



**Geometric Camera Calibration Report**  
**UAV Oblique Camera System**  
**CA502R SN:CA502R202115**



Issued by  
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15 December 2022



## Geometric Calibration of the Oblique Camera System

เอกสารนี้เป็นส่วนหนึ่งของ

โครงวิจัย การศึกษาการจัดทำจุดเข้าบังคับบนพื้นดินสำหรับยูเอวีเลเซอร์สแกน เลขที่ 001/2565  
ลงวันที่ 1 สิงหาคม 2565 ของคณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ประจำปี 2564



## Geometric Calibration of the Oblique Camera System (CU-UAV/Cal 1.0)





## Geometric Calibration of the Oblique Camera System

### 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  $f$ ,  $c_x$ ,  $c_y$ ,  $R_1$ ,  $R_2$ ,  $R_3$ ,  $T_1$ , and  $T_2$  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.

**Phisan Santitamnont (Dr.-Ing)**

**Thirawat Bannakulpiphat (M.Eng.)**



## Geometric Calibration of the Oblique Camera System

### Photogrammetric Block Information

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



## Geometric Calibration of the Oblique Camera System

### Quality Report

#### 1. Camera position from manufacturer note

Camera	X (mm)	Y (mm)	Z (mm)	Camera
CA502R	+30.00	-425.00	-229.38	Ortho view
	+30.00	-476.48	-251.56	Left view
	+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



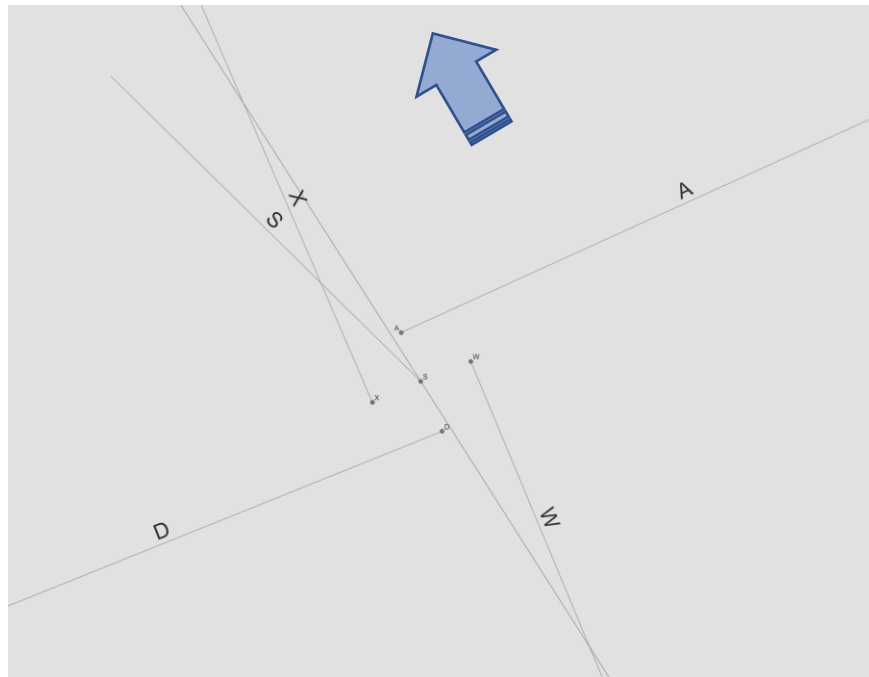
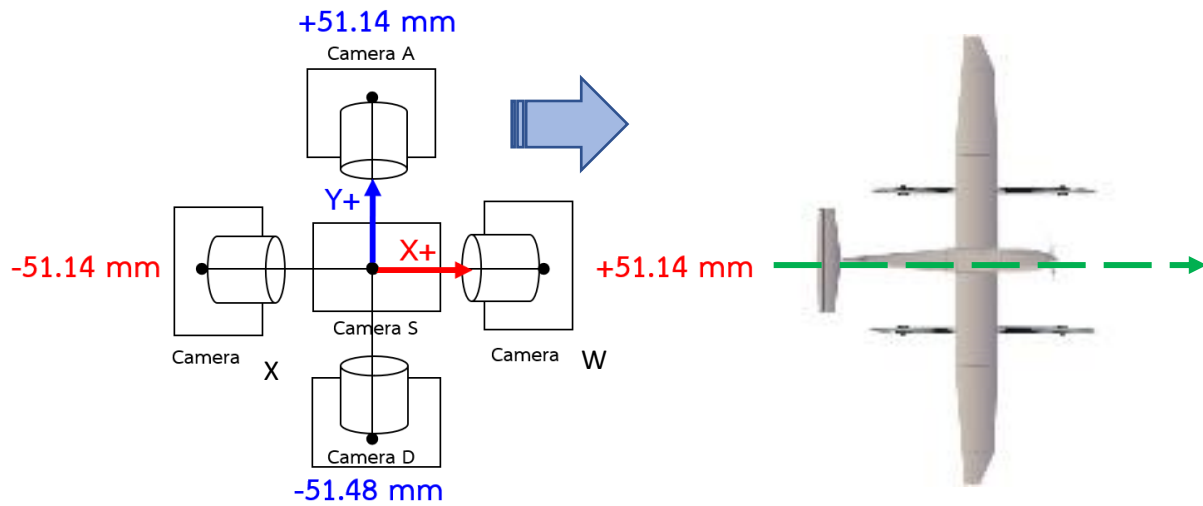
	Transl X[m]	Transl Y[m]	Transl Z[m]	Rot X[degree]	Rot Y[degree]	Rot Z[degree]
CA502R_NADIR_28.0_6000x4000 (RGB)	Reference Camera					
CA502R_RIGHT_43.0_6000x4000 (RGB)						
Initial Values	0.000	0.051	-0.022	0.000	-45.000	-90.000
Optimized values	0.000	0.051	-0.022	0.316	-45.746	-89.986
Uncertainties (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



## Geometric Calibration of the Oblique Camera System

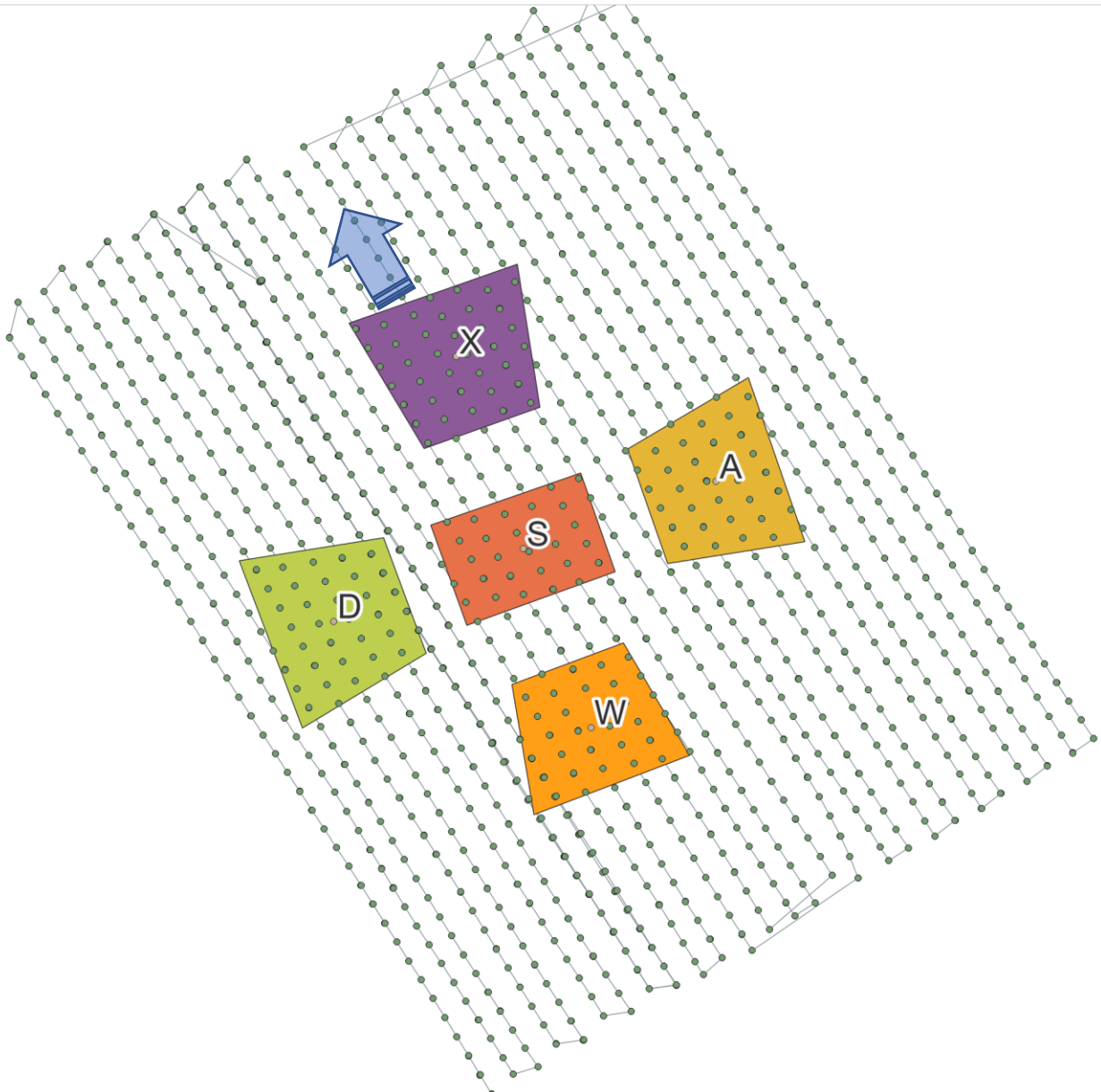
Evaluation result passed:

Uncertainty	Tx, Ty, Tz (mm)	Rot X (degrees)	Rot Y (degrees)	Rot Z (degrees)
Criterion	Constraint	0.015	0.015	0.015
Passed	✓	✓	✓	✓





## Geometric Calibration of the Oblique Camera System







## Geometric Calibration of the Oblique Camera System

### 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



## Geometric Calibration of the Oblique Camera System

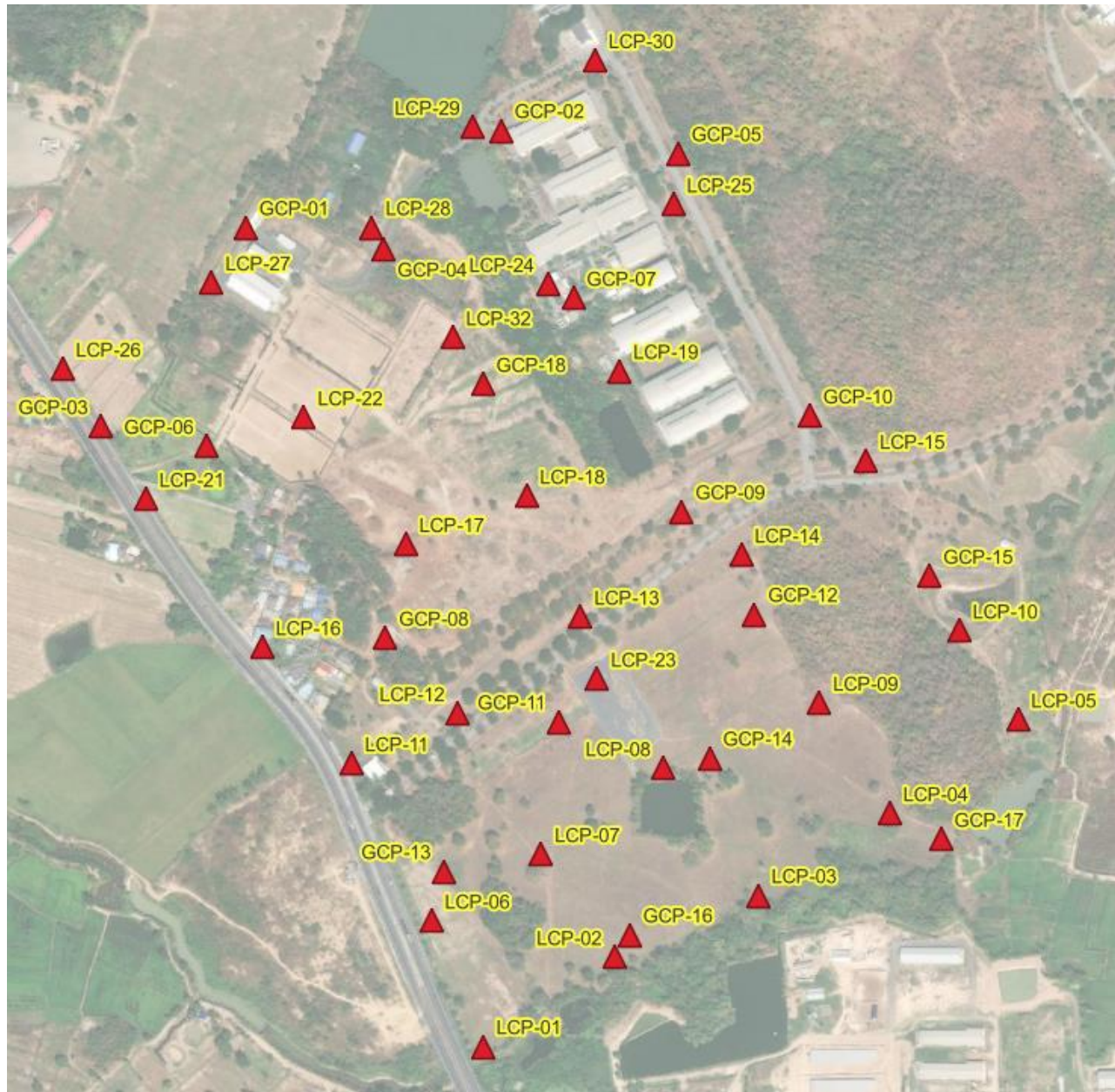
### Evaluation Results Passed:

	<b>f</b>	<b>cx</b>	<b>cy</b>	<b>R1</b>	<b>R2</b>	<b>R3</b>
Criterion	0.005 mm	0.015 mm	0.015 mm	0.005	0.060	0.400
NADIR	✓	✓	✓	✓	✓	✓
FRONT	✓	✓	✓	✓	✓	✓
REAR	✓	✓	✓	✓	✓	✓
LEFT	✓	✓	✓	✓	✓	✓
RIGHT	✓	✓	✓	✓	✓	✓



## Geometric Calibration of the Oblique Camera System

### 4. Distribution of Ground Control Point (GCP) and Check Point (CP)





## Geometric Calibration of the Oblique Camera System

### 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		





## Geometric Calibration of the Oblique Camera System

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

#### Ground Control Points

GCP Name	Accuracy XYZ [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		



## Geometric Calibration of the Oblique Camera System

### 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	✓	✓	✓	✓