PERVASIVE DISPLACEMENT MONITORING OF CIVIL ENGINEERING ASSETS

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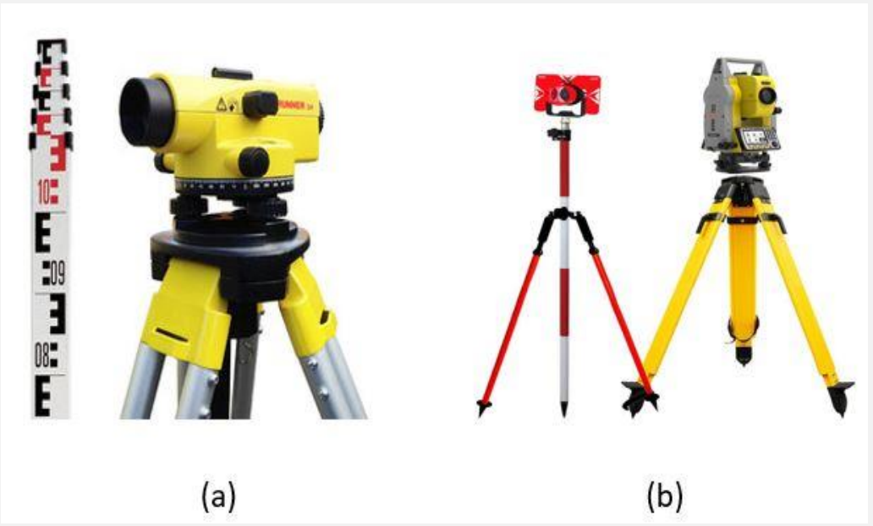
PROJECT MOTIVATION

- Rapid urbanization has increased the need to utilize underground space.
- However, structures built on shallow foundations are highly susceptible to damage induced by underground construction as shallow foundations are unable to utilize the strength provided by deeper soils.
- It is crucial that buildings nearby underground construction sites are tracked for displacements during and after the construction process to investigate changes in loading or structural conditions. This allows civil engineers to identify any construction-induced damage so that mitigating steps can be taken before further damage occurs.

Traditional monitoring technologies:



a) Invar levelling staff and optical telescope
b) Prism and total station

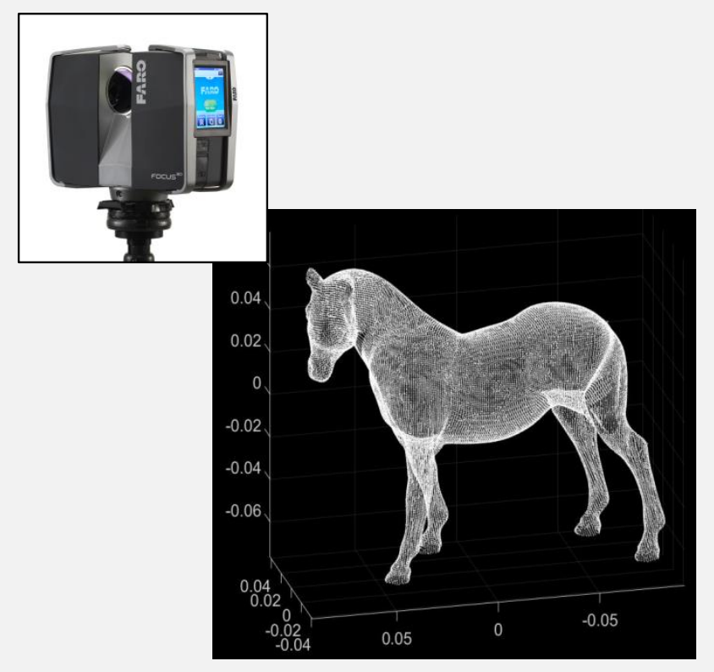
Advantages:

- High accuracy (up to 0.5mm)

Limitations:

- Only provide displacements at certain points
- High maintenance cost

3D Laser Scanners (Focus of this project) :



Advantages:

- Point clouds provide spatially-rich displacement data.
- 3D laser scanners are becoming increasingly inexpensive.

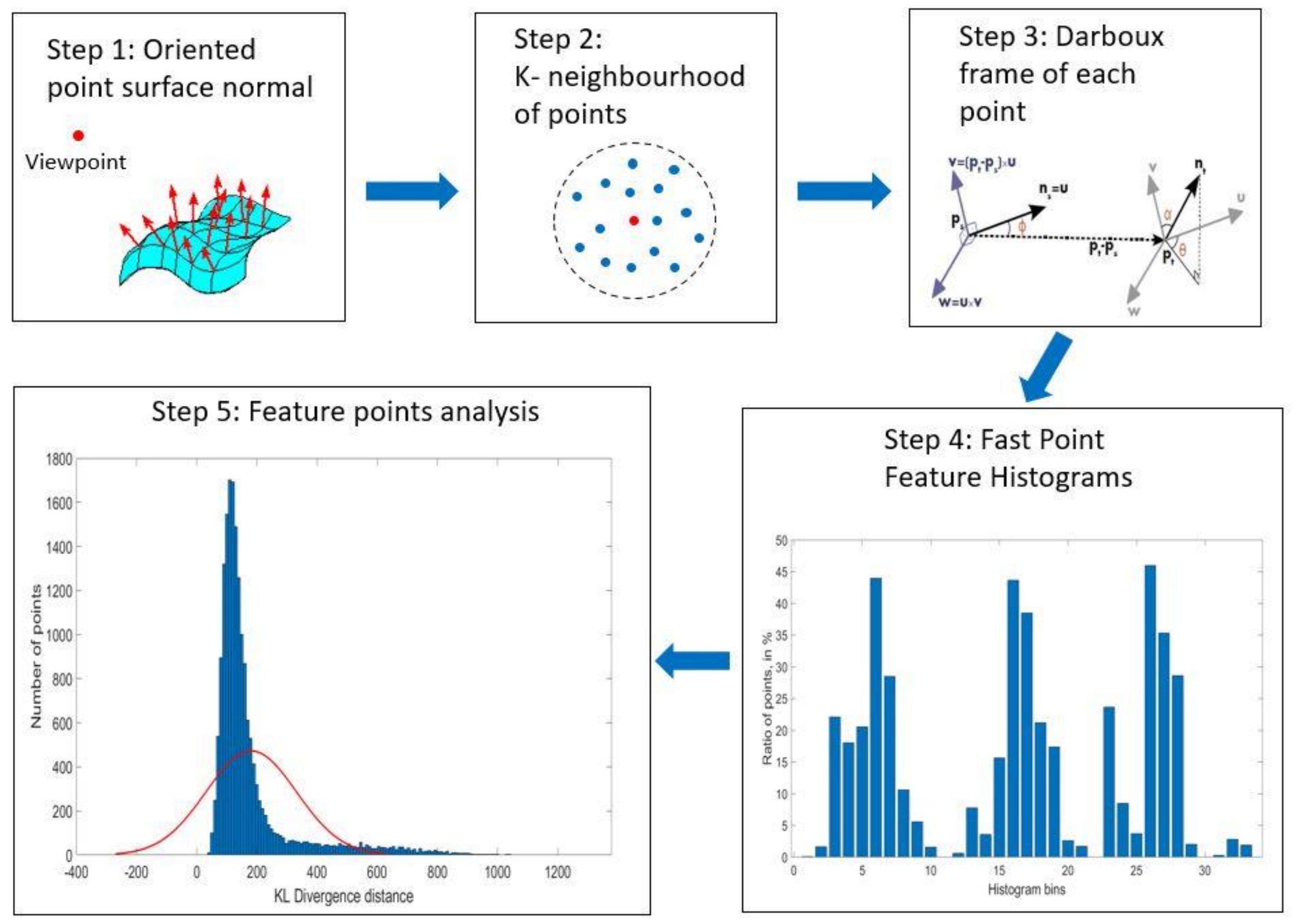
Limitations:

- Existing cloud comparison methods are unable to generate accurate and meaningful displacement profiles.

FAST POINT FEATURE HISTOGRAMS (FPFH)

FPFH was first proposed by Rusu et.al. (2009) to find correct point-to-point correspondences in real noisy data scans. FPFH uses an array of geometric features to fully represent the geometric properties of neighbourhood points for all points in a point cloud.

Algorithm steps:



Step 1: Oriented point surface normal

Step 2: K- neighbourhood of points

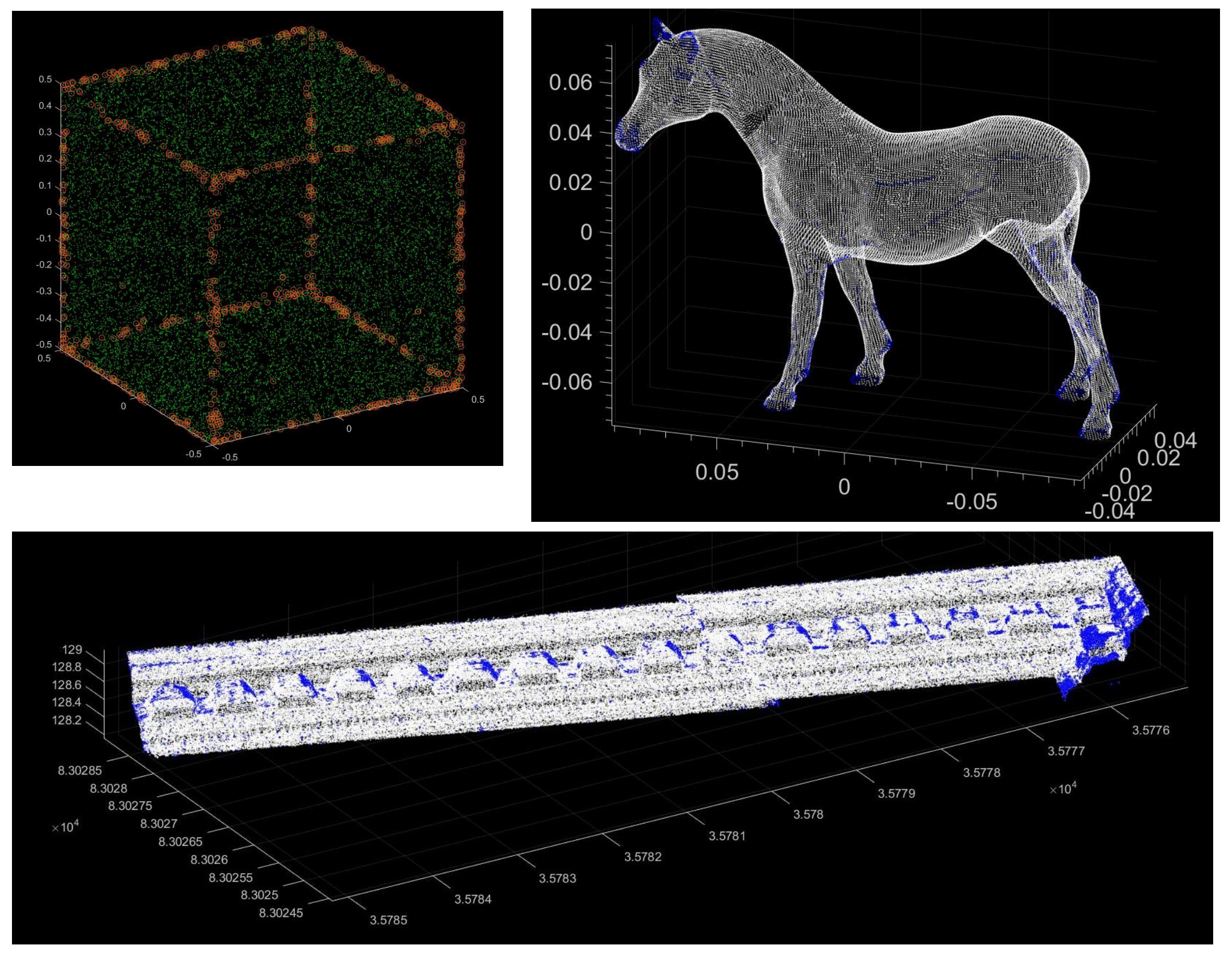
Step 3: Darboux frame of each point

Step 4: Fast Point Feature Histograms

Step 5: Feature points analysis

Results:

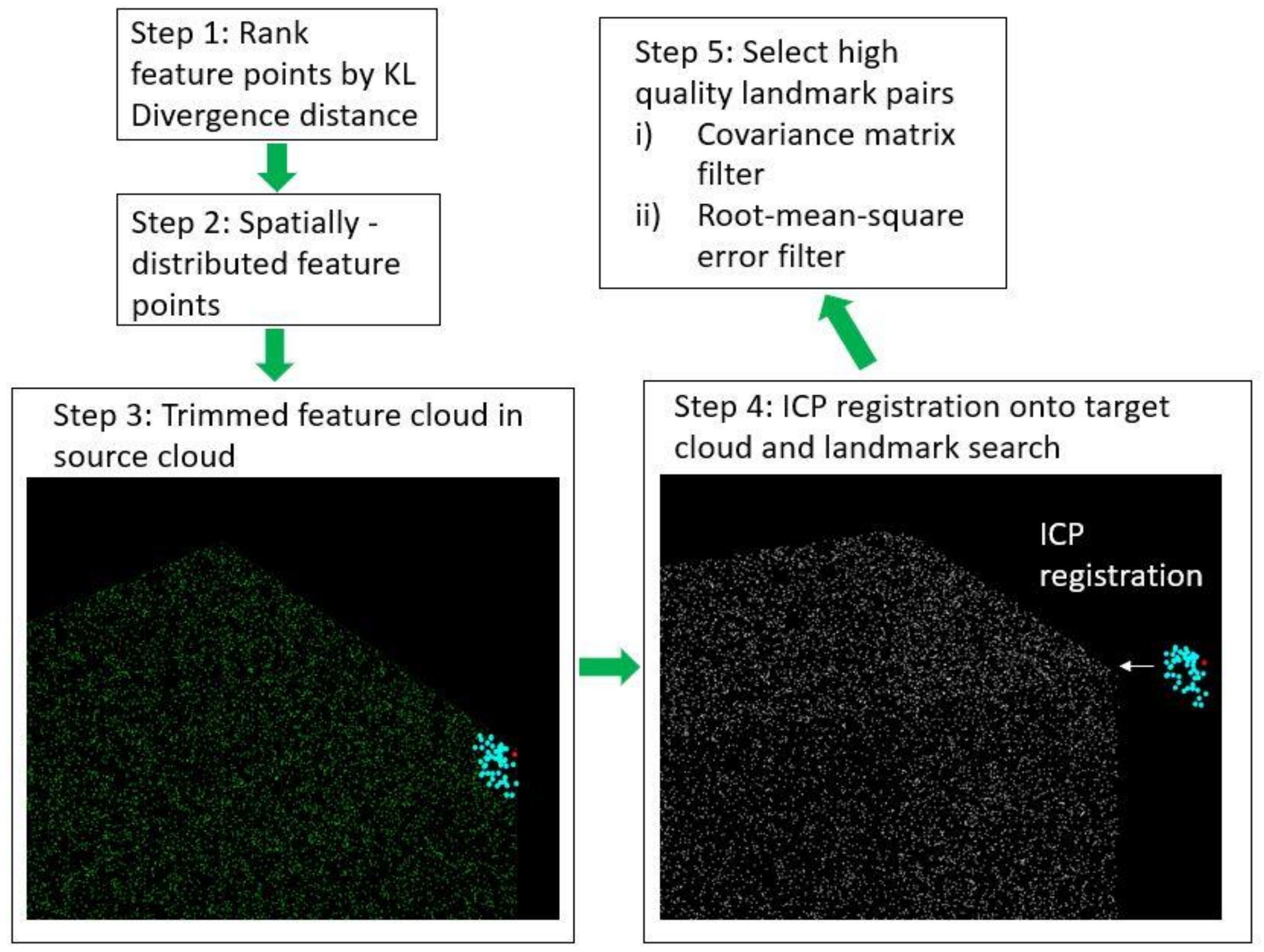
Identified feature points are labelled in orange or blue.



LOCALLY-RIGID LANDMARK SELECTION (LRLS)

Displacements in structural monitoring applications are usually small (several millimetres). Hence, feature points can be assumed to be locally-rigid. Based on this assumption, a novel point correspondence search algorithm, known as LRLS, is proposed in this report.

Algorithm steps:



Step 1: Rank feature points by KL Divergence distance

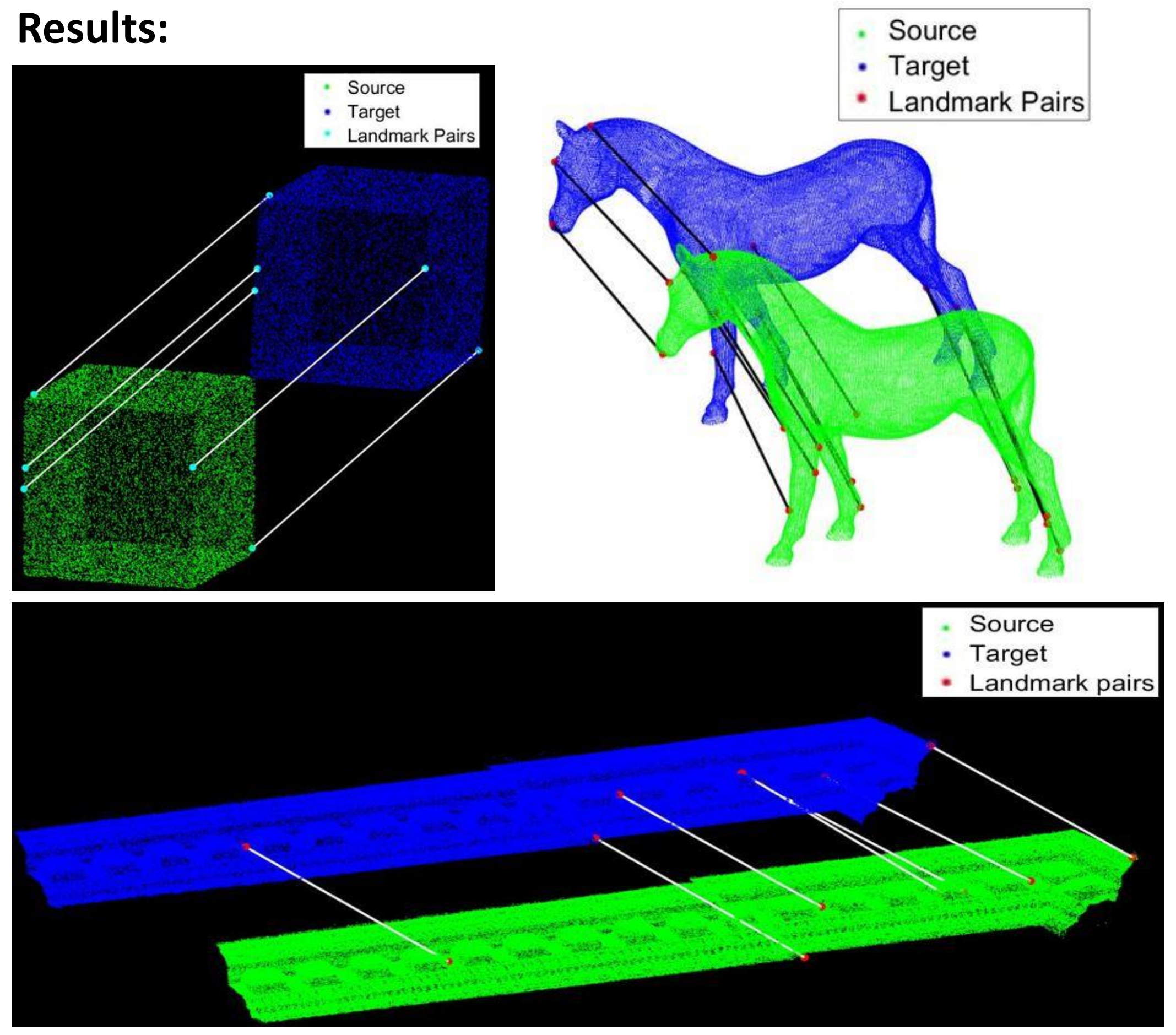
Step 2: Spatially - distributed feature points

Step 3: Trimmed feature cloud in source cloud

Step 4: ICP registration onto target cloud and landmark search

Step 5: Select high quality landmark pairs
i) Covariance matrix filter
ii) Root-mean-square error filter

Results:



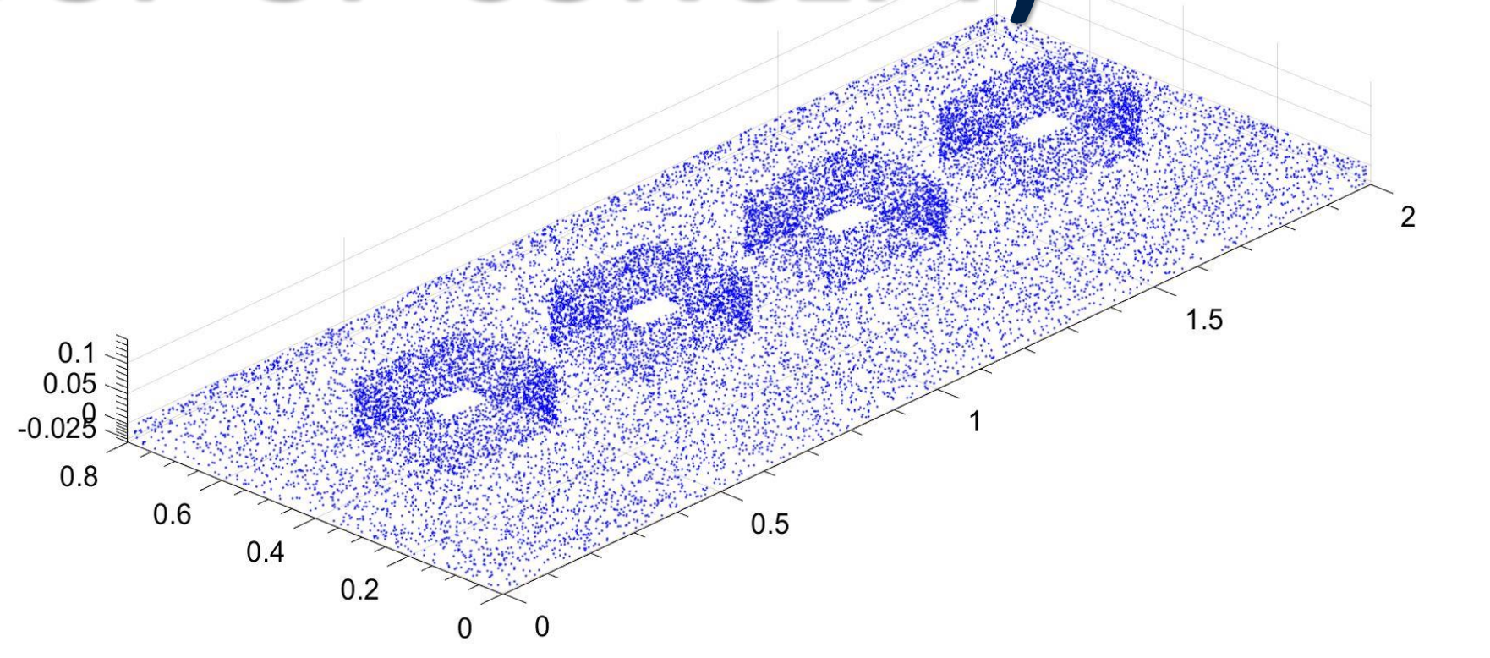
PROJECT OBJECTIVES

- Existing point cloud comparison methods have significant limitations as they compute only the distance between point clouds instead of deformations. A novel Non-rigid Iterative Closest Point (N-ICP) algorithm was developed by Liu et. al. (2020) to obtain accurate deformations between point clouds.
- An important component of the N-ICP algorithm is the inclusion of landmarks, which are essentially corresponding points between the source and target point cloud. Selecting landmarks manually can be cumbersome for point clouds with complex geometries and/or high point density.
- Therefore, a consistent methodology to select accurate landmarks based on the properties of the point cloud must be established.
- This is divided into two stages. The first stage involves identifying unique points from the source point cloud and the second stage involves finding their corresponding points in the target point cloud.
- The algorithms developed are validated through testing on three datasets– synthetic cube (simple and intuitive), horse (organic geometries) and Mansion House, London scans (real-life scans from an urban tunnelling project).

	Michaelmas 2020	Hilary 2021	
Objective	Develop feature detection algorithm, known as Fast Point Feature Histogram (FPFH) that was proposed by Rusu et. al. (2009).	Develop point correspondence search algorithm - Locally-Rigid Landmark Selection (LRLS)	Carry out numerical tests on a range of synthetically deformed point clouds with the automated landmark selection procedures.
Purpose	Extract feature points from the source point cloud.	Search for corresponding points in the target point cloud for each feature point generated by the FPFH algorithm.	Proof-of-concept of importance of landmarks in N-ICP registration.

SYNTHETIC BUILDING FAÇADE TESTS (PROOF-OF-CONCEPT)

Synthetic facade acts as an intermediary case between the synthetic cube and real point clouds.
Results are analysed in terms of their standard deviation:



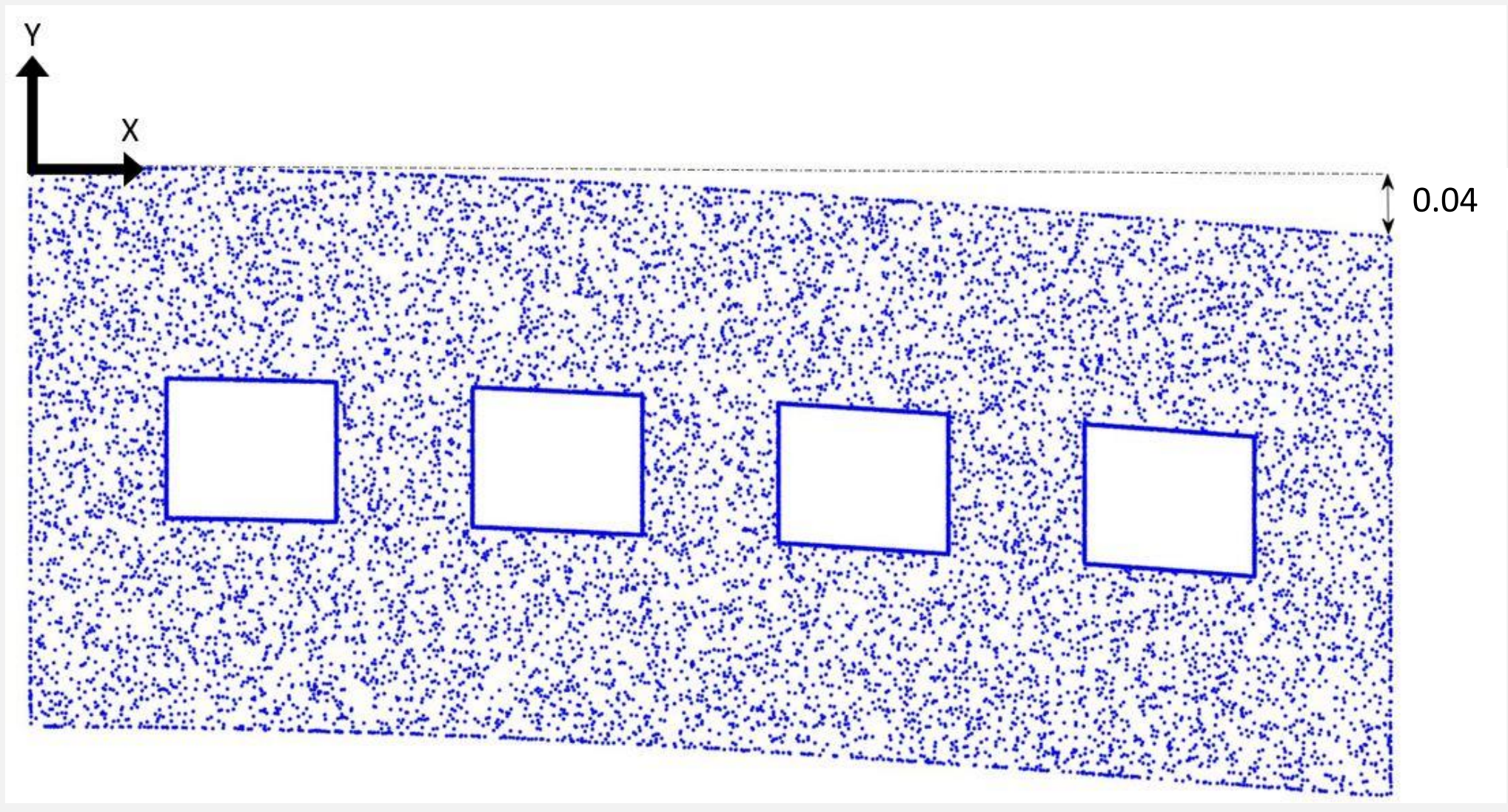
$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(d_i - d_i^t)^2}$$

where n is the number of points in the source point cloud, d^t is the true displacements and d is the experimental displacements.

In-plane displacements:

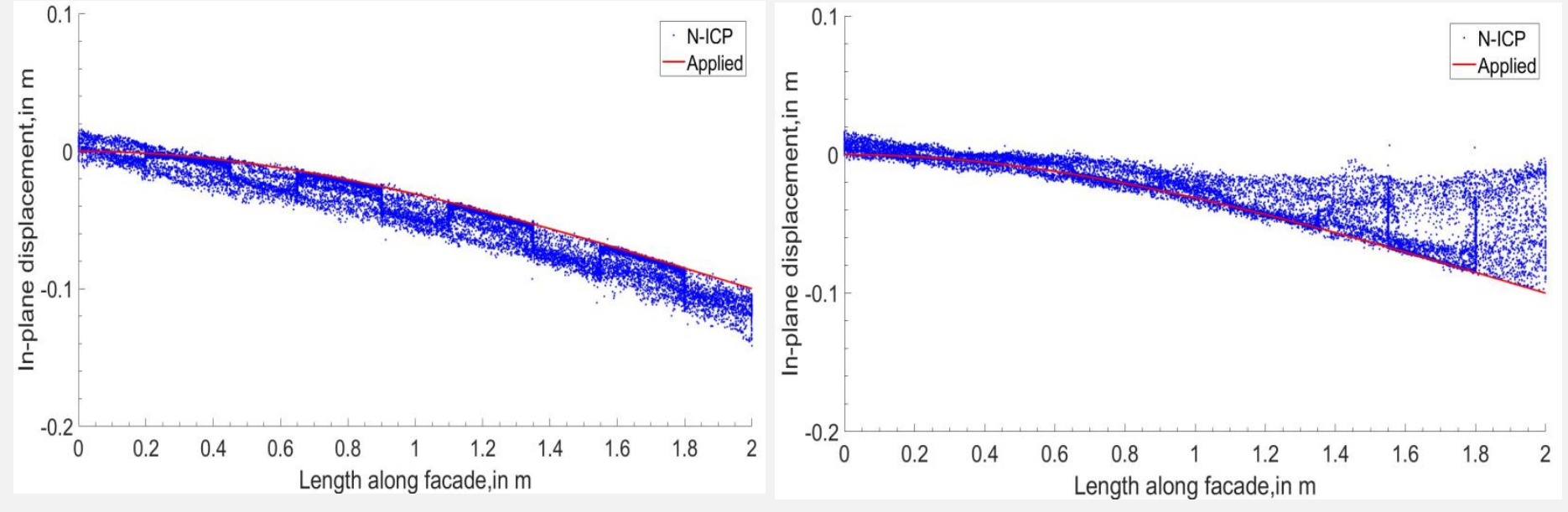
In-plane displacements occur when tunnelling works are being carried out closer to one side of the façade resulting in uneven settlement of the ground. The façade is modelled as a cantilever beam.

Applied displacement:



Results:

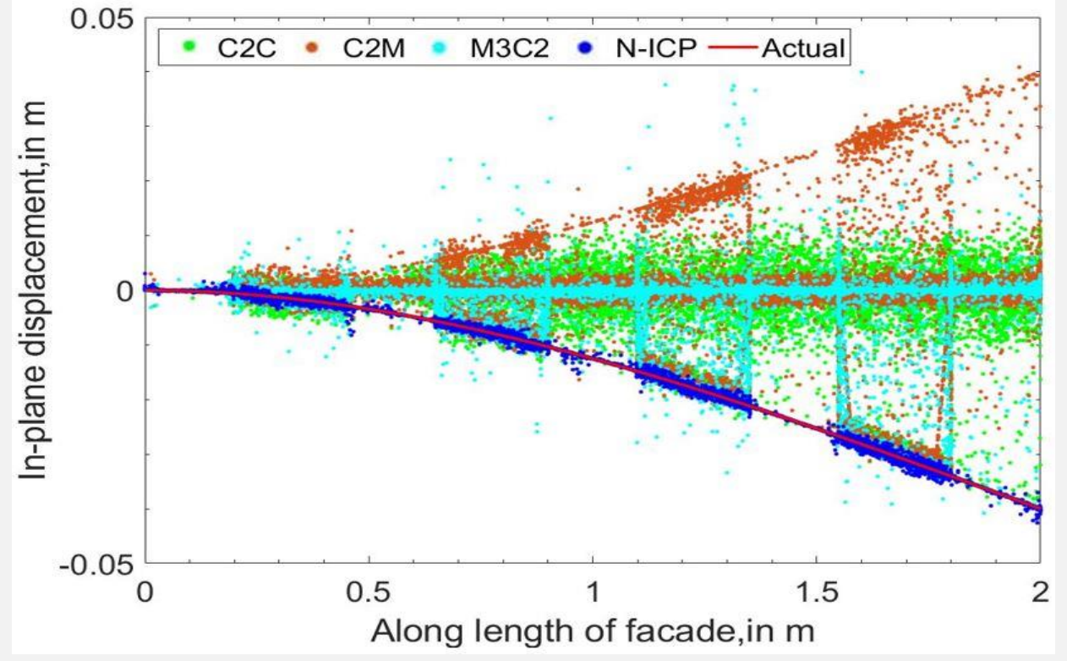
a) Landmarks quantity vs quality:



Left: 15 high quality landmarks
Right: 20 low quality landmarks

Therefore, landmarks quality should be prioritised over quantity.

b) Benchmarking:



Method	N-ICP with automated landmark selection	C2C	C2M	M3C2
σ	0.321×10^{-3}	19.6×10^{-3}	20.3×10^{-3}	16.9×10^{-3}

C2C, C2M and M3C2 failed to produce meaningful displacement profiles and have high errors. N-ICP is able to recover the applied displacements and outperforms all other methods for in-plane displacements.

KEY TAKEAWAYS

- The results showed that the FPFH and LRLS algorithms is effective at identifying landmarks between the source and target point cloud.
- Through the synthetic building façade tests, it is clear that landmarks play a significant role in improving the accuracy of N-ICP registration.
- The approach suggested in this project has several advantages over conventional surveying – using laser scanners allow 3-D deformation measurements to be taken over thousands of points instead of a handful of points and the entire workflow is digital, allowing automation for industrial applications.

References:

Liu Y.,Acikgoz S.,Burd H.,2020. Computer vision for performance assessment of masonry assets subjected to settlement induced by underground construction. University of Oxford.
Rusu R.B.,Boldow N.,Beetz M.,2009. Fast Point Feature Histograms(FPFH) for 3DRegistration. IEEE International Conference on Robotics and Automation, pp.3212-3217.

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