UAS-Based LiDAR Mapping

Video I

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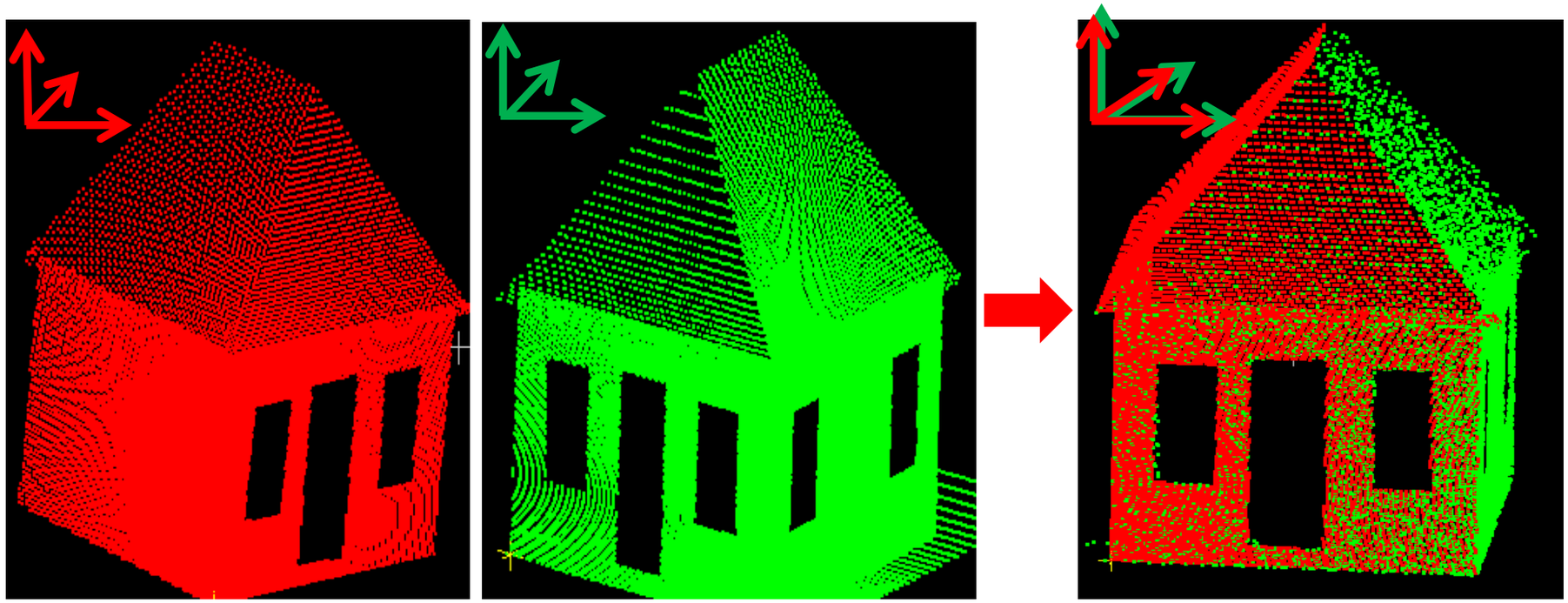
Point Cloud Registration

Introduction: Registration of Static Scans

- **Complex surfaces (or objects) require multiple scans with overlap for a full 3D model:**
  - The separate point clouds must be registered to a common reference frame.



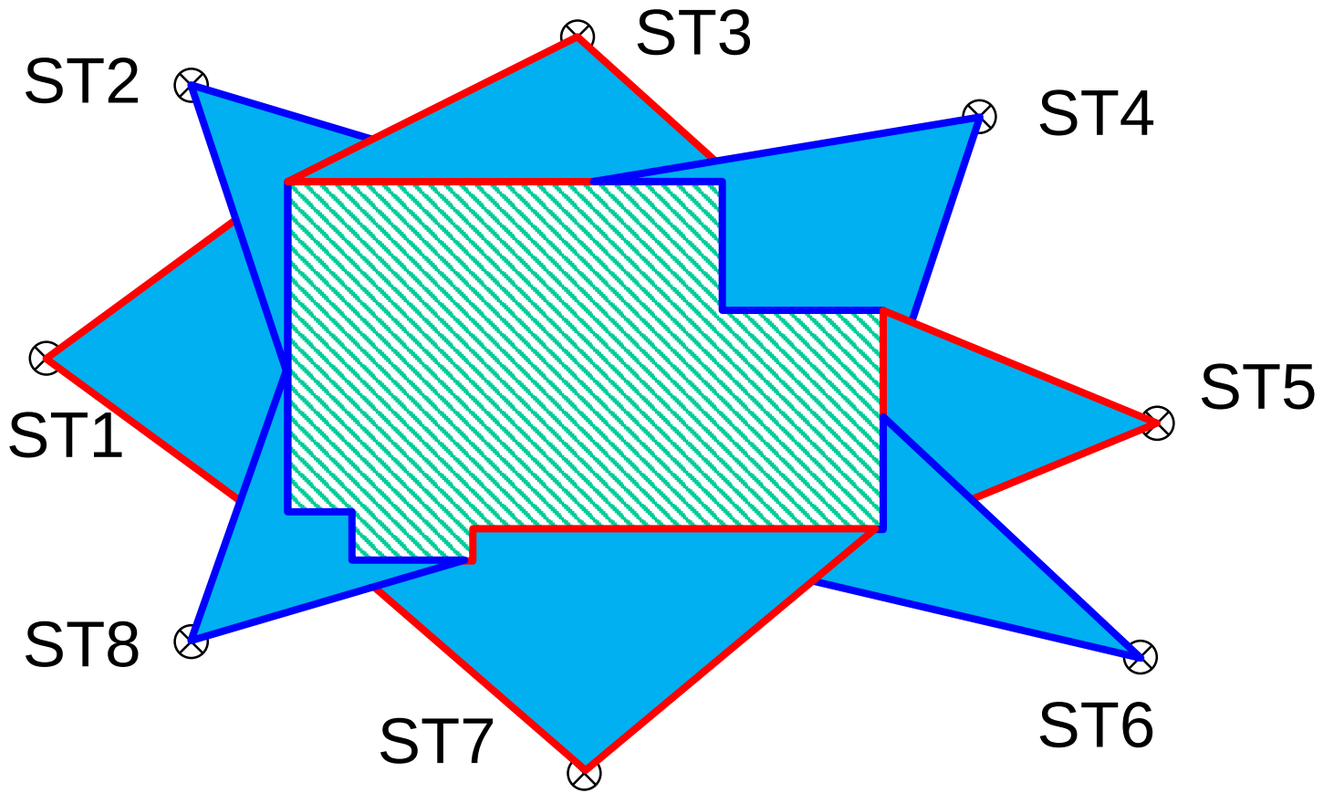
Original Scans

Registered Scans

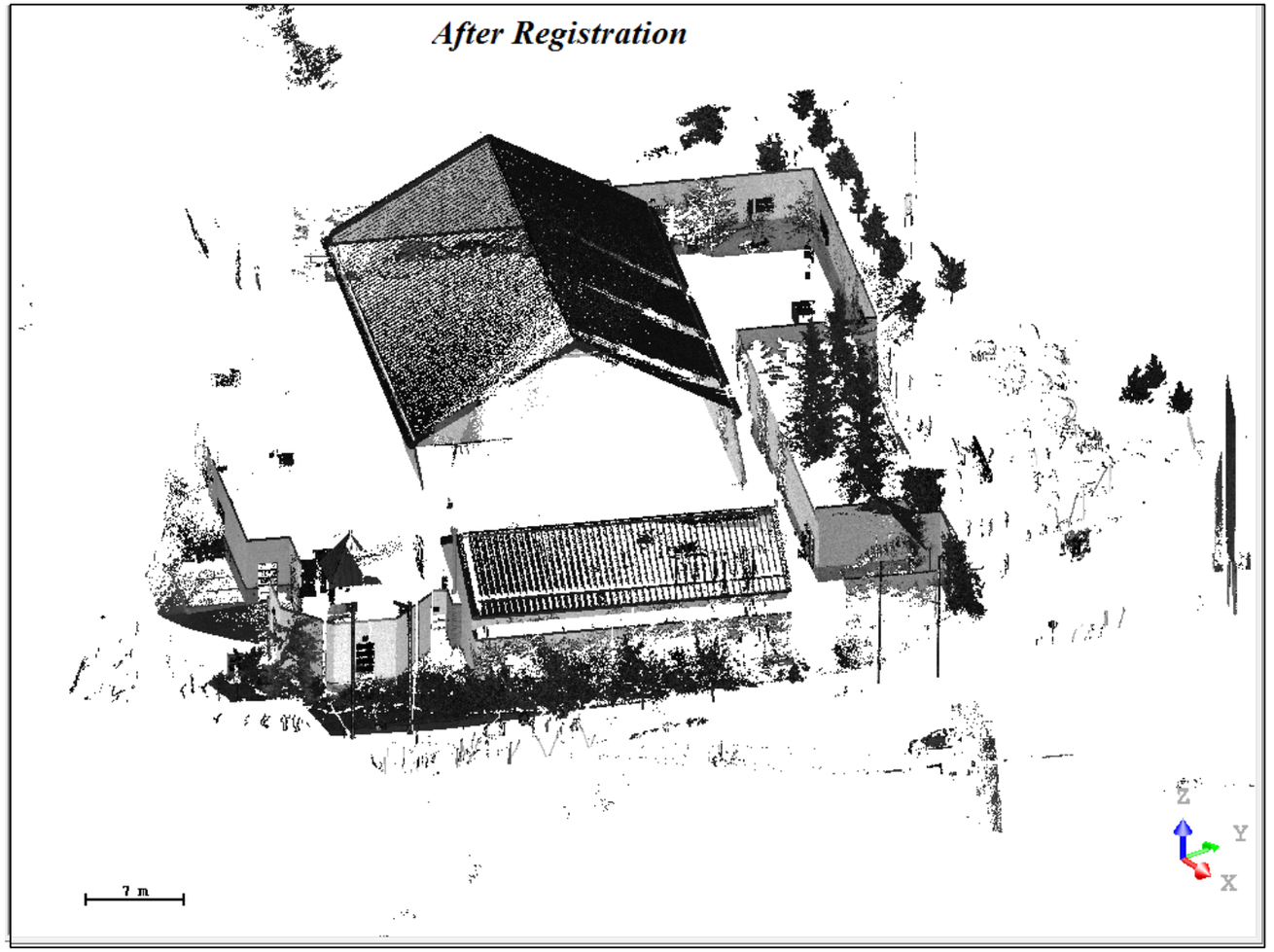
Introduction: Registration of Static Scans

- **Complex surfaces (or objects) require multiple scans with overlap for a full 3D model:**
  - The separate point clouds must be registered to a common reference frame.

X_n= ?
Y_n = ?
Z_n = ?
ω_n = ?
φ_n = ?
κ_n = ?



Introduction: Registration of Static Scans



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Introduction: Registration of Mobile Scans

- **For LiDAR data, which has been captured by a mobile system – whether terrestrial or airborne, the point cloud will be given relative to a unified coordinate system.**
  - Defined by the onboard GNSS/INS unit
- **Registration is not necessary for this type of data.**
- **However, in some situations, systematic errors in the data acquisition system will lead to discrepancies among overlapping point clouds.**
- **Therefore, we might need to register overlapping mobile LiDAR data.**
  - To ensure the alignment of the different datasets, and
  - To evaluate the quality of the system performance (QC).

Introduction: Registration of Mobile Scans

- **We are interested in evaluating the registration transformation parameters between point clouds from multiple flight lines/drive runs.**
  - These registration transformation parameters are used as quality control measures.

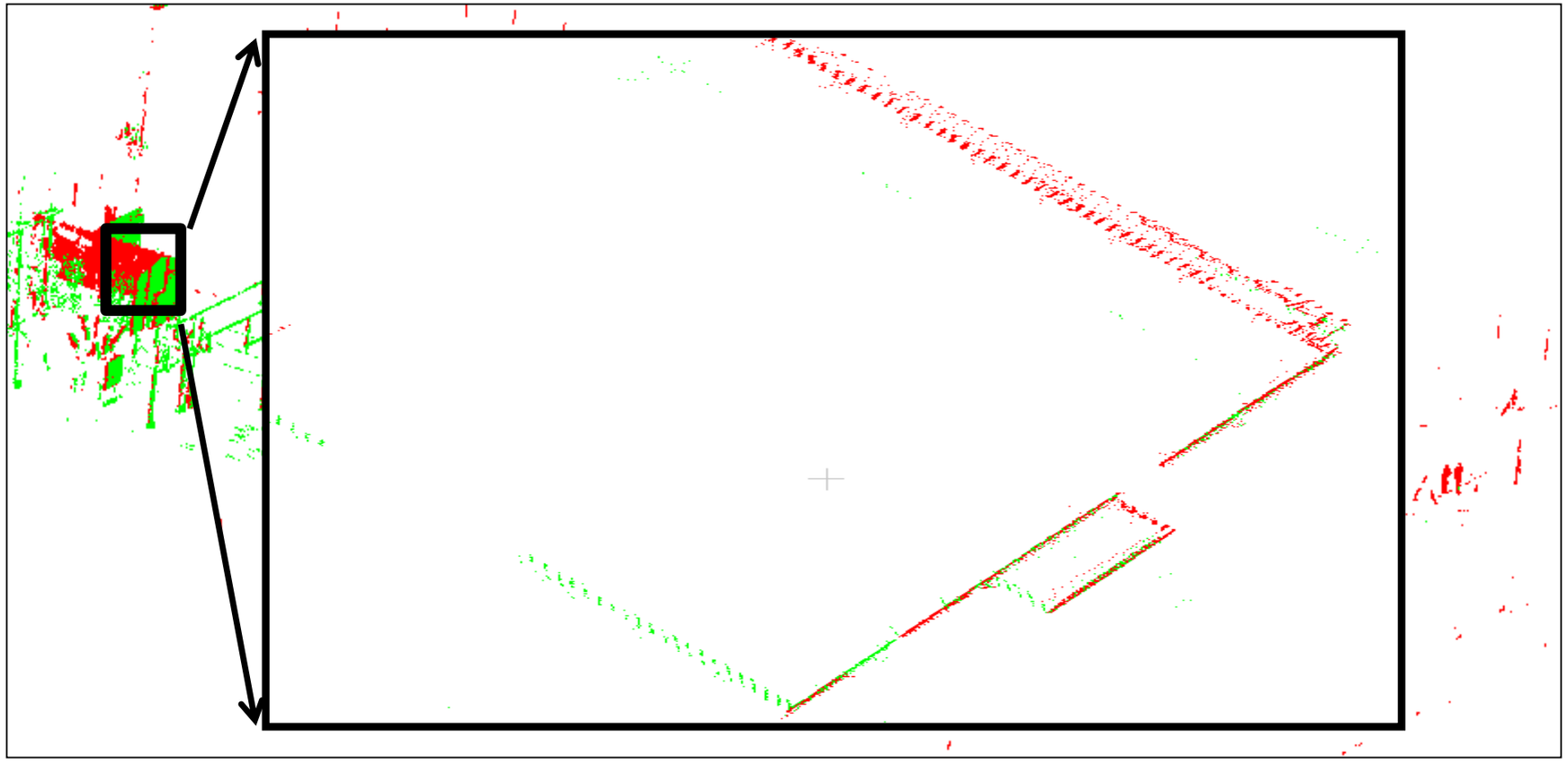
Overlapping strips

Discrepancies

3D Transformation

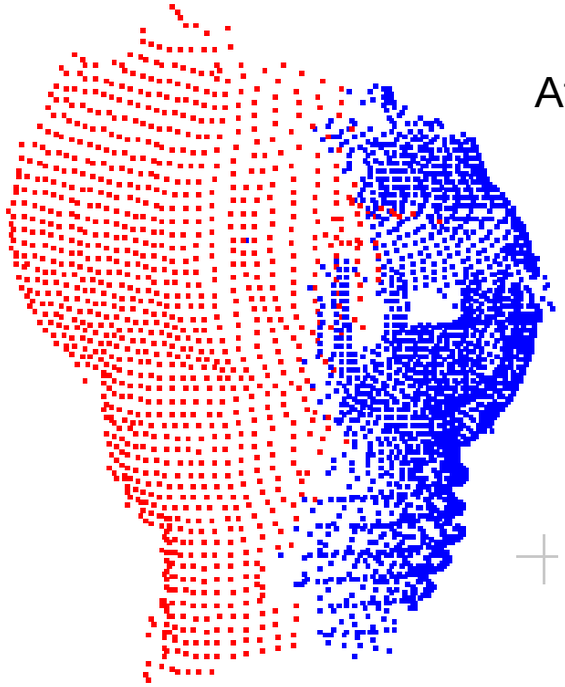
QC Procedure → Rotation Shifts

Introduction: Coarse Vs. Fine Registration

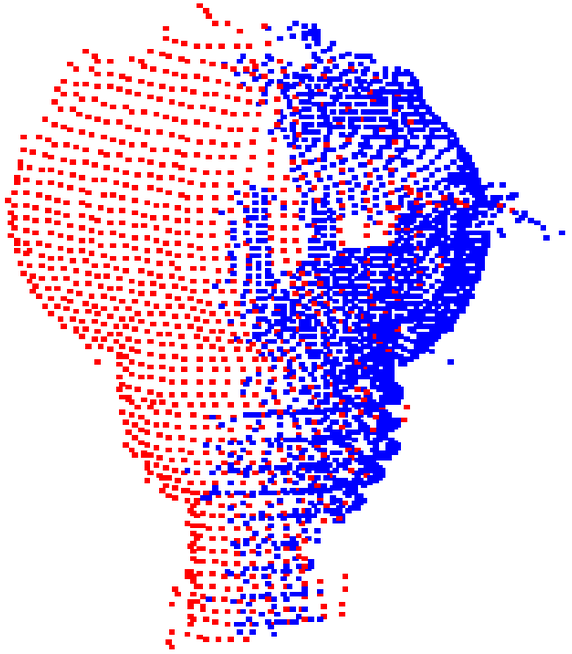


Coarse Registration Fine Registration

Introduction: Coarse Vs. Fine Registration



After Coarse Registration



After Fine Registration

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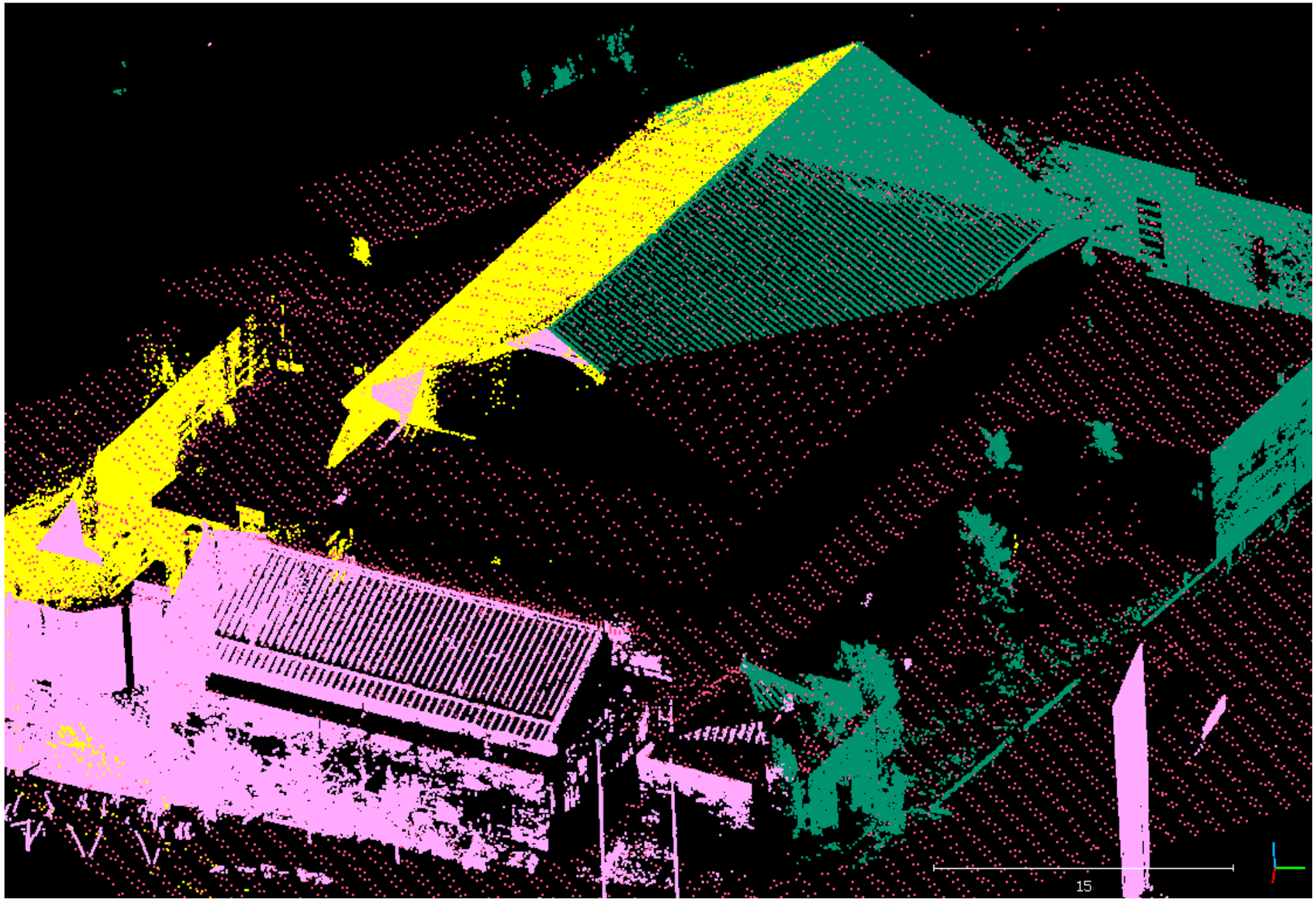
Introduction: Coarse Vs. Fine Registration

- **For the registration of static scans, we need to address both coarse and fine registration.**
- **For the registration of directly-georeferenced mobile scans, we only need to address the fine registration.**
  - The point clouds are already generated in a common reference frame defined by the onboard GNSS/INS unit.
  - The impact of erroneous system parameters on the alignment of point cloud is relative small.

Introduction: TLS & ALS Registration



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Registration Paradigm Elements

Registration Primitives	• Features that will be identified in the individual scans, e.g., Points, Lines, and Planar features
Transformation Parameters	• Transformation parameters that describe the relationship between the reference frames of the different scans
Similarity Measure	• Describes the coincidence of conjugate primitives after registering different scans to a common reference frame
Matching Strategy	• Controlling framework which is used for manipulating primitives, transformation parameters, and similarity measure

(*Habib A. & Al-Ruzouq R. , 2004*)

Registration using Exact Point Correspondence

Fine Registration

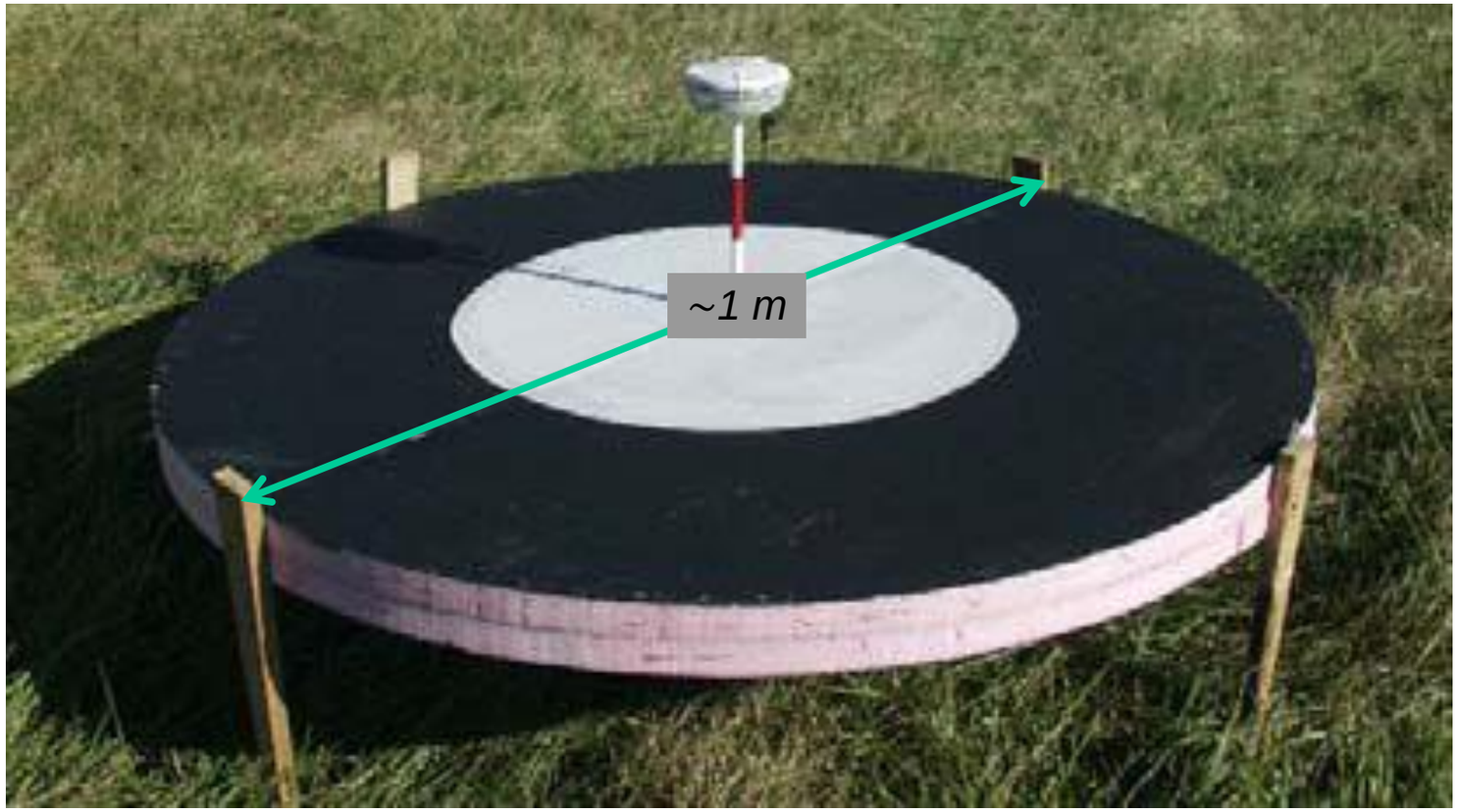
Registration Targets

- **Registration is performed using corresponding points, which could be signalized targets).**

Example of targets used in the registration of terrestrial laser scans (photos courtesy of leica-geosystems)

Registration Targets

- **Targets for ALS registration**



Example of targets that could be used in the registration of airborne laser scans (photo courtesy of Csanyi & Toth, 2007)

Registration: Point-Based Mathematical Model

$$r_{a_2}^{S_2} = r_{S_1}^{S_2} + SR_{S_1}^{S_2} r_{a_1}^{S_1}$$

- a_1 and a_2 are corresponding points in scans S_1 and S_2, respectively,
- $r_{a_2}^{S_2}$ is the coordinate of a_2 relative to the reference frame of scan S_2,
- $r_{a_1}^{S_1}$ is the coordinate of a_1 relative to the reference frame of scan S_1,
- $r_{S_1}^{S_2}$ is the shift between the reference frames of the two scans (relative to the reference frame of scan S_2),
- $R_{S_1}^{S_2}$ is the rotation matrix between the reference frames of the two scans, and
- S is the scale factor.

For LiDAR data, the scale might not be necessary.

Point-Based Registration without Exact Point-to-Point Correspondence

Fine Registration

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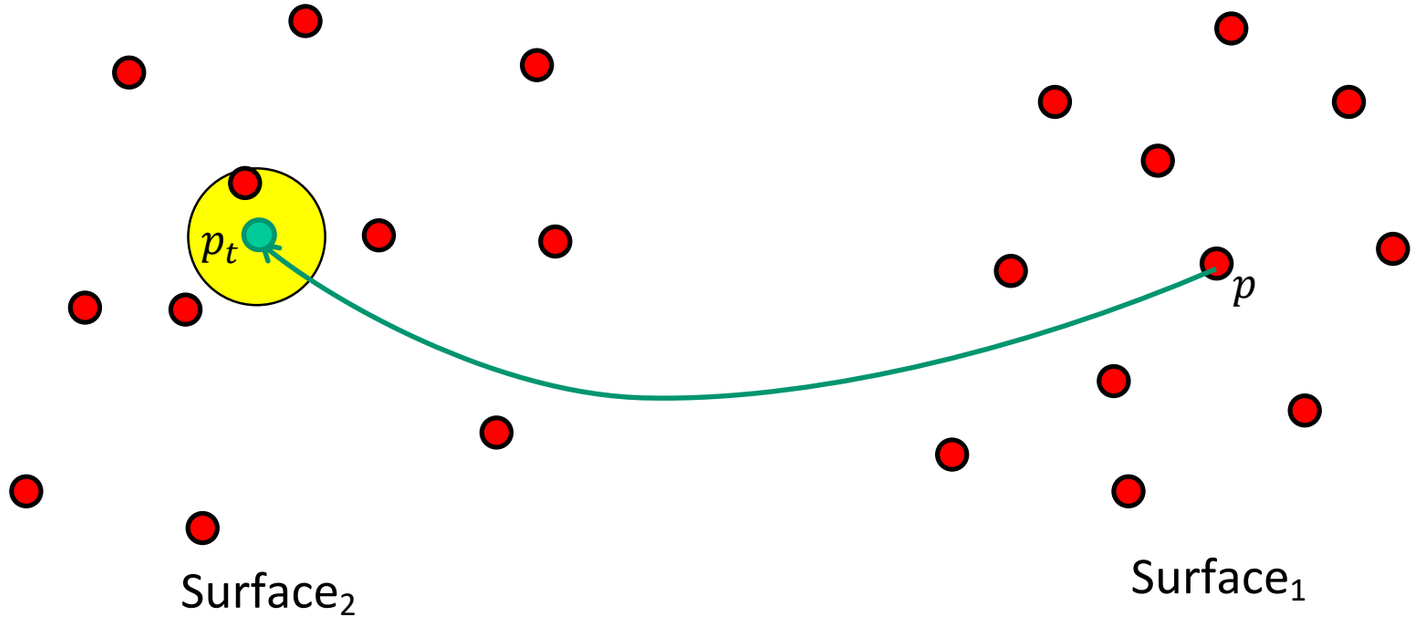
Registration: Automated Point-based Strategies

- **Commonly Adopted Point-Based Registration Methodologies without Exact Point-to-Point Correspondence:**
  - The Iterative Closest Point “ICP” (*Besl and Mckay, 1992*)
  - The Iterative Closest Patch “ICPatch” (*Habib et al., 2010*)
  - The Iterative Closest Projected Point “ICPP” (*Al-Durgham et al., 2011*)

- **Point-based registration methodologies require good initial approximations of the transformation parameters, which could be established through manual interaction.**

Registration: Automated Point-based Strategies

- **Iterative Closest Point (ICP):**



Note: ICP assumes point-to-point correspondence which is invalid among LiDAR points due to the irregular sampling nature of the points.

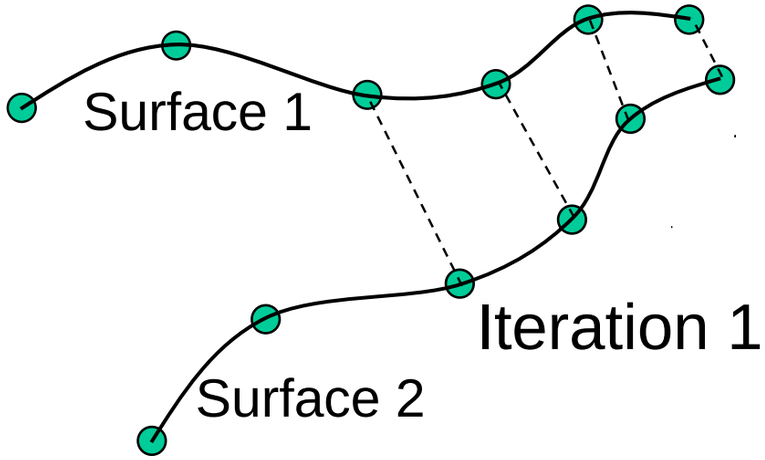
Registration: Automated Point-based Strategies

- **Iterative Closest Point (ICP):**

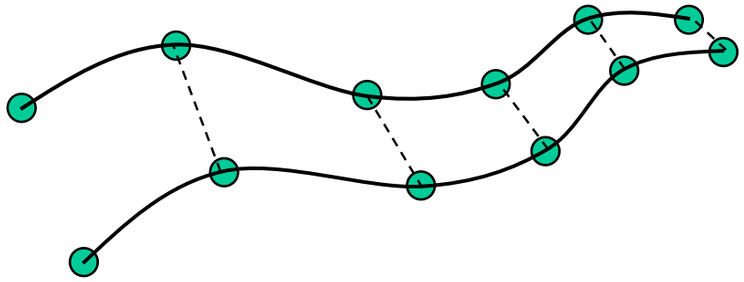
- Besl and McKay (1992)
  - Points as primitives
  - 3D rigid body transformation
  - Minimizes Euclidian distances
  - Performed iteratively

Problem:

- Exact point correspondences cannot be guaranteed when dealing with irregular point clouds.



Iteration 1

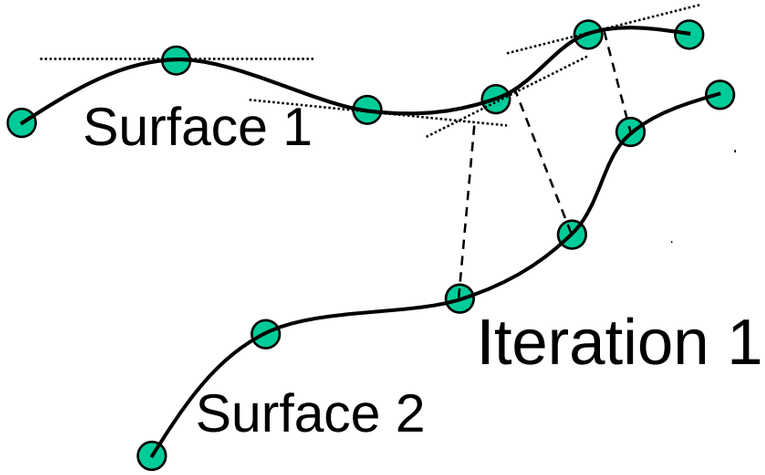


Iteration 2

Registration: Automated Point-based Strategies

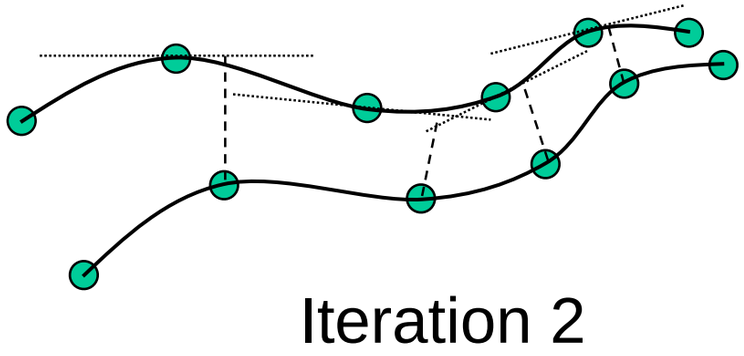
- **Iterative Closest Point (ICP):**

  - Chen and Medioni (1992)
    - Points and planes as primitives
    - Minimizes normal distances



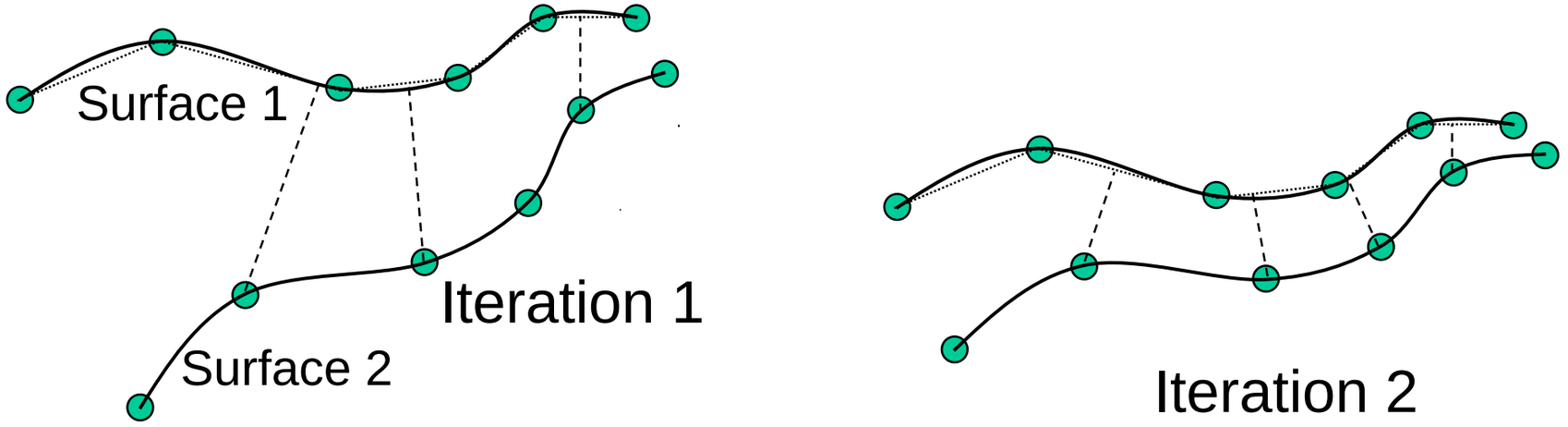
Prerequisite:

- The algorithm requires local plane fitting.



Registration: Automated Point-based Strategies

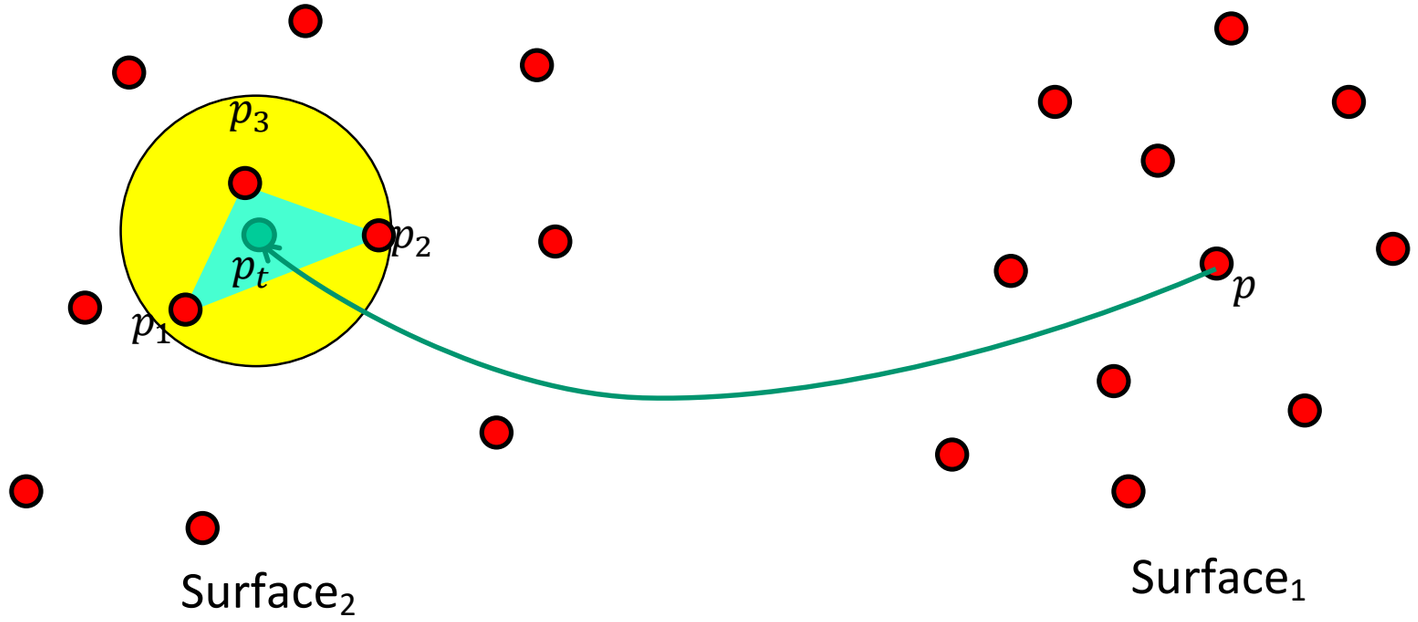
- **Iterative Closest Point (ICP): Variants**
  - Points and triangular irregular network (TIN) patches
  - 3D similarity transformation
  - Coplanarity constraint and modified weight matrix
  - Performed iteratively



ICPatch

Registration: Automated Point-based Strategies

- **Iterative Closest Patch (ICPatch):**

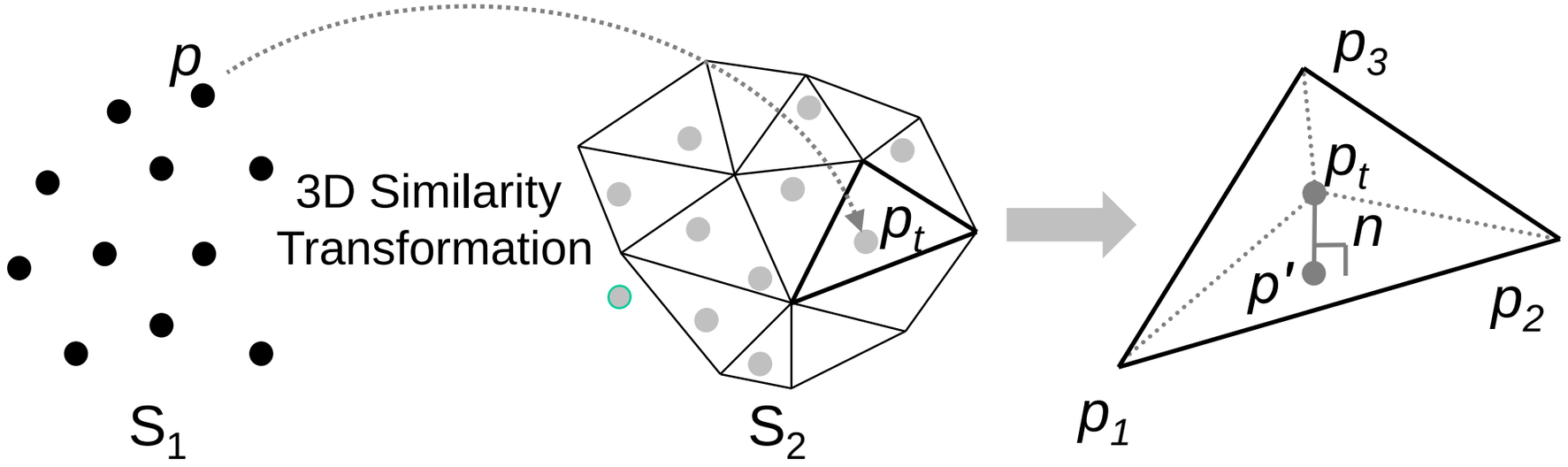


$$\boldsymbol{r_p^{s_2} = r_{s_1}^{s_2} + R_{s_1}^{s_2} r_p^{s_1}}$$

$$\boldsymbol{p_t = r_{s_1}^{s_2} + R_{s_1}^{s_2} p}$$

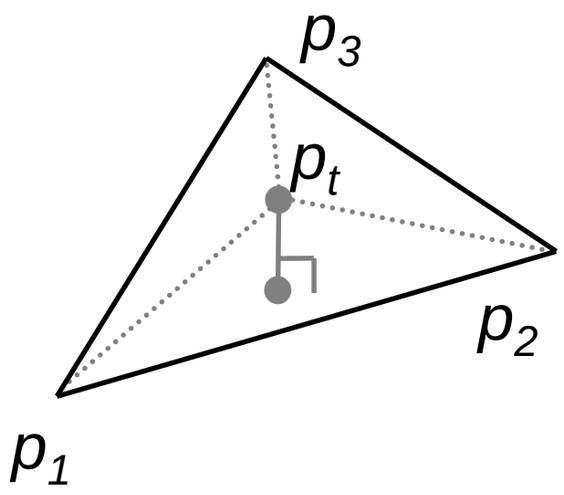
Registration: Automated Point-based Strategies

- **Iterative Closest Patch (ICPatch):**
  - Conditions for valid conjugate point-patch pairs:
    - ✓ Triangular patch $\Delta p_1 p_2 p_3$ must be the closest to the transformed point p_t, i.e. n=min.
    - ✓ The normal distance, n, must be within a threshold.
    - ✓ The projection of p_t, p', must fall within $\Delta p_1 p_2 p_3$.



Registration: Automated Point-based Strategies

- **Iterative Closest Patch (ICPatch):**
- **Similarity Measure: p_1, p_2, p_3 and p_t are assumed to be coplanar, i.e. the volume of the pyramid formed by vertices p_1, p_2, p_3 and p_t should be zero.**



$$\det\begin{bmatrix} X_{p_t} & Y_{p_t} & Z_{p_t} & 1 \\ X_{p_1} & Y_{p_1} & Z_{p_1} & 1 \\ X_{p_2} & Y_{p_2} & Z_{p_2} & 1 \\ X_{p_3} & Y_{p_3} & Z_{p_3} & 1 \end{bmatrix} = 0$$

$$\boldsymbol{p_t = r_{s_1}^{s_2} + R_{s_1}^{s_2} p}$$

Registration: Automated Point-based Strategies

- **Iterative Closest Projected Point (ICPP):**

  - For a point p in S_1, find the *closest* three points in S_2.
  - A match is established between a point in S_1 and a triangle (p_1, p_2, p_3) in S_2.

The pair (p_t, p') is used for matching through the conventional ICP techniques, thus named the ICPP.

$0 = r_2^m + R_2^m p' - (r_1^m + R_1^m p)$

Conditions:

- $p_t \in Convex(p_1, p_2, p_3, p_e)$
- Compatible surface normals