AKADEMIA GÓRNICZO-HUTNICZA
IM. STANISŁAWA STASZICA W KRAKOWIE

AGH UNIVERSITY OF SCIENCE
AND TECHNOLOGY

Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration

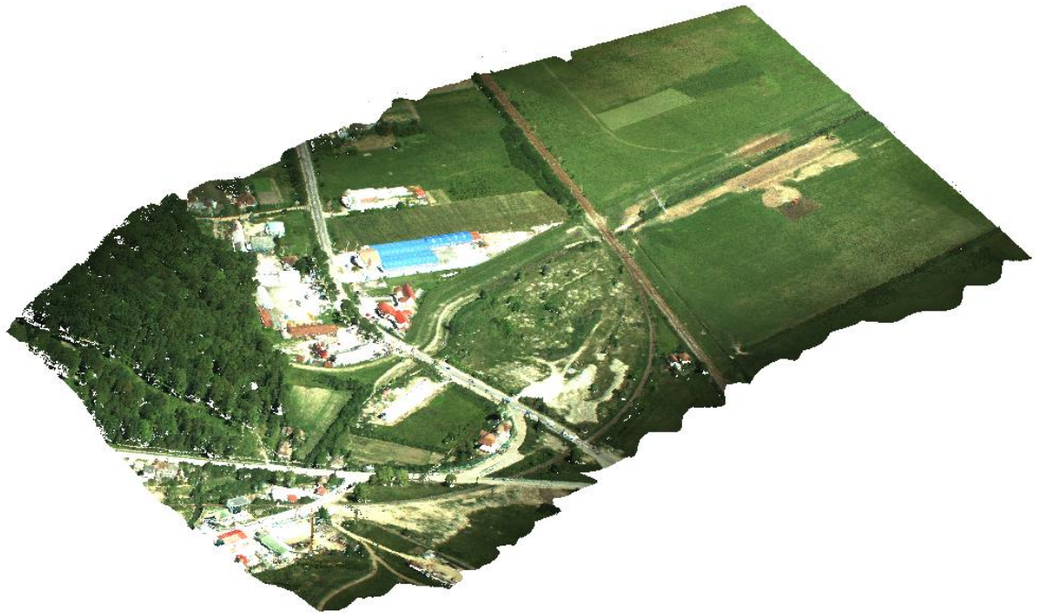
Antoni Rzonca

Lidargrammetry

1. **Genesis: Stereoplotting of LiDAR data**
2. Vertical accuracy enhancement of LiDAR data
3. Vertical and horizontal accuracy enhancement of LiDAR data
4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

1. Lidargrammetry - genesis

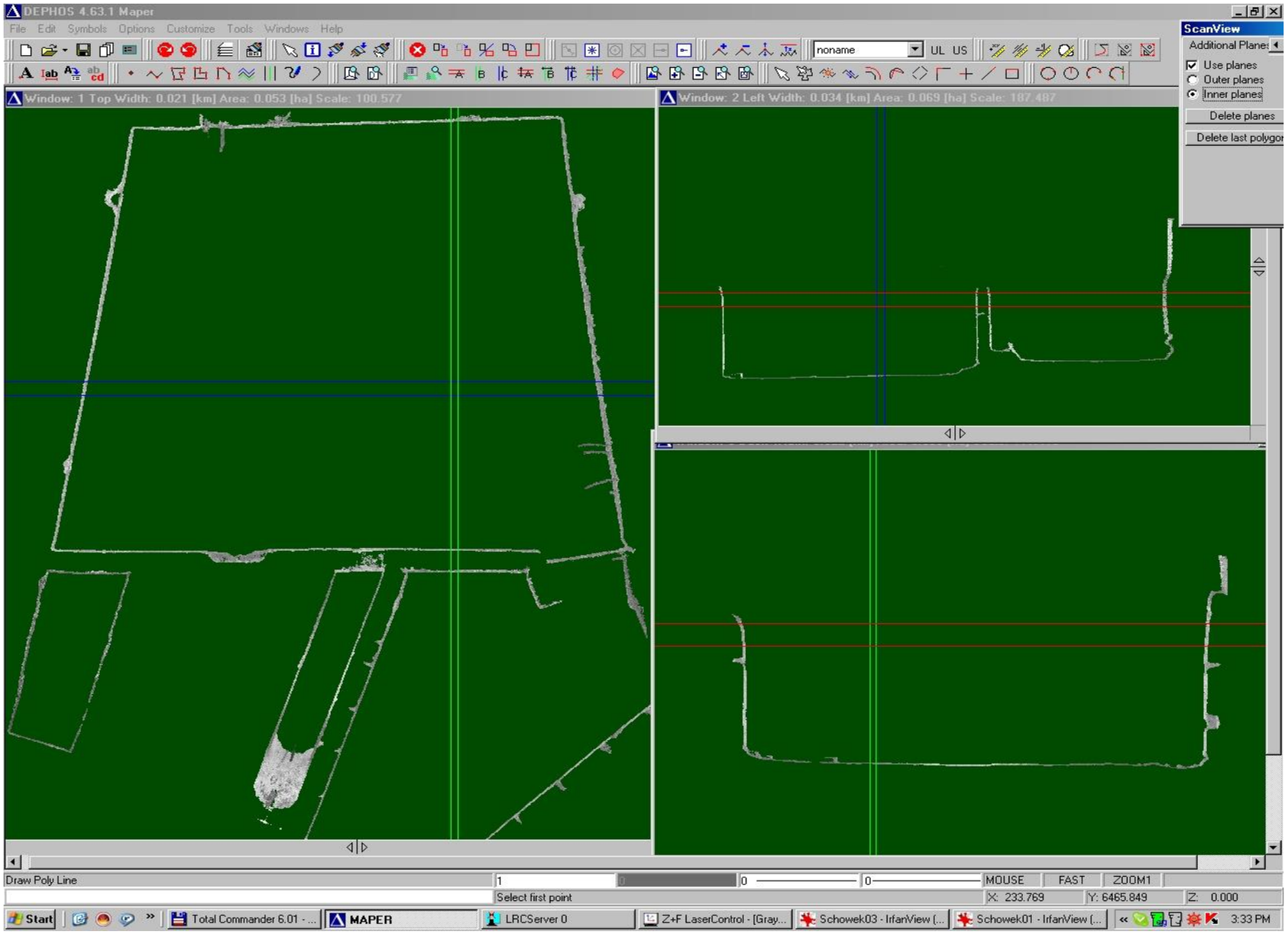
1. M. Brooks, B. Herman, M.F. **Lidargrammetry**. **2005**.
2. Ward, D. **Lidargrammetry**. **2006**.
3. Smith, D. 2013 WASHINGTON GIS CONFERENCE **Lidargrammetry:** Using 3D Stereo Photogrammetry for **Lidar Quality Control and Feature Extraction**. **2013**.
4. Fragkos, P.; Ioannidis, C. Assessment of **Lidargrammetry** for **Spatial Data Extraction**. Fourth Int. Conf. Remote Sens. Geoinf. Environ. **2016**, 9688, 96881L, doi:10.1117/12.2240653.
5. Rodríguez-Cielos, R.; Galán-García, J.L.; Padilla-Domínguez, Y.; Rodríguez-Cielos, P.; Bello-Patricio, A.B.; López-Medina, J.A. **LiDARgrammetry**: A New Method for Generating Synthetic Stereoscopic Products from **Digital Elevation Models**. Appl. Sci. **2017,** 7, doi:10.3390/app7090906.



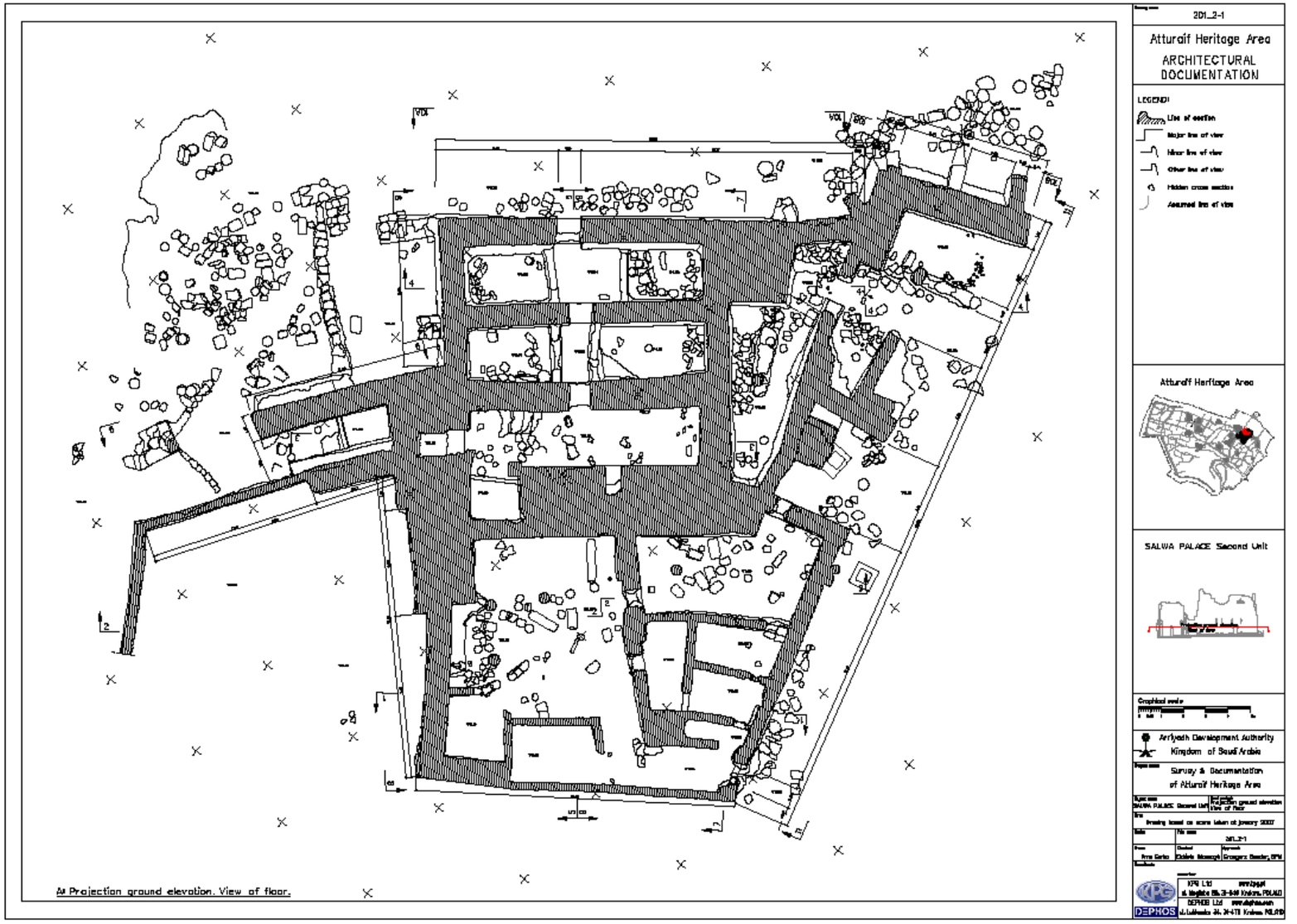
1. Lidargrammetry – genesis

Atturaif Project, Ad-Diriyyah, Riyad, Saudi Arabia, 2006/2007

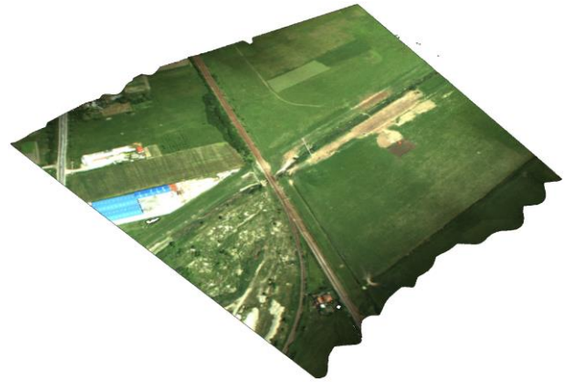
1. Lidargrammetry – genesis



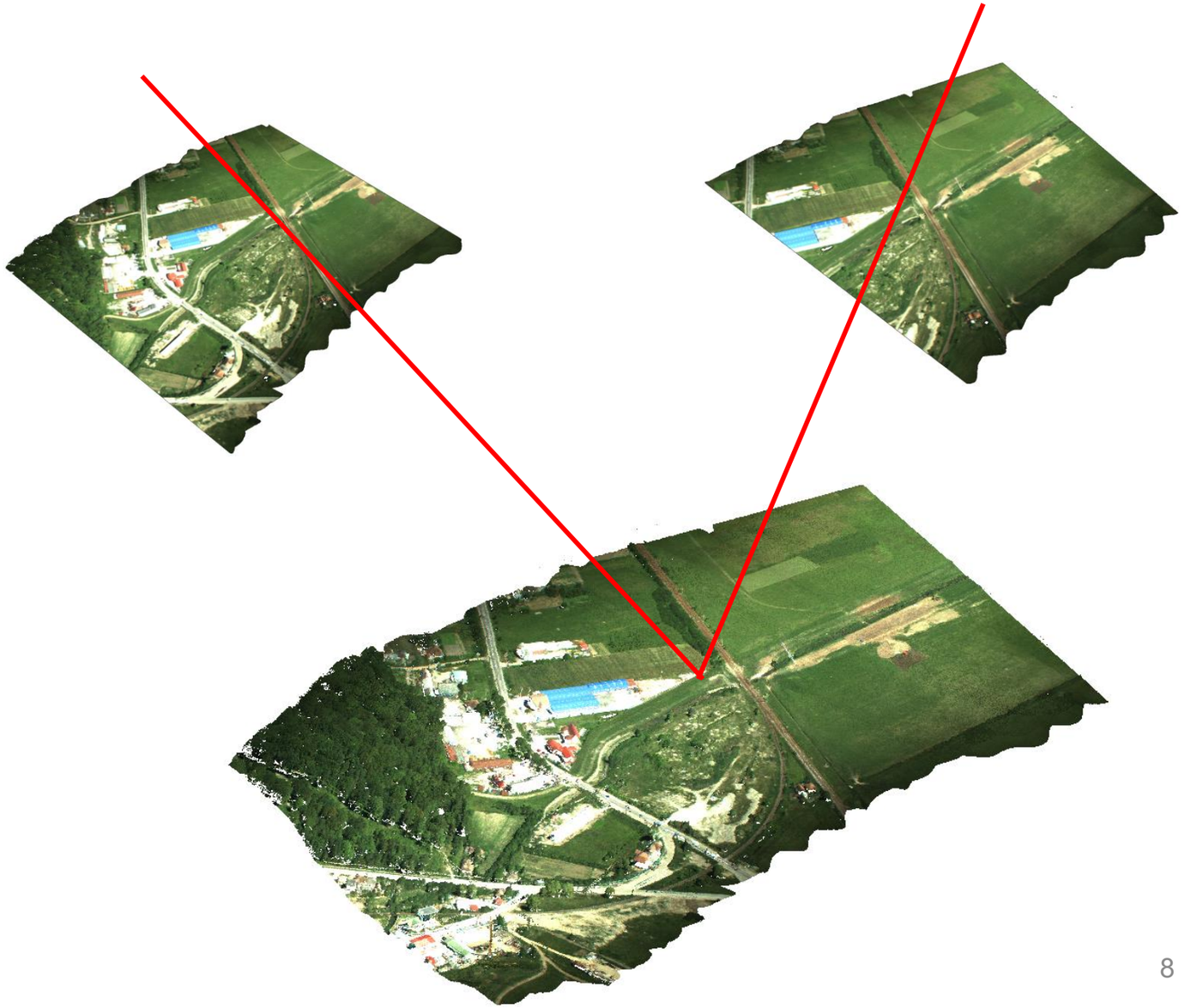
1. Lidargrammetry – genesis



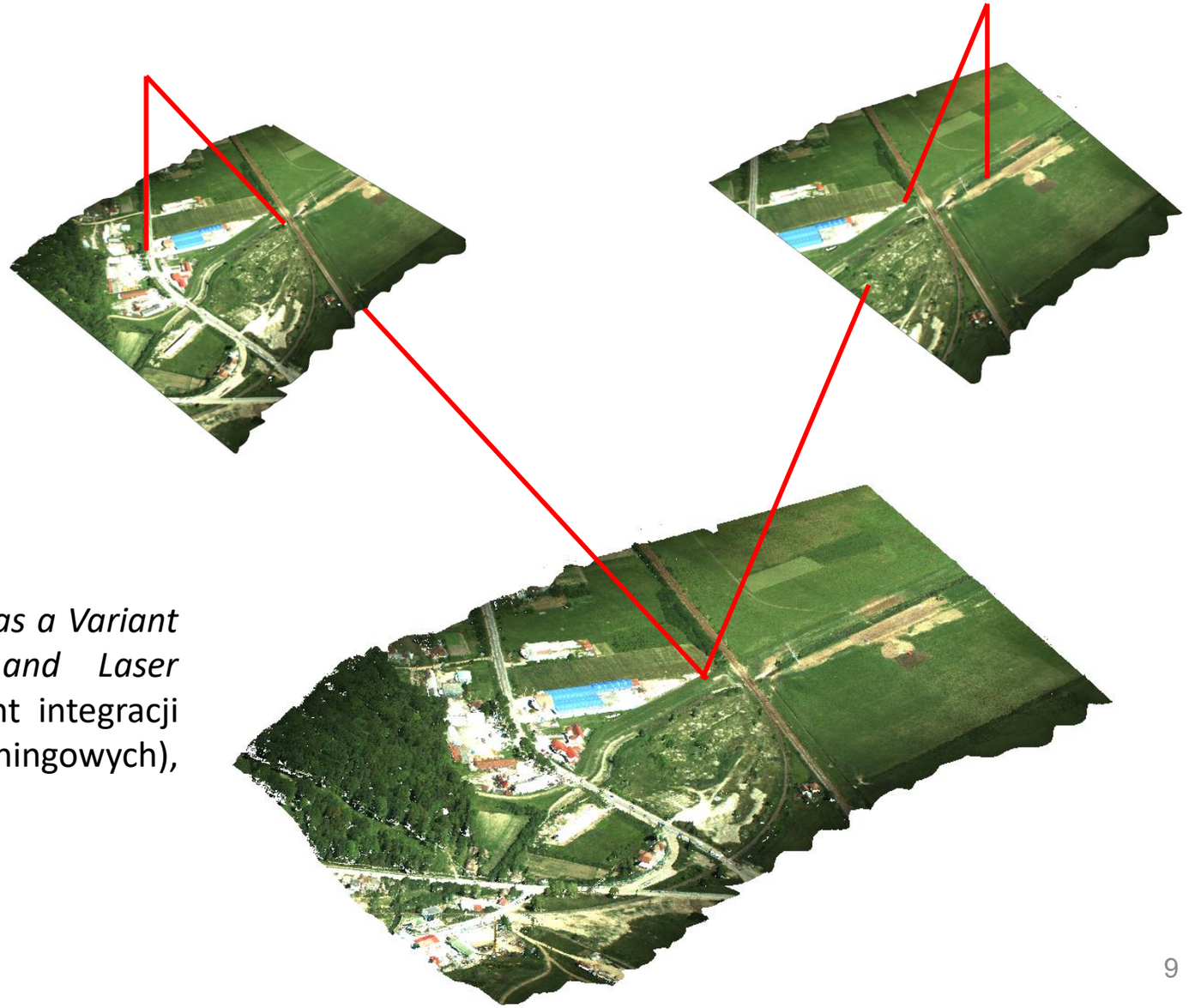
1. Lidargrammetry - genesis



1. Lidargrammetry - genesis

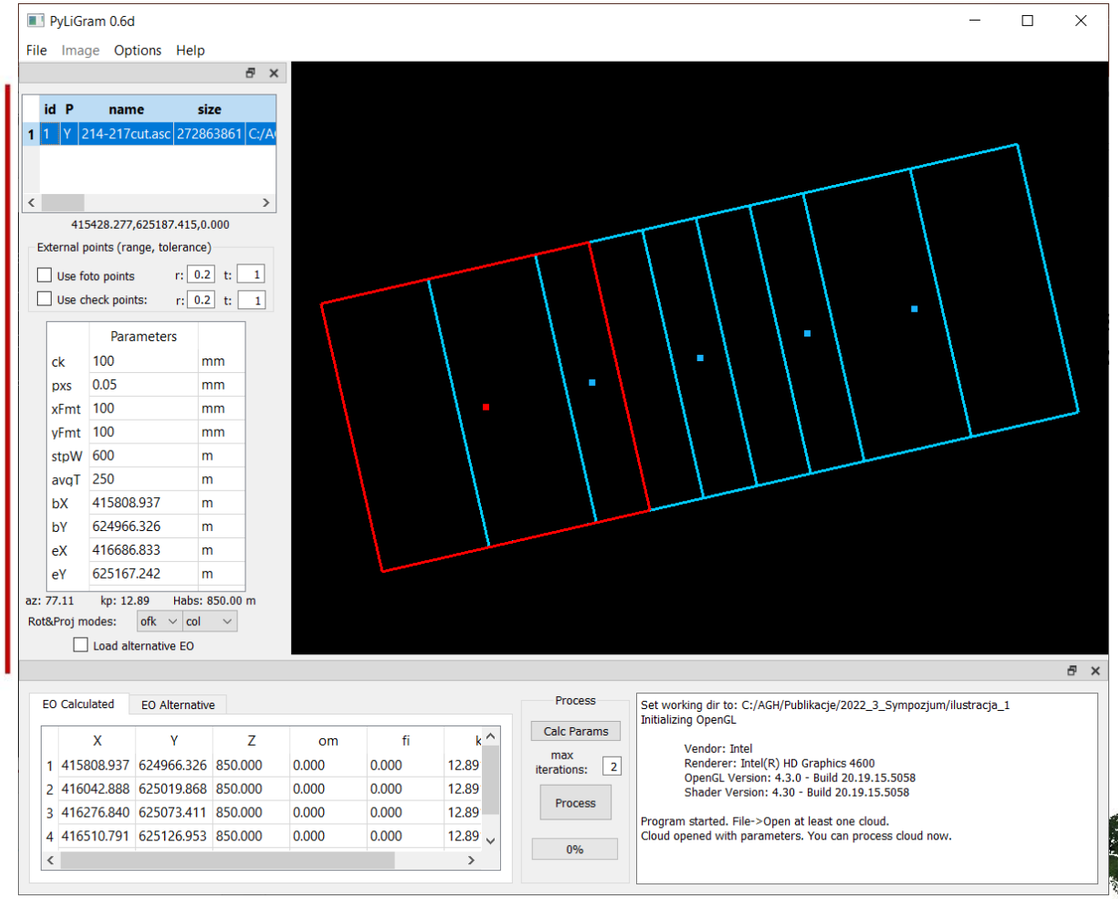


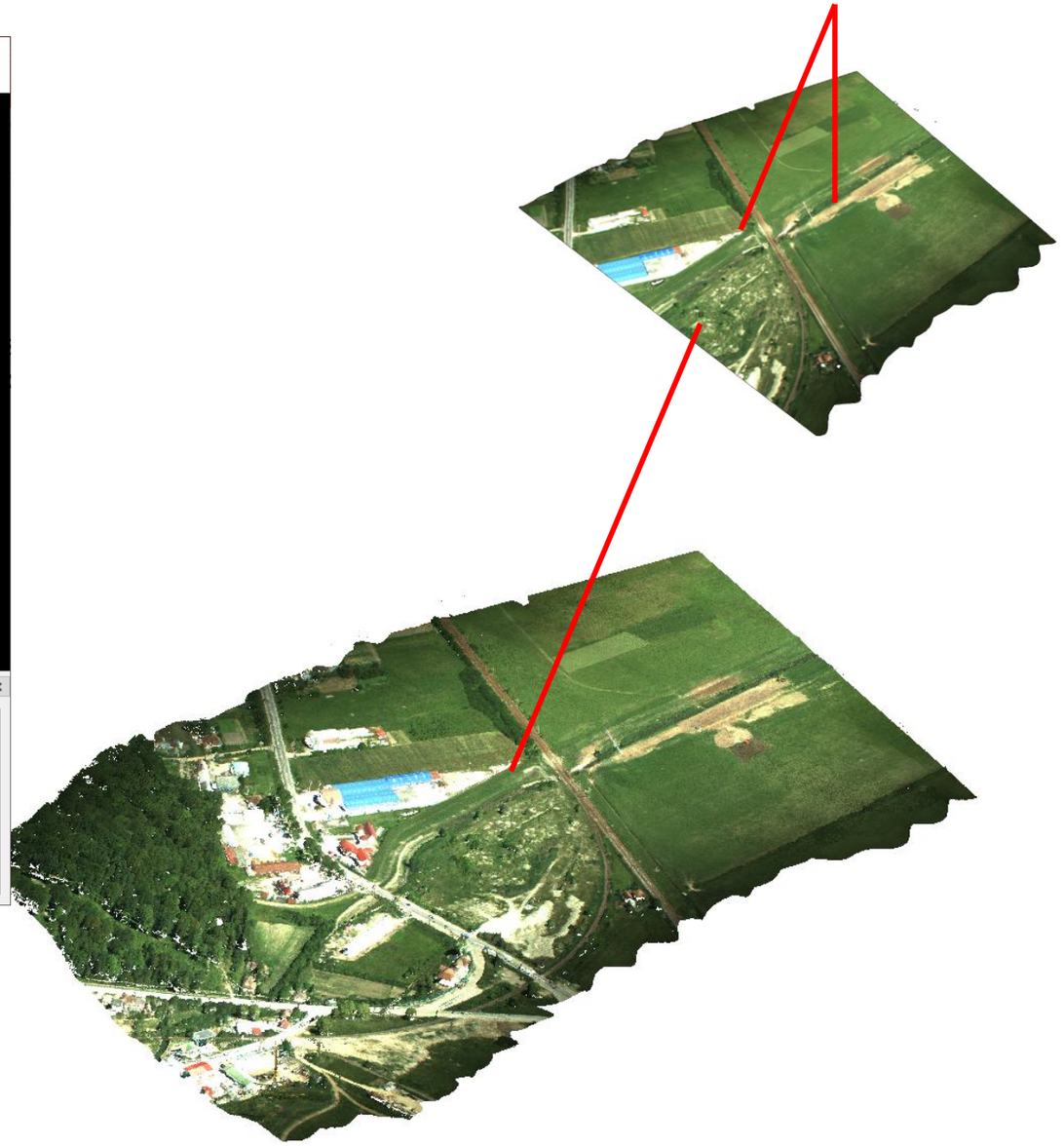
1. Lidargrammetry - genesis



Majek K., Rzonca A., 2016 - ***Lidarometry*** *as a Variant of Integration of Photogrammetric and Laser Scanning Data* (Lidarometria jako wariant integracji danych fotogrametrycznych oraz skaningowych), MAM 2016 nr 08, s. 268-273

1. Lidargrammetry + pixel-point idea





PyLiGram research tool since 2022

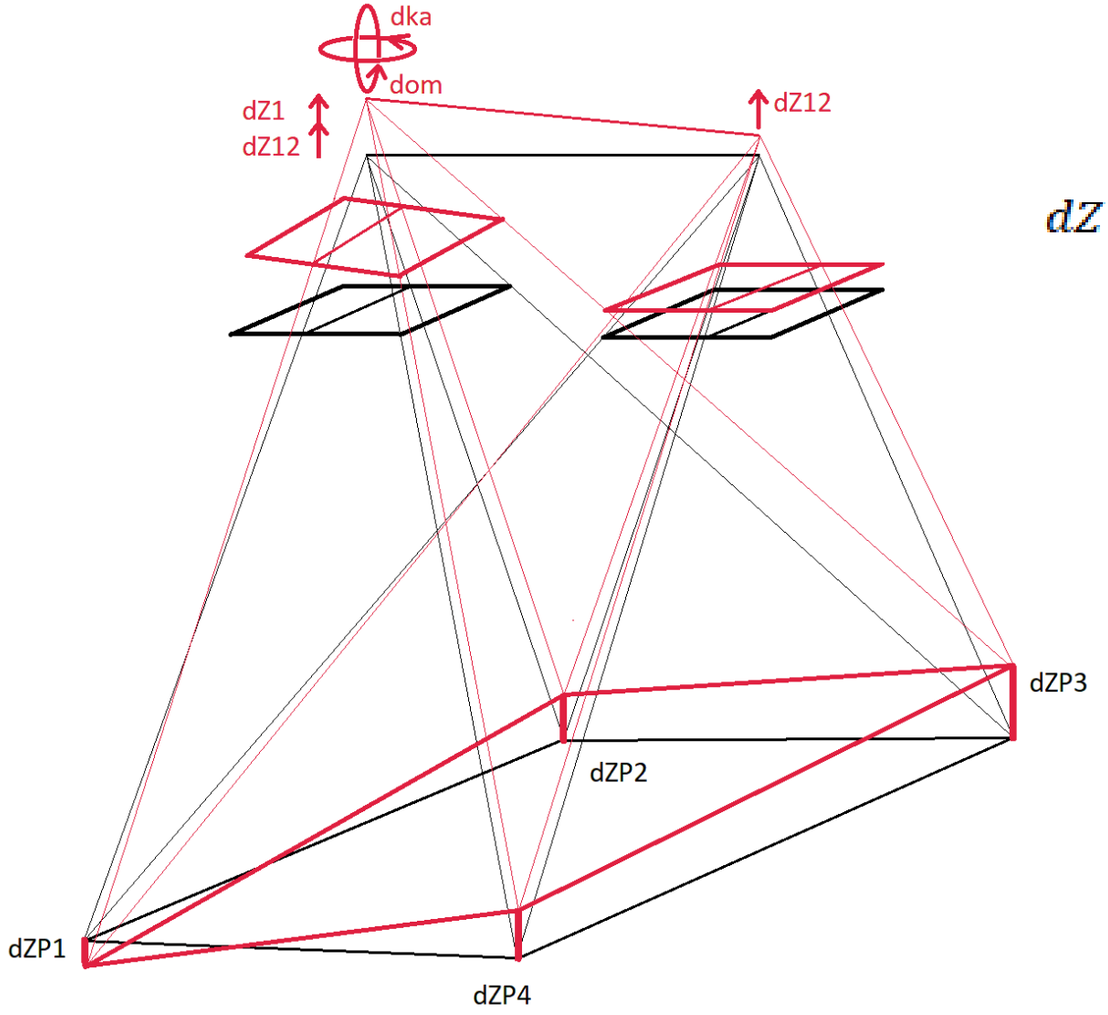
with Mariusz Twardowski, PhD Eng.

Lidargrammetry

1. Genesis: Stereoplotting of LiDAR data
2. **Vertical accuracy enhancement of LiDAR data**
3. Vertical and horizontal accuracy enhancement of LiDAR data
4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

2. Vertical accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., 2022, *The lidargrammetric model deformation method for altimetric UAV-ALS data enhancement*, Remote Sensing — 2022 — vol. 14 iss. 24 art. no. 6391, s. 1-17



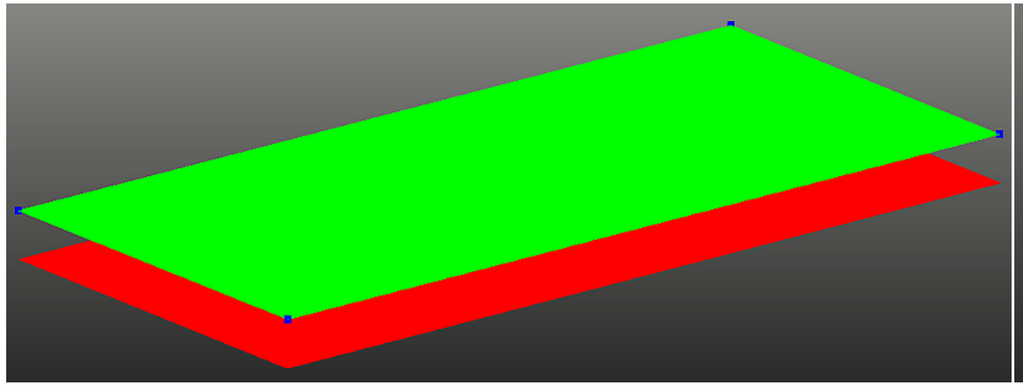
$$dZ = dZ_{12} - \frac{(X-B)}{B} dB_z + \frac{XY}{B} dom - \frac{YH}{B} dka$$

2. Vertical accuracy enhancement of LiDAR data

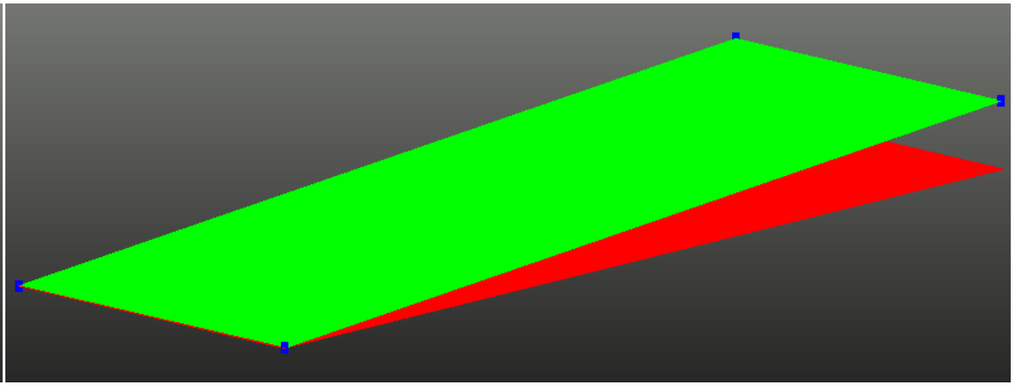
Rzonca A., Twardowski M., 2022, *The lidargrammetric model deformation method for altimetric UAV-ALS data enhancement*, Remote Sensing — 2022 — vol. 14 iss. 24 art. no. 6391, s. 1-17

2. Vertical accuracy enhancement of LiDAR data

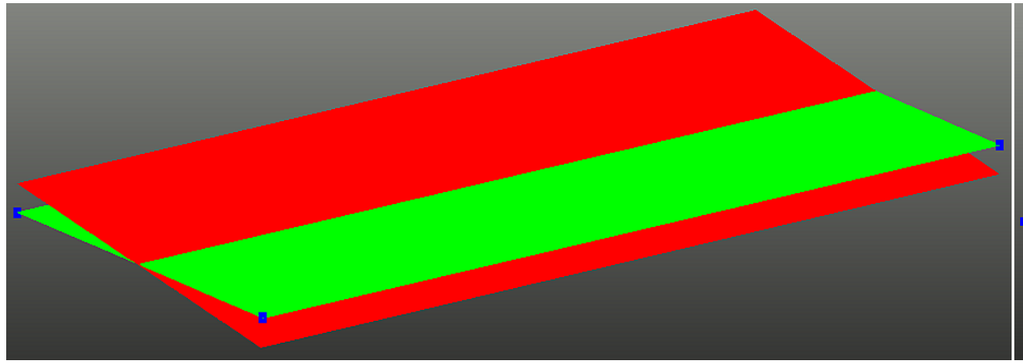
$$dZ = dZ_{12} - \frac{(x-B)}{B} dB_z + \frac{XY}{B} dom - \frac{YH}{B} dka$$



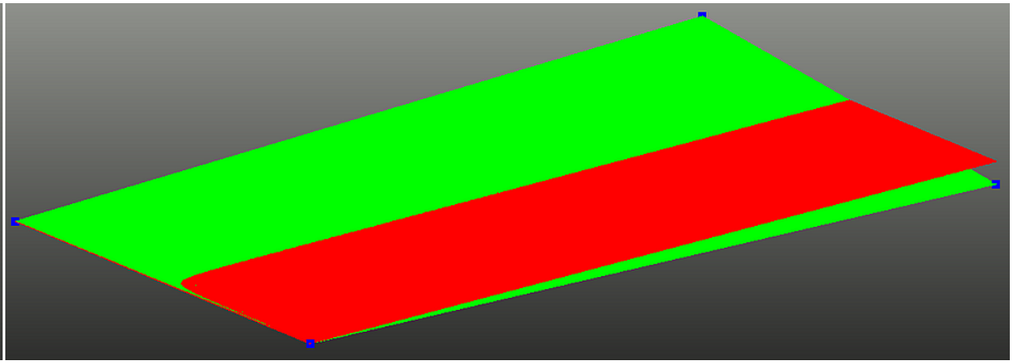
dZ12



dZ1



dω



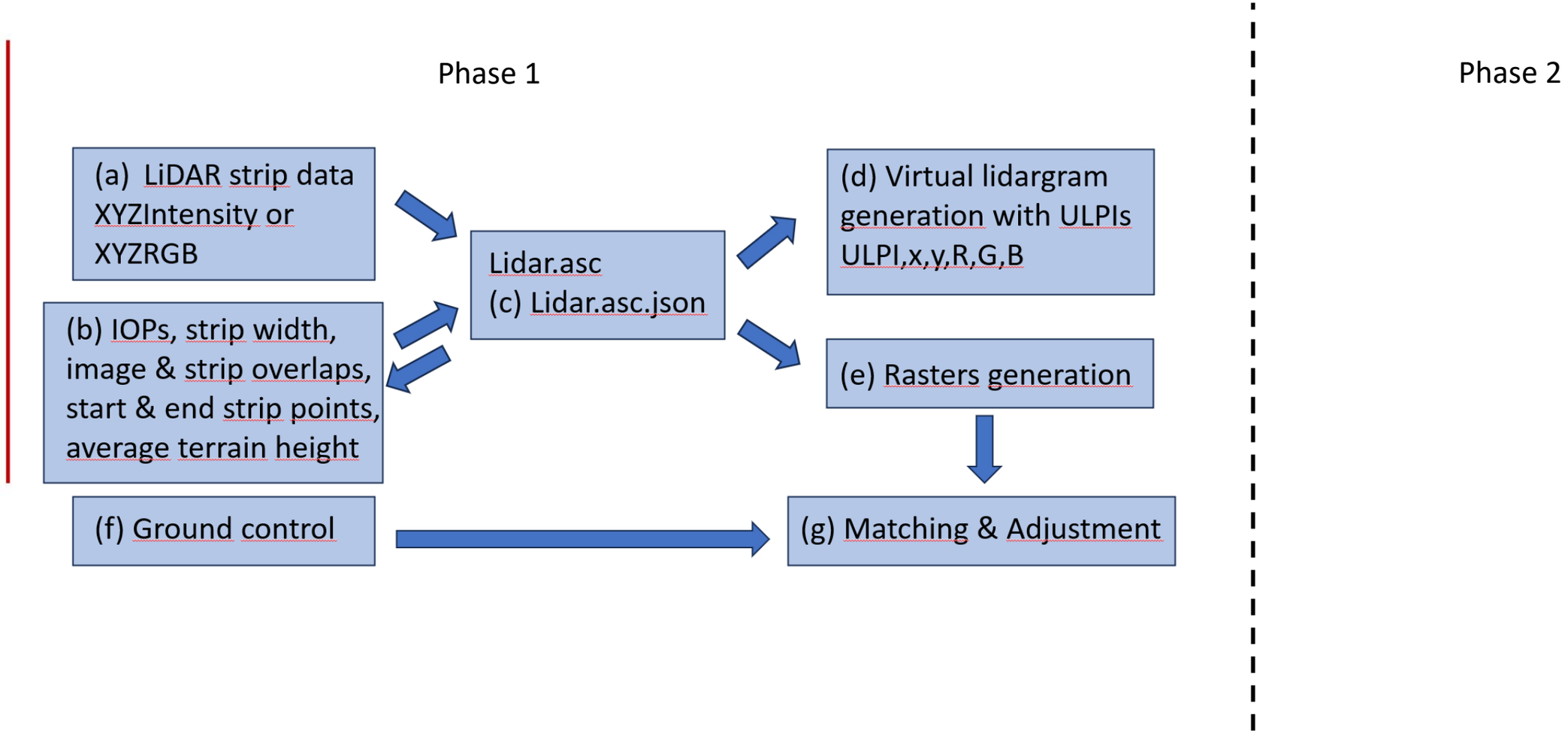
dκ

Lidargrammetry

1. Genesis: Stereoplotting of LiDAR data
2. Vertical accuracy enhancement of LiDAR data
3. **Vertical and horizontal accuracy enhancement of LiDAR data**
4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

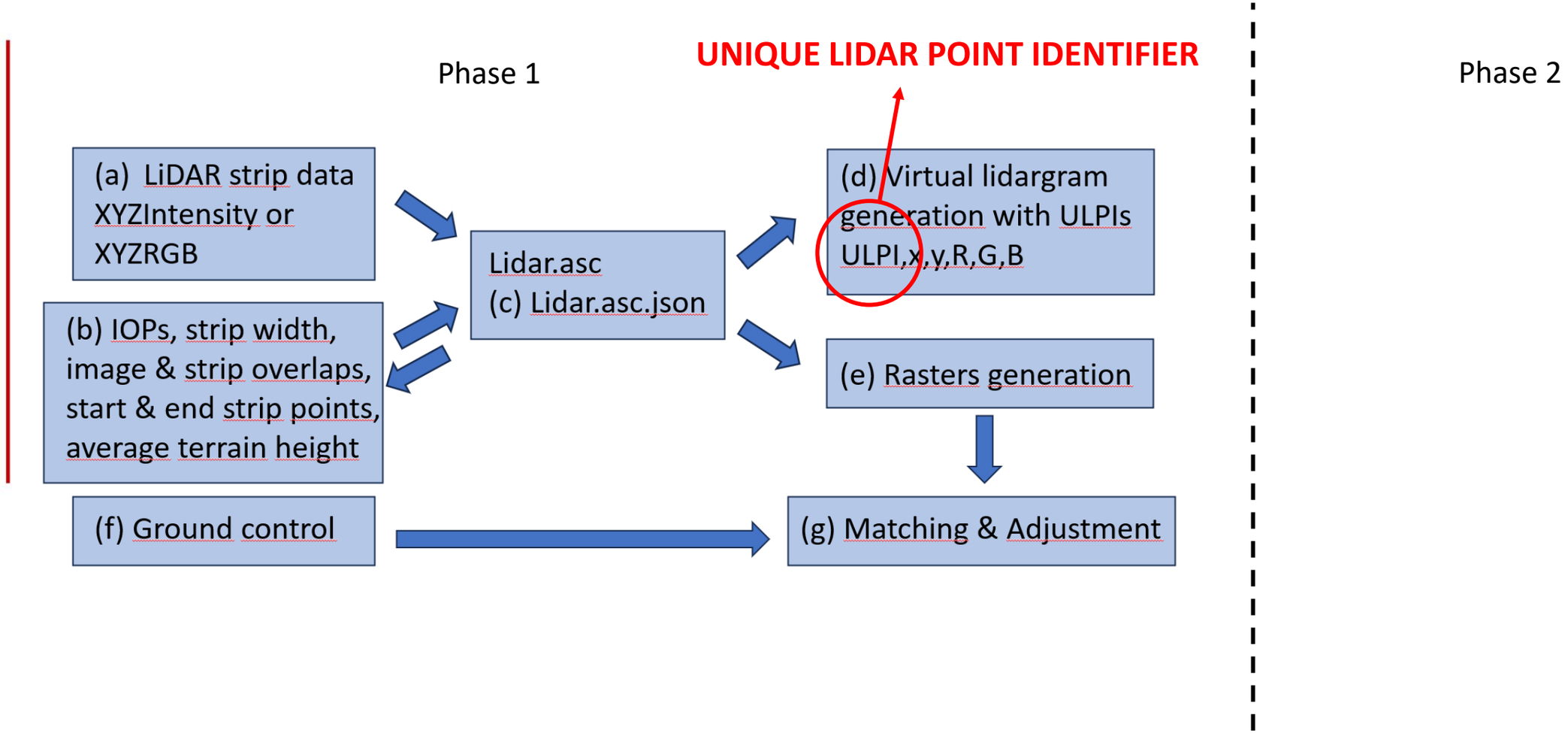
3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



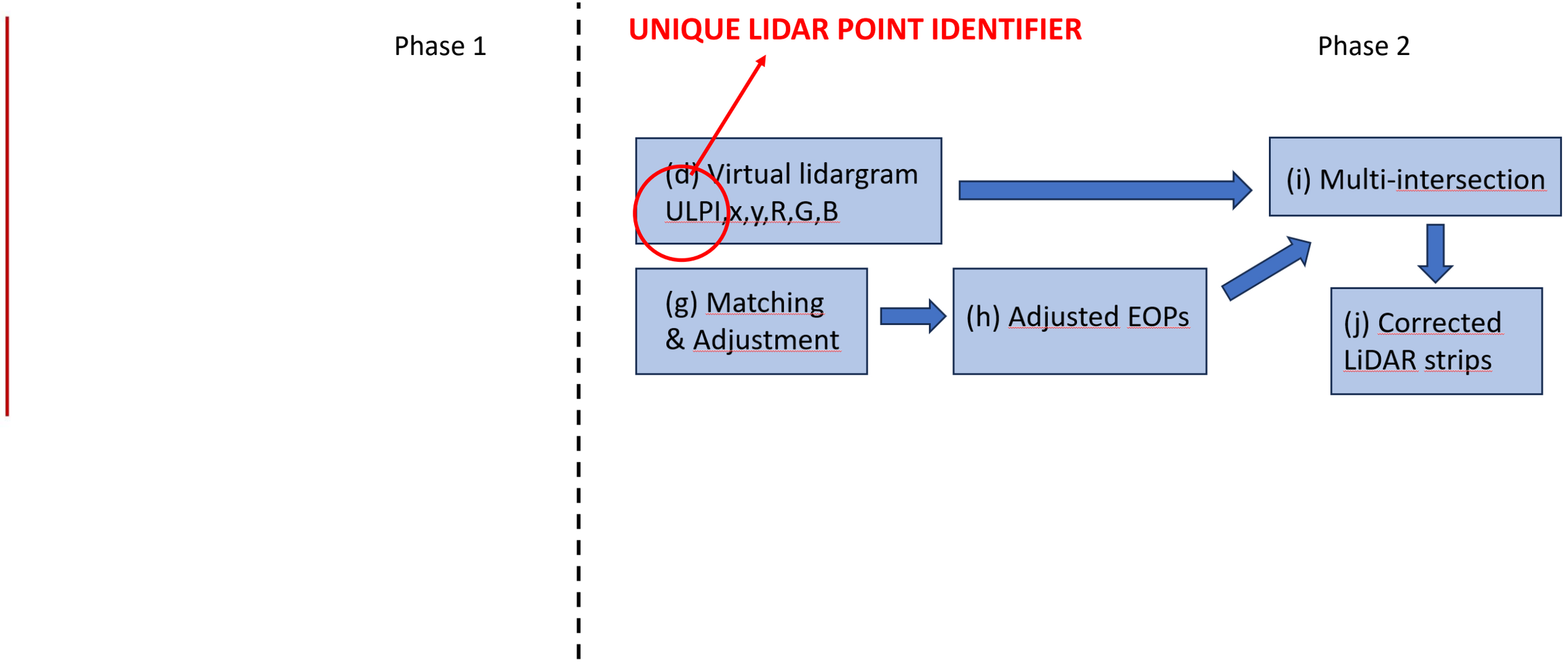
3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



3. Vertical and horizontal accuracy enhancement of LiDAR data

Pargieła K., Rzonca A., Twardowski M., 2023, *The utilization of **synthetic and semisynthetic** point clouds and images for testing novel approaches for correcting lidar,* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. —2023 — vol. 48-1/W3-2023, s. 145–151

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;

a) synthetic data (Biskupice test field)

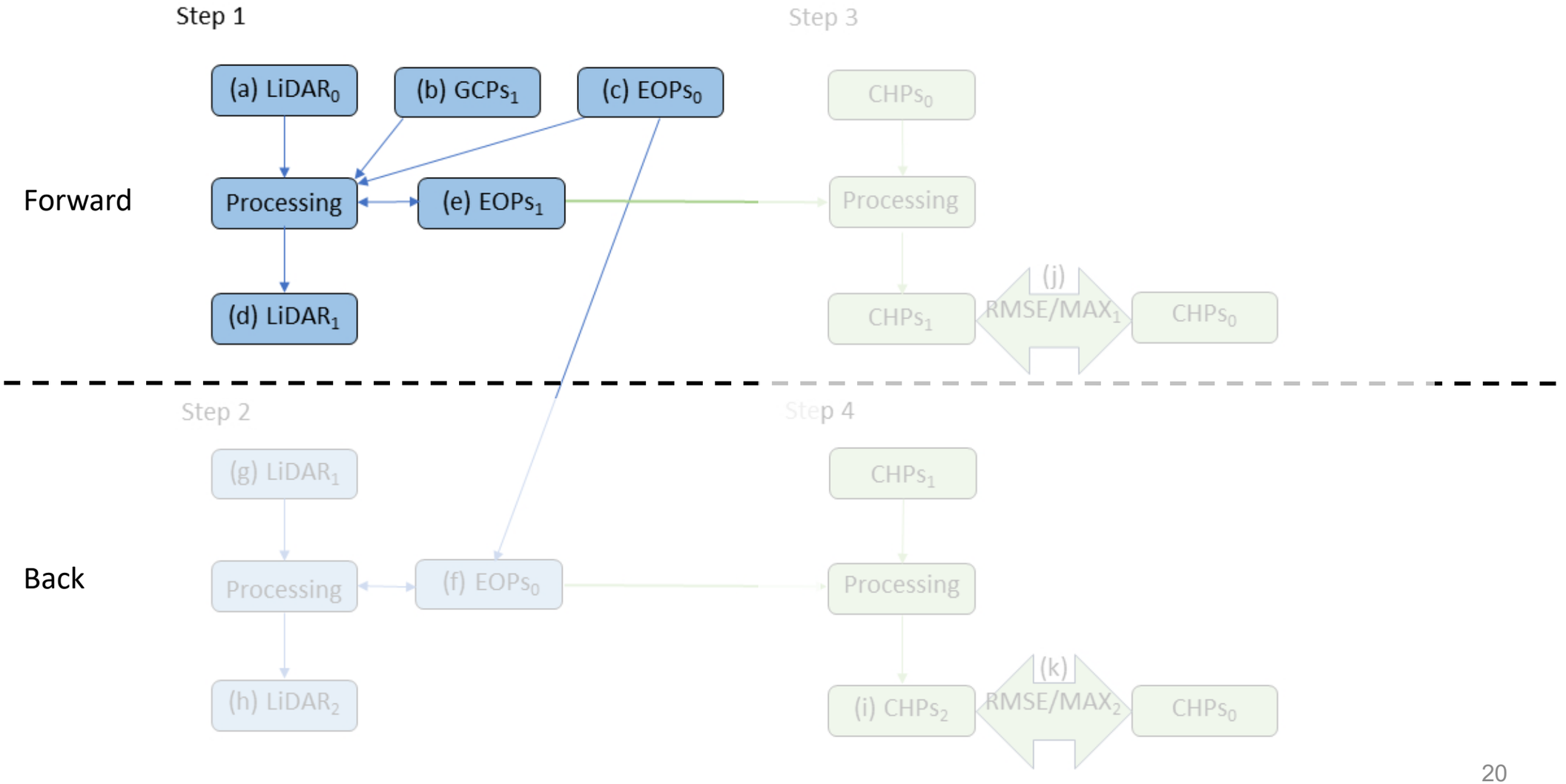
b) semisynthetic data

(Krakow Center test field)

c) real data (Wola Batorska test field)

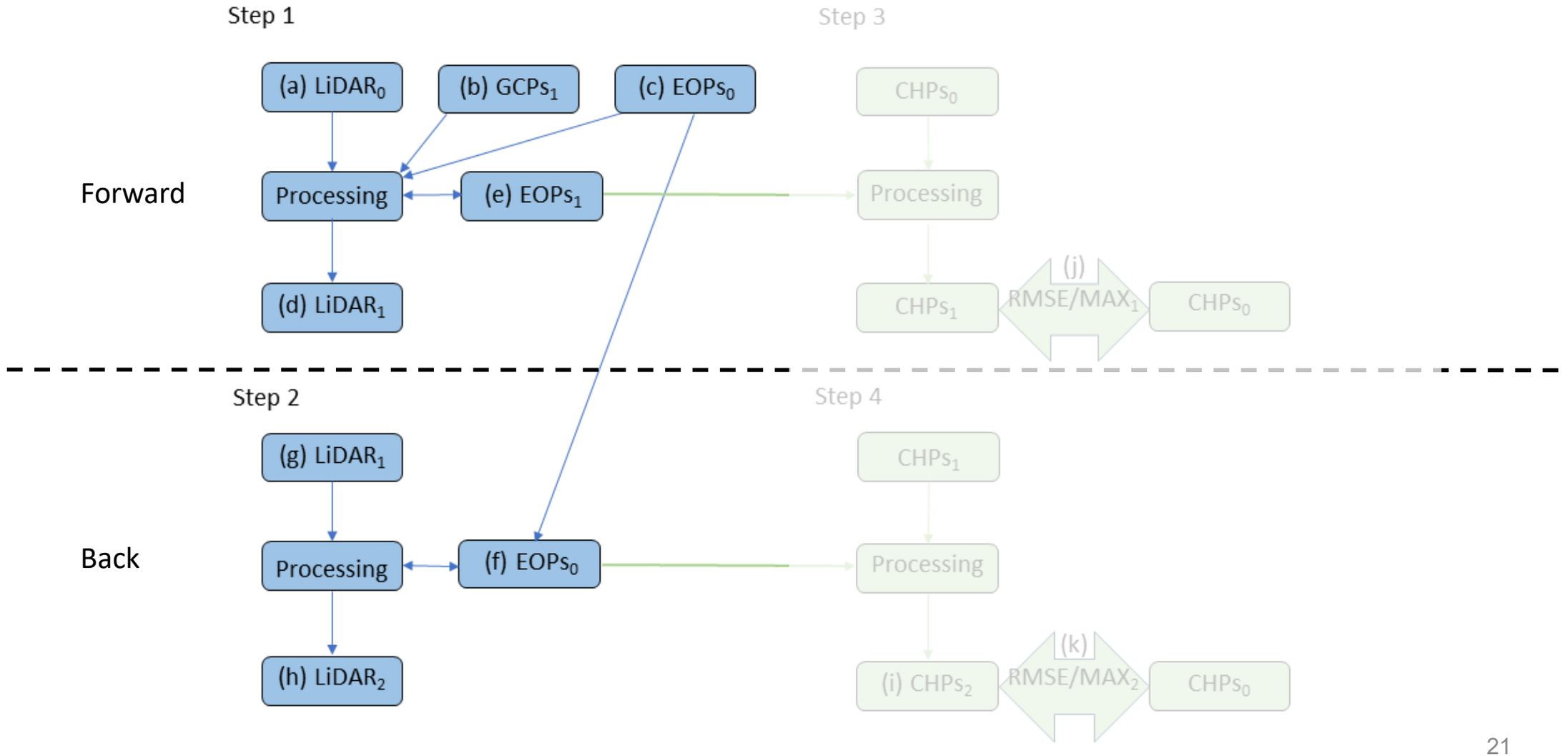
3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



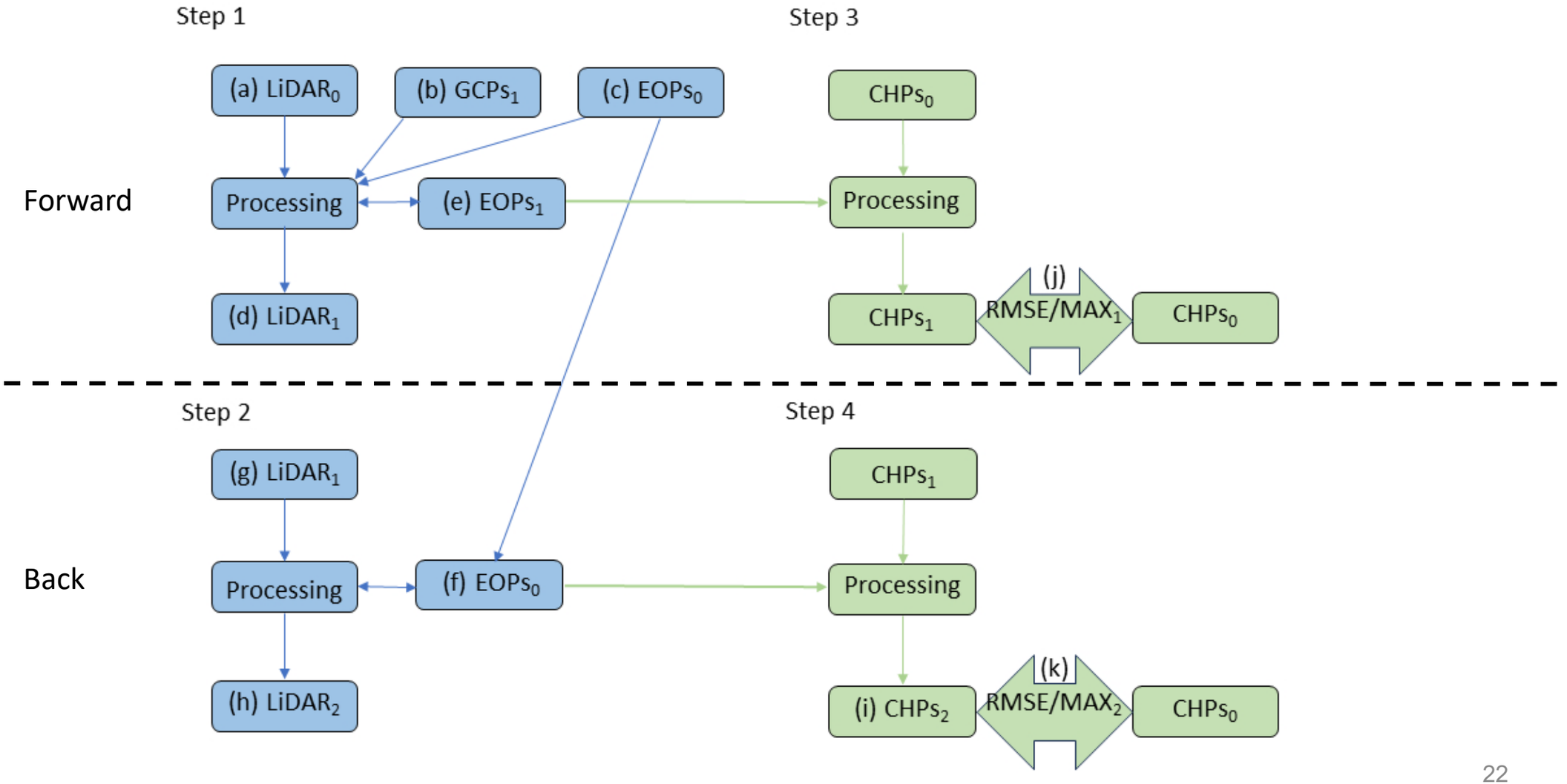
3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;



3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;

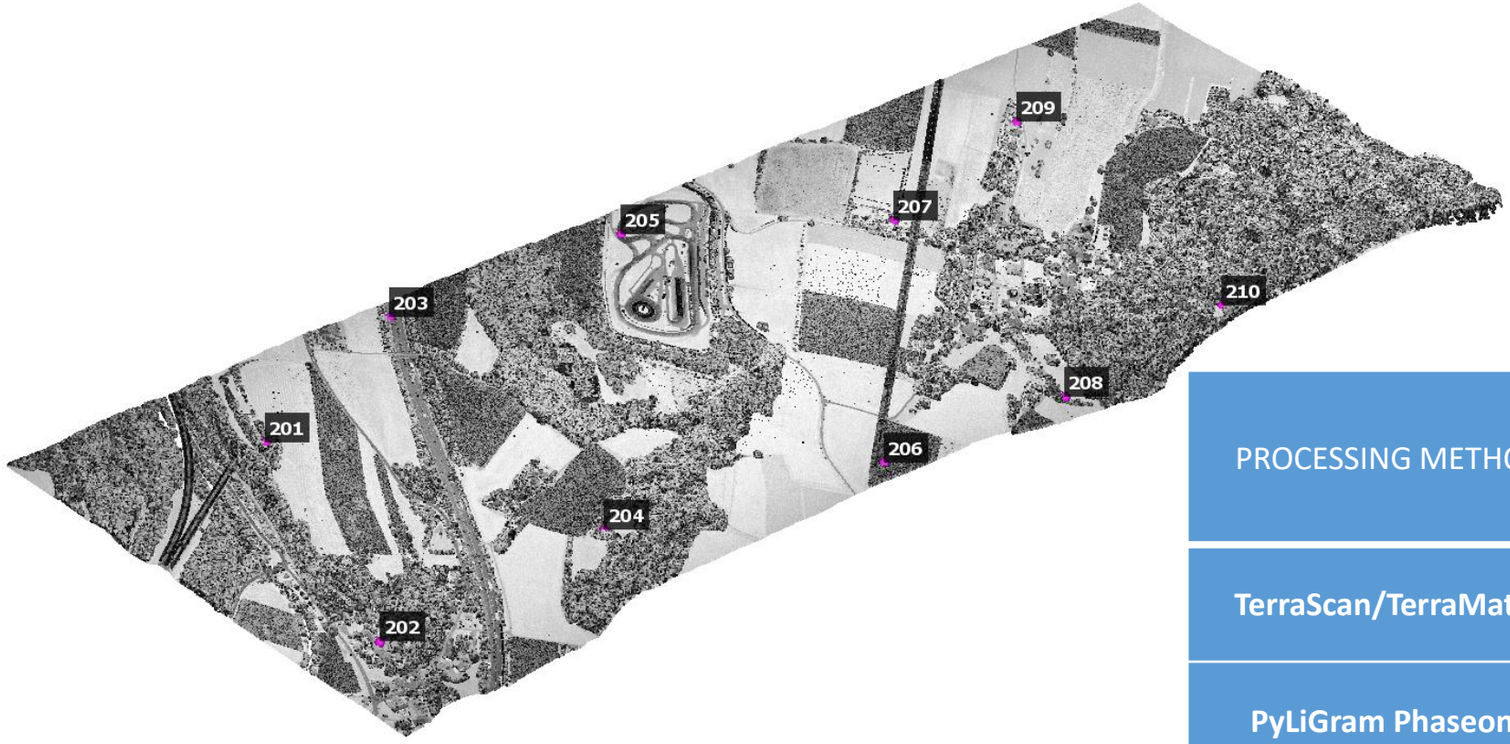
Results:

Data	Processing	RMSE					MAX VALUES				
		X [m]	Y [m]	Z [m]	XY [m]	XYZ [m]	X [m]	Y [m]	Z [m]	XY [m]	XYZ [m]
Synthetic	Before	0,267	0,263	0,359	0,377	0,522	0,648	0,637	1,083	1,017	1,636
	After	0,007	0,010	0,022	0,012	0,026	0,057	0,069	0,174	0,111	0,223
Semi-synthetic	Before	0,304	0,314	0,343	0,438	0,560	0,454	0,536	0,515	0,692	0,910
	After	0,014	0,035	0,026	0,038	0,046	0,053	0,076	0,070	0,162	0,196
Real	Before	0,252	0,241	0,322	0,355	0,480	0,543	0,482	0,608	0,609	0,934
	After	0,002	0,004	0,003	0,004	0,005	0,004	0,01	0,009	0,011	0,014

3. Vertical and horizontal accuracy enhancement of LiDAR data

Rzonca A., Twardowski M., One-step enhancement method of data registration based on the lidargrammetric approach; in review;

TerraMatch comparision



Loosdorf: density 25cm

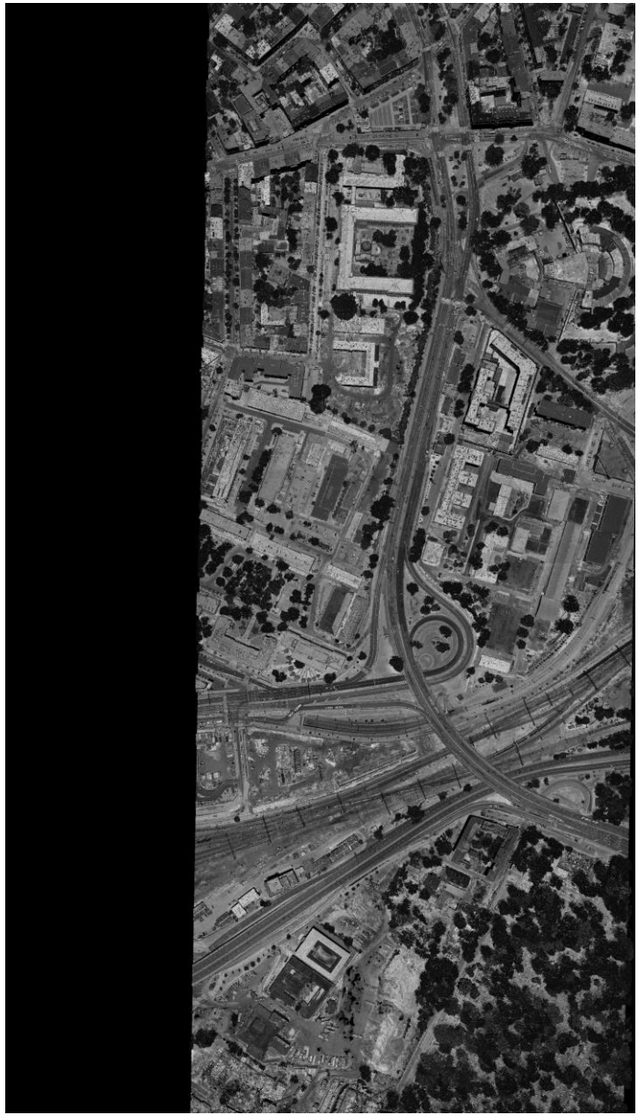
PROCESSING METHOD	SQUARES OF MEAN DIRRERENCES				
	dX [m]	dY [m]	dZ [m]	dXY [m]	dXYZ [m]
TerraScan/TerraMatch	0,062	0,038	0,028	0,073	0,078
PyLiGram Phaseone	0,077	0,074	0,083	0,107	0,136
PyLiGram Densified	0,098	0,103	0,075	0,143	0,161

Lidargrammetry

1. Genesis: Stereoplotting of LiDAR data
2. Vertical accuracy enhancement of LiDAR data
3. Vertical and horizontal accuracy enhancement of LiDAR data
4. **Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data:**
    - **4.1. Co-matching**
    - **4.2. Co-adjustment**

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

Kraków testfield
GSD=15cm ; density 10cm
Intensity



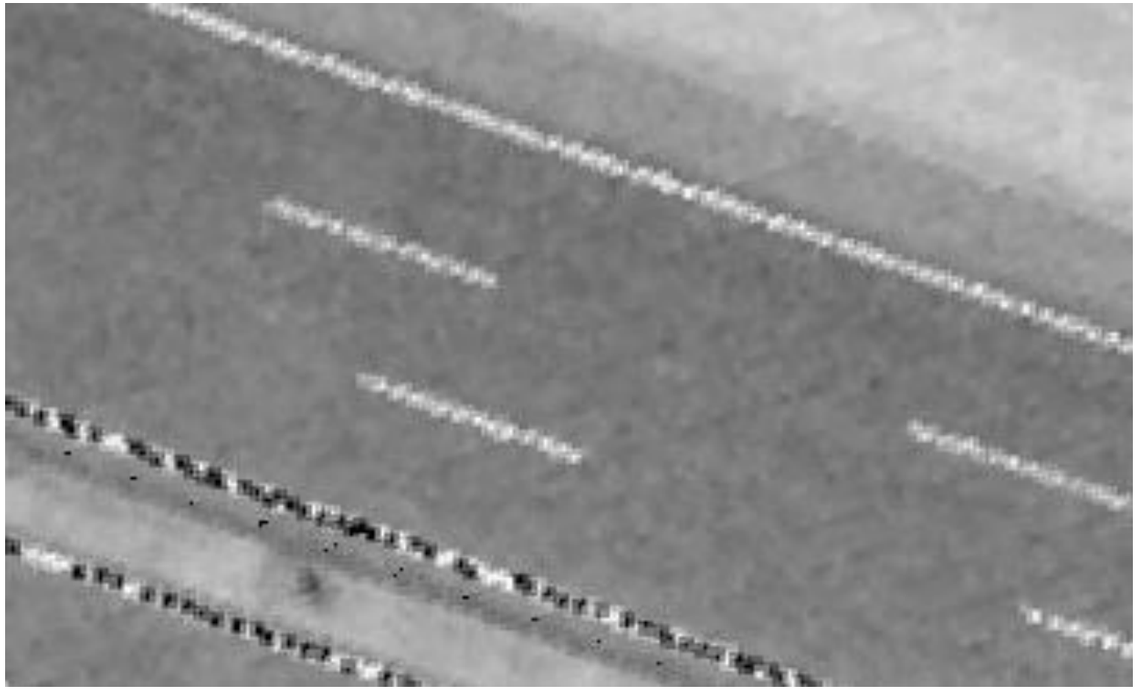
4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

Kraków testfield
GSD=15cm ; density 10cm
Intensity

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

Loosdorf testfield
GSD=7,4cm; density 3cm
NIR

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

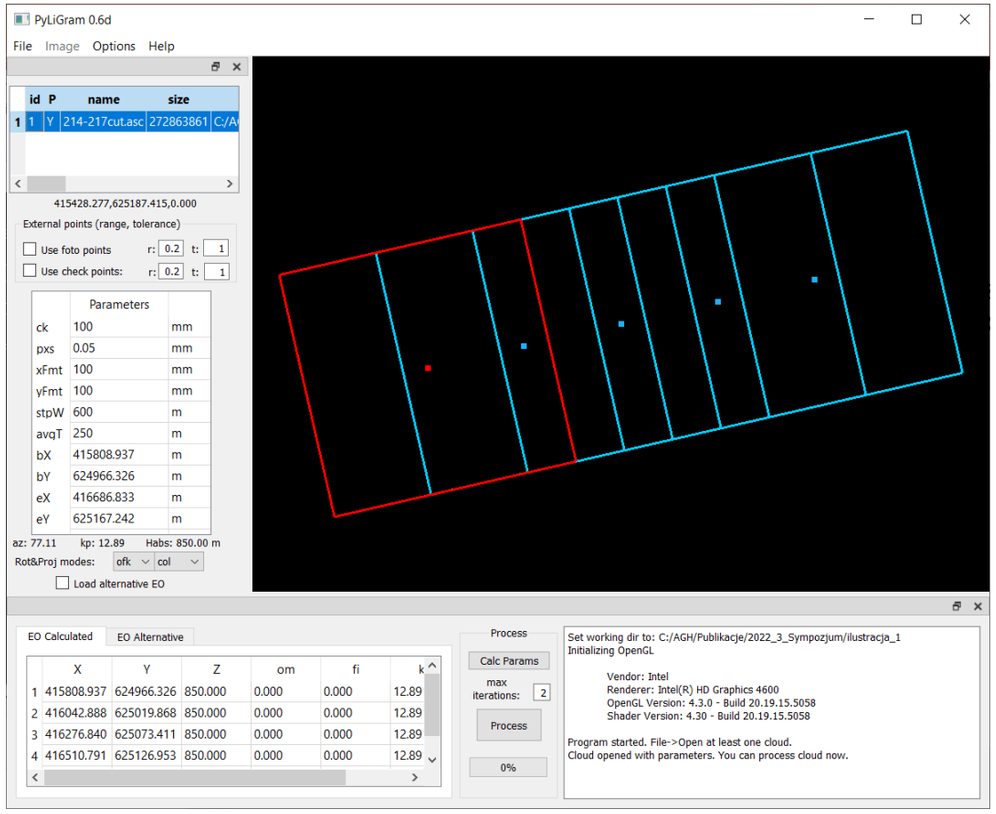


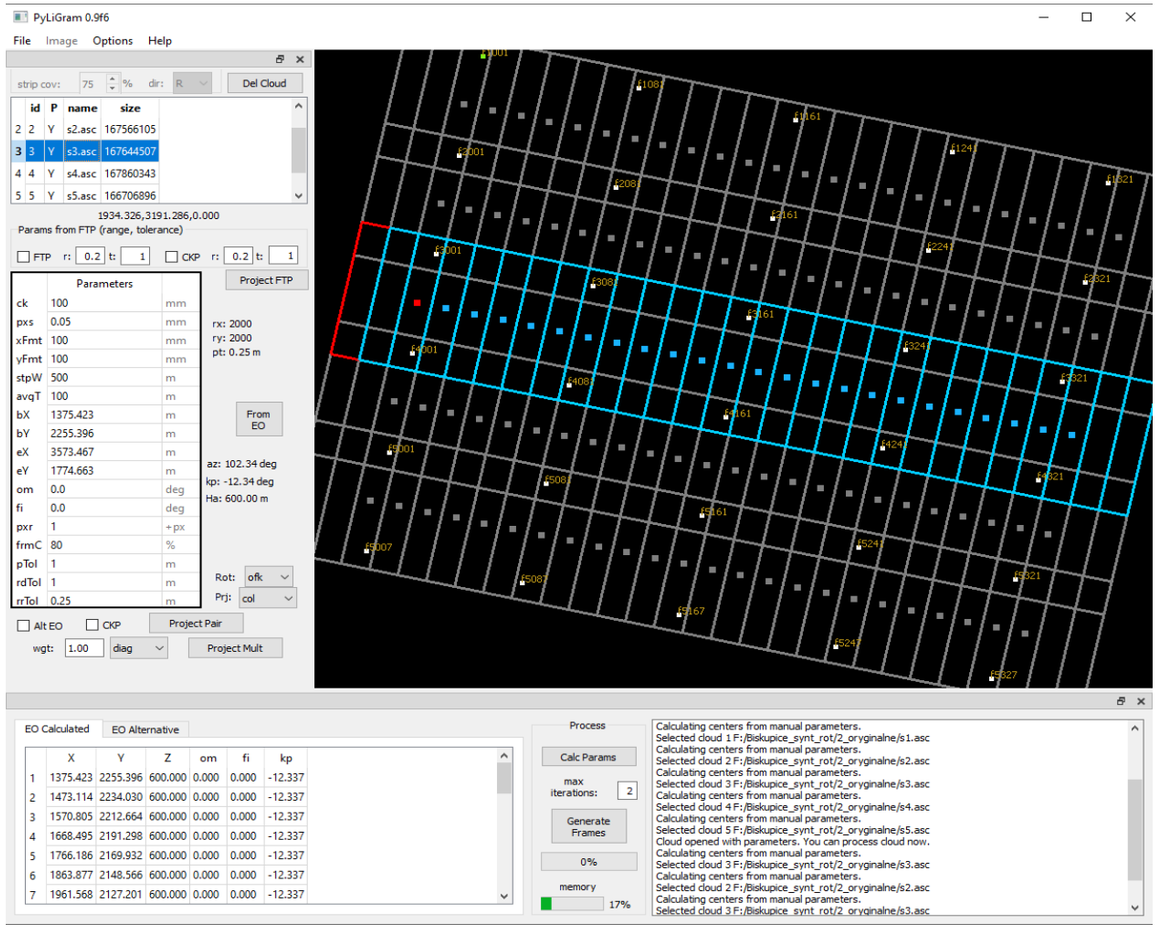
Loosdorf testfield
GSD=7,4cm; density 3cm
NIR

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

4.1. Co-matching

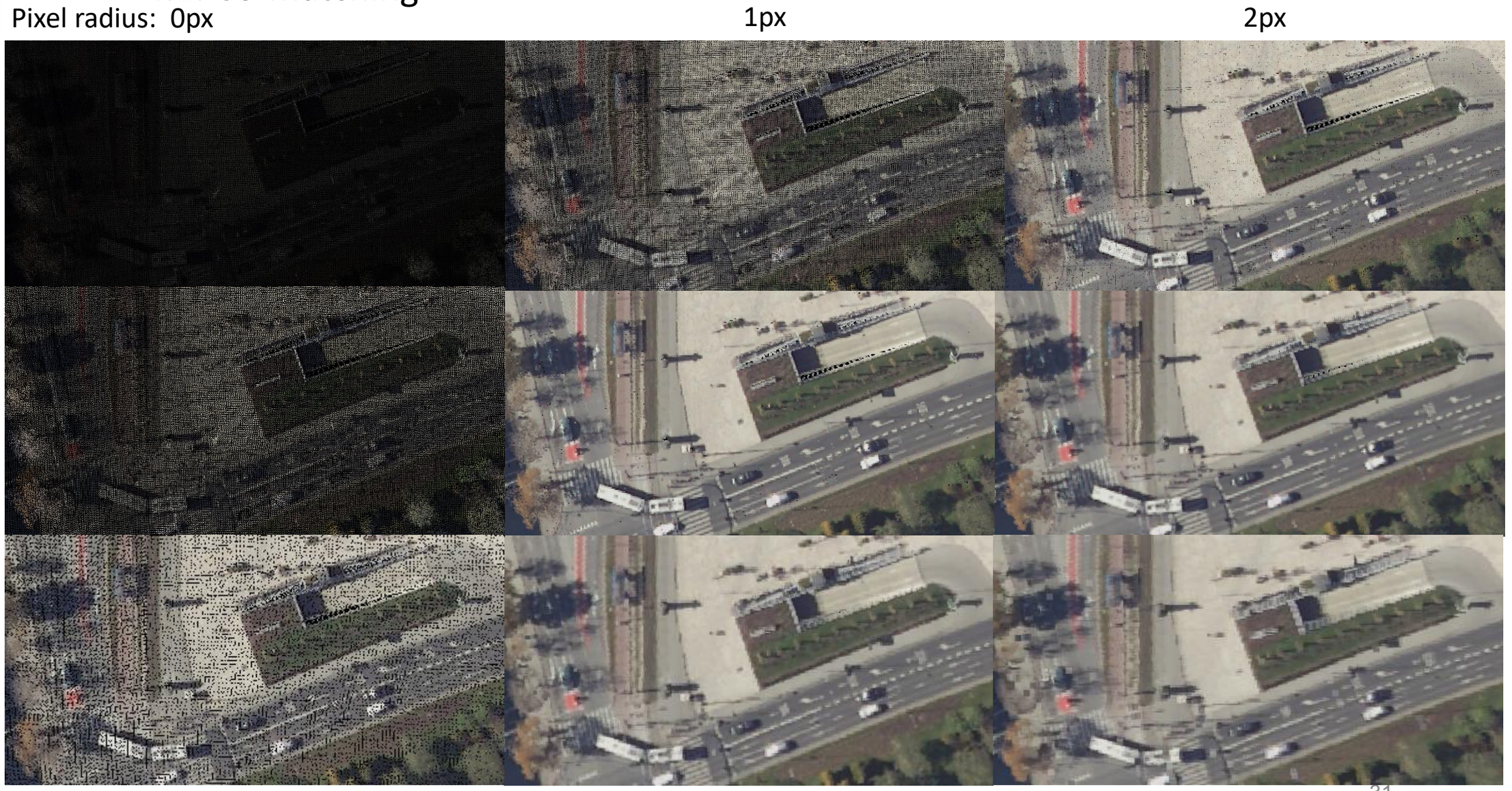
Rzonca A., Twardowski M., 2025, *PyLiGram – Research Application for Lidar Data Processing Based on Photogrammetric Methods*; Geomatics and Environmental Engineering (in printing)





4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

4.1. Co-matching



4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data

4.1. Co-matching

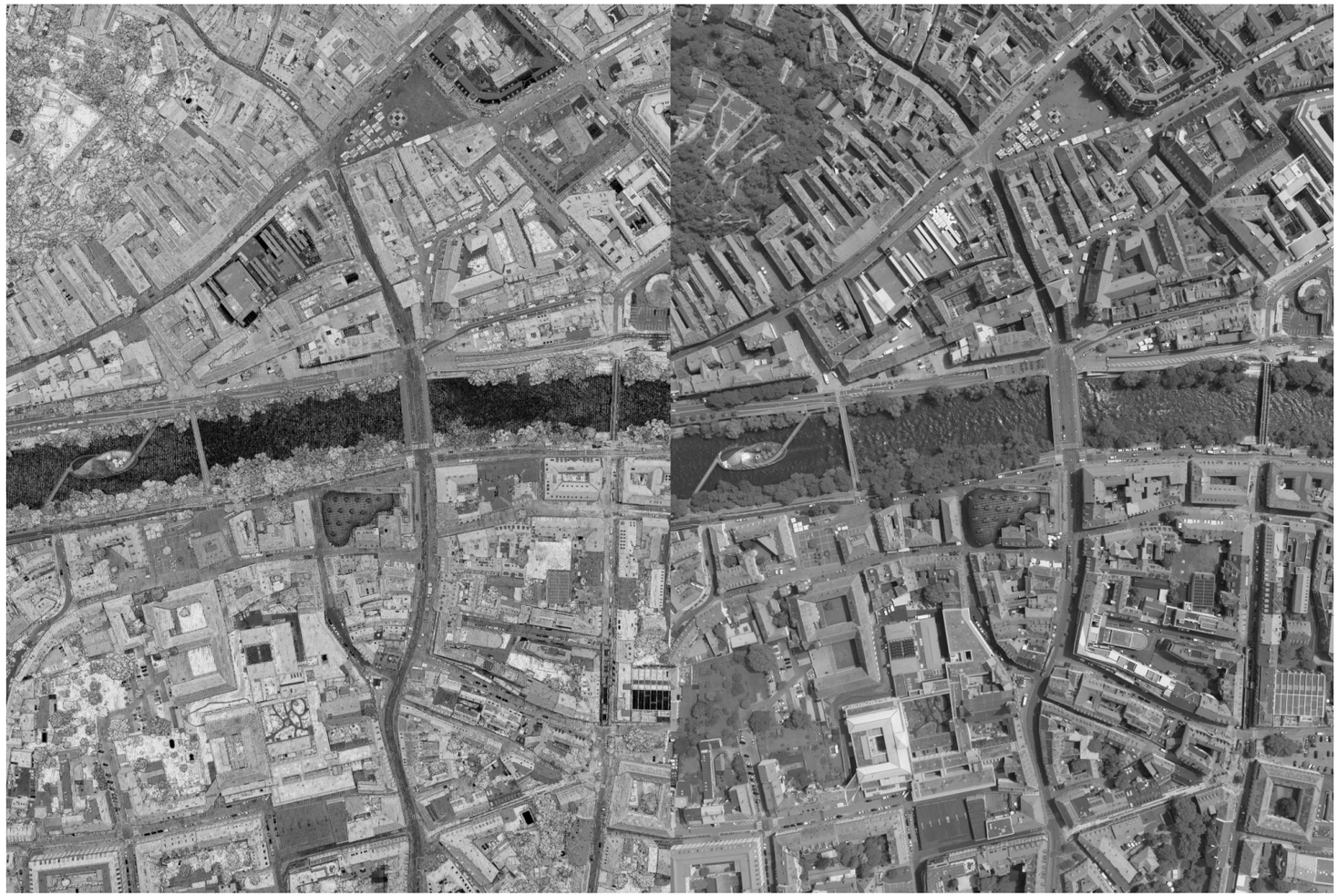
Pixel radius: 1px

Pixel size:

0,050mm

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa



4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.1. Co-matching

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Deep Image Matching
3DOM FBK Trento, Italy

Elisa Mariarosaria Farella
Luca Morelli
Fabio Remondino

SUPERPOINT+LIGHTGLUE

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Co-adjustment cases

Case 1

LiDAR to correct
Photos for reference

Weighting:
- EOPs of photos fixed
- EOPs of lidargrams free

Case 2

LiDAR to correct
Photos to correct

Weighting:
- EOPs of photos free
- EOPs of lidargrams free

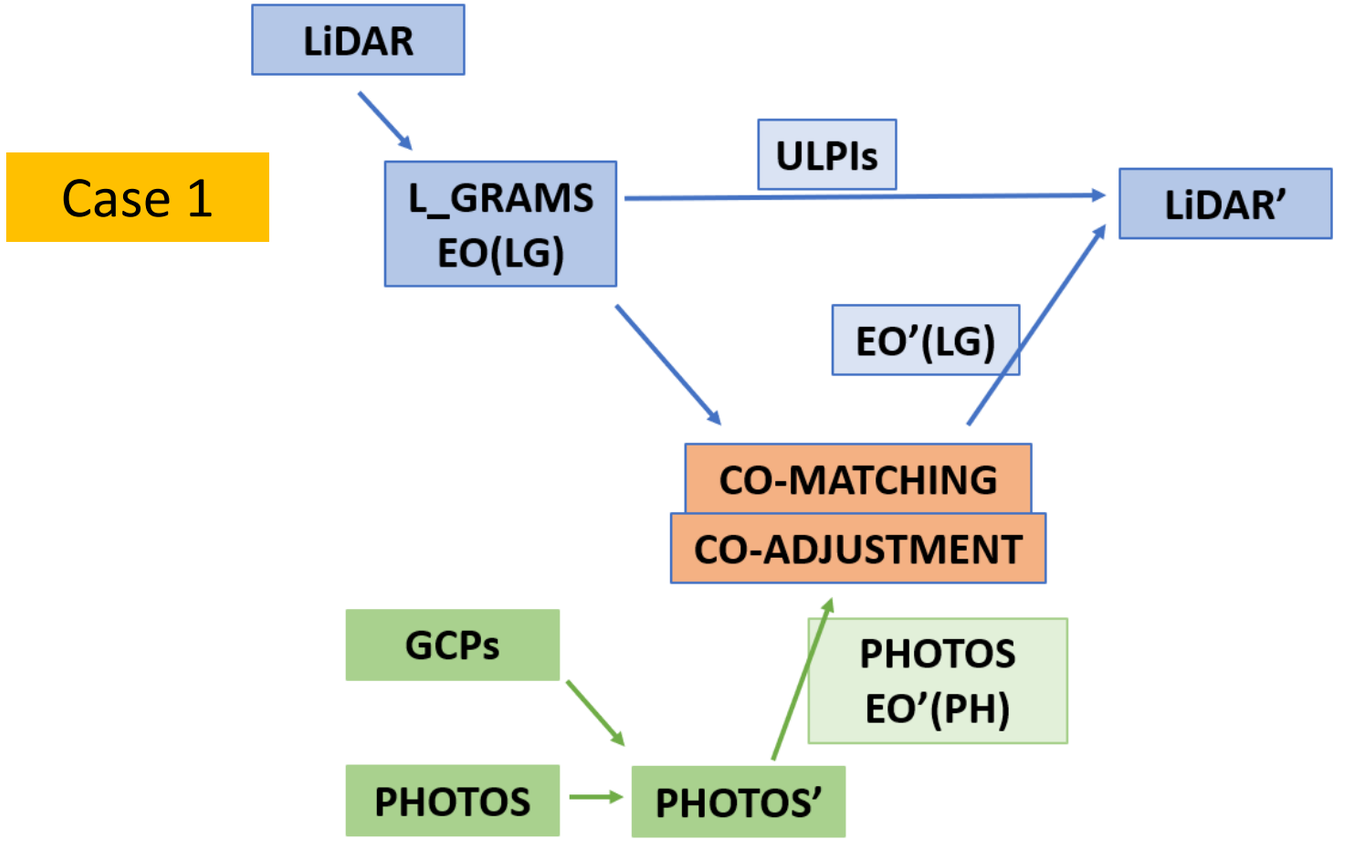
Case 3

Photos to correct
LiDAR for reference

Weighting:
- EOPs of photos free
- EOPs of lidargrams fixed

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa



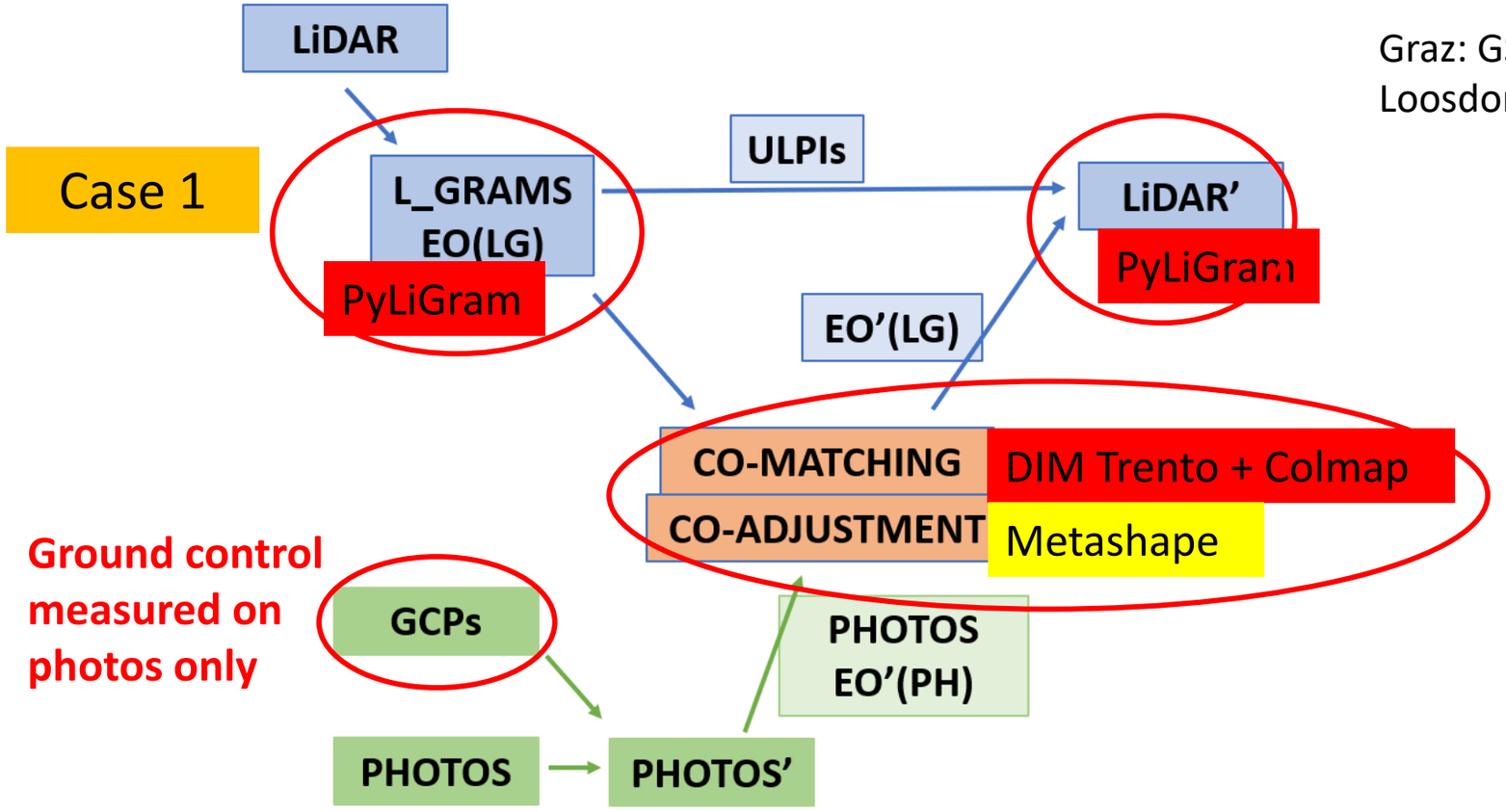
Graz (block)**:**
- GSD 5cm
- Density 13cm
- 3 strips of 10 photos each
- #images: 60

Loosdorf (corridor)**:**
- GSD 8cm
- Density 25cm
- 1 strip of 19 photos
- #images: 37

GNSS signal jamming

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

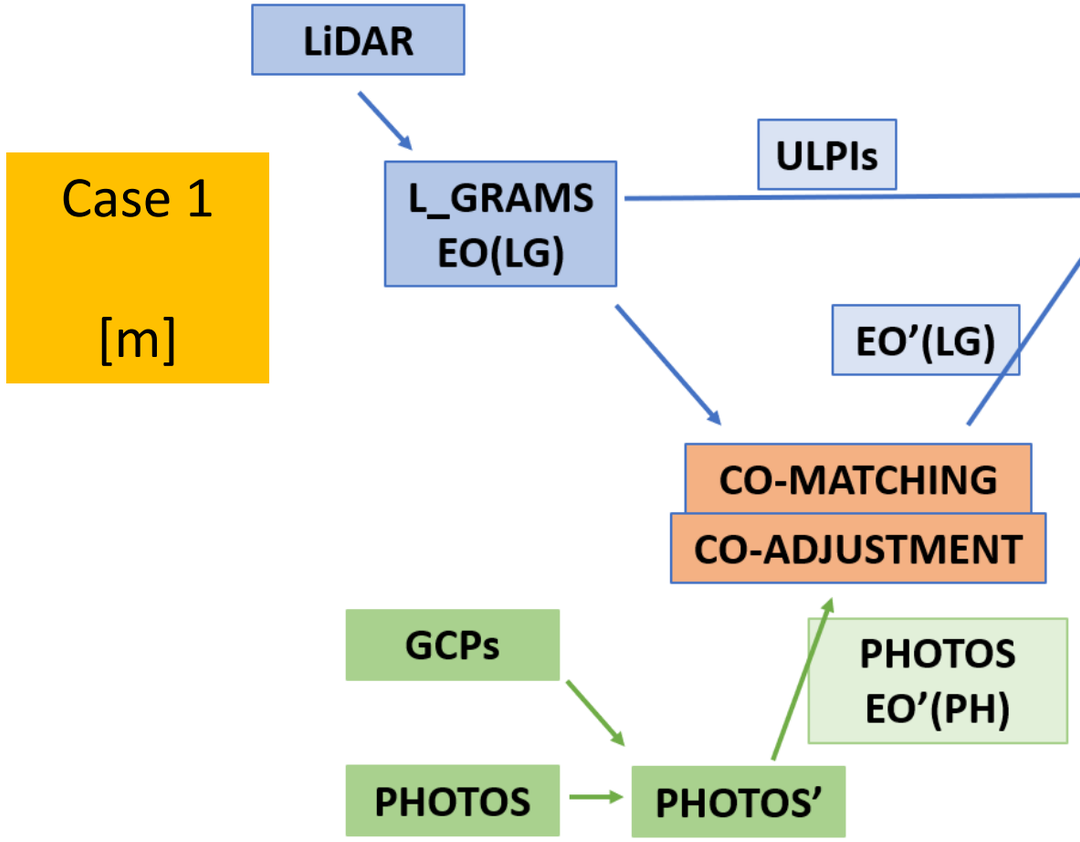
Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

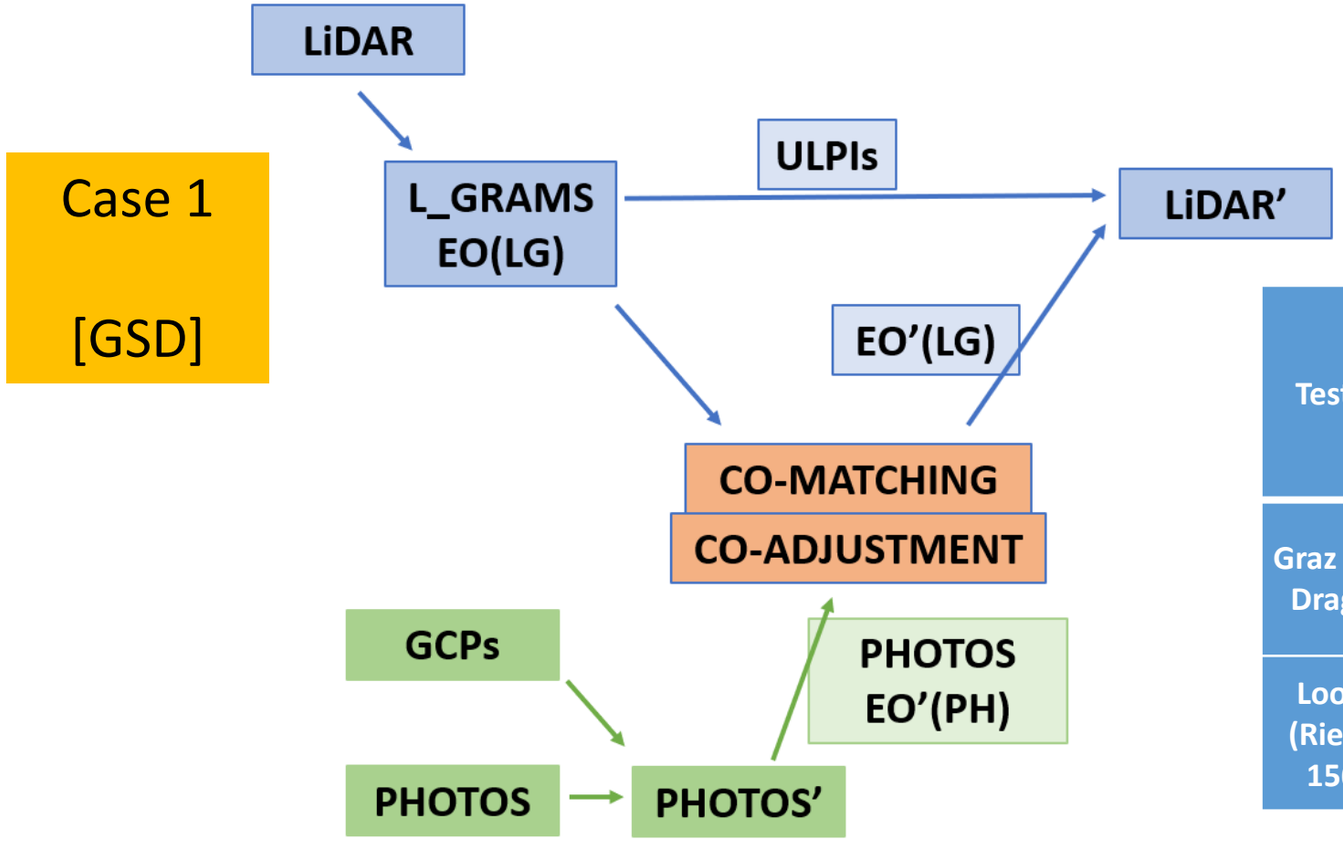


Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

Test field	Ground control	RMSE X [m]	RMSE Y [m]	RMSE Z [m]	Reprojection Error [px]
Graz (Vexcel Dragon 4)	GCPs (7)	0.079	0.059	0.126	0.459
	ChPs (13)	0.031	0.040	0.113	0.335
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0.044	0.138	0.074	0.131
	ChPs (19)	0.044	0.090	0.070	0.229

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

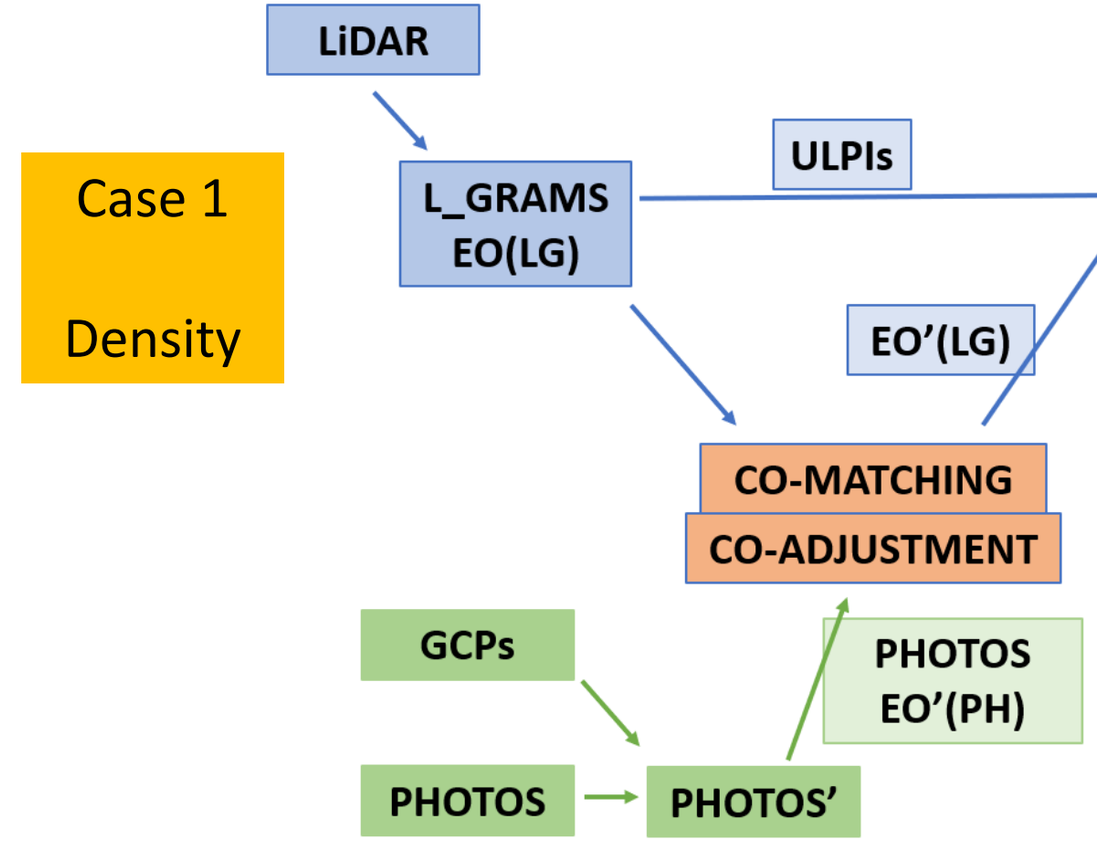
Test field	Ground control	RMSE X [GSD]	RMSE Y [GSD]	RMSE Z [GSD]
Graz (Vexcel Dragon 4)	GCPs (7)	1,580	1,180	2,520
	ChPs (13)	0,620	0,800	2,260
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0,550	1,725	0,925
	ChPs (19)	0,550	1,125	0,875

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 1

Density



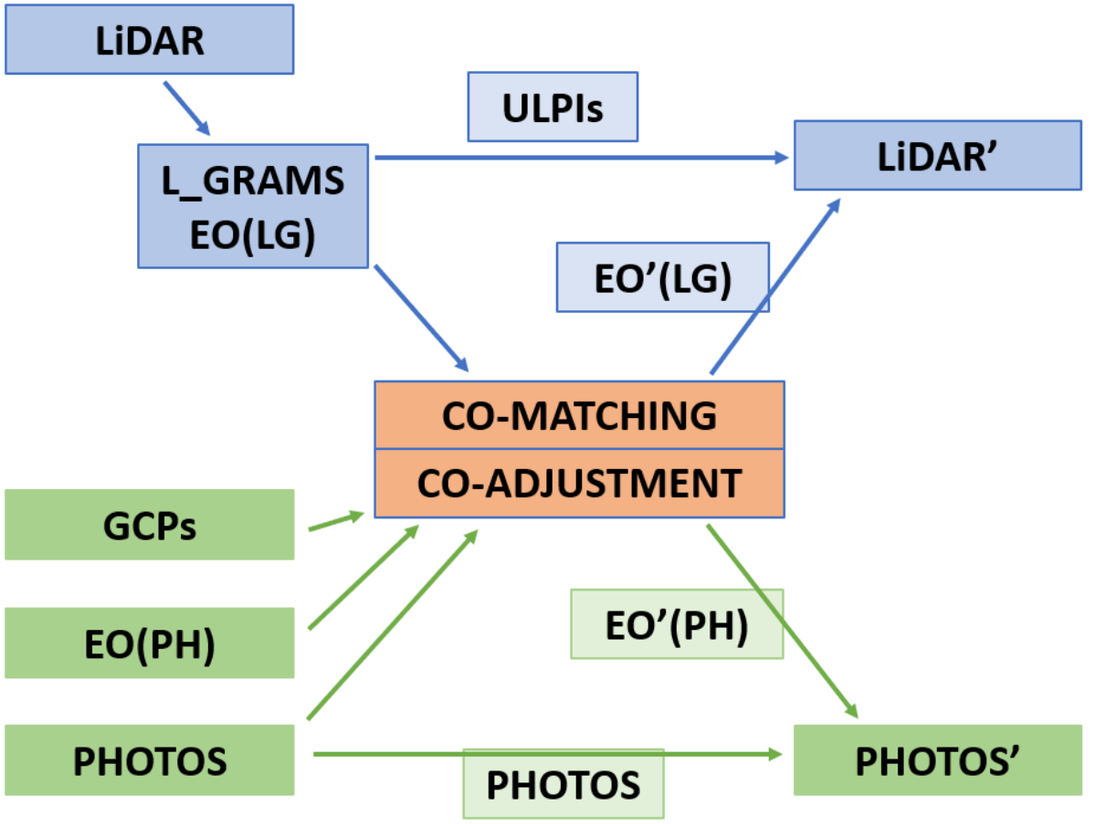
Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

Test field	Ground control	RMSE X [Density]	RMSE Y [Density]	RMSE Z [Density]
Graz (Vexcel Dragon 4)	GCPs (7)	0,608	0,454	0,969
	ChPs (13)	0,238	0,308	0,869
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0,176	0,552	0,296
	ChPs (19)	0,176	0,360	0,280

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 2



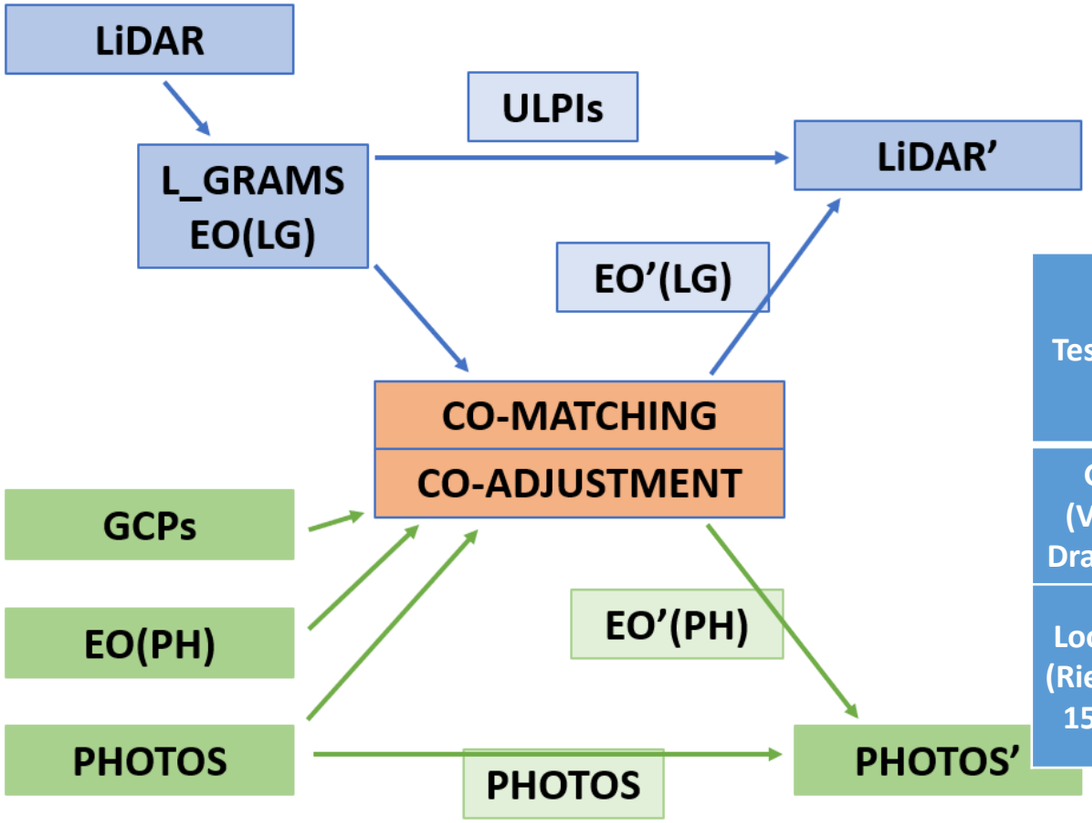
Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 2

[m]



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

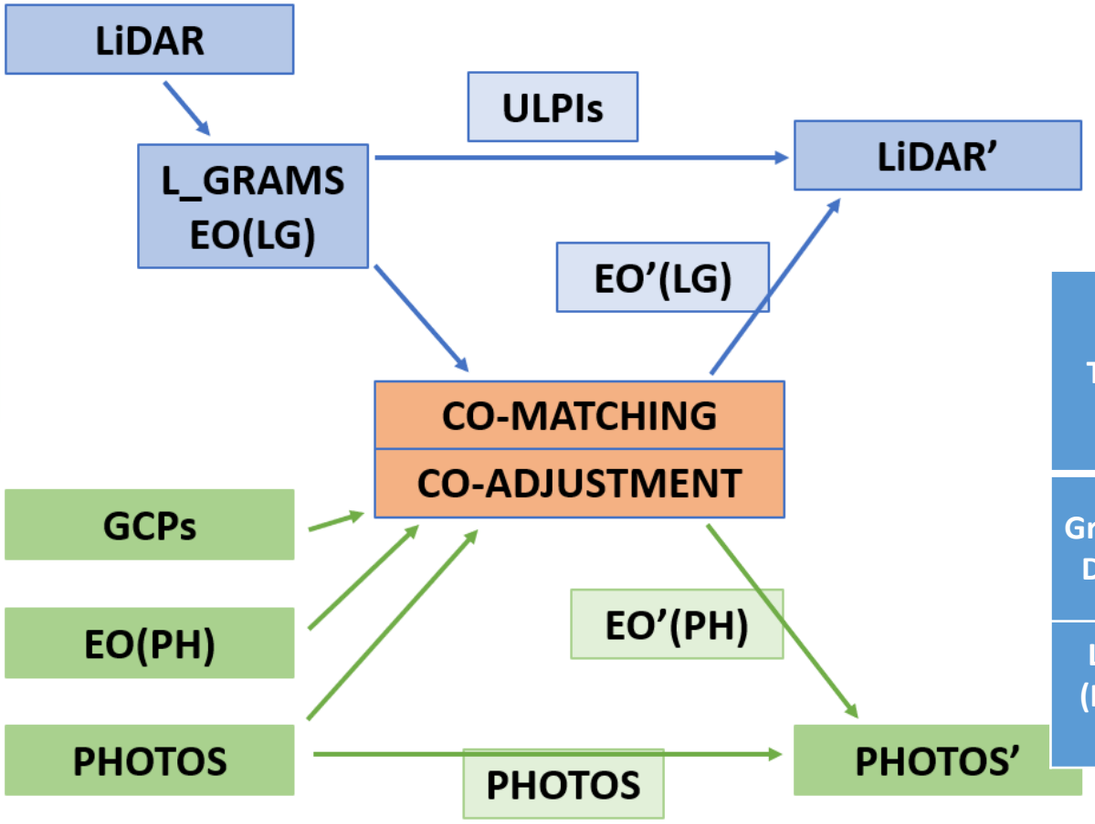
Test field	Ground control	RMSE X [m]	RMSE Y [m]	RMSE Z [m]	Reprojection Error [px]
Graz (Vexcel Dragon 4)	GCPs (7)	0.077	0.051	0.084	0.448
	ChPs (13)	0.012	0.028	0.111	0.335
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0.001	0.002	0.005	0.131
	ChPs (19)	0.002	0.002	0.005	0.229

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 2

[GSD]



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

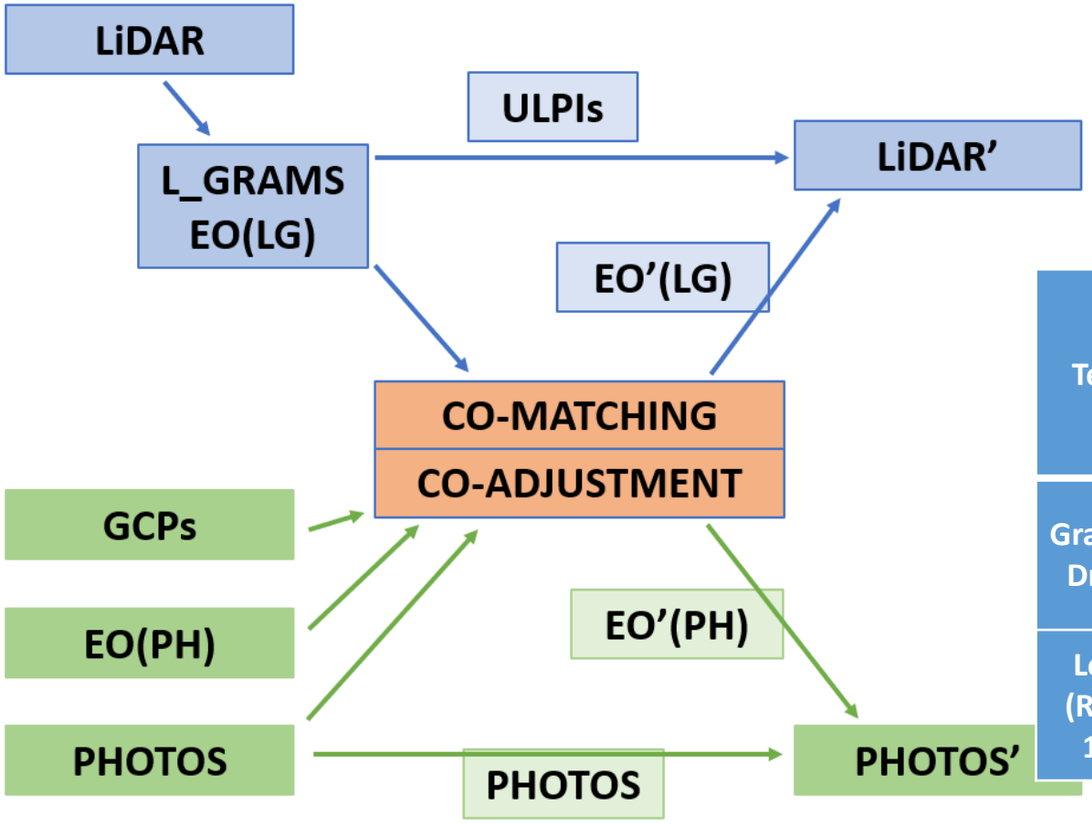
Test field	Ground control	RMSE X [GSD]	RMSE Y [GSD]	RMSE Z [GSD]
Graz (Vexcel Dragon 4)	GCPs (7)	1,540	1,020	1,680
	ChPs (13)	0,240	0,560	2,220
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0,013	0,025	0,063
	ChPs (19)	0,025	0,025	0,063

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 2

Density



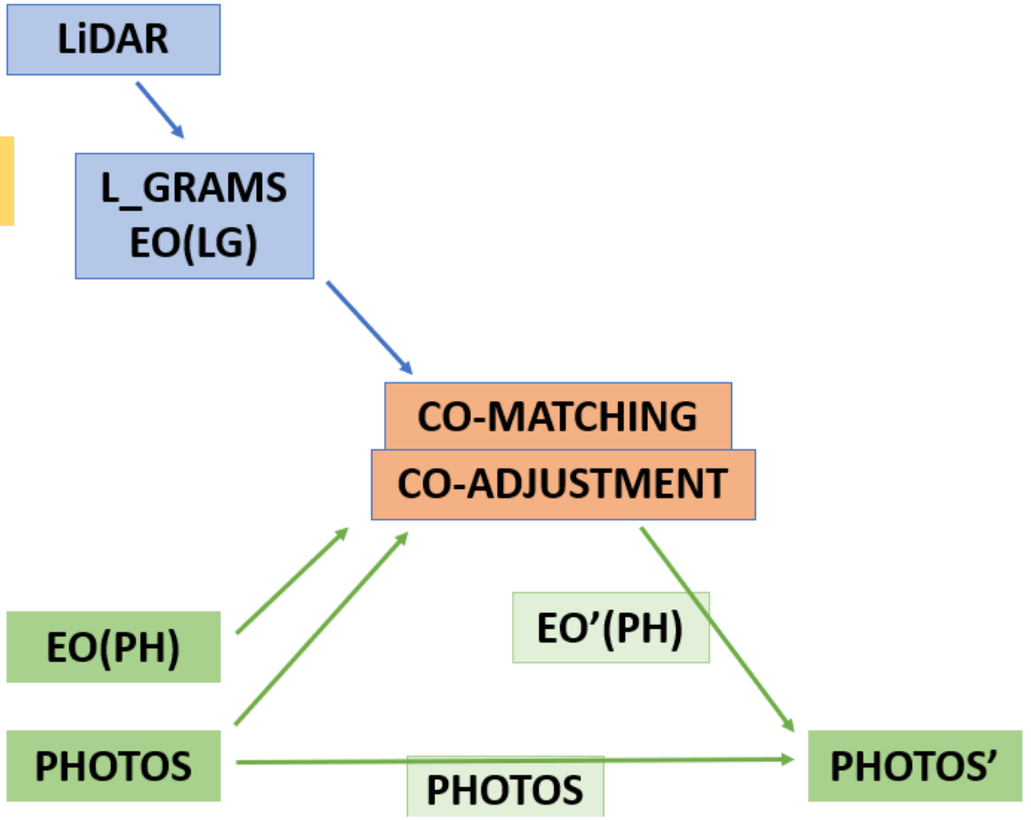
Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

Test field	Ground control	RMSE X [Density]	RMSE Y [Density]	RMSE Z [Density]
Graz (Vexcel Dragon 4)	GCPs (7)	0,592	0,392	0,646
	ChPs (13)	0,092	0,215	0,854
Loosdorf (Riegl VQ-1560 II)	GCPs (4)	0,004	0,008	0,020
	ChPs (19)	0,008	0,008	0,020

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 3



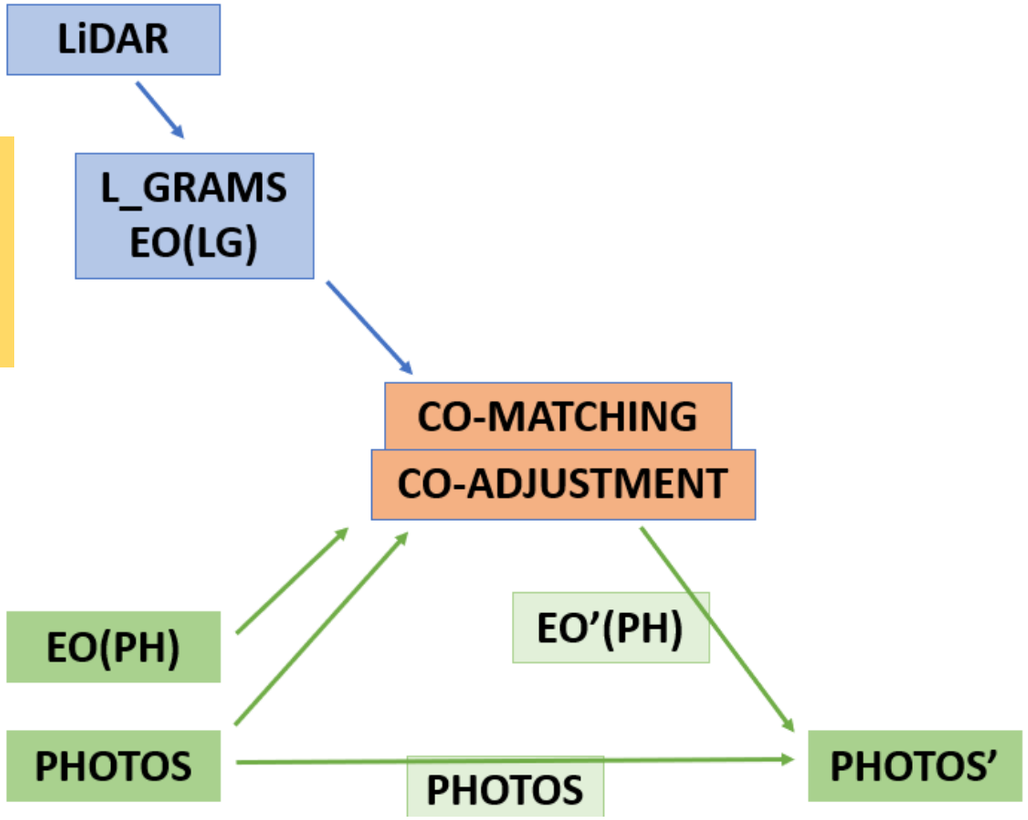
Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 3

[m]



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

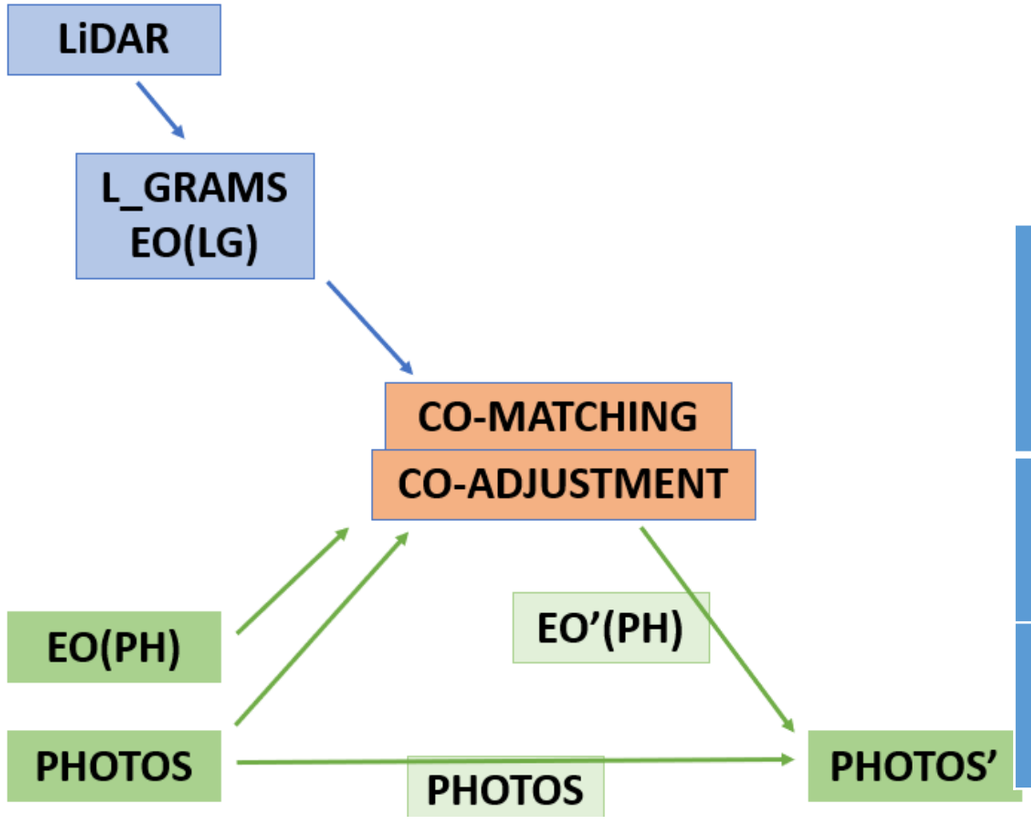
Test field	Ground control	RMSE X [m]	RMSE Y [m]	RMSE Z [m]	Reprojection Error [px]
Graz (Vexcel Dragon 4)	GCPs (0)	-	-	-	-
	ChPs (20)	0.077	0.043	0.211	0.375
Loosdorf (Riegl VQ-1560 II)	GCPs (0)	-	-	-	-
	ChPs (23)	0.022	0.022	0.033	0.219

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 3

[GSD]



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

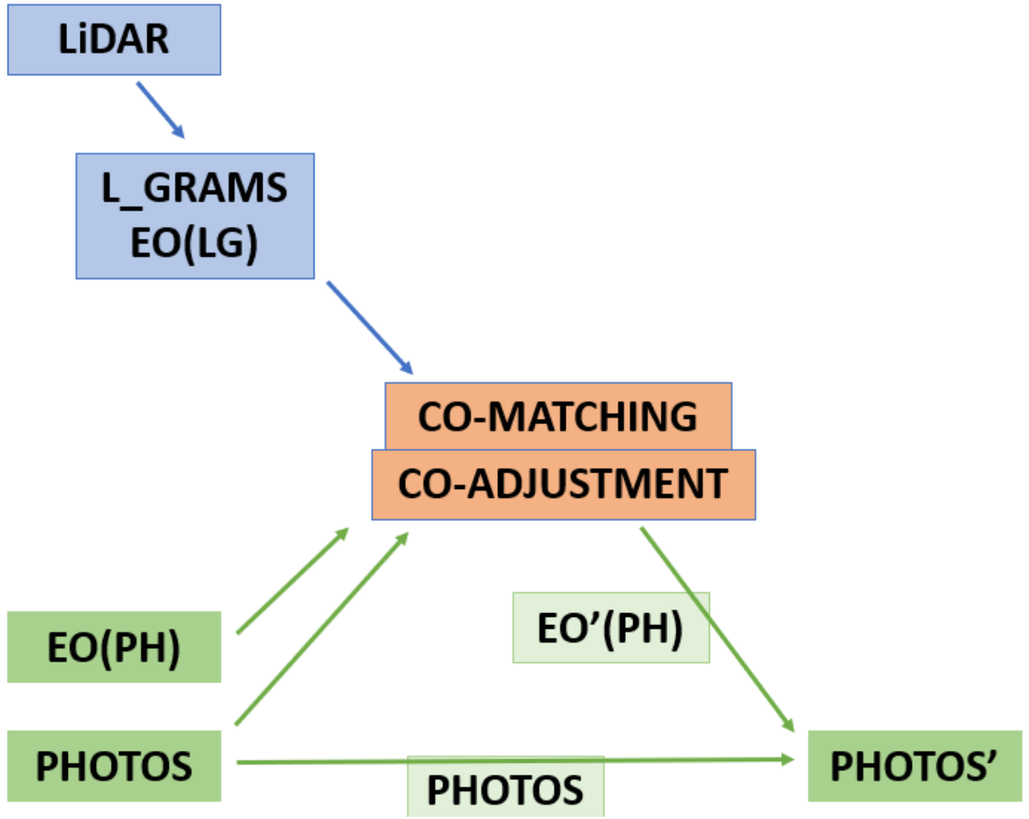
Test field	Ground control	RMSE X [GSD]	RMSE Y [GSD]	RMSE Z [GSD]
Graz (Vexcel Dragon 4)	GCPs (0)	-	-	-
	ChPs (20)	1,540	0,860	4,220
Loosdorf (Riegl VQ-1560 II)	GCPs (0)	-	-	-
	ChPs (23)	0,275	0,275	0,413

4. Vertical and horizontal accuracy enhancement of LiDAR and RGB/CIR data
4.2. Co-adjustment

Rzonca A, Twardowski M., 2025, *Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration*, EuroCOW 2025, Warszawa

Case 3

Density



Graz: GSD 5cm Density 13cm
Loosdorf: GSD 8cm Density 25cm

Test field	Ground control	RMSE X [Density]	RMSE Y [Density]	RMSE Z [Density]
Graz (Vexcel Dragon 4)	GCPs (0)	-	-	-
	ChPs (20)	0,592	0,331	1,623
Loosdorf (Riegl VQ-1560 II)	GCPs (0)	-	-	-
	ChPs (23)	0,088	0,088	0,132

5. Conclusions

- Quality of the synthetic images should be **improved** (adaptive interpolation, super resolution, inpainting,…)
- RMSEs of GCPs are bigger than GSD but smaller than mean density.
- Precise co-matching is possible by **deep image matching** methods
- The level of enhancement depends on **homogeneity** of the LiDAR data…
- …and ratio GSD/density

…

5. Conclusions

- …
- Proved usefulness of old pixel-point abstractive idea (**unique lidar point identifiers**)
- Co-adjustment is possible in **several variants** according to:
  - ❑ Weighting/fixing of the knowns/estimated values
  - ❑ Number and distribution of GCPs/ChPs
- Presented process leads to **homogeneous accuracy** of the data
- Lidargammetry in **future research**: densifing point cloud, system calibration, oblique images co-matching

Lidargrammetric co-matching and co-adjustment – a new method of photogrammetric and LiDAR data integration

Thank you!

Antoni Rzonca