UAS-Based LiDAR Mapping

Video D

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LiDAR System Calibration

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Quality Assurance & Quality Control

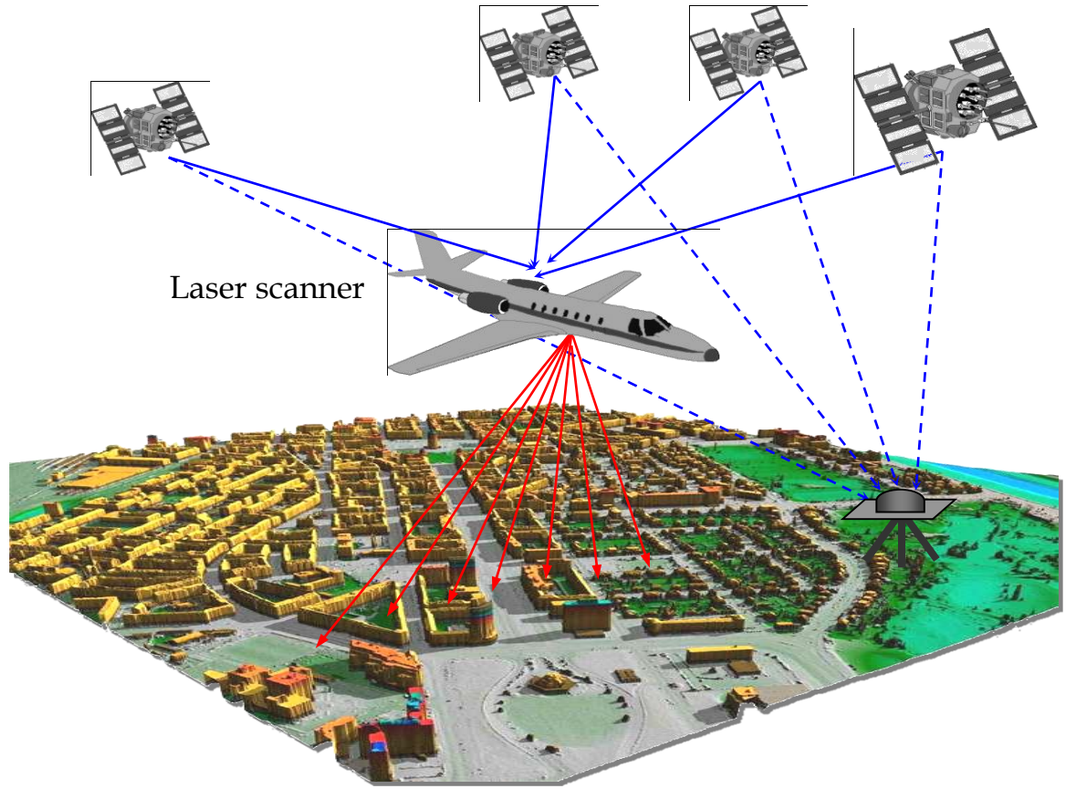
- **Quality Assurance (pre-mission):**
  - Management activities to ensure that a process, item, or service **will be** of the quality needed by the user
  - It deals with creating management controls that cover planning, implementation, and review of data collection.
  - Key activity in QA is the calibration procedure.
- **Quality Control (post-mission):**
  - Provide routines and consistent checks to ensure **available** data integrity, correctness, and completeness
  - Check whether the desired quality has been achieved

Quality Assurance & Quality Control

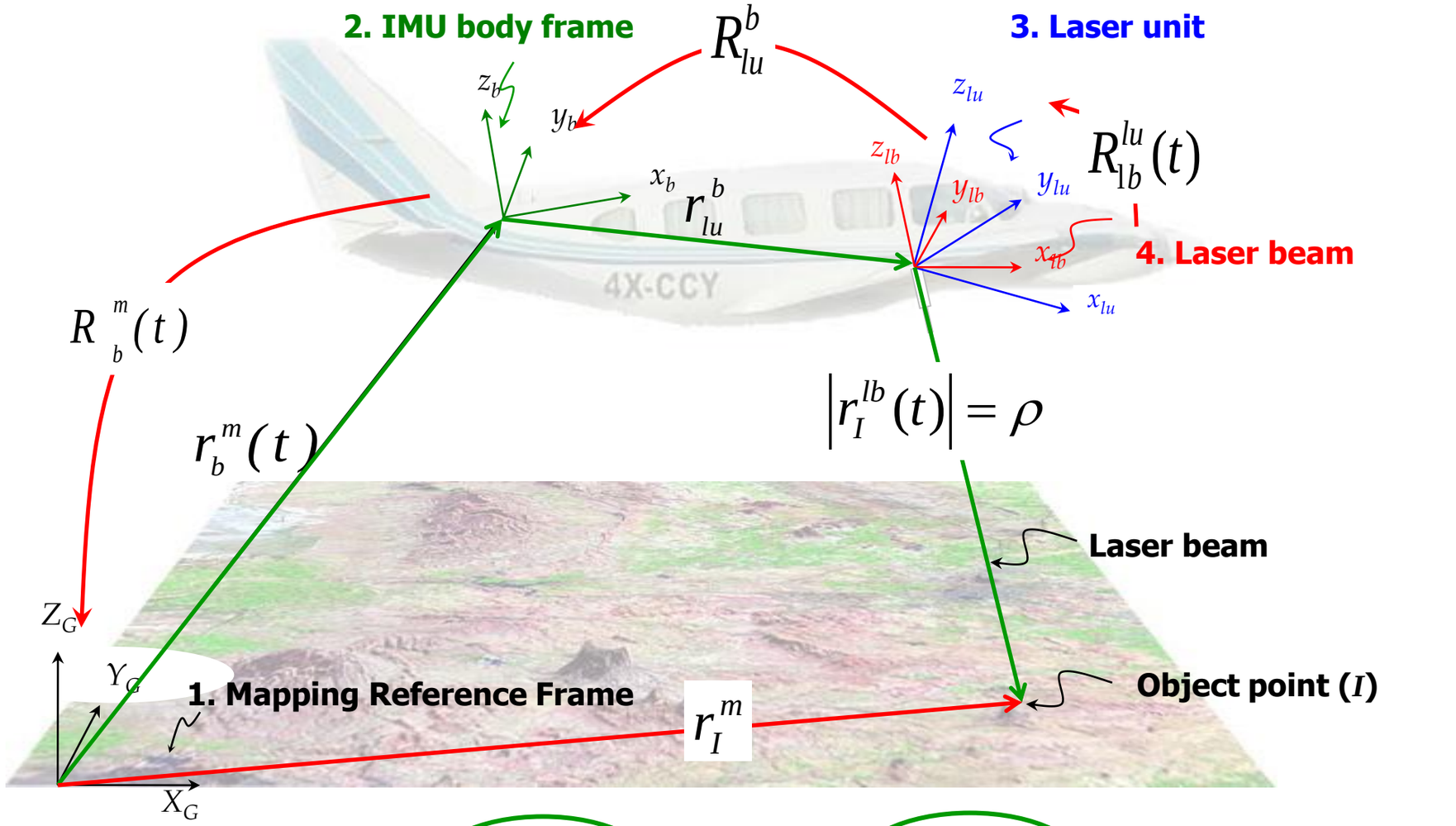
- **To develop effective QA/QC procedures, we need to understand the mechanism of the mapping process including:**
  - Data acquisition systems,
  - Error sources (random and systematic),
  - How to mitigate the impact of these error sources,
  - Nature of available data,
  - Data processing algorithms, and
  - Nature of delivered product.

LiDAR Quality Assurance

- **QA activities/measures include:**
  - Optimum mission time
  - Distance to GNSS base station
  - Flying height
  - Pulse repetition rate
  - Beam divergence angle
  - Scan angle
  - Percentage of overlap
  - System calibration
  - Stability analysis

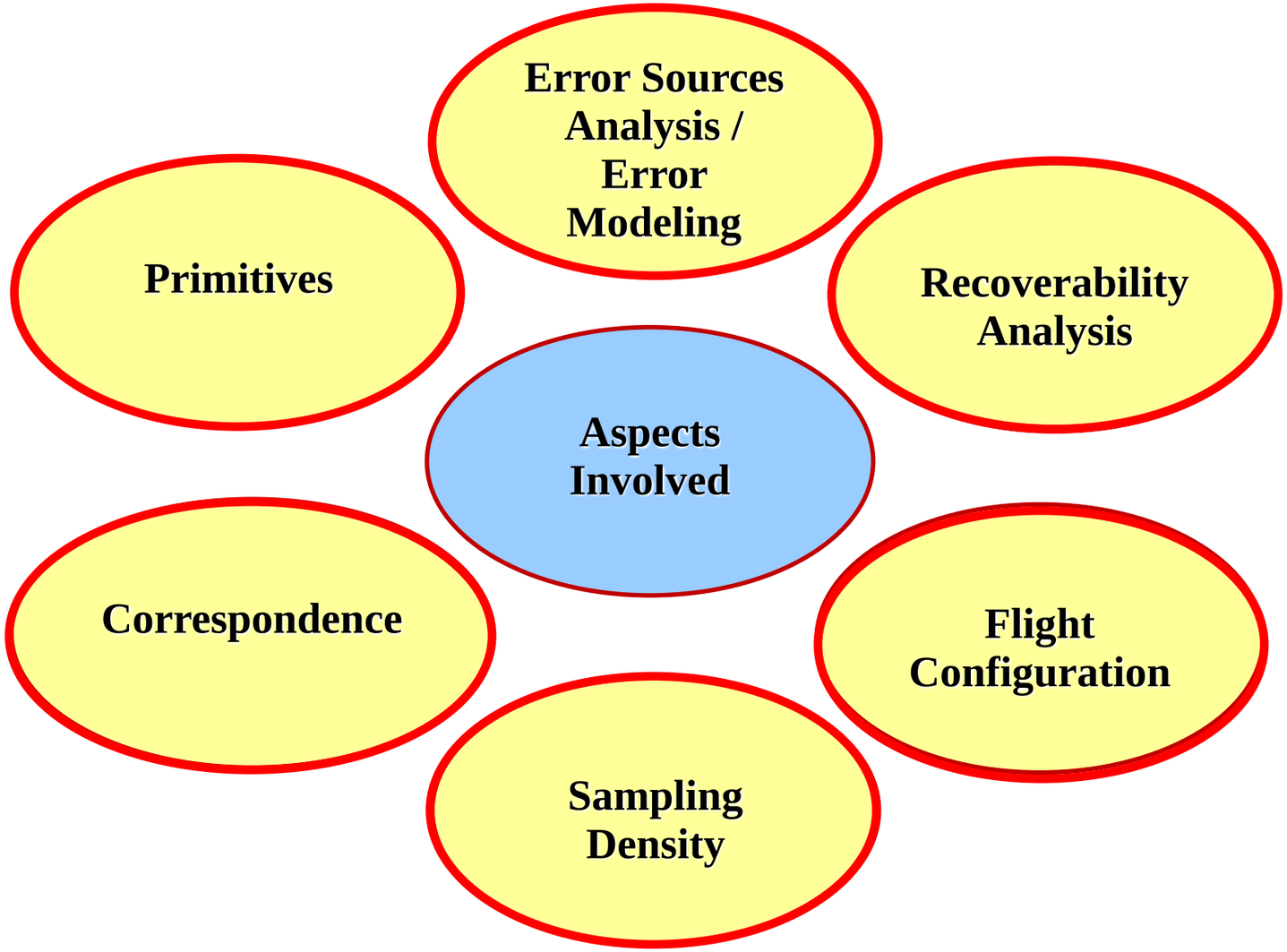


LiDAR QA: System Calibration



$$r_I^m = r_b^m(t) + R_b^m(t)\, r_{lu(\Delta X,\Delta Y,\Delta Z)}^{b} + R_b^m(t)\, R_{lu(\Delta\omega,\Delta\varphi,\Delta\kappa)}^{b}\, R_{lb(S_\alpha\alpha,S_\beta\beta)}^{lu}\, r_{I(\rho,\Delta\rho)}^{lb}$$

LiDAR QA: System Calibration



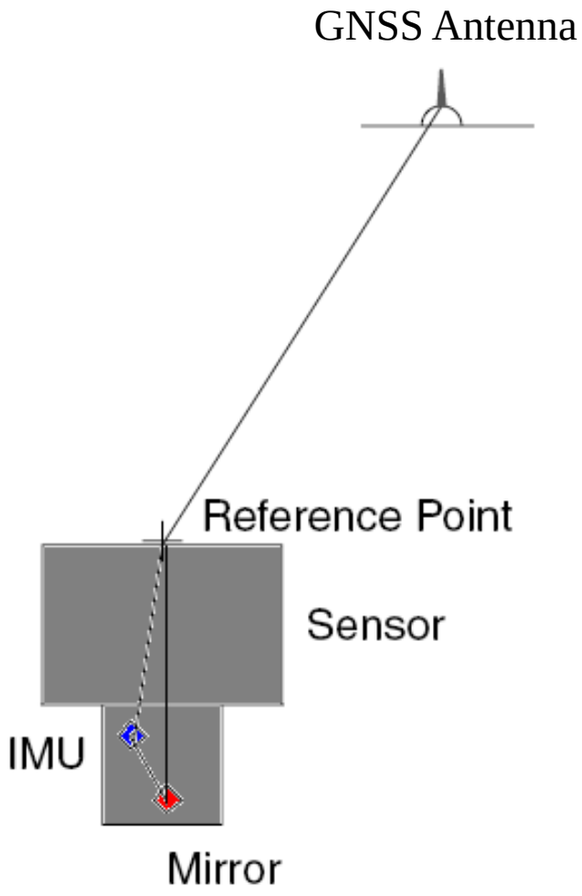
LiDAR QA: System Calibration

- **The calibration of a LiDAR system aims at the estimation of systematic errors, which describe the deviation from the assumed theoretical model.**
  - One can assume that the derived point cloud after system calibration are only contaminated by random errors.
- **Usually accomplished in several steps:**
  - Laboratory calibration,
  - Platform calibration, and
  - In-flight calibration

LiDAR QA: System Calibration

- **Laboratory Calibration (conducted by the system manufacturer)**
  - Calibration of individual system components,
  - Mirror to IMU misalignment,
  - Mirror to IMU lever arm, and
  - Mirror to reference point

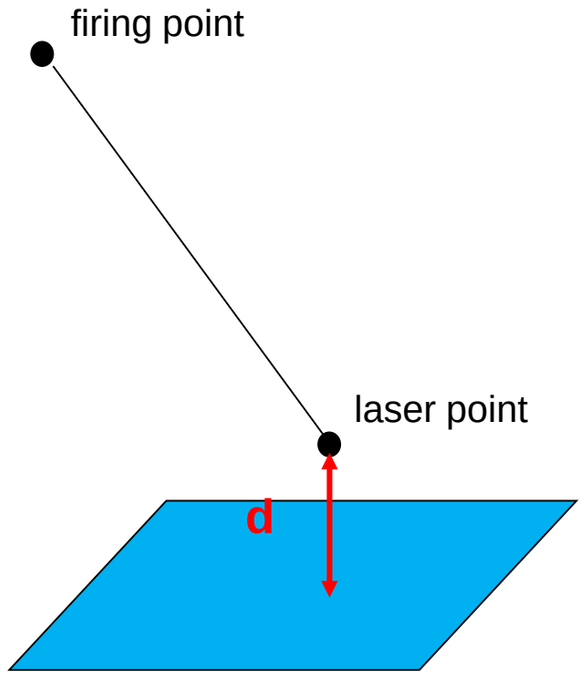
- **Platform Calibration**
  - Reference point to GNSS antenna



Usually refined during the in-flight calibration

LiDAR QA: System Calibration

- **In-Flight Calibration:**
  - Utilizes a calibration test field composed of control surfaces for the estimation of the LiDAR system parameters.
  - The observed discrepancies between the LiDAR and control surfaces are used to determine the system parameters (e.g., boresight roll and pitch angles and scale parameters).
- **<u>Target Function:</u> minimize the normal distance between the laser point footprint and a known (control) surface.**
- **Use the LiDAR equation to estimate the system parameters that minimize the cost of the target function.**
- **Caution: flight and control surface configurations should be carefully established.**



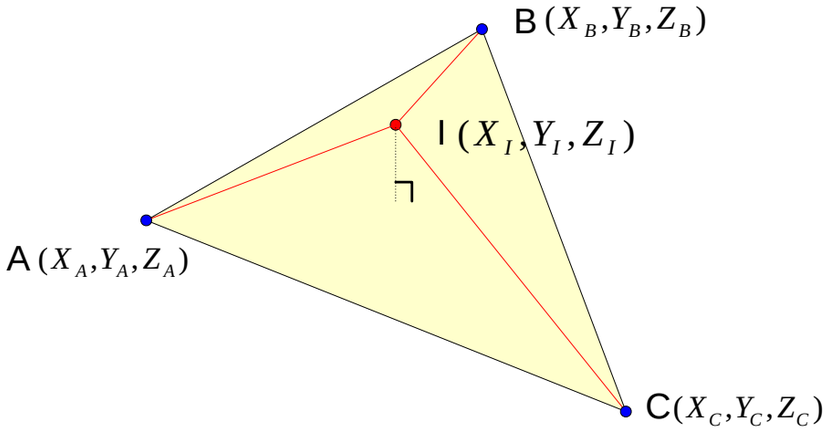
Only possible if we are dealing with a transparent system

LiDAR QA: System Calibration

$$\text{Volume} = \frac{\text{Determinan t (D)}}{6} = 0$$

$$\text{Normal Distance} = \frac{\text{Volume}}{\text{Area}}$$

$$D = \begin{vmatrix} X_I & Y_I & Z_I & 1 \\ X_A & Y_A & Z_A & 1 \\ X_B & Y_B & Z_B & 1 \\ X_C & Y_C & Z_C & 1 \end{vmatrix} = 0$$

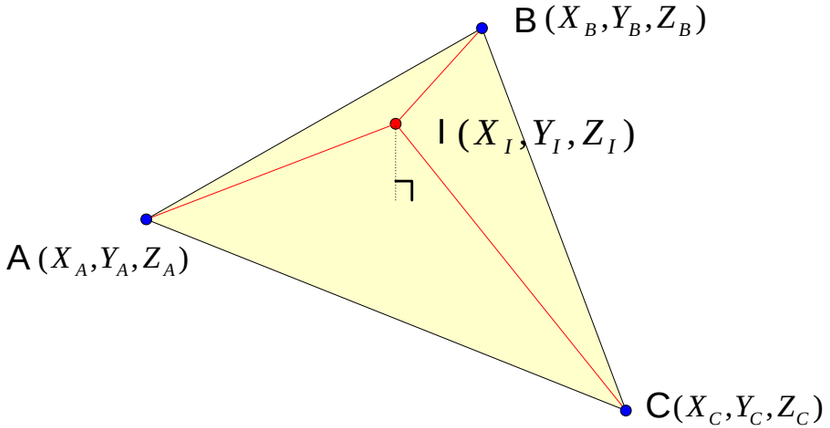


- (X_I, Y_I, Z_I) coordinates of laser beam footprint
- (X_A, Y_A, Z_A), (X_B, Y_B, Z_B), and (X_C, Y_C, Z_C) ground coordinates of the control patch

LiDAR QA: System Calibration

$$r_I^m = r_b^m(t) + R_b^m(t)\, r_{lu}^b + R_b^m(t)\, R_{lu}^b\, R_{lb}^{lu}(t)\, r_I^{lb}(t)$$

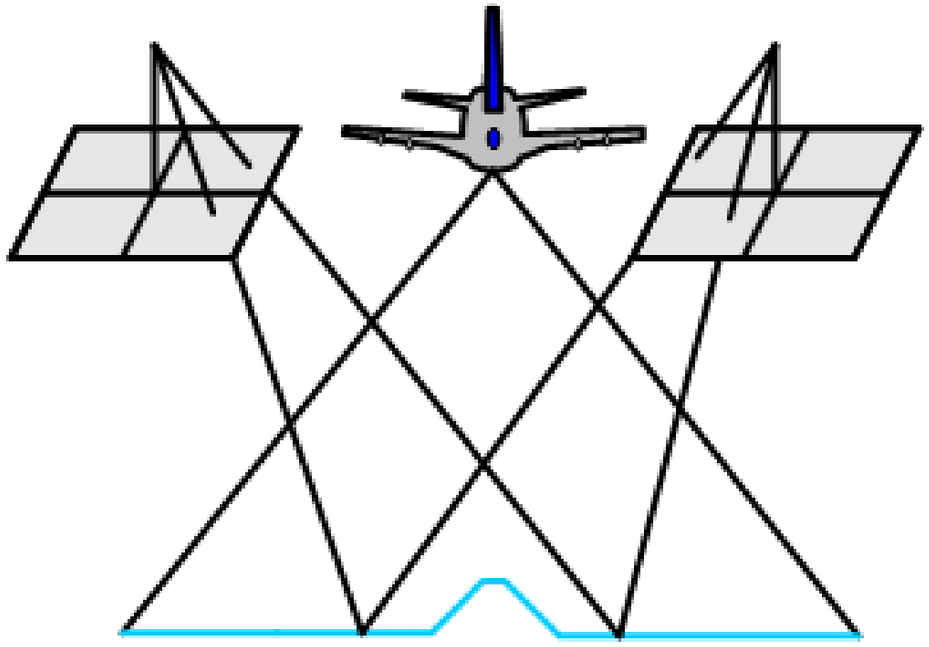
$$D = \begin{vmatrix} X_I & Y_I & Z_I & 1 \\ X_A & Y_A & Z_A & 1 \\ X_B & Y_B & Z_B & 1 \\ X_C & Y_C & Z_C & 1 \end{vmatrix} = 0$$



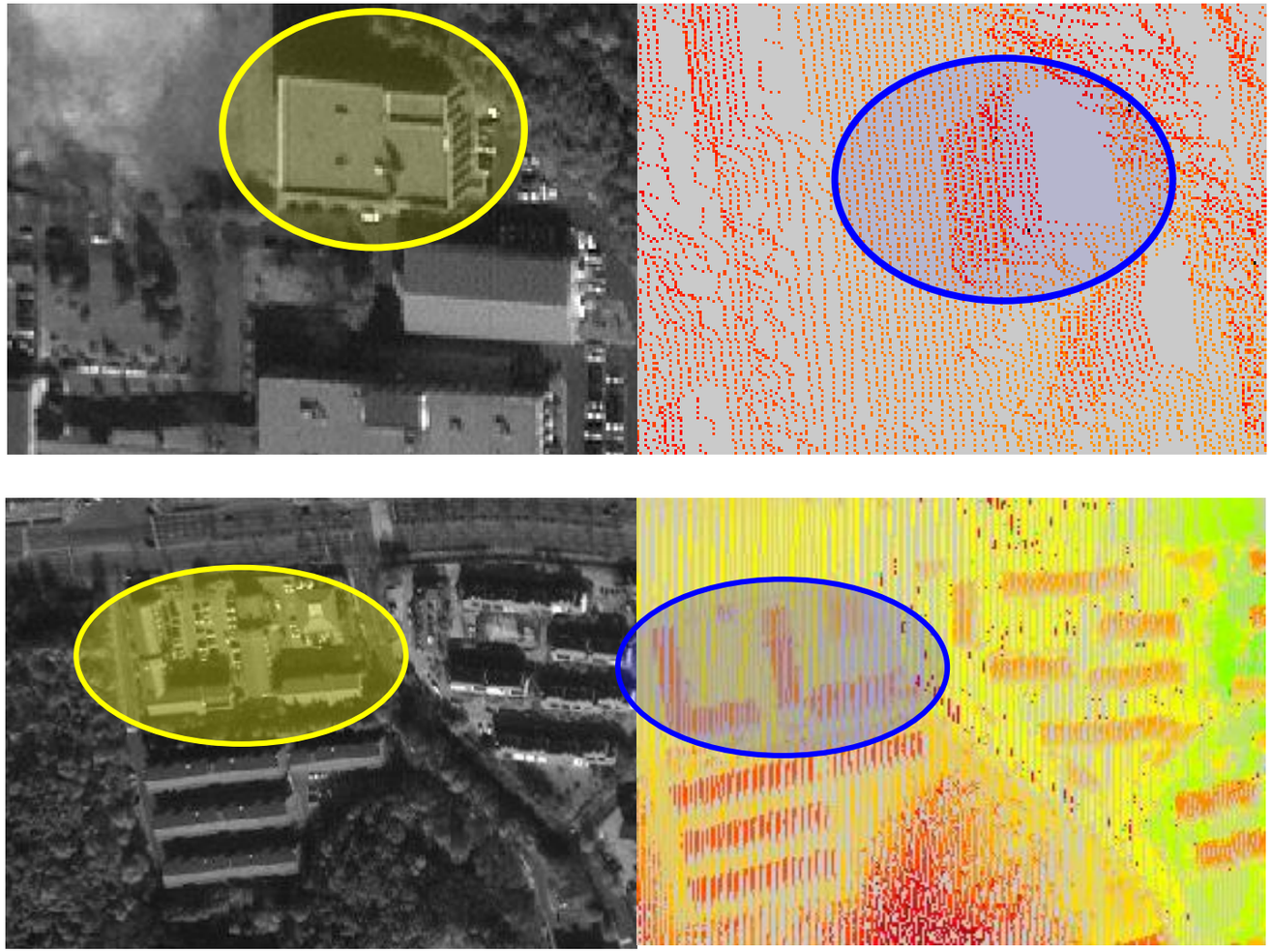
- Target function: determine the system parameters that minimize the determinant values for the given control patches.
- Challenges:
  - How can we acquire control surfaces?
  - LiDAR raw measurements $(r_b^m(t),\ R_b^m(t), R_{lb}^{lu}(t),\ r_I^{lb}(t))$ are needed (not always available).

LiDAR QA: System Calibration

- **The ground control surface can be generated from a well-calibrated and well-georeferenced photogrammetric system.**



LiDAR QA: System Calibration



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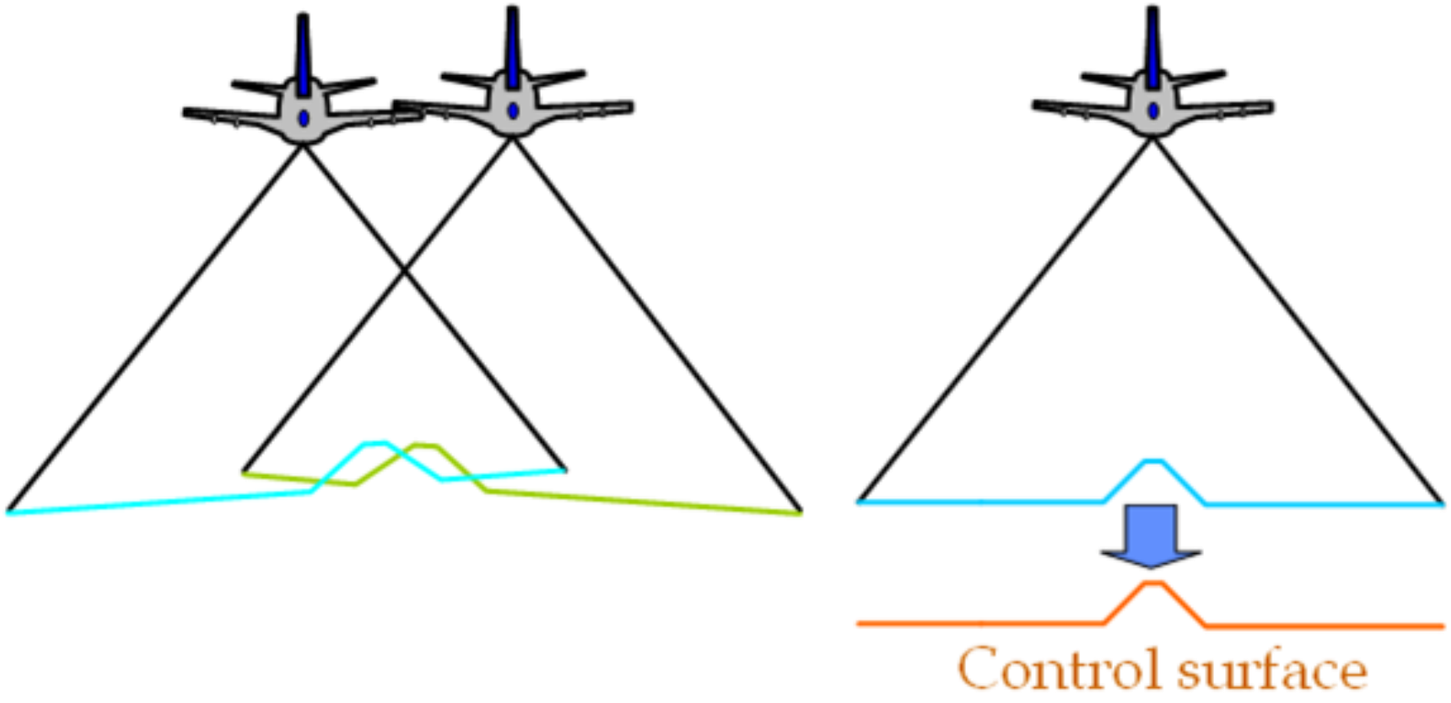
LiDAR QA: System Calibration

- **Status of current calibration methods:**
  - There is lack of a commonly accepted calibration methodology.
  - System raw measurements are required.
  - Estimated parameters are limited.
  - Manual and empirical approaches are utilized.
  - Calibration sites with control targets are required.
    - For example, buildings and runways
  - Calibration is not possible for end-users using point cloud coordinates in overlapping strips.

LiDAR QA: System Calibration

- **<u>Conceptual Basis:</u> Estimate the system parameters that minimize discrepancies between derived surfaces from multiple flight lines while reducing ground control requirements**
  - This process requires establishing the optimal flight configuration that maximizes the impact of biases in the system parameters.

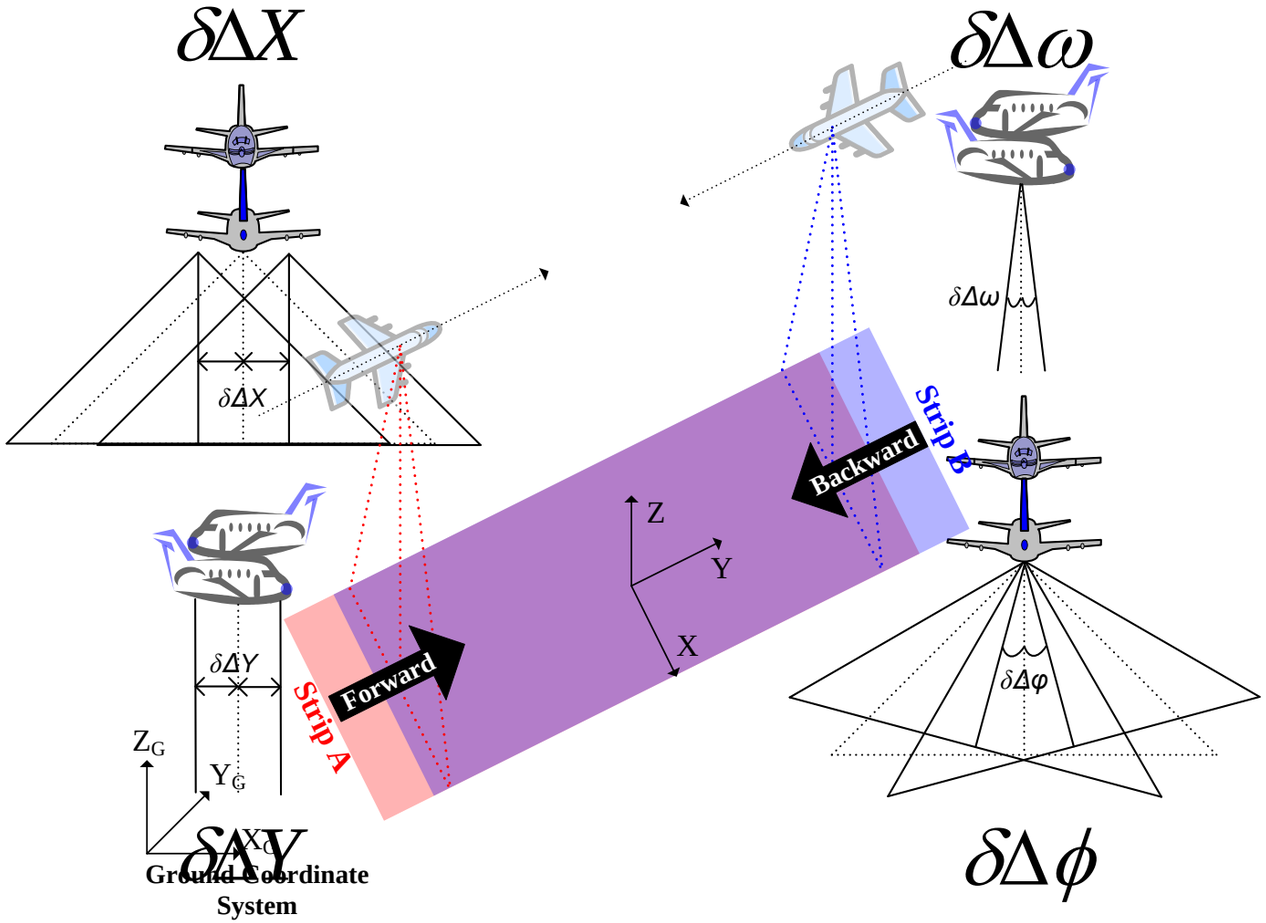


LiDAR QA: System Calibration

Optimum Flight Configuration

Opposite directions with 100% overlap ratio

Biases in system parameters
Lever-arm $\delta\Delta X$
Lever-arm $\delta\Delta Y$
Lever-arm $\delta\Delta Z$
Boresight $\delta\Delta\omega$
Boresight $\delta\Delta\varphi$
Boresight $\delta\Delta\kappa$
Range bias $\delta\Delta\rho$
Scale bias of S.A. δS

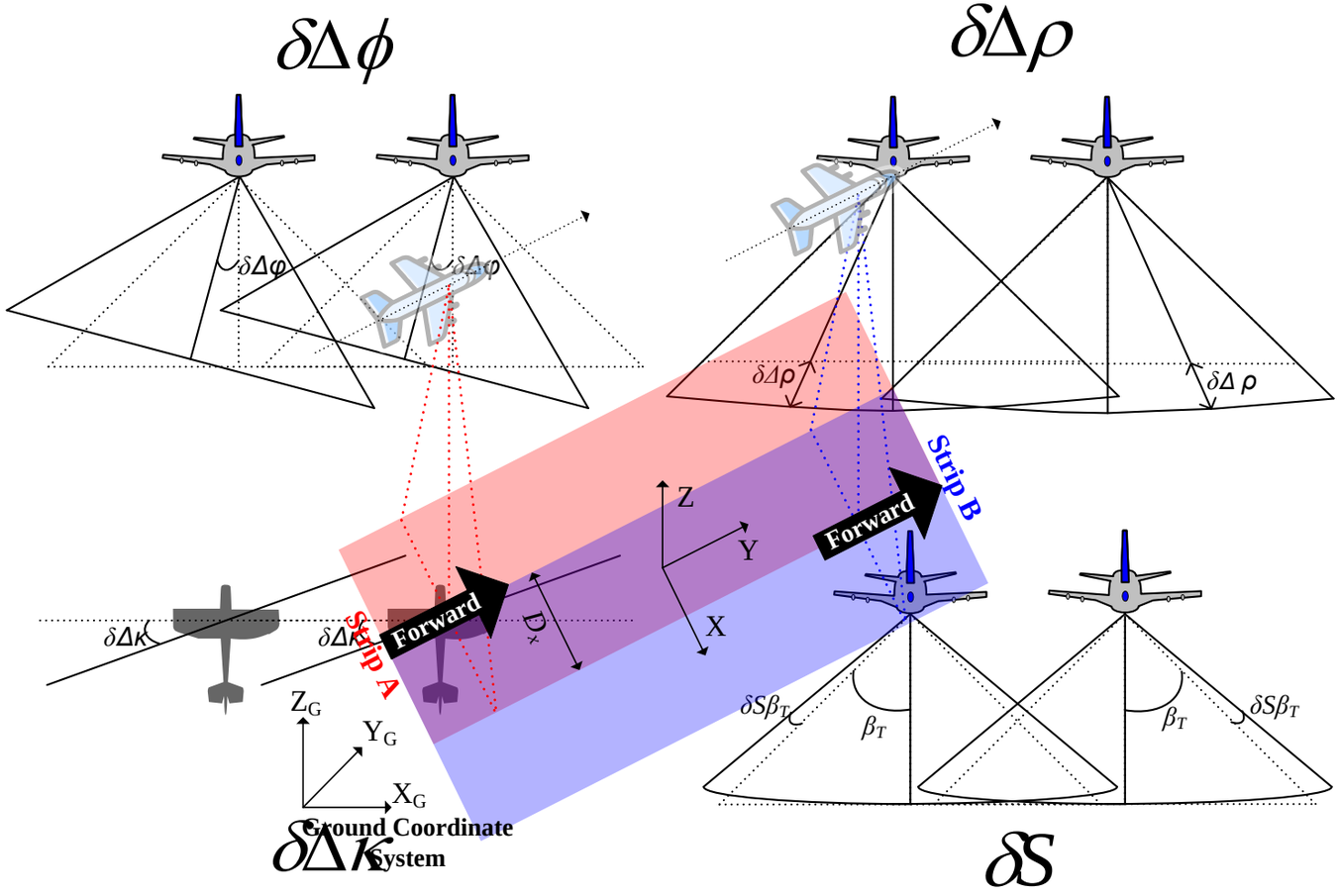


LiDAR QA: System Calibration

Optimum Flight Configuration

Same direction with some sidelap

Biases in system parameters
Lever-arm $\delta\Delta X$
Lever-arm $\delta\Delta Y$
Lever-arm $\delta\Delta Z$
Boresight $\delta\Delta\omega$
Boresight $\delta\Delta\varphi$
Boresight $\delta\Delta\kappa$
Range bias $\delta\Delta\rho$
Scale bias of S.A. δS



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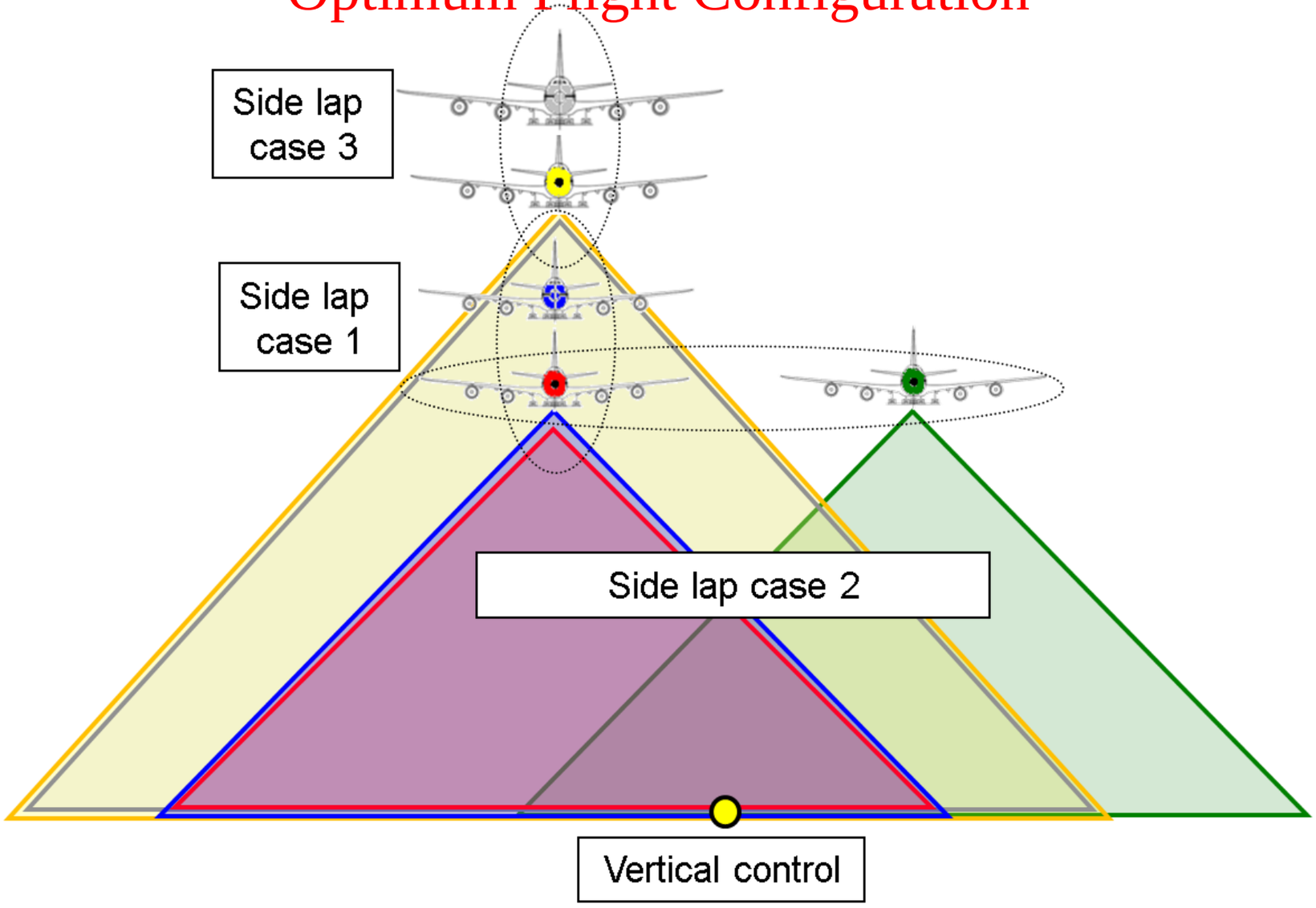
LiDAR QA: System Calibration

Optimum Flight Configuration



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LiDAR QA: System Calibration

- **Several LiDAR system calibration techniques can be introduced according to the nature of available data.**
  - **Simplified Calibration:** With some constraints on the flight configuration and ground coverage, we can conduct the calibration using only the point cloud coordinates.
  - **Quasi-Rigorous Calibration:** Using the trajectory data and time-tagged point cloud coordinates, we can estimate the system parameters with fewer constraints on the flight configuration.
  - **Rigorous Calibration:** With the availability of raw measurements, the calibration can be conducted without any assumptions regarding the flight configuration and ground coverage.

LiDAR QA: System Calibration

Simplified Calibration

- LiDAR Data in Overlapping Parallel Strips
  - ✓ Point cloud coordinates
  - ✓ Raw measurements are not necessarily available

Overlapping strips

Discrepancies

3D Transformation

Rotation

Shifts

→ **Calibration Parameters**

LiDAR QA: System Calibration

Simplified Calibration

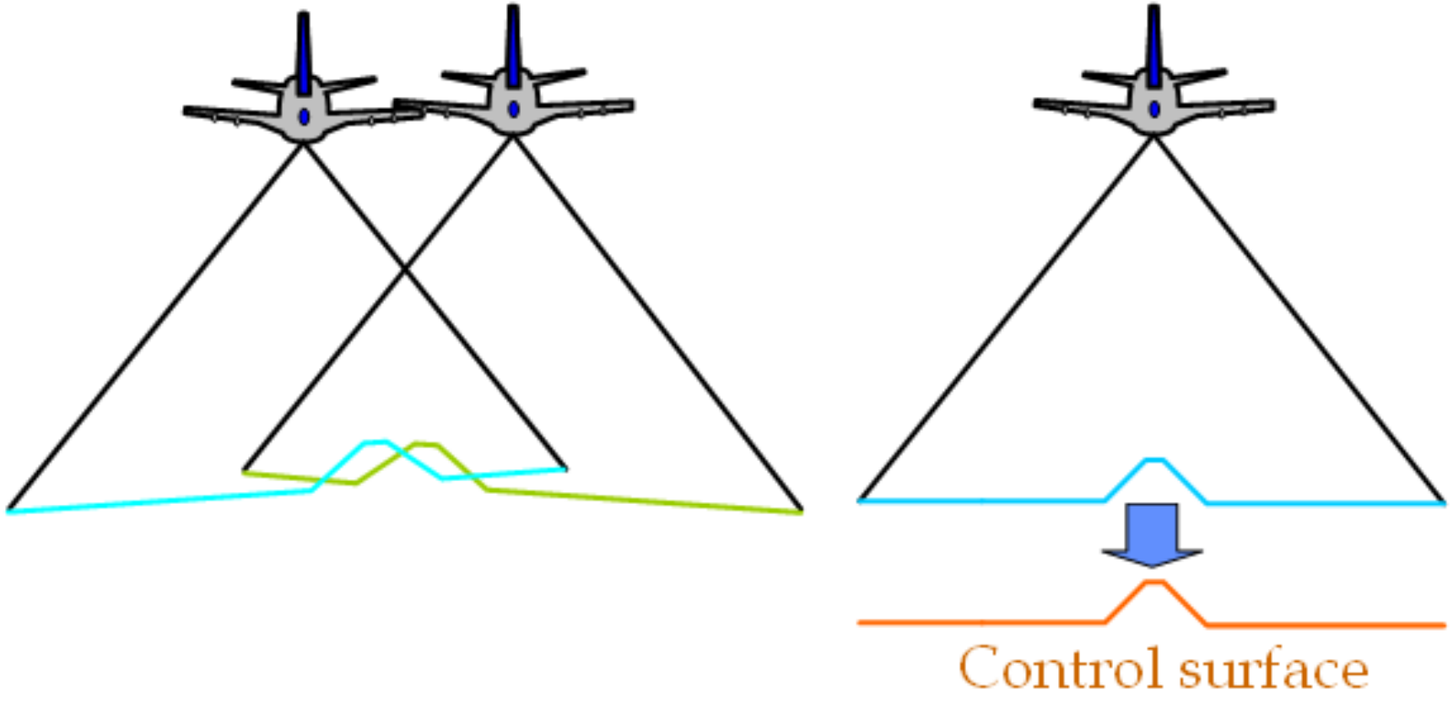
- LiDAR Data in Overlapping Parallel Strips
  - ✓ Point cloud coordinates
  - ✓ Raw measurements are not necessarily available

- Assumptions:
  - Linear scanner,
  - Vertical scanner,
  - Parallel flight lines,
  - Terrain-height variations are minimal compared to the flying height, and
  - Small biases in the boresight angles
- Can handle any type of terrain coverage
- Cannot handle control points

LiDAR QA: System Calibration

Quasi-Rigorous Calibration

- LiDAR Data in Overlapping Strips
  - ✓ Point cloud coordinates with the time tag
  - ✓ Time-tagged trajectory



LiDAR QA: System Calibration

Quasi-Rigorous Calibration

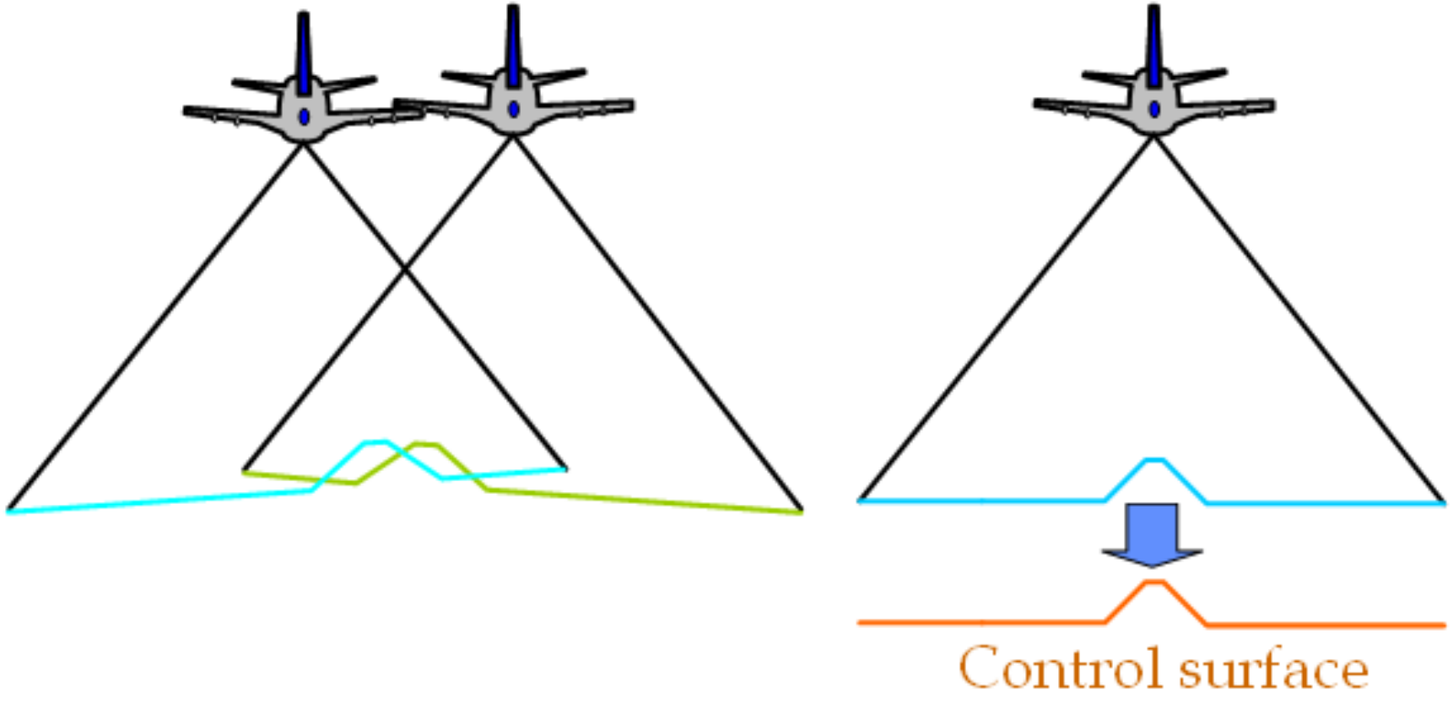
- LiDAR Data in Overlapping Strips
  - ✓ Point cloud coordinates with the time tag
  - ✓ Time-tagged trajectory

- Assumptions:
  - Vertical scanner,
  - Small biases in the boresight angles
- Can handle parallel & cross strips
- Can handle any type of terrain coverage
- Can handle control points

LiDAR QA: System Calibration

Rigorous Calibration

- LiDAR Data in Overlapping Strips
  - ✓ Point cloud coordinates together with the system raw measurements (position and the attitude of each pulse as well as the measured scan angles and ranges)



LiDAR QA: System Calibration

Rigorous Calibration

- LiDAR Data in Overlapping Strips
  - ✓ Point cloud coordinates together with the system raw measurements (position and the attitude of each pulse as well as the measured scan angles and ranges)

- Assumptions:
  - None
- Can handle parallel & cross strips
- Can handle any type of terrain coverage
- Can handle control points

LiDAR System Calibration: Target Setup

LiDAR Calibration Flight

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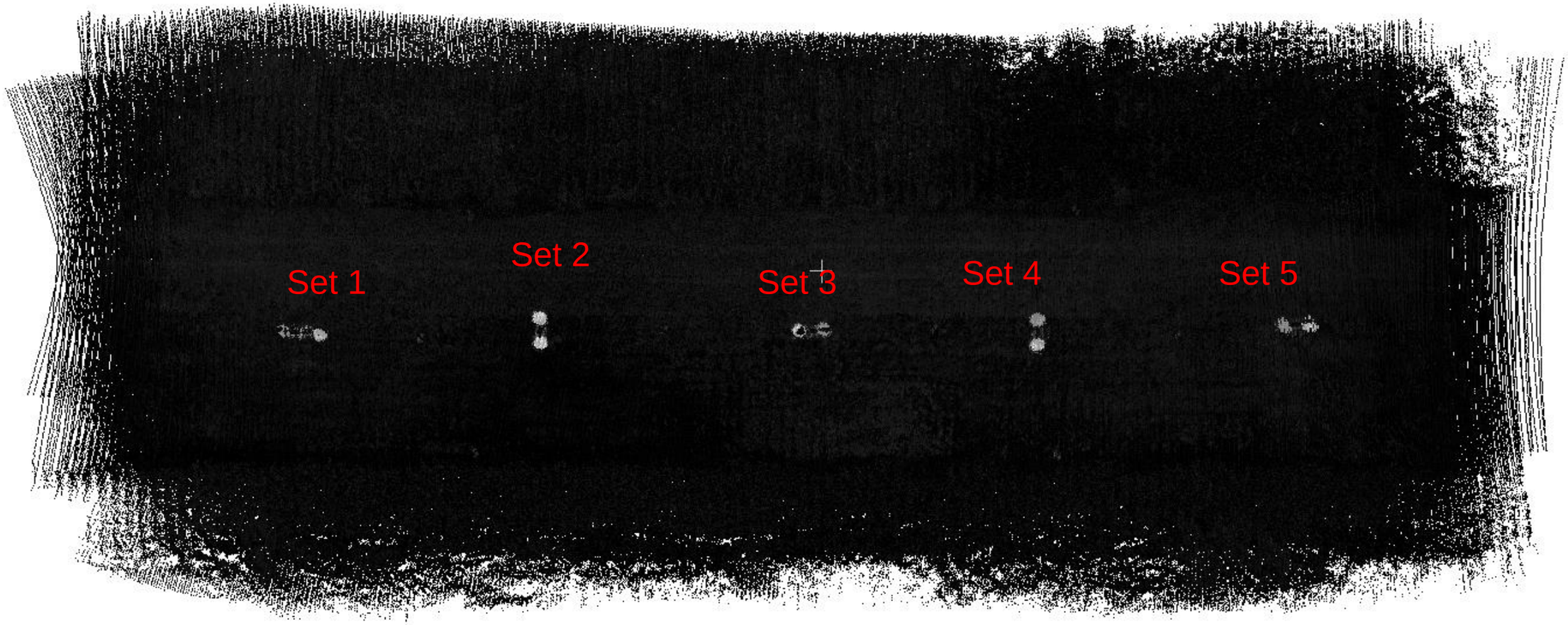
LiDAR Mapped Area – Before Calibration

North



- Colored by Intensity
- 9 Tracks
- APX15 & VLP16-2
- Range = 70 m
- Collected on 2016/10/25

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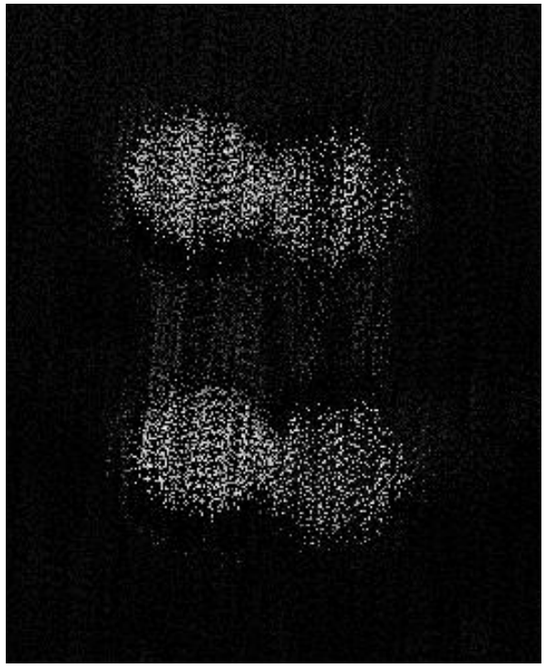
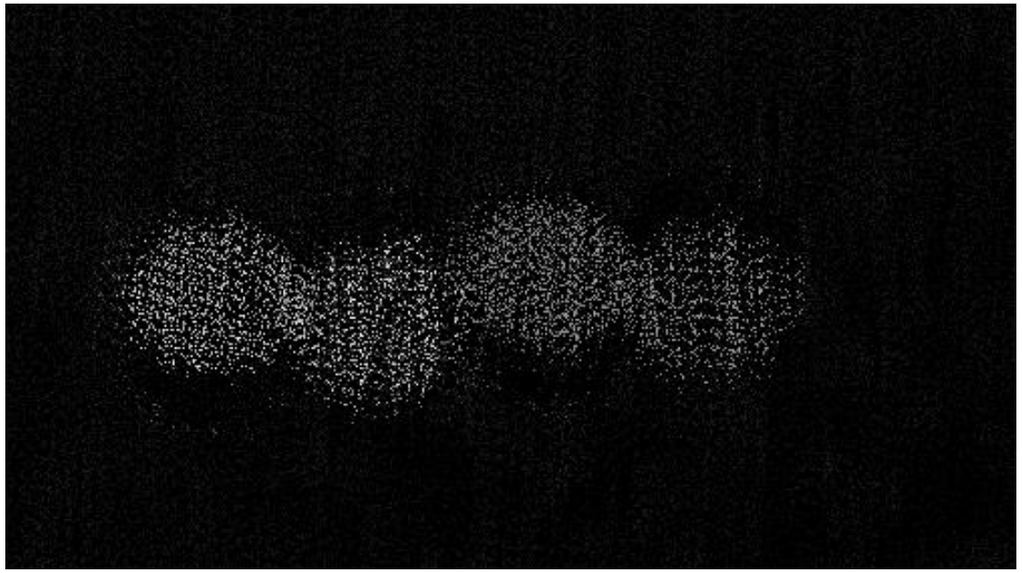
Target Boards – Before Calibration



- Target set 2 (North-south direction)

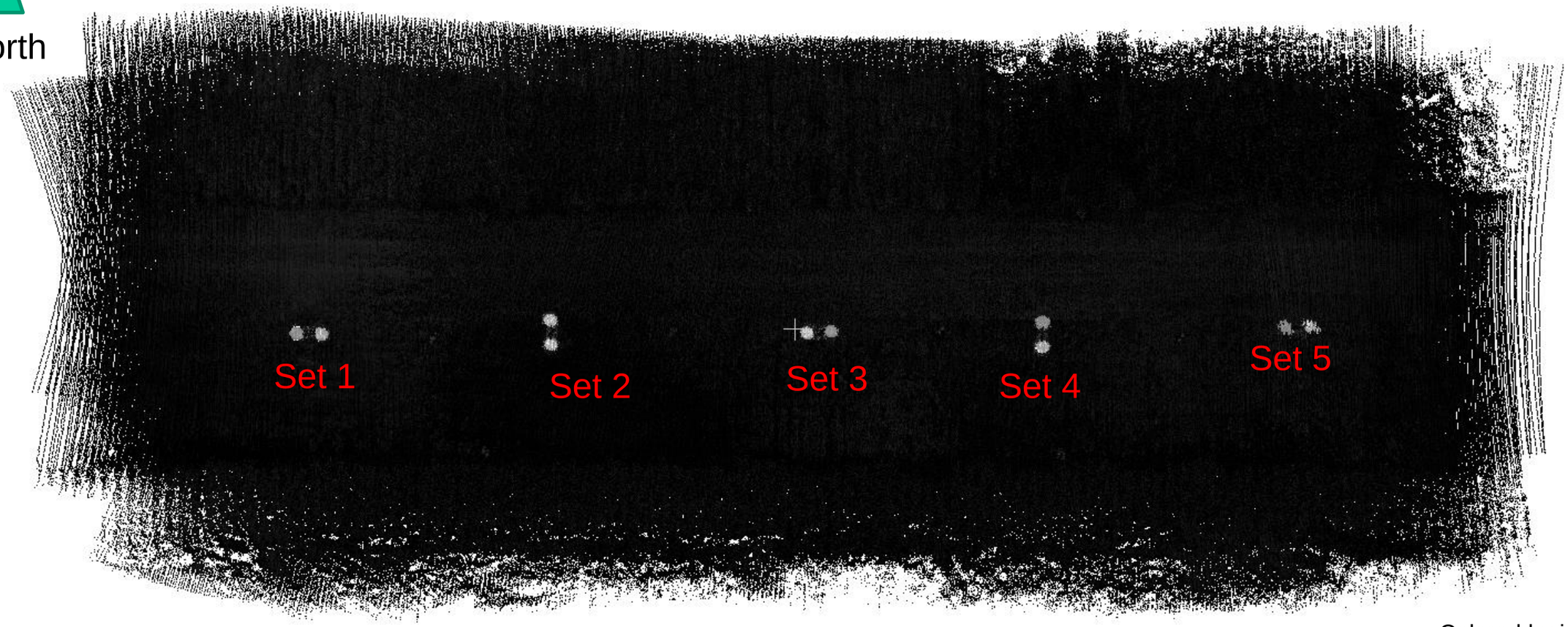


- Target set 3 (East-west direction)

Note: From the above figure, we can see that there are multi-versions of every target.

LiDAR Mapped Area – After Calibration

North



- Colored by intensity
- 9 Tracks
- APX15 & VLP16-2
- Range = 70 m
- Collected on 2016/10/25

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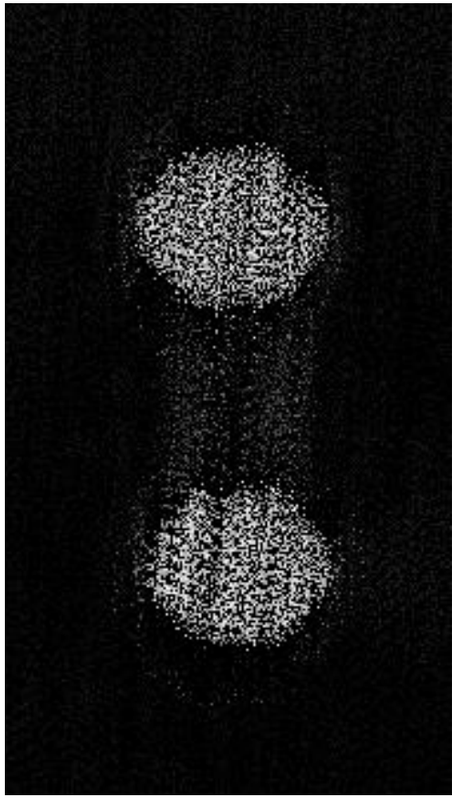
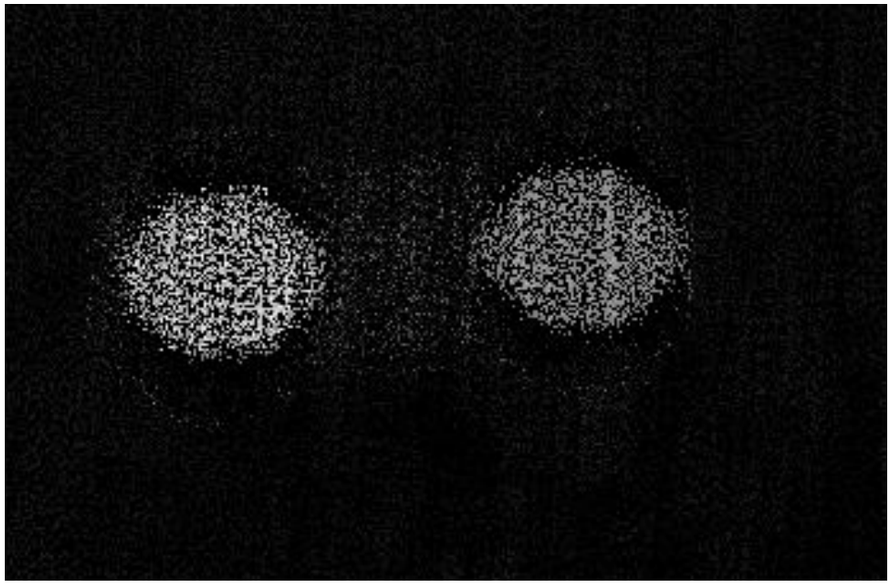
Target Boards – After Calibration



- Target set 2 (North-south direction)



- Target set 3 (East-west direction)