Study on the Minimum and Maximum Number of Ground Control Points on the when Making an Orthophoto Plane

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Key words: ground control point, pixel, precision, orthophoto plane

SUMMARY

Currently, in Romania, flights are carried out to obtain the orthophoto plane for 170 cities, considered photogrammetric blocks. The pixel size is 4, 9 and 15 centimeters, depending on the type of city: municipality, county seat, municipality, city. In order to scale the orthophoto plan, the beneficiary requested that the number of control points on the ground be at least 20 for the county seat municipality and at least 10 for the municipality and city. Also, the minimum number of checkpoints is identical to that of ground checkpoints.
The beneficiary requested that ground control points and check points be pre-marked with white paint at certain dimensions.
The present study does a data processing starting from only five control points/block, then increasing the number of points until using all the measured points in the field.
Finally, the results obtained on the verification points are compared to determine if the accuracy of the orthophoto plane improves significantly depending on the number of control points on the ground and their distribution.

REZUMAT

În prezent în România se efectuează zboruri pentru obținerea ortofotoplanului pentru 170 de orașe, considerate blocuri fotogrammetrice. Mărimea pixelului este de 4, 9 și 15 centimetri, funcție de tipul orașului: municipiu reședință de județ, municipiu, oraș. Pentru a pune în scară ortofotoplanul beneficiarul a cerut ca numărul de puncte de control la sol să fie de minim 20 pentru municipiu reședință de județ și de minim 10 pentru municipiu și oraș. De asemenea, numărul punctelor de verificare minim este identic cu cel al punctelor de control la sol.
Beneficiarul a cerut ca punctele de control la sol și punctele de verificare să fie premarcate cu vopsea albă la anumite dimensiuni.
Prezentul studiu face o prelucrare a datelor pornind doar de la cinci puncte de control/bloc, apoi mărind numărul punctelor până la folosirea tuturor punctelor măsurate la teren.
În final se compară rezultatele obținute pe punctele de verificare pentru a stabili dacă precizia ortofotoplanului se îmbunătățește semnificativ funcție de numărul de puncte de control la sol și distribuția acestora.

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1. GENERAL

In January 2022, the National Center for Cartography in Romania launched a tender for the realization of a photogrammetric flight for 170 localities, respectively cities, municipalities and county seat municipalities. Each locality constitutes a photogrammetric block.
One of the conditions imposed by the Terms of Reference was related to the number of GPC ground control points. Thus, table 1 named GCP Distribution was presented.

Table 1 - Number of points/block

Type Cities	Mandatory points distribution	Minimum points/block
County seat municipalities	2 GCP/ corner block + 2 GCP middle block	20
Municipalities	1 GCP/ corner block + 2 GCP middle block	10
Cities		

Also, another imposed condition was related to the number of checkpoints (CHK), according to table 2 Distribution of checkpoints.

Table 2 - Distribution of check points

Type Cities	Mandatory points distribution	Minimum points/block
County seat municipalities	1 pct/4 kmp	20
municipalities		10
Cities		

The tender was won by a consortium of which I was a part. Through this paper we would like to demonstrate that the number of field control points is too high compared to what is needed.
We chose the city of Ștei, Bihor county, for the study. The area of the block was 60856 square kilometers. The flight was made with a CESNA 402 B airplane. The photogrammetric camera was of the UltraCam Eagle Mark 3 type, 431S61680X916102-f100 and the flight height was 3931 meters. The pixel size was 4 centimeters for county seat municipalities, 9 centimeters for municipalities and 15 centimeters for cities (including the town of Ștei). The method of pre-marking the GCPs is of the letter T type (Figure 1). The size of the pre-mark is 150x100 square centimeters. 35 images were retrieved.

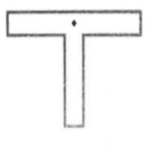


Figure 1 – T-type Premark

2. CARRYING OUT GCP PRELIMINARIES AND FIELD MEASUREMENTS.

2.1 Making pre-markings

The block made and accepted by CNC is the one in figure 2.

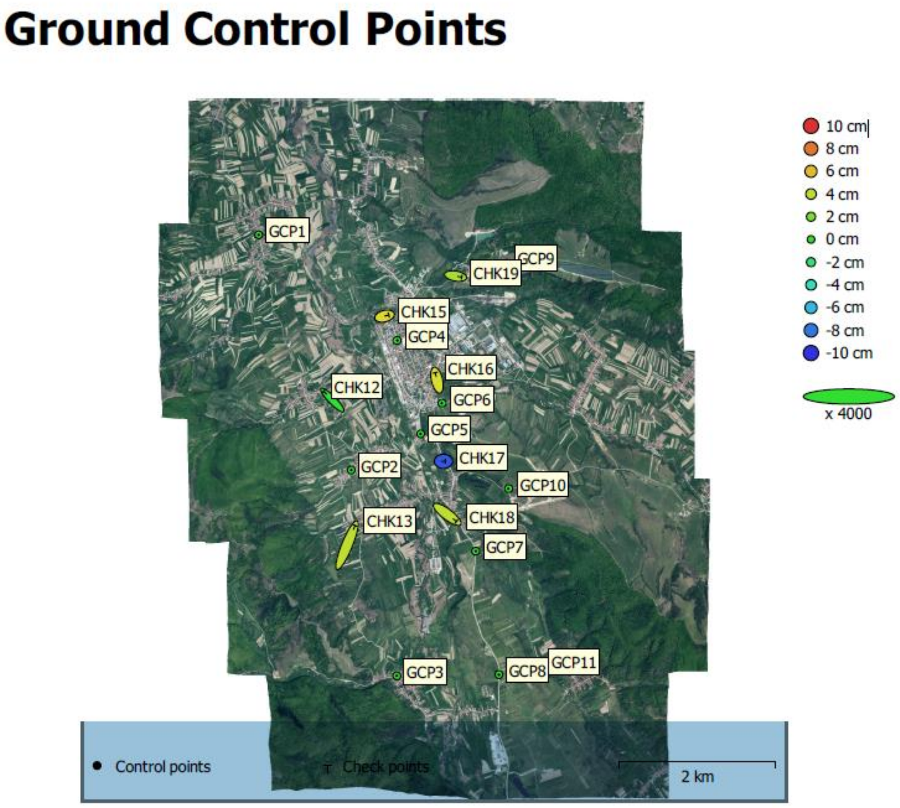


Figure 2 - The designed flight block for the town of Ștei. Disposition of GCP and CHK.

11 GCP points (GCP1,...GCP11) and 6 CHK type points (CHK12,...CHK19) were designed. The conditions required in the specifications regarding homogeneous distribution and compliance with the minimum distance from the projection center of each frame were taken into account.
All 17 points were pre-marked a week before the flight, taking weather conditions into account.

2.2 Field measurements

After the pre-marking and the flight, the measurement teams were sent to the field to determine the planimetric and altimetric position of each GCP and CHK. In accordance with the requirements of the Task Book, the position determination was carried out with GNSS technology, staying at least two hours on each of the 17 points. To determine the altitude, it was recommended to carry out high-precision leveling with a connection to the national altimetric network.

Each point was stationed for two hours, creating a network linked to the permanent stations of the National Agency for Cadaster and Land Registration (ANCPI). Since several receivers were used simultaneously the network was realized and compensated unitarily. 6 permanent stations were used as points with known position, as can be seen from Figure 3 - Sketch of the geodetic support network.
For altitudes, the elevation from the two closest points in the national leveling network in the area was transmitted.

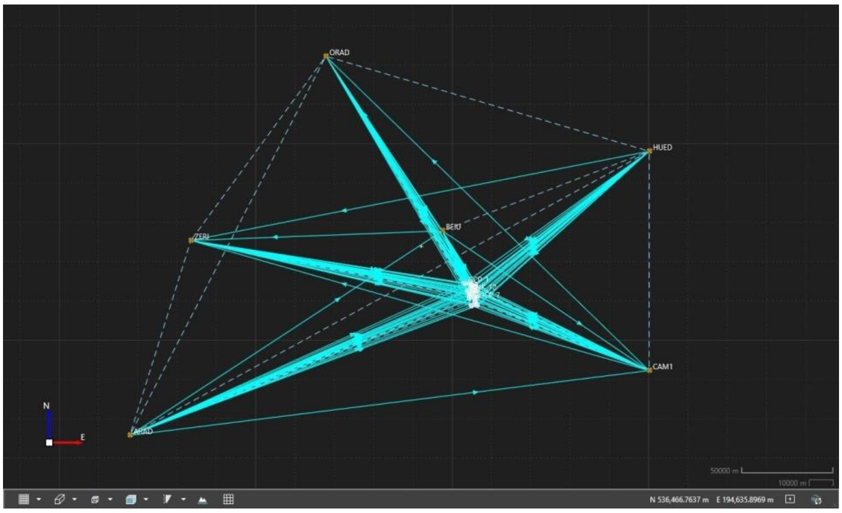


Figure 3 - Sketch of the geodetic support network

3. PROCESSING MEASUREMENTS

In Romania there is a network of 73 permanent stations (Figure 4) homogeneously distributed throughout the country.

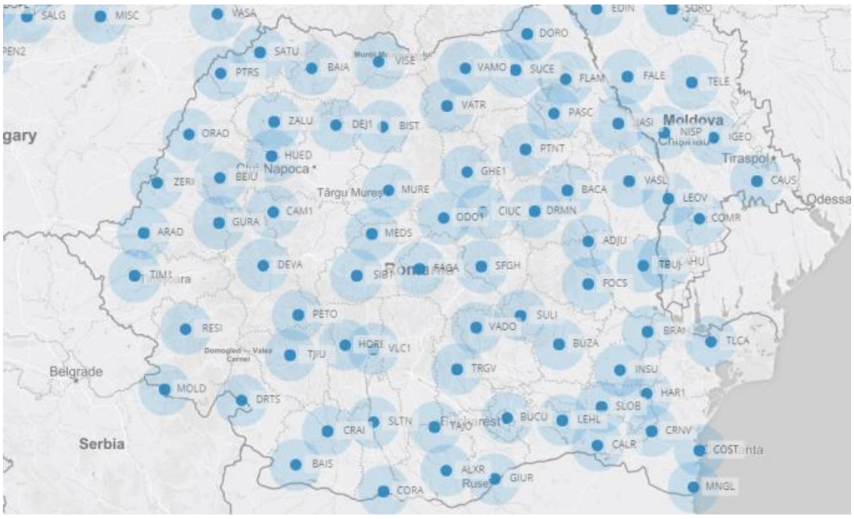


Figure 4 - ROMPOS network of permanent stations.

The processing was done with the program LEICA INFINITY. This is an easy-to-use geospatial software application for measurement professionals. It is designed to manage, process, analyze and verify the quality of all survey data, including total stations, digital levels, GNSS data and unmanned aerial vehicles (UAVs). Infinity will combine, extract, generate and export various types of data (BIM, CAD, GIS) seamlessly, and the use of integrated data exchange services, including Leica Exchange, Leica ConX, makes data management much more efficient. The way of working, the tools to use and the configuration of parameters are easily accessible in Leica Infinity, in an intuitive way. The graphic interface is a modern one, organized in menu bars and tools, configurable, with the possibility of choosing the sizes of the text and icons. Leica Infinity Software is perfectly integrable in the Windows environment.

Grid compensation was based on 6 points with known coordinates and 21 points whose coordinates were determined, of which 11 were GCPs. Number of baselines, 123.

Table 3 Standard Deviations

Station	SD WGS84 Lat [m]	SD WGS84 Long [m]	SD Height [m]	Total [m]
ARAD	—	—	—	—
BEIU	—	—	—	—
CAM1	—	—	—	—
CHK_12	0,0031	0,0025	0,0177	0,0181
CHK_13	0,008	0,0058	0,0465	0,0475
CHK_14	0,0064	0,0062	0,0480	0,0488
CHK_15	0,0037	0,0029	0,0263	0,0267
CHK_16	0,0035	0,0027	0,0231	0,0235
CHK_17	0,0041	0,0034	0,0236	0,0242
CHK_18	0,0034	0,0027	0,0196	0,0201
CHK_19	0,0023	0,0019	0,0129	0,0132
C H K_20	0,0027	0,0022	0,0146	0,0150
CHK_21	0,0024	0,0019	0,0148	0,0151
GCP_1	0,0068	0,0058	0,0508	0,0516
GCP_10	0,0027	0,0022	0,0144	0,0148
GCP_11	0,0027	0,0021	0,0155	0,0159
GCP_2	0,0083	0,0078	0,0454	0,0468
GCP_3	0,0029	0,0023	0,0181	0,0185
GCP_4	0,0036	0,0027	0,0214	0,0219
GCP_5	0,0046	0,0033	0,0235	0,0241
GCP_6	0,0039	0,0031	0,0242	0,0247
GCP_7	0,0033	0,0027	0,0213	0,0217
GCP_8	0,0022	0,0018	0,012	0,0123
GCP_9	0,0029	0,0024	0,0156	0,0161
HUED	—	—	—	—

ORAD	—	—	—	—
ZERI	—	—	—	—

As can be seen, the largest total error is below 5 centimeters, corresponding to the accuracy required by the Specifications of ± 5 centimeters on each axis.

4. OBTAINING THE ORTHOPHOTO PLANE AND THE DIGITAL TERRAIN MODEL

We used two data processing software: Agisoft Metashape Professional and Trimble INPHO. Thus we obtained several variants of the orthophoto plan and the digital terrain model.

- Agisoft Metashape Professional program in three variants: 11 GCP, 8 GCP and 5 GCP
- Trimble INPHO program in three variants: 11 GCP, 8 GCP and 5 GCP

4.1 Agisoft Metashape Professional

Agisoft Metashape Professional 2.0 is a powerful photogrammetric software designed to process digital images and generate comprehensive 3D spatial data, including 3D models, point clouds, true orthophoto and precisely georeferenced maps. This versatile tool finds applications across various fields such as surveying, agriculture, mapping, and environmental monitoring.
Agisoft Agisoft Metashape Professional 2.0 stands as an indispensable tool for professionals seeking comprehensive 3D spatial data solutions, especially in the creation of true orthophotos that meet the highest standards of accuracy and reliability.

4.2 Trimble INPHO

Trimble INPHO software is a comprehensive and powerful toolset for generating accurate 3D models and orthophotos from aerial and ground-based photographs. Its automated workflows and advanced algorithms enable efficient and reliable processing of high-resolution imagery. With its range of modules covering image preprocessing, tie point generation, bundle adjustment, orthorectification, and output generation, Trimble Inpho caters to a wide range of photogrammetry applications, from surveying and civil engineering to archaeology and environmental monitoring. Its integration with other Trimble solutions further streamlines workflows and expands the capabilities of the software.
Key features of Trimble Inpho software include:
Automated processing: Trimble Inpho software can automate many of the tasks involved in photogrammetry, such as image pre-processing, tie point generation, and triangulation. This can save users a significant amount of time and effort.
High accuracy: Trimble Inpho software is known for its high accuracy, which is essential for many applications. It can achieve accuracies of up to a few centimeters.
Flexible workflows: Trimble Inpho software provides a variety of workflows to fit the needs of different users. This includes workflows for processing aerial images, ground-based images, and satellite images.

Wide range of outputs: Trimble Inpho software can generate a wide range of outputs, including 3D models, orthophotos, ground control points, and point clouds.
Trimble Inpho software is a powerful and versatile tool that can be used to create accurate 3D models and maps from a variety of images. It is an essential tool for many professionals who need to collect and analyze spatial data.

5. RESULTS OBTAINED

After making the orthophoto plan and the digital terrain model, we checked the quality with the help of check points (CHK). Thus, I read the planimetric coordinates on the orthophoto plan and the altitudes for the control points on the digital model and compared them with those obtained from the field data processing for the 6 orthophoto plans and digital models. I obtained comparative tables.

5.1 Coordinate difference tables on the data processed with the Agisoft Metashape Professional program

Table 4 – Coordinates of the check points (CHK) measured and taken from the orthophoto plane and digital model made with the Agisoft Metashape Professional program and 5 control points (GCP)

5 GCP	RTK MEASURED COORDINATES			MEASUREAD COORDINATES IN ORTHO		
	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
CHK 12	562437,816	303947,661	250,722	562437,813	303947,671	250,697
CHK 13	560715,863	304349,354	258,934	560715,906	304349,421	258,889
CHK 15	563413,052	304780,601	246,030	563413,070	304780,602	246,059
CHK 16	562674,880	305375,792	254,879	562674,926	305375,785	254,882
CHK 17	561540,384	305505,776	255,433	561540,400	305505,717	255,265
CHK 18	560770,868	305646,986	258,888	560770,885	305646,904	258,822
CHK 19	563899,421	305714,441	282,769	563899,425	305714,447	282,778

Table 5 – Coordinates of the check points (CHK) measured and taken from the orthophoto plane and digital model made with the Agisoft Metashape Professional program and 8 control points (GCP)

8 GCP	RTK MEASURED COORDINATES			MEASUREAD COORDINATES IN ORTHO		
	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
CHK 12	562437,816	303947,661	250,722	562437,713	303947,716	250,713
CHK 13	560715,863	304349,354	258,934	560715,981	304349,474	258,972
CHK 15	563413,052	304780,601	246,030	563413,085	304780,613	246,106
CHK 16	562674,880	305375,792	254,879	562674,792	305375,835	254,939

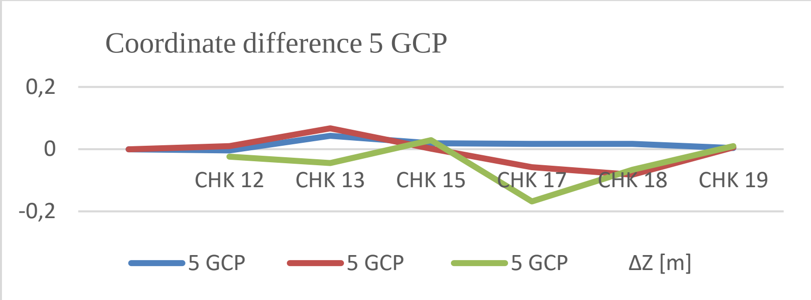
CHK 17	561540,384	305505,776	255,433	561540,393	305505,774	255,361
CHK 18	560770,868	305646,986	258,888	560770,980	305646,940	258,935
CHK 19	563899,421	305714,441	282,769	563899,484	305714,439	282,811

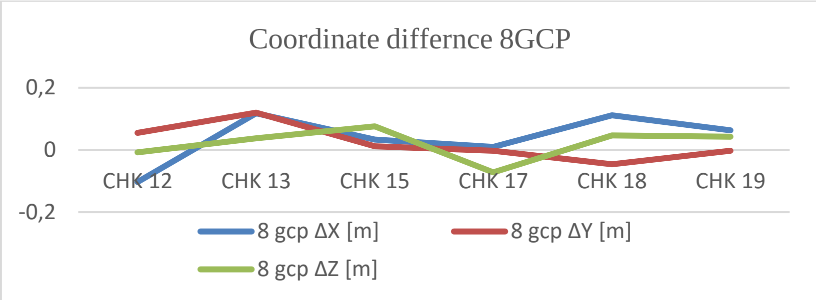
Table 6 – Check point coordinates (CHK) measured and taken from the orthophoto plane and digital model made with the Agisoft Metashape Professional program and 11 control points (GCP)

11 GCP	**RTK MEASURED COORDINATES**			**MEASUREAD COORDINATES IN ORTHO**		
	X [m]	**Y [m]**	**Z [m]**	**X [m]**	**Y [m]**	**Z [m]**
CHK 12	562437,816	303947,661	250,722	562437,761	303947,718	250,720
CHK 13	560715,863	304349,354	258,934	560715,914	304349,479	258,975
CHK 15	563413,052	304780,601	246,030	563413,079	304780,607	246,082
CHK 16	562674,880	305375,792	254,879	562674,869	305375,840	254,927
CHK 17	561540,384	305505,776	255,433	561540,396	305505,776	255,344
CHK 18	560770,868	305646,986	258,888	560770,927	305646,941	258,928
CHK 19	563899,421	305714,441	282,769	563899,460	305714,434	282,802

Table 7 – The differences in coordinates on the three variants obtained in tables 4, 5 and 6

	1->5GCP			**2->8GCP**			**3->11GCP**		
Punct verificare [CHK]	**5 GCP ΔX [m]**	**5 GCP ΔY [m]**	**5 GCP ΔZ [m]**	**8 gcp ΔX [m]**	**8 gcp ΔY [m]**	**8 gcp ΔZ [m]**	**11 GCP ΔX [m]**	**11 GCP ΔY [m]**	**11 GCP ΔZ [m]**
CHK 12	-0,004	0,010	-0,024	-0,103	0,055	-0,008	-0,056	0,057	-0,002
CHK 13	0,043	0,067	-0,045	0,118	0,120	0,038	0,051	0,125	0,041
CHK 15	0,019	0,002	0,029	0,033	0,012	0,076	0,027	0,007	0,051
CHK 17	0,017	-0,058	-0,168	0,010	-0,002	-0,072	0,013	0,000	-0,089
CHK 18	0,017	-0,082	-0,066	0,112	-0,046	0,047	0,059	-0,045	0,041
CHK 19	0,004	0,006	0,010	0,063	-0,002	0,043	0,039	-0,007	0,034
Δ Med	**0,016**	**-0,009**	**-0,044**	**0,039**	**0,023**	**0,021**	**0,022**	**0,023**	**0,013**
Δ Max	**0,043**	**0,067**	**0,029**	**0,118**	**0,120**	**0,076**	**0,059**	**0,125**	**0,051**
RMSE(x,y,z)	**0,04041**	**0,05081**	**0,07136**	**0,08015**	**0,04863**	**0,05219**	**0,04109**	**0,05770**	**0,04983**
RMSEr	**0,06492**			**0,09375**			**0,07084**		
RMSEr=SQRT(RMSEx * RMSEx + RMSEy * RMSEy)									





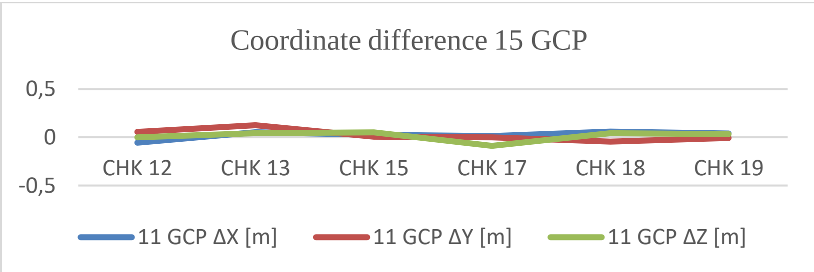


Table 8 – The difference between the coordinates obtained in the three variants

Punct verificare [CHK]	**Δ 12 X[m]**	**Δ 12 Y [m]**	**Δ 12 Z [m]**	**Δ 13 X [m]**	**Δ 13 Y [m]**	**Δ 13 Z [m]**	**Δ 23 X [m]**	**Δ 23 Y [m]**	**Δ 23 Z [m]**
CHK 12	0,100	-0,045	-0,016	0,052	-0,047	-0,023	-0,048	-0,001	-0,006
CHK 13	-0,075	-0,053	-0,083	-0,008	-0,058	-0,086	0,066	-0,005	-0,003
CHK 15	-0,015	-0,011	-0,047	-0,009	-0,005	-0,022	0,006	0,006	0,024
CHK 17	0,007	-0,056	-0,096	0,004	-0,059	-0,079	-0,003	-0,002	0,017
CHK 18	-0,095	-0,036	-0,113	-0,042	-0,037	-0,107	0,052	-0,001	0,007
CHK 19	-0,059	0,008	-0,033	-0,034	0,013	-0,024	0,024	0,005	0,009
Δ Med	**-0,023**	**-0,032**	**-0,065**	**-0,006**	**-0,032**	**-0,057**	**0,016**	**0,000**	**0,008**
Δ Max	**0,100**	**0,008**	**-0,016**	**0,052**	**0,013**	**-0,022**	**0,066**	**0,006**	**0,024**
Δ RMSE(x,y,z)	**-0,040**	**0,002**	**0,019**	**-0,001**	**-0,007**	**0,022**	**0,039**	**-0,009**	**0,002**
Δ RMSEr	**-0,0288**			**-0,0059**			**0,0229**		

Δ 12 = of coordinates between the variant with 5 control points and 8 control points
Δ 13 = of coordinates between the variant with 5 control points and 11 control points
Δ 12 = of coordinates between the variant with 8 control points and 11 control points

5.2 Tables of coordinate differences on the data processed with the Trimble INPHO program

Table 9 – Coordinates of the check points (CHK) measured and taken from the orthophoto plane and digital model made with the Trimble INPHO program and 5 control points (GCP)

5 GCP	RTK MEASURED COORDINATES			MEASUREAD COORDINATES IN ORTHO		
	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
CHK 12	562437,816	303947,661	250,722	562437,794	303947,715	250,724
CHK 13	560715,863	304349,354	258,934	560715,847	304349,372	258,701
CHK 15	563413,052	304780,601	246,030	563413,059	304780,568	245,786
CHK 17	561540,384	305505,776	255,433	561540,388	305505,755	255,362
CHK 18	560770,868	305646,986	258,888	560770,890	305647,018	258,726
CHK 19	563899,421	305714,441	282,769	563899,465	305714,427	282,679

Table 10 – Coordinates of the check points (CHK) measured and taken from the orthophoto plane and digital model made with the Trimble INPHO program and 8 control points (GCP)

8 GCP	RTK MEASURED COORDINATES			MEASUREAD COORDINATES IN ORTHO		
	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
CHK 12	562437,816	303947,661	250,722	562437,796	303947,727	250,758
CHK 13	560715,863	304349,354	258,934	560715,844	304349,383	258,718
CHK 15	563413,052	304780,601	246,030	563413,064	304780,578	245,837
CHK 17	561540,384	305505,776	255,433	561540,388	305505,763	255,396
CHK 18	560770,868	305646,986	258,888	560770,888	305647,025	258,753
CHK 19	563899,421	305714,441	282,769	563899,472	305714,435	282,742

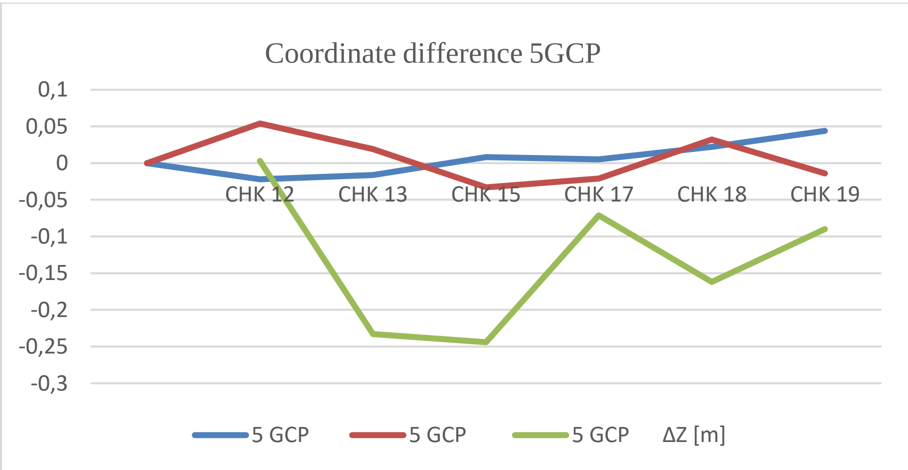
Table 11 – Check point coordinates (CHK) measured and taken from the orthophoto plane and digital model made with the Trimble INPHO program and 11 control points (GCP)

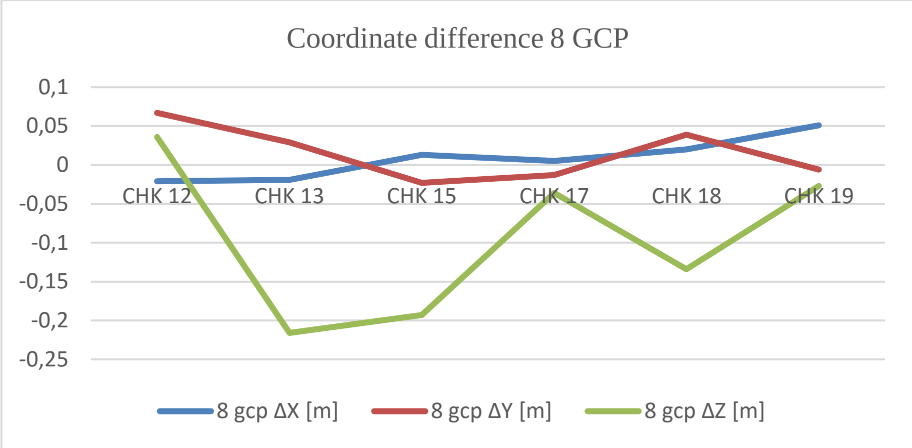
11 GCP	RTK MEASURED COORDINATES			MEASUREAD COORDINATES IN ORTHO		
	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
CHK 12	562437,816	303947,661	250,722	562437,792	303947,728	250,766
CHK 13	560715,863	304349,354	258,934	560715,840	304349,379	258,729
CHK 15	563413,052	304780,601	246,030	563413,063	304780,581	245,849
CHK 17	561540,384	305505,776	255,433	561540,388	305505,760	255,413

CHK 18	560770,868	305646,986	258,888	560770,887	305647,020	258,771
CHK 19	563899,421	305714,441	282,769	563899,473	305714,439	282,759

Table 12 – The differences in coordinates on the three variants obtained in tables 9, 10 and 11

	1->5GCP			**2->8GCP**			**3->11GCP**		
Punct verificare [CHK]	**5 GCP ΔX [m]**	**5 GCP ΔY [m]**	**5 GCP ΔZ [m]**	**8 gcp ΔX [m]**	**8 gcp ΔY [m]**	**8 gcp ΔZ [m]**	**11 GCP ΔX [m]**	**11 GCP ΔY [m]**	**11 GCP ΔZ [m]**
CHK 12	-0,022	0,054	0,003	-0,021	0,067	0,036	-0,024	0,068	0,044
CHK 13	-0,016	0,019	-0,233	-0,019	0,029	-0,216	-0,023	0,025	-0,205
CHK 15	0,008	-0,033	-0,244	0,013	-0,023	-0,193	0,012	-0,020	-0,181
CHK 17	0,005	-0,021	-0,071	0,005	-0,013	-0,036	0,004	-0,016	-0,019
CHK 18	0,022	0,032	-0,162	0,020	0,039	-0,134	0,019	0,034	-0,117
CHK 19	0,044	-0,014	-0,090	0,051	-0,006	-0,027	0,052	-0,002	-0,010
Δ Mean	**0,003**	**0,006**	**-0,149**	**0,008**	**0,015**	**-0,095**	**0,007**	**0,015**	**-0,081**
Δ Max	**0,044**	**0,054**	**-0,244**	**0,051**	**0,067**	**-0,216**	**0,052**	**0,068**	**-0,205**
RMSE(x, y,z)	**0,0229**	**0,0293**	**0,1743**	**0,0255**	**0,0353**	**0,1325**	**0,0269**	**0,034**	**0,123**
RMSEr	**0,03719**			**0,04355**			**0,04351**		
RMSEr=SQRT(RMSEx * RMSEx + RMSEy * RMSEy)									





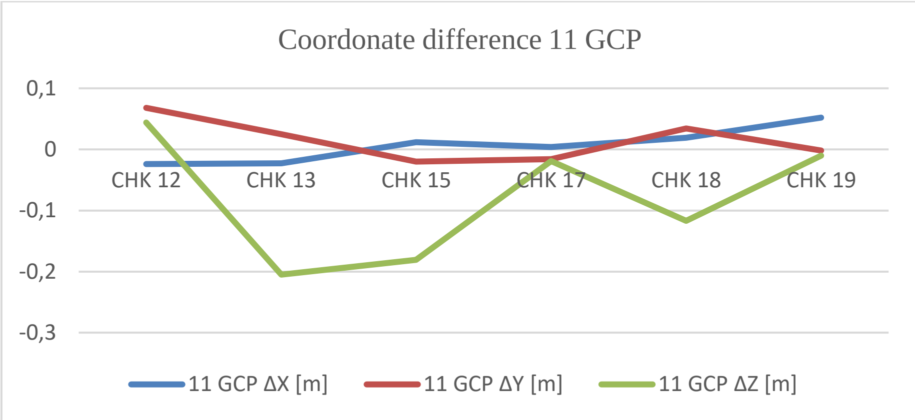


Table 13 – The difference between the coordinates obtained in the three variants

Punct verificare [CHK]	Δ 12 X [m]	Δ 12 Y [m]	Δ 12 Z [m]	Δ 13 X [m]	Δ 13 Y [m]	Δ 13 Z [m]	Δ 23 X [m]	Δ 23 Y [m]	Δ 23 Z [m]
CHK 12	-0,002	-0,012	-0,034	0,002	-0,013	-0,041	0,004	-0,001	-0,008
CHK 13	0,003	-0,011	-0,017	0,007	-0,007	-0,028	0,004	0,004	-0,011
CHK 15	-0,005	-0,010	-0,051	-0,004	-0,013	-0,063	0,001	-0,003	-0,012
CHK 17	0,000	-0,008	-0,035	0,001	-0,005	-0,051	0,000	0,003	-0,017
CHK 18	0,002	-0,007	-0,027	0,003	-0,002	-0,045	0,001	0,005	-0,018
CHK 19	-0,006	-0,008	-0,063	-0,008	-0,011	-0,080	-0,001	-0,004	-0,017
Δ Med	**-0,001**	**-0,009**	**-0,038**	**0,000**	**-0,009**	**-0,051**	**0,001**	**0,001**	**-0,014**
Δ Max	**-0,006**	**-0,120**	**-0,063**	**-0,008**	**-0,013**	**-0,080**	**0,004**	**0,005**	**-0,018**
Δ RMSE(x,y,z)	**-0,003**	**-0,006**	**0,042**	**-0,004**	**-0,005**	**0,051**	**-0,001**	**0,001**	**0,009**
Δ RMSEr	**-0,00636**			**-0,00632**			**0,00004**		

Δ 12 = of coordinates between the variant with 5 control points and 8 control points
Δ 13 = of coordinates between the variant with 5 control points and 11 control points
Δ 12 = of coordinates between the variant with 8 control points and 11 control points

6. RESULTS OBTAINED

By analyzing Tables 9 and 14, the RMSEr line we can evaluate how each variant of orthophoto plane and digital model responded compared to the check points.
In the analysis, we start from the idea that the error of the points determined on the ground (Table 1) is a maximum of 5 centimeters. Also, the pixel size is 150x100 square centimeters. The possibility of scoring is thus limited to these dimensions.
Apparently, the accuracies obtained with the models that used the Agisoft Metashape Professional program are much better than those obtained with the Trimble INPHO program. Thus, the biggest error for the Agisoft Metashape Professional software is 0.08015 meters on the X axis, the version with 8 GCP.
The largest error for the Trimble INPHO software is 0.1743 meters per elevation, the 5 GCP version.
Given the pixel size the correct values would be those obtained with Trimble INPHO software.
The aim of the work is to obtain an orthophoto plan for the inner city of a city. The minimum number of field control points, namely 5, is sufficient to achieve the precision required by the Terms of Reference.

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