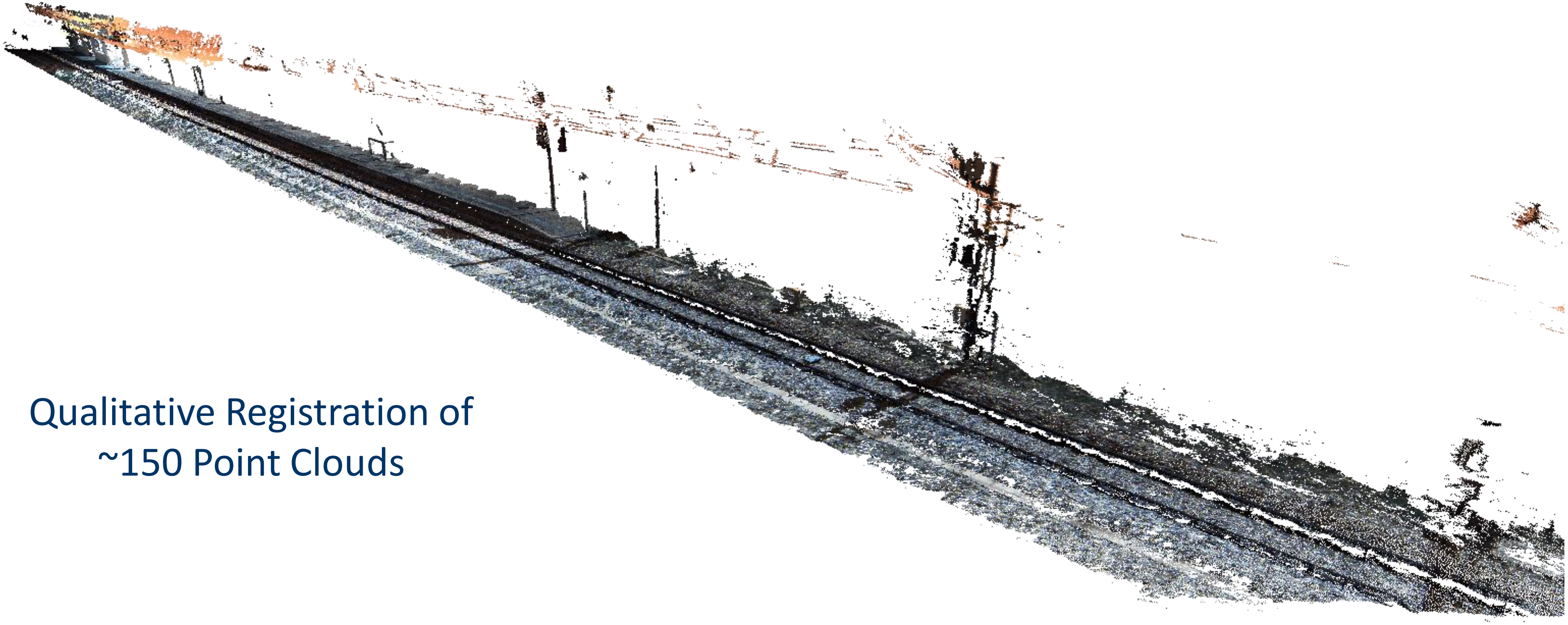
with $X \in [-4.0, 4.0], Y \in [0.0, 3.0], Z \in [-0.5, 8.0]\ mt.$











Qualitative Registration of
~150 Point Clouds

3D Stereo reconstruction with wide baseline

Conclusions

- Comparative analysis of image-based registration of Point Clouds from railway context
- The SIFT key point detector provided good performance observing the number of robust match and the number of inlier even if the median error of SURF is slightly better than the SIFT
- A constant pitch rotation is present in the method and must be considered in a realistic fusion or compensated using other measurements system (gps or inertial platform). Probably it is due to the resolution of sensor that ranges from 2 cm (6 m distance) to 5 cm (10 m distance)
- The calculated sampling space is approximately 2.1 m
- Future works will be devoted to an extensive analysis of real data sampled from the field as well as new registration algorithms specifically designed to the railway context

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Thank you

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