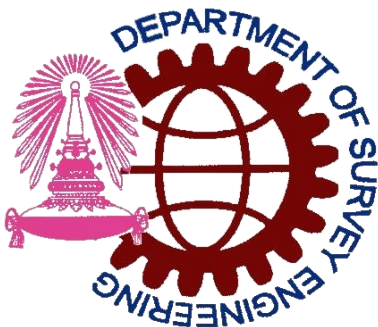## CA502 SN:CA205R202115 (Calibrated on 05/11/2022)

รายงานผลการวัดสอบทางเรขาคณิตสำหรับระบบกล้องเฉียง
ติดตั้งบนยูเอวี

Geometric camera calibration report for UAV-equipped

oblique camera system

PCV & LS Lab

Department of Survey Engineer,

Faculty of Engineering,

Chulalongkorn University

รายงานผลการวัดสอบทางเรขาคณิตสำหรับระบบกล้องเฉียงติดตั้งบนยูเอวี

Geometric camera calibration report for UAV-equipped oblique camera system

จัดทำโดย

รศ.ดร.ไพศาล สันติธรรมนนท์ Phisan Santitamnont (Dr.-Ing., Leibniz Hannover)

นายถิรวัฒน์ บรรณกุลพิพัฒน์ Thirawat Bannakulpiphat (M.Eng Chula)

ภาควิชาวิศวกรรมสำรวจ

คณะวิศวกรรมศาสตร์  จุฬาลงกรณ์มหาวิทยาลัย

รศ. ดร. ไพศาล สันติธรรมนนท์ และ นายถิรวัฒน์ บรรณกุลพิพัฒน์

## Traceability

This calibration report documents the International System of Units (SI) and calibration procedures of the 5-camera rig system. The 5-camera comprises a centered 'NADIR' camera and the other four rigged oblique-camera, namely 'FRONT', 'REAR', 'LEFT', and 'RIGHT'. Providing rig parameters relative to the 'nadir' camera from the manufacturer, four translations were constrained with a weight of 5 millimeters and the Euler's rotations were weight with 5 degrees. In the calibration field, 48 ground control points (GCP) and checkpoints (CP) were erected and accurately measured by GNSS RTK with 3.5- and 6.5-centimeter accuracy for the horizontal and vertical components. The parameters f, cx, cy, R1, R2, R3, T1, and T2 have opted for camera modeling. All photogrammetric measurements for tie-points were accomplished by Pix4D mapper software and GCP and CP points were measured by visual marking. Then all parameters and unknowns were solved simultaneously together with the aforementioned constraints. All uncertainty criterions are empirically defined from long-term observations.

<div style="text-align: right;">

Phisan Santitamnont (Dr.-Ing)

Thirawat Bannakulpiphat (M.Eng.)

</div>

# Photogrammetric Block Information

| | |
|---|---|
| Photogrammetrist<br><br>UAV Camera Operator | 1. Phisan Santitamnont (Dr.-Ing)<br>2. Thirawat Bannakulpiphat (M.Eng.)<br>3. Jakkrapong Puntho |
| Flight Date and Time | 05/11/2022 (After 12.00 PM.) |
| Report Date / Release | 12/12/2022 |
| Test Field | Geodetic GNSS and UAV Testing Field, Chulalongkorn University |
| Location | Saraburi, Thailand (Latitude: 14°.5236N, Longitude: 101°.0235E) |
| Aircraft | JOUAV CW-15 |
| Camera | CA502-R 120MP |
| Block Name | Full block CU-SBR |
| Number of Photo | 6,065 (1,213 photo per camera) |
| Nadir Photo Overlap (%) | 80% |
| Nadir Photo Side-lap (%) | 80% |
| Number of Rig Station | 1,213 |
| Number of Flight-Strip | 27 |
| Number of GCP/CP | Total 48 |
| Photogrammetric Processing Software | Pix4D Mapper version 4.7.5 |

# Camera Specification

| Parameter | Description |
|---|---|
| Number of CCD | 5 pcs |
| CMOS Size | 23.5 × 15.6 mm (APS-C) |
| Pixel | 24 MP x 5 |
| Resolution (Single CCD) | 6000 x 4000 |
| Exposure Interval | 0.8 s |
| Type of Lens | Aspheric |
| Focal Length (Ortho/Oblique) | 28 mm/43 mm |
| Weight | 950 g |
| Damping Structure | Internal |
| Power Supply | External |
| Data Storage | 5 x 128 GB SD Card |

# Quality Report

## 1. Camera position from manufacturer note

| Camera | X (mm) | Y (mm) | Z (mm) | Camera |
|---|---|---|---|---|
| | +30.00 | -425.00 | -229.38 | Ortho view |
| | +30.00 | -476.48 | -251.56 | Left view |
| CA502R | +30.00 | -373.86 | -251.26 | Right view |
| | +81.14 | -425.00 | -251.26 | Forward view |
| | -21.14 | -425.00 | -251.26 | Backward view |

## 2. Initial and adjusted rig relative parameters

**Camera Rig «CA502_OBLIQUE_RIG» Relatives. Images: 6065**

| | Transl X[m] | Transl Y[m] | Transl Z[m] | Rot X[degree] | Rot Y[degree] | Rot Z[degree] |
|---|---|---|---|---|---|---|
| CA502R_NADIR_28.0_6000x4000 (RGB) | Reference Camera | | | | | |
| CA502R_RIGHT_43.0_6000x4000 (RGB) | | | | | | |
| Initial Values | 0.000 | 0.051 | -0.022 | 0.000 | -45.000 | -90.000 |
| Optimized values | 0.000 | 0.051 | -0.022 | 0.316 | -45.746 | -89.986 |
| Uncertainties (sigma) | | | | 0.009 | 0.007 | 0.014 |
| CA502R_LEFT_43.0_6000x4000 (RGB) | | | | | | |
| Initial Values | 0.000 | -0.051 | -0.022 | 0.000 | 45.000 | 90.000 |
| Optimized values | 0.000 | -0.051 | -0.022 | 0.389 | 44.285 | 89.550 |
| Uncertainties (sigma) | | | | 0.010 | 0.007 | 0.014 |
| CA502R_REAR_43.0_6000x4000 (RGB) | | | | | | |
| Initial Values | -0.051 | 0.000 | -0.022 | 45.000 | 0.000 | 0.000 |
| Optimized values | -0.051 | 0.000 | -0.022 | 43.396 | -0.884 | 0.082 |
| Uncertainties (sigma) | | | | 0.007 | 0.002 | 0.010 |
| CA502R_FRONT_43.0_6000x4000 (RGB) | | | | | | |
| Initial Values | 0.051 | 0.000 | -0.022 | -45.000 | 0.000 | 180.000 |
| Optimized values | 0.051 | 0.000 | -0.022 | -44.886 | -0.357 | 179.113 |
| Uncertainties (sigma) | | | | 0.010 | 0.013 | 0.001 |

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Evaluation result passed:

| Uncertainty | Tx, Ty, Tz (mm) | Rot X (degrees) | Rot Y (degrees) | Rot Z (degrees) |
|---|---|---|---|---|
| Criterion | Constraint | 0.015 | 0.015 | 0.015 |
| Passed | ✅ | ✅ | ✅ | ✅ |
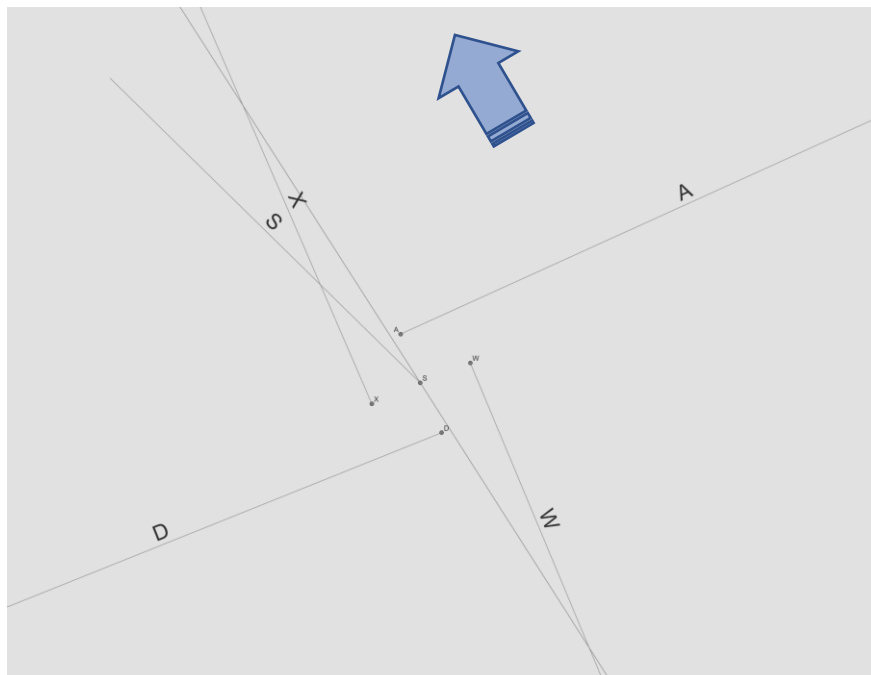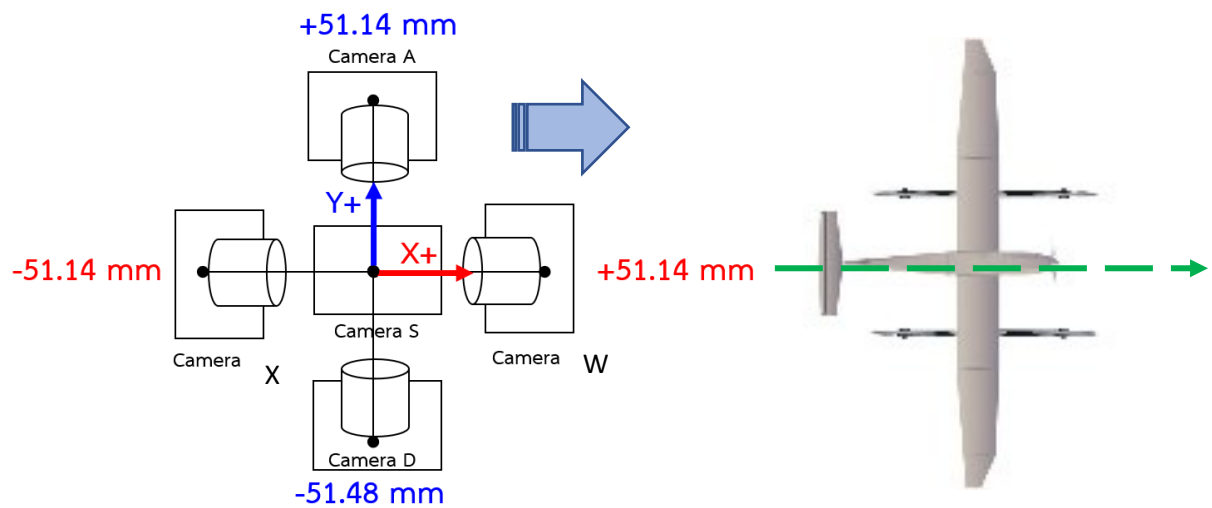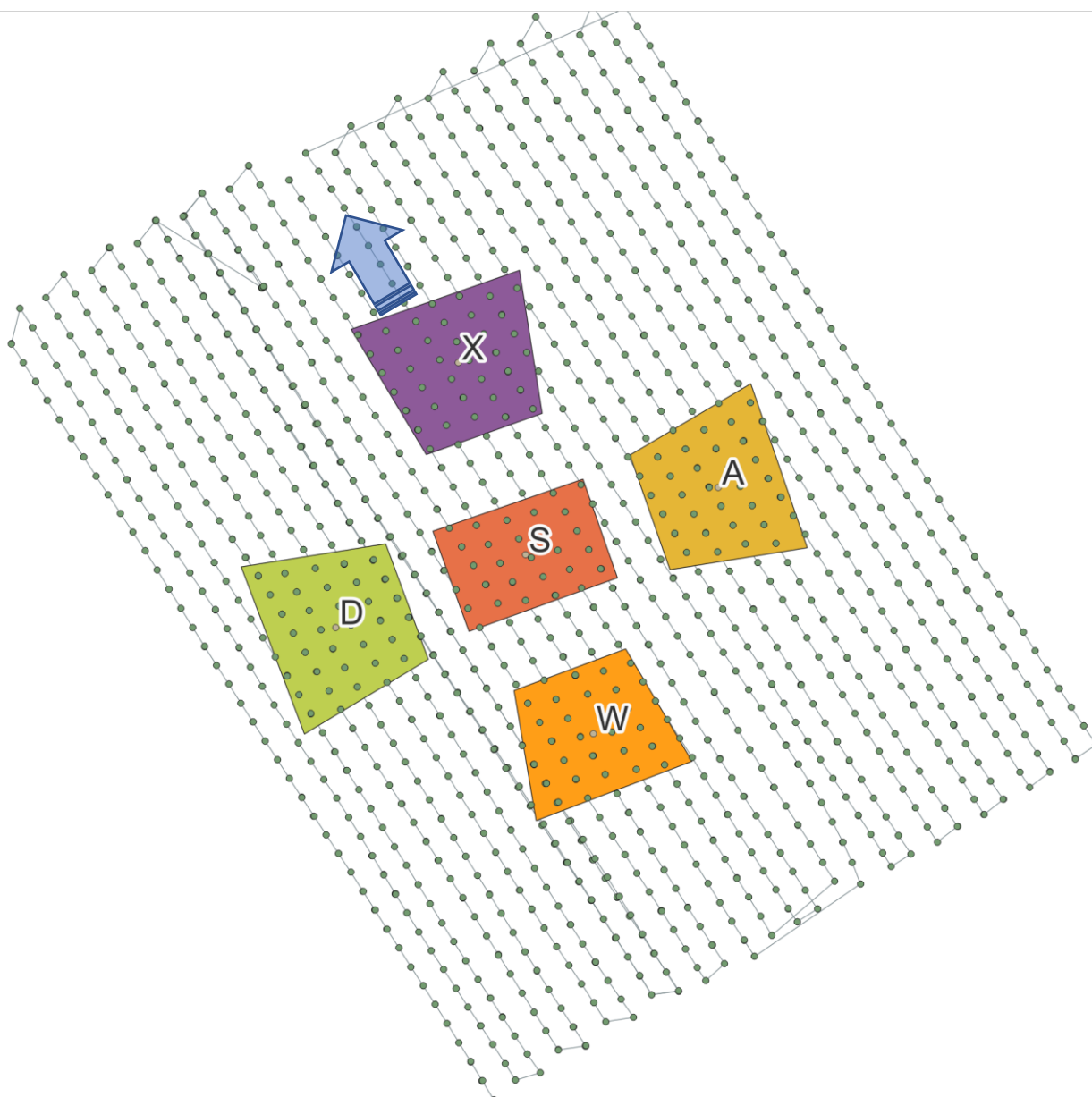
## 3. Internal Camera Parameter

CA502R_NADIR_28.0_6000x4000 (RGB). Sensor Dimensions: 23.520 [mm] x 15.680 [mm]

EXIF ID: ILCE-5100_0.0_6000x4000

|  | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 7142.860 [pixel] 28.000 [mm] | 3000.000 [pixel] 11.760 [mm] | 2000.000 [pixel] 7.840 [mm] | -0.048 | 0.037 | -0.011 | -0.000 | -0.001 |
| Optimized Values | 7147.838 [pixel] 28.020 [mm] | 3030.942 [pixel] 11.881 [mm] | 1919.940 [pixel] 7.526 [mm] | -0.106 | -0.006 | 0.006 | -0.001 | 0.001 |
| Uncertainties (Sigma) | 0.252 [pixel] 0.001 [mm] | 0.231 [pixel] 0.001 [mm] | 0.171 [pixel] 0.001 [mm] | 0.000 | 0.003 | 0.007 | 0.000 | 0.000 |

CA502R_RIGHT_43.0_6000x4000 (RGB). Sensor Dimensions: 23.520 [mm] x 15.680 [mm]

EXIF ID: ILCE-5100_0.0_6000x4000

|  | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 10969.400 [pixel] 43.000 [mm] | 3000.000 [pixel] 11.760 [mm] | 2000.000 [pixel] 7.840 [mm] | -0.048 | 0.037 | -0.011 | -0.000 | -0.001 |
| Optimized Values | 11059.523 [pixel] 43.353 [mm] | 3082.015 [pixel] 12.081 [mm] | 1962.364 [pixel] 7.692 [mm] | -0.013 | -0.032 | 0.113 | 0.001 | 0.001 |
| Uncertainties (Sigma) | 0.402 [pixel] 0.002 [mm] | 2.287 [pixel] 0.009 [mm] | 1.391 [pixel] 0.005 [mm] | 0.002 | 0.049 | 0.327 | 0.000 | 0.000 |

CA502R_LEFT_43.0_6000x4000 (RGB). Sensor Dimensions: 23.520 [mm] x 15.680 [mm]

EXIF ID: ILCE-5100_0.0_6000x4000

|  | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 10969.400 [pixel] 43.000 [mm] | 3000.000 [pixel] 11.760 [mm] | 2000.000 [pixel] 7.840 [mm] | -0.048 | 0.037 | -0.011 | -0.000 | -0.001 |
| Optimized Values | 11004.383 [pixel] 43.137 [mm] | 3065.859 [pixel] 12.018 [mm] | 1925.817 [pixel] 7.549 [mm] | 0.002 | -0.214 | 0.521 | 0.000 | -0.000 |
| Uncertainties (Sigma) | 0.427 [pixel] 0.002 [mm] | 2.497 [pixel] 0.010 [mm] | 1.411 [pixel] 0.006 [mm] | 0.002 | 0.052 | 0.333 | 0.000 | 0.000 |

CA502R_REAR_43.0_6000x4000 (RGB). Sensor Dimensions: 23.520 [mm] x 15.680 [mm]

EXIF ID: ILCE-5100_0.0_6000x4000

|  | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 10969.400 [pixel] 43.000 [mm] | 3000.000 [pixel] 11.760 [mm] | 2000.000 [pixel] 7.840 [mm] | -0.048 | 0.037 | -0.011 | -0.000 | -0.001 |
| Optimized Values | 11033.312 [pixel] 43.251 [mm] | 3006.846 [pixel] 11.787 [mm] | 1945.103 [pixel] 7.625 [mm] | 0.012 | -0.319 | 0.956 | 0.000 | -0.001 |
| Uncertainties (Sigma) | 0.459 [pixel] 0.002 [mm] | 1.892 [pixel] 0.007 [mm] | 1.452 [pixel] 0.006 [mm] | 0.003 | 0.055 | 0.352 | 0.000 | 0.000 |

CA502R_FRONT_43.0_6000x4000 (RGB). Sensor Dimensions: 23.520 [mm] x 15.680 [mm]

EXIF ID: ILCE-5100_0.0_6000x4000

|  | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 10969.400 [pixel] 43.000 [mm] | 3000.000 [pixel] 11.760 [mm] | 2000.000 [pixel] 7.840 [mm] | -0.048 | 0.037 | -0.011 | -0.000 | -0.001 |
| Optimized Values | 11045.945 [pixel] 43.300 [mm] | 3016.789 [pixel] 11.826 [mm] | 1952.475 [pixel] 7.654 [mm] | -0.013 | -0.173 | 1.245 | 0.001 | 0.000 |
| Uncertainties (Sigma) | 0.521 [pixel] 0.002 [mm] | 2.468 [pixel] 0.010 [mm] | 2.027 [pixel] 0.008 [mm] | 0.003 | 0.060 | 0.368 | 0.000 | 0.000 |

Evaluation Results Passed:

|  | f | cx | cy | R1 | R2 | R3 |
|---|---|---|---|---|---|---|
| Criterion | 0.005 mm | 0.015 mm | 0.015 mm | 0.005 | 0.060 | 0.400 |
| NADIR | ✅ | ✅ | ✅ | ✅ | ✅ | ✅ |
| FRONT | ✅ | ✅ | ✅ | ✅ | ✅ | ✅ |
| REAR | ✅ | ✅ | ✅ | ✅ | ✅ | ✅ |
| LEFT | ✅ | ✅ | ✅ | ✅ | ✅ | ✅ |
| RIGHT | ✅ | ✅ | ✅ | ✅ | ✅ | ✅ |

## 4. Distribution of Ground Control Points (GCPs) and Check Point (CPs)
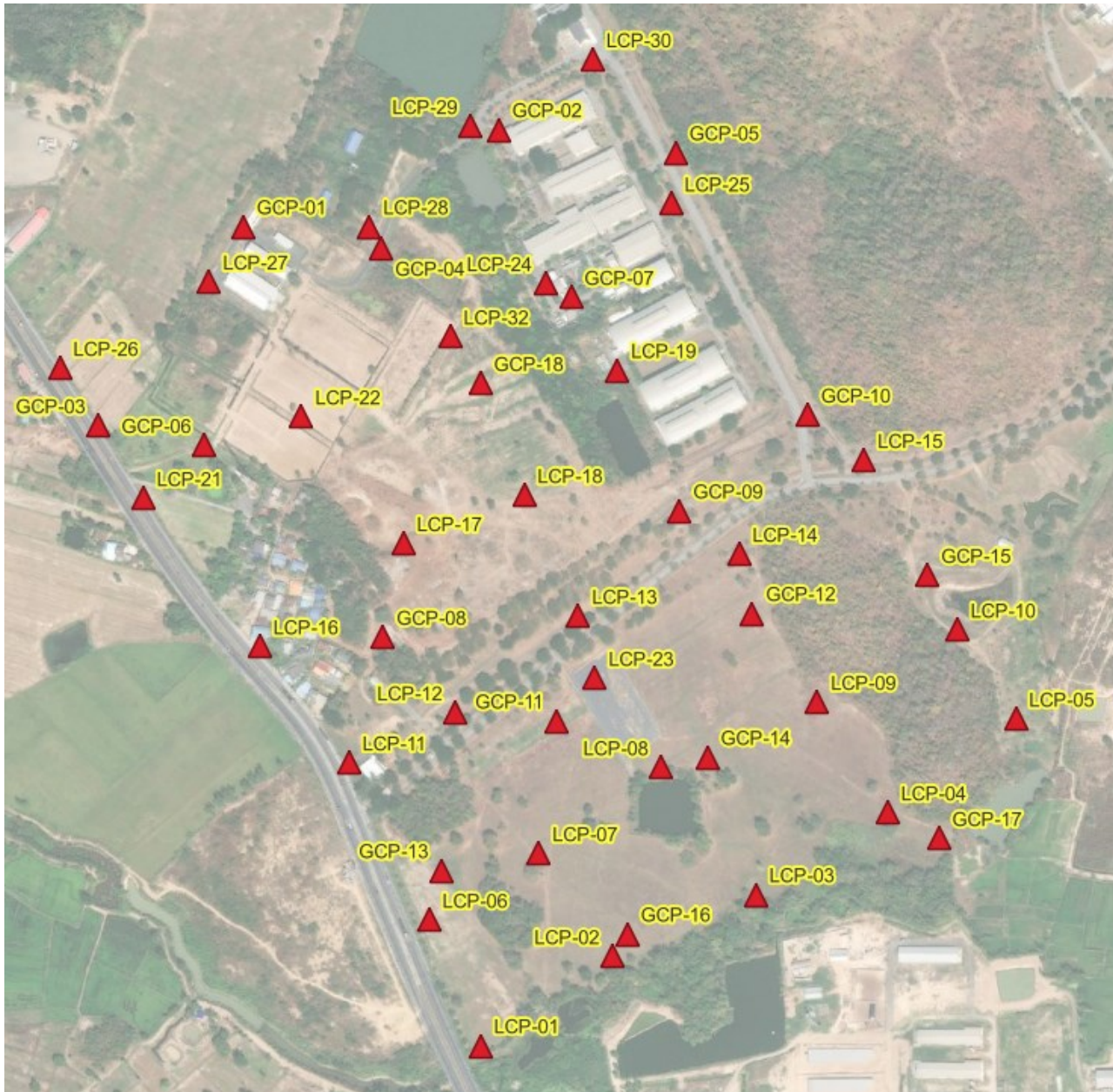
5. Aerial Triangulation Result: partial GCP (24 points) vs partial Check Points (24 points)

**Ground Control Points**

| GCP Name | Accuracy XY/Z [m] | Error X [m] | Error Y [m] | Error Z [m] | Projection Error [pixel] | Verified/Marked |
|---|---|---|---|---|---|---|
| LCP-01 (3D) | 0.020/ 0.050 | 0.041 | 0.021 | 0.015 | 0.173 | 30 / 30 |
| LCP-05 (3D) | 0.020/ 0.050 | -0.004 | -0.021 | -0.005 | 0.170 | 30 / 30 |
| LCP-16 (3D) | 0.020/ 0.050 | 0.027 | 0.024 | 0.041 | 0.170 | 30 / 30 |
| LCP-17 (3D) | 0.020/ 0.050 | -0.002 | 0.008 | 0.043 | 0.185 | 30 / 30 |
| LCP-22 (3D) | 0.020/ 0.050 | -0.031 | 0.023 | 0.025 | 0.181 | 30 / 30 |
| LCP-23 (3D) | 0.020/ 0.050 | -0.007 | -0.011 | 0.040 | 0.226 | 30 / 30 |
| GCP-01 (3D) | 0.020/ 0.050 | -0.031 | 0.022 | -0.025 | 0.233 | 30 / 30 |
| GCP-02 (3D) | 0.020/ 0.050 | -0.016 | 0.001 | -0.009 | 0.311 | 30 / 30 |
| GCP-03 (3D) | 0.020/ 0.050 | 0.017 | 0.032 | -0.003 | 0.297 | 30 / 30 |
| GCP-04 (3D) | 0.020/ 0.050 | -0.025 | 0.011 | -0.003 | 0.244 | 30 / 30 |
| GCP-05 (3D) | 0.020/ 0.050 | -0.037 | -0.035 | 0.007 | 0.141 | 30 / 30 |
| GCP-06 (3D) | 0.020/ 0.050 | -0.003 | 0.034 | -0.013 | 0.283 | 30 / 30 |
| GCP-07 (3D) | 0.020/ 0.050 | -0.002 | -0.010 | 0.008 | 0.312 | 30 / 30 |
| GCP-08 (3D) | 0.020/ 0.050 | 0.039 | 0.009 | -0.019 | 0.304 | 30 / 30 |
| GCP-09 (3D) | 0.020/ 0.050 | -0.014 | -0.011 | -0.039 | 0.242 | 30 / 30 |
| GCP-10 (3D) | 0.020/ 0.050 | -0.014 | -0.019 | -0.026 | 0.096 | 30 / 30 |
| GCP-11 (3D) | 0.020/ 0.050 | -0.003 | 0.005 | -0.012 | 0.226 | 30 / 30 |
| GCP-12 (3D) | 0.020/ 0.050 | -0.008 | -0.033 | 0.006 | 0.260 | 30 / 30 |
| GCP-13 (3D) | 0.020/ 0.050 | 0.022 | 0.016 | -0.063 | 0.266 | 30 / 30 |
| GCP-14 (3D) | 0.020/ 0.050 | 0.027 | -0.018 | 0.027 | 0.272 | 30 / 30 |
| GCP-15 (3D) | 0.020/ 0.050 | -0.018 | -0.018 | -0.004 | 0.310 | 30 / 30 |
| GCP-16 (3D) | 0.020/ 0.050 | 0.027 | -0.007 | -0.012 | 0.171 | 30 / 30 |
| GCP-17 (3D) | 0.020/ 0.050 | 0.031 | -0.030 | 0.015 | 0.208 | 30 / 30 |
| GCP-18 (3D) | 0.020/ 0.050 | -0.023 | 0.003 | 0.000 | 0.245 | 30 / 30 |
| **Mean [m]** | | -0.000306 | -0.000218 | -0.000200 | | |
| **Sigma [m]** | | 0.023007 | 0.020138 | 0.024829 | | |
| **RMS Error [m]** | | 0.023009 | 0.020139 | 0.024830 | | |

| Check Point Name | Accuracy XY/Z [m] | Error X [m] | Error Y [m] | Error Z [m] | Projection Error [pixel] | Verified/Marked |
|---|---|---|---|---|---|---|
| LCP-02 | | 0.0182 | -0.0078 | 0.0314 | 0.2292 | 30 / 30 |
| LCP-03 | | 0.0011 | 0.0075 | 0.0661 | 0.1819 | 30 / 30 |
| LCP-04 | | 0.0685 | -0.0314 | 0.0770 | 0.1626 | 30 / 30 |
| LCP-06 | | 0.0199 | 0.0411 | -0.0404 | 0.2429 | 30 / 30 |
| LCP-07 | | 0.0568 | 0.0268 | 0.0820 | 0.2596 | 30 / 30 |
| LCP-08 | | 0.0133 | -0.0011 | 0.0781 | 0.2390 | 30 / 30 |
| LCP-09 | | 0.0084 | -0.0469 | 0.0769 | 0.3326 | 30 / 30 |
| LCP-10 | | 0.0302 | -0.0662 | 0.0523 | 0.2056 | 30 / 30 |
| LCP-11 | | 0.0483 | 0.0264 | 0.0376 | 0.2904 | 30 / 30 |
| LCP-12 | | 0.0342 | 0.0042 | 0.0329 | 0.2385 | 30 / 30 |
| LCP-13 | | -0.0201 | -0.0197 | 0.0496 | 0.2456 | 30 / 30 |
| LCP-14 | | 0.0075 | -0.0254 | 0.0284 | 0.2769 | 30 / 30 |
| LCP-15 | | -0.0063 | -0.0203 | 0.0093 | 0.0726 | 30 / 30 |
| LCP-18 | | 0.0997 | -0.0312 | 0.0005 | 0.1560 | 30 / 30 |
| LCP-19 | | -0.0093 | -0.0237 | -0.0059 | 0.1504 | 30 / 30 |
| LCP-21 | | 0.0044 | 0.0428 | 0.0671 | 0.2255 | 30 / 30 |
| LCP-24 | | -0.0189 | 0.0109 | 0.0261 | 0.3319 | 30 / 30 |
| LCP-25 | | -0.0378 | -0.0369 | 0.0367 | 0.1317 | 30 / 30 |
| LCP-26 | | -0.0007 | 0.0413 | 0.0439 | 0.2573 | 30 / 30 |
| LCP-27 | | -0.0224 | 0.0267 | 0.0360 | 0.1213 | 30 / 30 |
| LCP-28 | | -0.0287 | 0.0263 | 0.0056 | 0.2567 | 30 / 30 |
| LCP-29 | | -0.0292 | 0.0318 | 0.0341 | 0.1851 | 30 / 30 |
| LCP-30 | | -0.0056 | -0.0036 | -0.0047 | 0.1328 | 30 / 30 |
| LCP-32 | | -0.0171 | 0.0410 | 0.0651 | 0.2348 | 30 / 30 |
| **Mean [m]** | | 0.008923 | 0.000527 | 0.036904 | | |
| **Sigma [m]** | | 0.033056 | 0.030895 | 0.030821 | | |
| **RMS Error [m]** | | 0.034239 | 0.030900 | 0.048082 | | |

## 6. Aerial Triangulation Result: full GCP (48 points)

**?** Ground Control Points                                                                                    ℹ

| GCP Name | Accuracy XY/Z [m] | Error X [m] | Error Y [m] | Error Z [m] | Projection Error [pixel] | Verified/Marked |
|---|---|---|---|---|---|---|
| LCP-01 (3D) | 0.020/ 0.050 | 0.033 | 0.011 | 0.010 | 0.176 | 30 / 30 |
| LCP-02 (3D) | 0.020/ 0.050 | 0.008 | -0.010 | 0.006 | 0.226 | 30 / 30 |
| LCP-03 (3D) | 0.020/ 0.050 | -0.007 | 0.013 | 0.024 | 0.180 | 30 / 30 |
| LCP-04 (3D) | 0.020/ 0.050 | 0.056 | -0.020 | 0.043 | 0.171 | 30 / 30 |
| LCP-05 (3D) | 0.020/ 0.050 | -0.013 | -0.004 | -0.024 | 0.171 | 30 / 30 |
| LCP-06 (3D) | 0.020/ 0.050 | 0.007 | 0.030 | -0.046 | 0.244 | 30 / 30 |
| LCP-07 (3D) | 0.020/ 0.050 | 0.043 | 0.022 | 0.053 | 0.258 | 30 / 30 |
| LCP-08 (3D) | 0.020/ 0.050 | 0.004 | 0.004 | 0.043 | 0.240 | 30 / 30 |
| LCP-09 (3D) | 0.020/ 0.050 | -0.003 | -0.034 | 0.036 | 0.312 | 30 / 30 |
| LCP-10 (3D) | 0.020/ 0.050 | 0.019 | -0.046 | 0.028 | 0.211 | 30 / 30 |
| LCP-11 (3D) | 0.020/ 0.050 | 0.032 | 0.021 | 0.023 | 0.286 | 30 / 30 |
| LCP-12 (3D) | 0.020/ 0.050 | 0.022 | 0.002 | 0.014 | 0.246 | 30 / 30 |
| LCP-13 (3D) | 0.020/ 0.050 | -0.027 | -0.016 | 0.027 | 0.239 | 30 / 30 |
| LCP-14 (3D) | 0.020/ 0.050 | -0.000 | -0.018 | 0.009 | 0.253 | 30 / 30 |
| LCP-15 (3D) | 0.020/ 0.050 | -0.014 | -0.009 | 0.001 | 0.077 | 30 / 30 |
| LCP-16 (3D) | 0.020/ 0.050 | 0.018 | 0.021 | 0.030 | 0.171 | 30 / 30 |
| LCP-17 (3D) | 0.020/ 0.050 | -0.010 | 0.007 | 0.028 | 0.185 | 30 / 30 |
| LCP-18 (3D) | 0.020/ 0.050 | 0.088 | -0.030 | -0.012 | 0.165 | 30 / 30 |
| LCP-19 (3D) | 0.020/ 0.050 | -0.011 | -0.018 | -0.016 | 0.161 | 30 / 30 |
| LCP-21 (3D) | 0.020/ 0.050 | 0.004 | 0.031 | 0.042 | 0.239 | 30 / 30 |
| LCP-22 (3D) | 0.020/ 0.050 | -0.030 | 0.016 | 0.010 | 0.186 | 30 / 30 |
| LCP-23 (3D) | 0.020/ 0.050 | -0.015 | -0.009 | 0.018 | 0.228 | 30 / 30 |
| LCP-24 (3D) | 0.020/ 0.050 | -0.013 | 0.009 | 0.013 | 0.335 | 30 / 30 |
| LCP-25 (3D) | 0.020/ 0.050 | -0.030 | -0.031 | 0.016 | 0.134 | 30 / 30 |
| LCP-26 (3D) | 0.020/ 0.050 | 0.002 | 0.024 | 0.018 | 0.242 | 30 / 30 |
| LCP-27 (3D) | 0.020/ 0.050 | -0.018 | 0.013 | 0.016 | 0.125 | 30 / 30 |
| LCP-28 (3D) | 0.020/ 0.050 | -0.022 | 0.017 | -0.004 | 0.255 | 30 / 30 |
| LCP-29 (3D) | 0.020/ 0.050 | -0.021 | 0.025 | 0.025 | 0.185 | 30 / 30 |
| LCP-30 (3D) | 0.020/ 0.050 | 0.002 | -0.005 | -0.010 | 0.137 | 30 / 30 |
| LCP-32 (3D) | 0.020/ 0.050 | -0.016 | 0.036 | 0.050 | 0.224 | 30 / 30 |
| GCP-01 (3D) | 0.020/ 0.050 | -0.027 | 0.011 | -0.038 | 0.233 | 30 / 30 |
| GCP-02 (3D) | 0.020/ 0.050 | -0.008 | -0.004 | -0.019 | 0.316 | 30 / 30 |
| GCP-03 (3D) | 0.020/ 0.050 | 0.019 | 0.018 | -0.027 | 0.284 | 30 / 30 |
| GCP-04 (3D) | 0.020/ 0.050 | -0.020 | 0.002 | -0.014 | 0.249 | 30 / 30 |
| GCP-05 (3D) | 0.020/ 0.050 | -0.031 | -0.030 | -0.008 | 0.143 | 30 / 30 |
| GCP-06 (3D) | 0.020/ 0.050 | -0.003 | 0.024 | -0.030 | 0.284 | 30 / 30 |
| GCP-07 (3D) | 0.020/ 0.050 | 0.002 | -0.011 | -0.004 | 0.325 | 30 / 30 |
| GCP-08 (3D) | 0.020/ 0.050 | 0.030 | 0.008 | -0.033 | 0.302 | 30 / 30 |
| GCP-09 (3D) | 0.020/ 0.050 | -0.020 | -0.007 | -0.050 | 0.270 | 30 / 30 |
| GCP-10 (3D) | 0.020/ 0.050 | -0.019 | -0.012 | -0.033 | 0.093 | 30 / 30 |
| GCP-11 (3D) | 0.020/ 0.050 | -0.013 | 0.005 | -0.034 | 0.229 | 30 / 30 |
| GCP-12 (3D) | 0.020/ 0.050 | -0.016 | -0.025 | -0.017 | 0.260 | 30 / 30 |
| GCP-13 (3D) | 0.020/ 0.050 | 0.009 | 0.007 | -0.073 | 0.276 | 30 / 30 |
| GCP-14 (3D) | 0.020/ 0.050 | 0.017 | -0.012 | -0.006 | 0.267 | 30 / 30 |
| GCP-15 (3D) | 0.020/ 0.050 | -0.029 | -0.001 | -0.023 | 0.309 | 30 / 30 |
| GCP-16 (3D) | 0.020/ 0.050 | 0.017 | -0.009 | -0.037 | 0.172 | 30 / 30 |
| GCP-17 (3D) | 0.020/ 0.050 | 0.022 | -0.018 | -0.019 | 0.209 | 30 / 30 |
| GCP-18 (3D) | 0.020/ 0.050 | -0.024 | -0.001 | -0.014 | 0.242 | 30 / 30 |
| **Mean [m]** | | -0.000117 | -0.000097 | -0.000178 | | |
| **Sigma [m]** | | 0.024438 | 0.018848 | 0.028810 | | |
| **RMS Error [m]** | | 0.024439 | 0.018848 | 0.028811 | | |

Evaluation Result:

| | Error X | Error Y (m) | Error Z (m) | Projection Error |
|---|---|---|---|---|
| Criterion | 0.035 m | 0.035 m | 0.065 m | 0.5 pixel |
| Partial GCPs | ✅ | ✅ | ✅ | ✅ |
| Partial CPs | ✅ | ✅ | ✅ | ✅ |
| Full GCPs | ✅ | ✅ | ✅ | ✅ |