Swedish University of Agricultural Sciences
Umeå
August 29, 2019

Evaluation of DJI Phantom 4 RTK in forestry

Axel Östman
ostmanaxel@gmail.com

Daniel Tonvall
dato0029@student.umu.se

Jonas Lindgren
joli0394@student.umu.se

Abstract

As technology advances, drones are taking place in a wider range of applications. One of these is 3D-modelling of forests by photogrammetry. However, to get any useful results the time consuming process of marking out ground control points (GCPs) in the desired area has to be conducted. The hope is that drones equipped with a high precision GPS can remove the need for this process. One example of such a drone is the DJI Phantom 4 RTK, which in this project has been evaluated for a number of different configurations of GCPs. It was found that the use of GCPs does not make a significant decrease in the error in the plane for the DJI Phantom 4 RTK, the mean errors are still $<$5 cm. However, without any GCPs the mean error in altitude is around 50 cm. To decrease this to $<$5 cm there is need for GCPs, but it is sufficient with only a few and they do not have to be particularly spread out.

Development Work in Co-operation with the Private Sector
Supervisors: Mattias Nyström, Jonas Bohlin

Contents

1 Introduction

Drones are becoming a more common tool when planning and monitoring actions in forestry. So far drones have not been used to its full potential, since the full extent of its use is time consuming and not profitable to carry through. The time consuming step is that one will mark out ground control points in the measuring area and then measure these points with very expensive GNSS-equipment. However with better positioning on the drone one could get around this problem and thus directly analyse the data combined with other sources. e.g an available terrain model of the ground. This creates a lot of potential applications which was previously not profitable. The Swedish University of Agricultural Sciences have recently acquired a drone of the model DJI Phantom 4 RTK which should cope with none or a few ground control points. Nevertheless the accuracy in forest environment is still unclear as well as how the height of the flight and the overlap of the pictures affect the accuracy in the 3D- data that are built from the pictures.

The target of the project was to review how well the drone can perform in a forest environment with main focus on how many (if any) ground control points used and the distribution of them.

2 Background

2.1 Photogrammetry

The process of creating 3D-models from still images, called photogrammetry, allow for forests to be modelled from aerial images taken with the use of drones. These models can help in deciding when and where to apply necessary actions such as, fertilizing, thinning, harvesting etc.

The core in creating a good model from still images lies in knowing the position from which each image is taken. Knowing this position with a higher accuracy leads to a more accurate model. Drones usually use GPS to monitor their position. However, this GPS position is not accurate enough to produce satisfactory 3D-models. There are techniques one can use to improve the accuracy; Post-Processing Kinematic (PPK), and Real-Time Kinematic (RTK).

2.2 RTK and PPK

In Swepos, which is a support system for satellite positioning in Sweden, there are a number of positions which coordinates are practically unchanged over time. Hence, these are positions that are well known and can be used as references to approximate the error in the positioning at the time of each image. By using the approximated error, the position of each image can be corrected.

PPK and RTK are very similar in that they use these reference positions to correct the position of the image with one distinction, RTK does the correction in real-time. Thus, to use RTK the drone must be able to connect to Swepos and is therefore required have an internet connection. PPK has the obvious disadvantage of needing some afterwork before the positions of the images are corrected.

2.3 GCPs

The accuracy can be increased to a satisfactory degree with the use of Ground Control Points (GCPs). These are points in the area which position is well known and with a high accuracy. As these points are found in the images during post-processing, they can be used as a correction for the position of the images taken by the drone.

3 Method

3.1 Collection of data

On the 24th of April 2019, the accuracy of the Phantom 4 RTK was tested in forestry. A total number of 36 GCPs were placed inside a designated area (36 824m^2), presented in figure 1. The centre of these points were tagged with the use of the GNSS-equipment Trimble GeoXR 6000. The Trimble uses RTK and connects to Swepos using Telia cellular network. It can measure a point in a few seconds with centimetre resolution, given that it has a clear view of satellites. With the GCPs tagged, the use of the Phantom 4 RTK began. Coordinates for the designated area along with the following settings was used as input into the DJI GS RTK app.

- Flight altitude: 120 m above ground level (130 m above sea level)
- Speed: 5 m/s
- Angle camera: -90°
- Forward overlap: 80 %
- Side overlap: 75 %
- Number of flight lines: 6
- GSD (cm/pix): 3.29
- No shutter prio
- No distortion correction
- Margin auto
- Dist shooting

This flight took 7 minutes and 35 seconds and a total number of 84 photos were taken. During the flight there was a clear sky and wind speed of about 0.5 m/s.

3.2 Data analysis

The photos from the Phantom 4 RTK were imported into Agisoft Metashape Professional, version 1.5.2 build 7838. To start with, the photos were aligned using the command "Align photos". This was done with "Accuracy" set to "High", "Generic preselection" and "Reference preselection" checked, "Key point limit" set to 40 000 and "Tie point limit" set to 4 000. This was followed by the command "Optimize cameras" with the following filters checked: f, cx, cy, k1, k2, k3, p1, p2 (this command is used very often in the following procedure). Under "Gradual selection" in the "Model"-menu, a number of filters can be found. Out of these the "Reconstruction uncertainty" and "projection accuracy" are firstly run, with "Optimize cameras" after each of them. When this was done, the GCPs were imported to finally run "Reprojection error" followed by "Optimize cameras" twice, with aim to get a value of 1 to 0.5. [2]

Next step was to make sure that the GCPs and the photos are located in the same coordinate system, namely the SWEREF99 TM + RH2000 geoid height, with the help of "Convert" in the "Reference"-window. All of the he GCPs were manually pointed out in the photos. Again "Optmize cameras" was used vigorously, but now with all of the filters checked. During this process it was also found that 4 out of the 36 GCPs taken with the GNSS-equipment didn't show up on enough photos and thus could not be used.

5 out of the remaining 32 GCPs were chosen to be used as control points (CPs). These are the points in which the accuracy will be measured for all of the different scenarios that will be presented later on. By doing so it is possible to compare the scenarios in a consistent manner. These control points along with the designated area can be seen in figure 1 below:

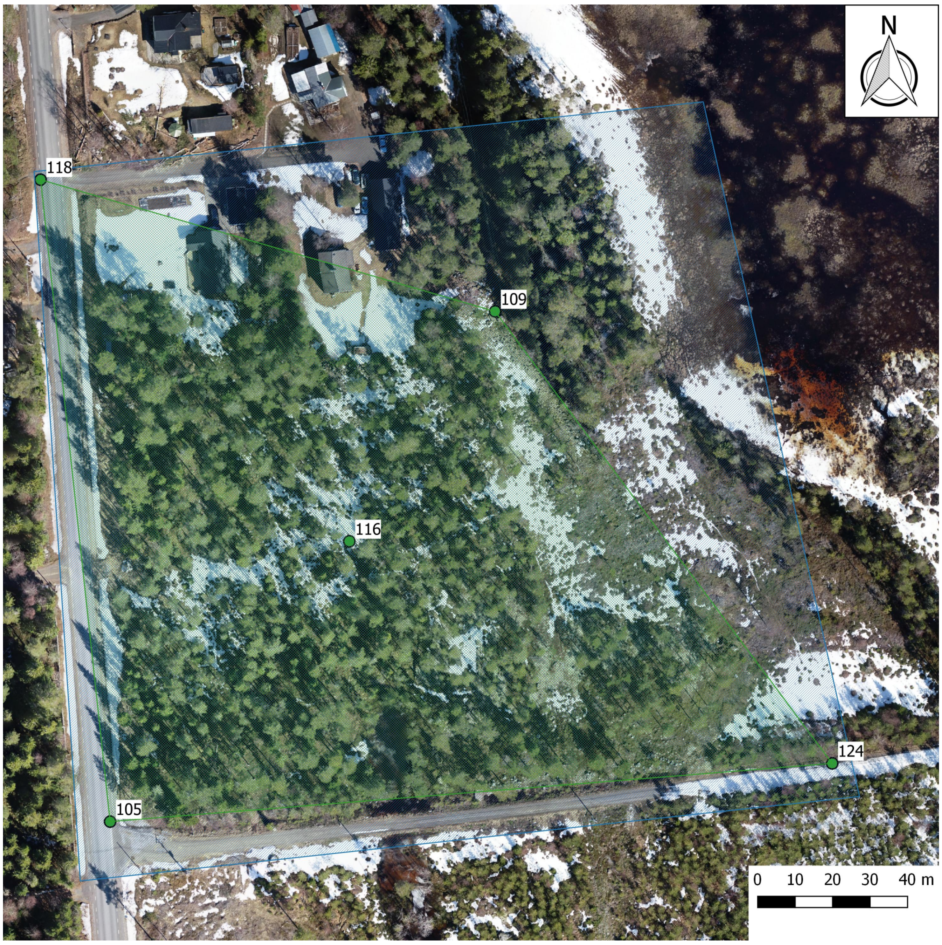


Figure 1 – A map of the designated area (the transparent blue area, 36 824 m^2) as well as the control points used in the analysis between scenarios (green dots) and their covered area (the transparent green area, 22 423m^2).

To simulate different configurations of GCPs a number of sets were created to represent cases that are easily achieved with little time or effort, as well as cases that takes a lot of time and effort to construct. Maps of the different cases along with their respective data can be seen in section 4.

Finally, to validate the positions of the points that are being used in this analysis, and thus check that Agisoft is not biased, a dense point cloud was created in Agisoft with no GCPs active. Thus it is only the RTK in the drone that is used to pinpoint the coordinates for the CPs. This dense point cloud was imported into Quick Terrain Modeler v8.1.0 (QTM) and the CPs coordinates were compared between the two softwares. The results from this can be seen in table 1 below:

Table 1 – Table with comparison of coordinates for the CPs as well as the estimated error acquired from Agisoft. In the best case, the difference in the results from two softwares is smaller than the error according to Agisoft.

CP	**Difference between CP and measured CP in QTM (m)**			**Difference between CP and placed marker in the photos in Agisoft (m)**		
	Easting	*Northing*	*Altitude*	*Easting*	*Northing*	*Altitude*
105	0.013	0.015	0.394	0.035	0.031	0.415
109	0.006	0.029	0.382	0.016	0.032	0.442
116	0.004	0.049	0.383	0.006	0.059	0.423
118	0.009	0.005	0.411	0.005	0.019	0.393
124	0.001	0.013	0.284	0.002	0.002	0.340

As we can see in table 1, the only coordinates that lie outside of Agisofts estimated error are *Easting* and *Altitude* for CP 118 and *Northing* for CP 124. However, they are still quite close and when using QTM it is only possible to get coordinates in points that often differ in the magnitude of cm to adjacent ones. Taking this into account, the difference between the softwares is still quite small and it is thus reasonable to say that the data can be considered verified.

4 Results

For each case, the positions of the CPs were analysed in two ways; one when the image positions are used, and one when they are not used. These two analyses can then be compared to see the effect that the addition of the image position has on the measurement.

In the maps for the different cases showcased below, the diameter of the dots marking the CPs represent the magnitude of the error in Easting and Northing. This way, the relative magnitude of the error can be estimated roughly from simply looking in the map. The diameter of the GCPs correspond to no errror. The exact numbers are listed in the table following each map.

A color scale was also introduced to represent the error in altitude. The color green is given to errors between 0-5 cm and are considered desirable for this specific project. Orange represent an error between 5-10 cm and is considered usable but not desirable. Red represent an error larger than 10 cm and is considered unusable.

In table 2 below the different cases are listed along with some basic information about them. For quick comparison of area, the CPs as well as the total flight area is also shown in the table.

The different cases chosen are listed below along with their respective section in parenthesis and a short description:

1. **No GCPs (4.1)** - no GCPs are used.
2. **Tarmac (4.2)** - a setup of GCPs placed in a straight line, in this case along a tarmac road at the west border of the area.
3. **Yard (4.3)** - a setup of GCPs situated close to the take-off position of the drone.
4. **Upper half (4.4)** - a setup of GCPs spread out over the upper half of the area.
5. **Tarmac and gravel (4.5)** - a setup of GCPs in an L-shape, in this case along roads on the the west and south border of the area.
6. **Dice five (4.6)** - a setup of GCPs resembling the five of a dice, one in each corner and one in the middle of the area.
7. **Half of GCPs (4.7)** - a setup of GCPs spread out over the entire area. It uses fewer GCPs than the case "All GCPs" but does not reduce the percentage of images that contains GCPs significantly. Note that the amount of GCPs is not actually half, so the name can be somewhat misleading.
8. **All GCPs (4.8)** - a setup of GCPs spread out quite densely over the entire area. This specific case uses all of the GCPs that usable, making this a very unrealistic case.
9. **Outer edge (4.9)** - a setup of the GCPs that are located along the edges of the area.

Table 2 – Table showing the covered area of each set of GCPs along with their percentage coverage of the total flight area. The sets "All GCPs" and "Outer edge" should of course be exactly the same, but the area calculation was done manually afterwards, resulting in this difference. However, since it is marginal it will be disregarded.

	Area [m^2]	**Coverage of total flight area**	**Number of GCPs**	**Percentage of images containing GCPs**
No GCPs	0	0 %	0	0
Tarmac	763	2.1 %	5	66.7 %
Yard	1 094	3.0 %	9	45.5 %
Upper half	7 105	19.3 %	12	72.7 %
Tarmac and gravel	15 476	42.0 %	9	83.3 %
Dice five	17 403	47.3 %	5	87.9 %
Control points	22 423	60.9 %	-	-
Half of GCPs	22 754	61.8 %	19	98.5 %
All GCPs	25 234	68.5 %	27	98.5 %
Outer edge	25 267	68.6 %	14	97.0 %
Flight area	36 824	100 %	-	-

4.1 Case 1 - No GCPs

4.1.1 Using the image position

Figure 2 – A map of the set of "No GCPs" when the image position is used, with the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 3 – Errors for the five control points when using only the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0352	-0.0314	0.4147
109	-0.0157	0.0317	0.4419
116	0.0065	-0.0588	0.4233
118	0.0051	0.0186	0.3934
124	0.0023	0.0016	0.3395
Mean absolute value (std)	0.0130 (0.0134)	0.0284 (0.0210)	0.4026 (0.0393)

4.2 Case 2 - Tarmac road

4.2.1 Using the image position

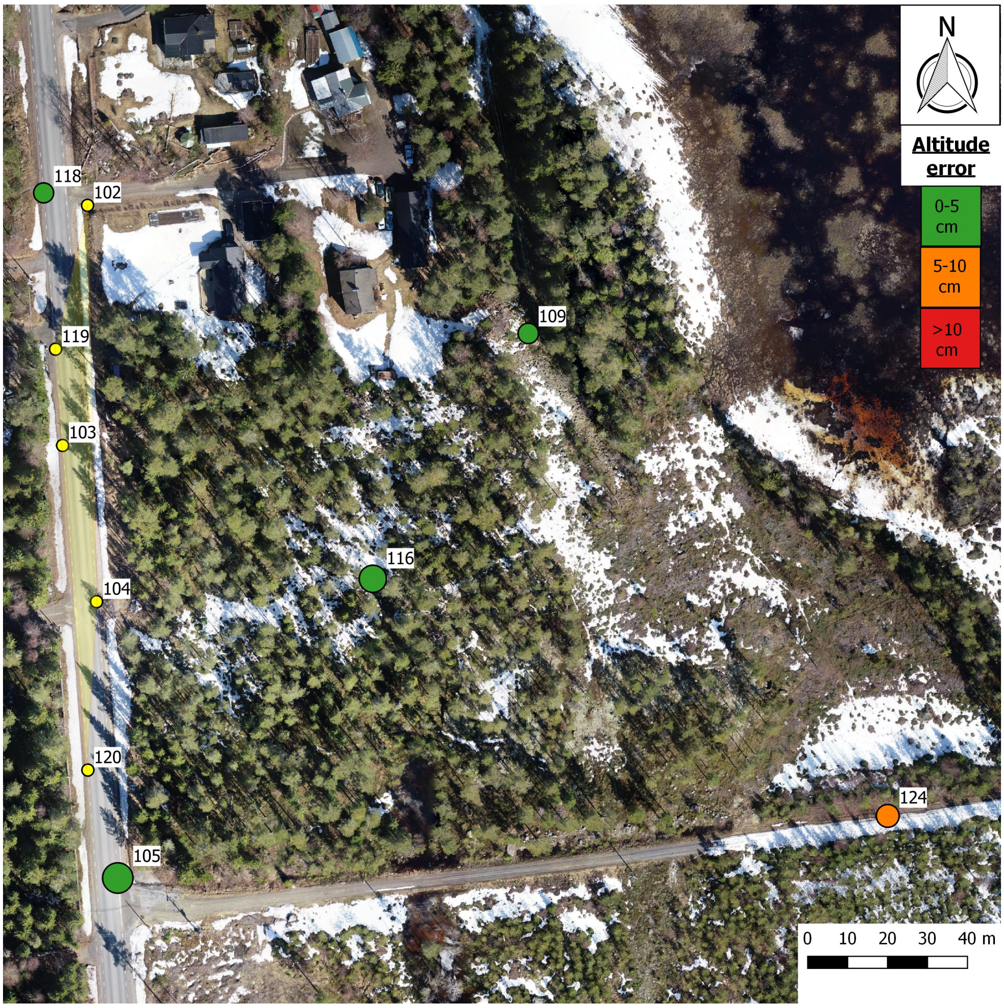


Figure 3 – A map of the GCPs (yellow dots) in the set of "Tarmac road" when the image position is used, along with their covered area (763 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 4 – Errors for the five control points when the GCPs are spread according to case 2 (Tarmac road). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0439	-0.0493	0.0247
109	-0.0115	0.0308	0.0380
116	0.0068	-0.0688	0.0230
118	-0.0186	0.0211	-0.0022
124	0.0347	-0.0198	-0.0575
Mean absolute value (std)	**0.0231 (0.0157)**	**0.0380 (0.0209)**	**0.0291 (0.0204)**

4.2.2 Without the use of the image position

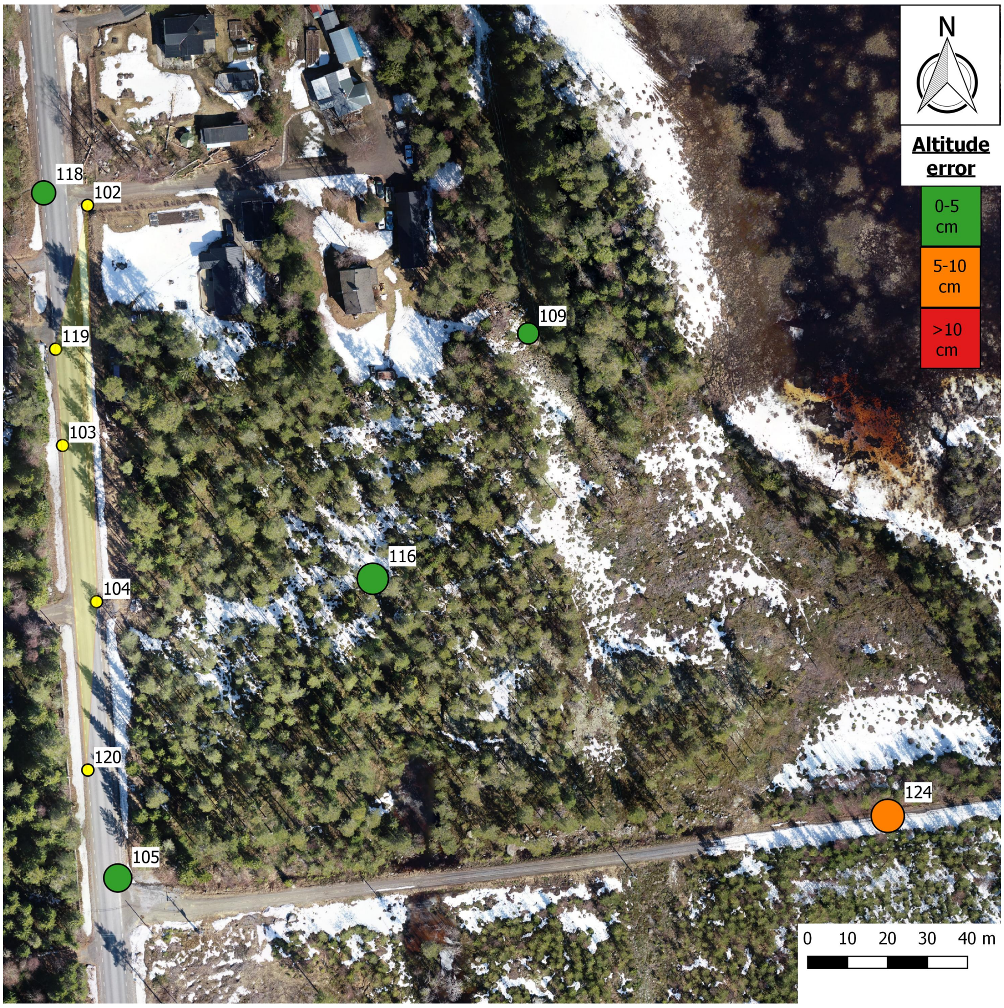


Figure 4 – A map of the GCPs (yellow dots) in the set of "Tarmac road" when the image position is not used, along with their covered area (763 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 5 – Errors for the five control points when the GCPs are spread according to case 2 (Tarmac road). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0101	-0.0702	0.0416
109	-0.0229	0.0241	-0.0346
116	0.0182	-0.0812	-0.0485
118	-0.0440	0.0158	0.0213
124	0.0721	-0.0343	-0.0765
Mean absolute value (std)	**0.0335 (0.0250)**	**0.0451 (0.0289)**	**0.0445 (0.0205)**

4.3 Case 3 - Yard

4.3.1 Using the image position

Figure 5 – A map of the GCPs (yellow dots) in the set of "Yard" when the image position is used, along with their covered area (1 094 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 6 – Errors for the five control points when the GCPs are spread according to case 3 (Yard). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0353	-0.0341	0.0037
109	-0.0083	0.0176	0.0236
116	0.0121	-0.0689	0.0105
118	-0.0047	-0.0021	-0.0278
124	0.0281	-0.0082	-0.0734
Mean absolute value (std)	**0.0177 (0.0133)**	**0.0262 (0.0268)**	**0.0278 (0.0273)**

4.3.2 Without the use of the image position

Figure 6 – A map of the GCPs (yellow dots) in the set of "Yard" when the image position is not used, along with their covered area (1 094 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 7 – Errors for the five control points when the GCPs are spread according to case 3 (Yard). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0378	-0.1330	0.3791
109	0.0365	-0.0293	-0.0244
116	0.0427	-0.1387	0.0710
118	-0.0315	0.0216	0.0270
124	0.1435	-0.1744	0.2855
Mean absolute value (std)	**0.0584 (0.0477)**	**0.0994 (0.0694)**	**0.1574 (0.1641)**

4.4 Case 4 - Upper half

4.4.1 Using the image position

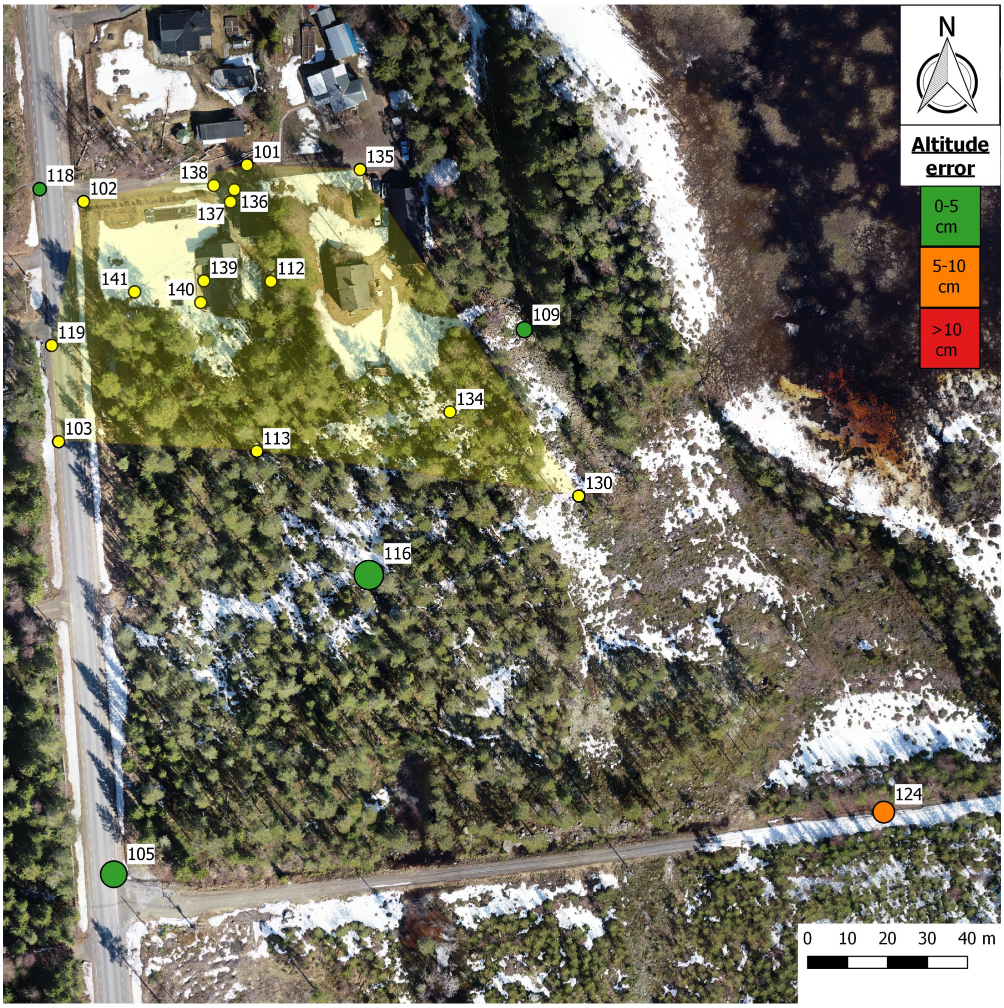


Figure 7 – A map of the GCPs (yellow dots) in the set of "Upper half" when the image position is used, along with their covered area (7 105 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 8 – Errors for the five control points when the GCPs are spread according to case 4 (Upper half). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0353	-0.0372	0.0071
109	-0.0033	0.0161	0.0271
116	0.0153	-0.0710	0.0136
118	-0.0059	0.0010	-0.0268
124	0.0378	-0.0106	-0.0623
Mean absolute value (std)	**0.0195 (0.0162)**	**0.0272 (0.0279)**	**0.0274 (0.0213)**

4.4.2 Without the use of the image position

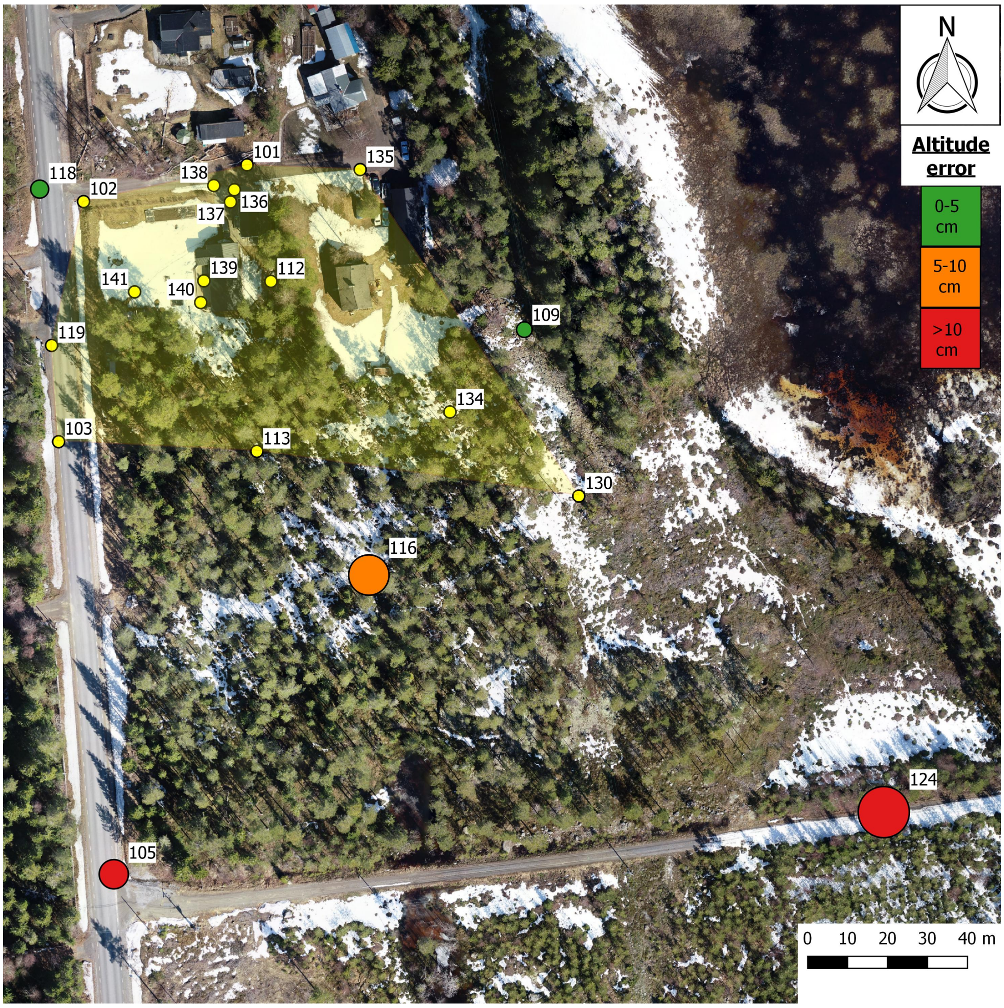


Figure 8 – A map of the GCPs (yellow dots) in the set of "Upper half" when the image position is not used, along with their covered area (7 105 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 9 – Errors for the five control points when the GCPs are spread according to case 4 (Upper half). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0038	-0.0827	0.2464
109	0.0173	0.0003	0.0203
116	0.0445	-0.0986	0.0546
118	-0.0215	0.0089	-0.0004
124	0.1190	-0.0769	0.2557
Mean absolute value (std)	**0.0412 (0.0459)**	**0.0535 (0.0454)**	**0.1155 (0.1253)**

4.5 Case 5 - Tarmac and gravel road

4.5.1 Using the image position

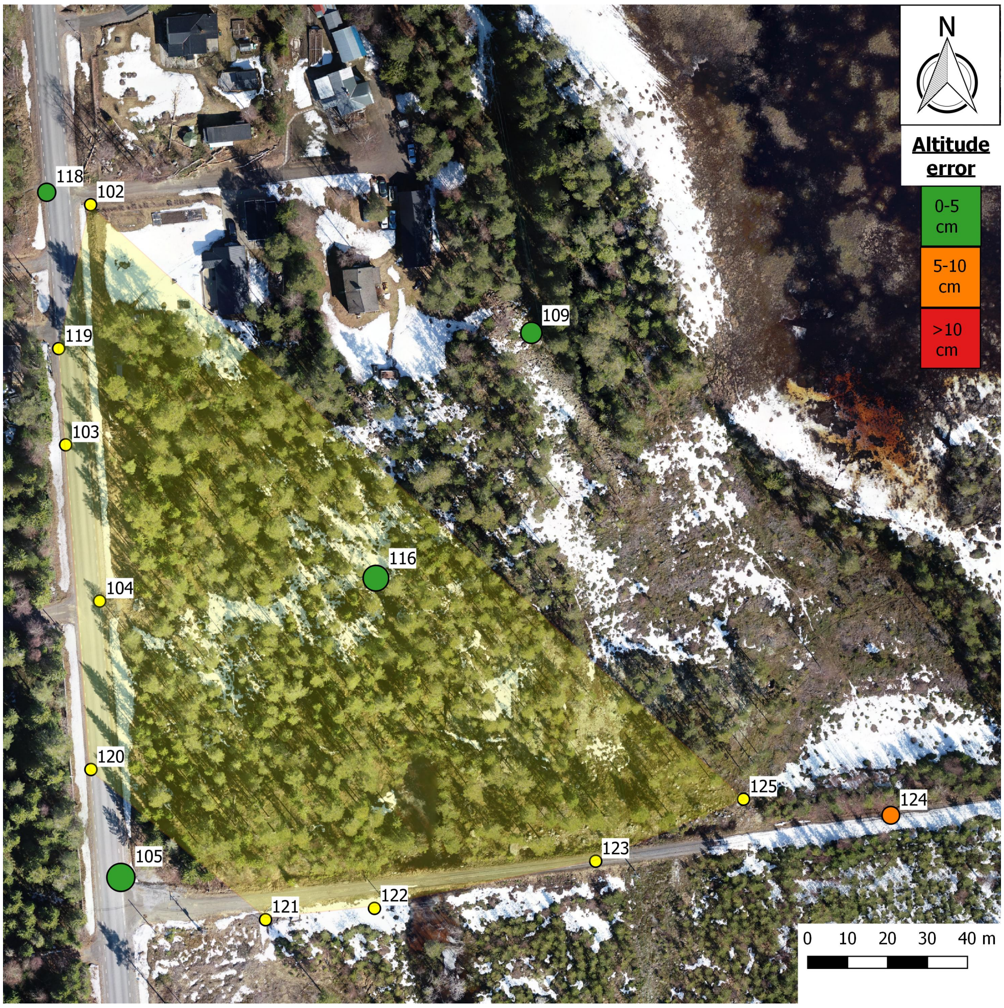


Figure 9 – A map of the GCPs (yellow dots) in the set of "Tarmac and gravel road" when the image position is used, along with their covered area (15 476 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 10 – Errors for the five control points when the GCPs are spread according to case 5 (Tarmac and gravel road). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0423	-0.0378	0.0262
109	-0.0147	0.0313	0.0458
116	0.0052	-0.0630	0.0297
118	-0.0142	0.0160	0.0034
124	0.0239	-0.0049	-0.0597
Mean absolute value (std)	**0.0201 (0.0141)**	**0.0306 (0.0222)**	**0.0330 (0.0213)**

4.5.2 Without the use of the image position

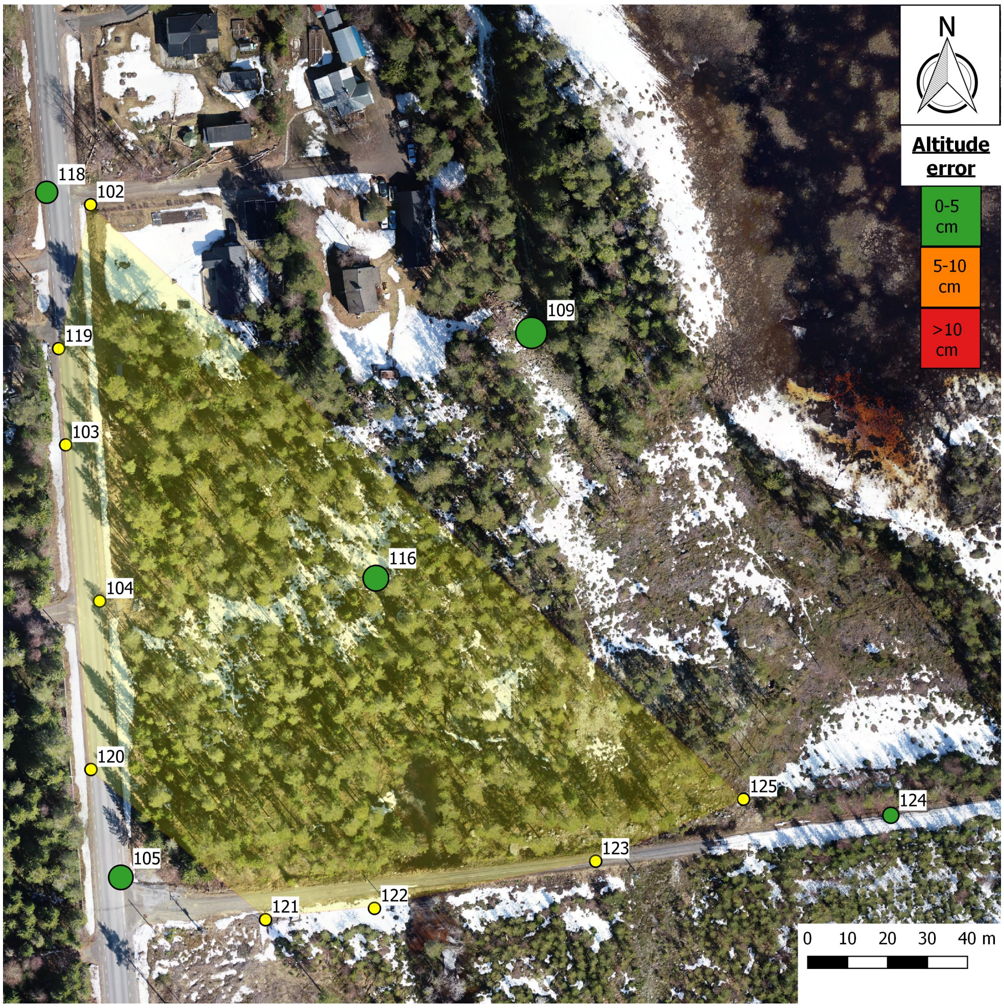


Figure 10 – A map of the GCPs (yellow dots) in the set of "Tarmac and gravel road" when the image position is not used, along with their covered area (15 476 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 11 – Errors for the five control points when the GCPs are spread according to case 5 (Tarmac and gravel road). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0207	-0.0426	0.0257
109	-0.0578	0.0382	0.0228
116	-0.0088	-0.0604	-0.0204
118	-0.0425	0.0082	0.0180
124	0.0080	0.0137	-0.0180
Mean absolute value (std)	**0.0276 (0.0219)**	**0.0326 (0.0215)**	**0.0210 (0.0033)**

4.6 Case 6 - Dice five

4.6.1 Using the image position

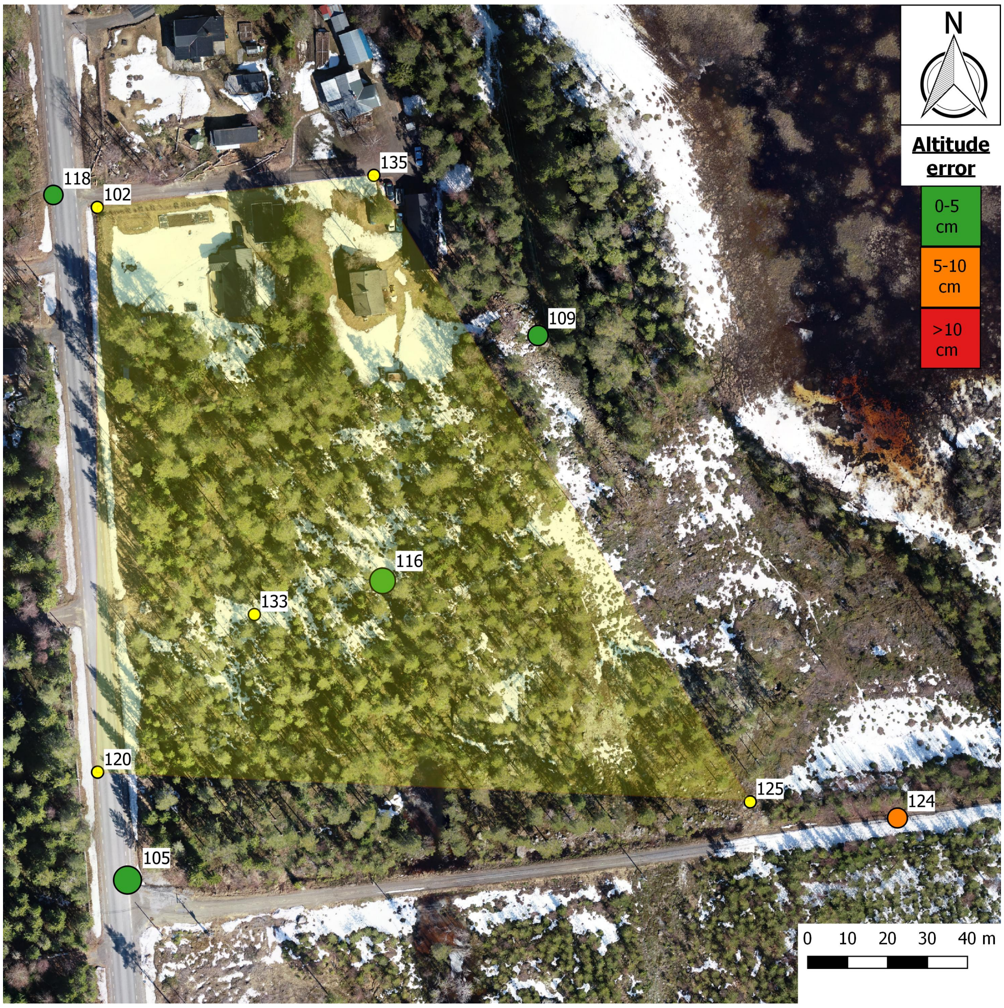


Figure 11 – A map of the GCPs (yellow dots) in the set of "Dice five" when the image position is used, along with their covered area (17 403 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 12 – Errors for the five control points when the GCPs are spread according to case 6 (Dice five). Using the image positions.

Control point	Easting error (m)	Northing error (m)	Altitude error (m)
105	-0.0456	-0.0328	0.0242
109	-0.0139	0.0273	0.0443
116	0.0049	-0.0631	0.0291
118	-0.0196	0.0160	0.0043
124	0.0308	-0.0077	-0.0561
Mean absolute value (std)	**0.0230 (0.0158)**	**0.0294 (0.0212)**	**0.0316 (0.0198)**

4.6.2 Without the use of the image position

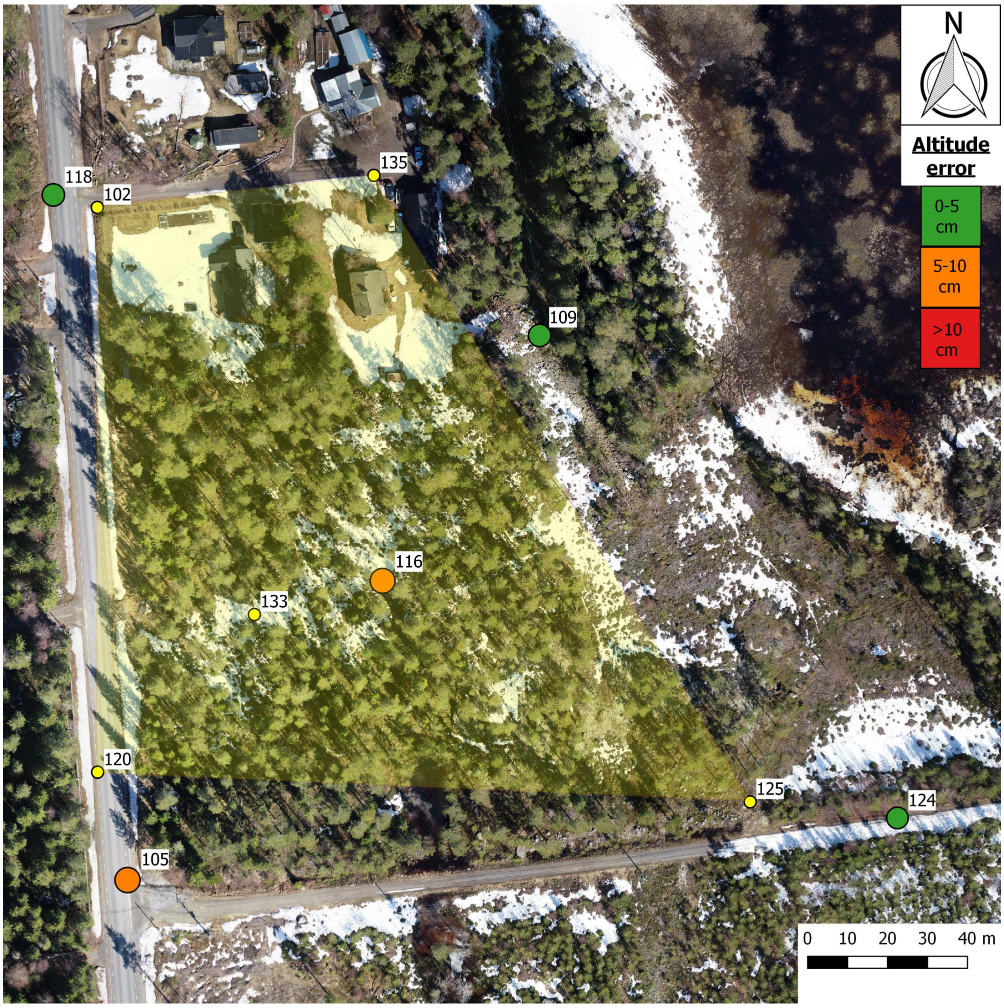


Figure 12 – A map of the GCPs (yellow dots) in the set of "Dice five" when the image position is not used, along with their covered area (17 403 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 13 – Errors for the five control points when the GCPs are spread according to case 6 (Dice five). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0426	-0.0257	0.0598
109	-0.0315	0.0211	-0.0260
116	-0.0015	-0.0626	-0.0536
118	-0.0341	0.0186	0.0181
124	0.0308	-0.0173	0.0178
Mean absolute value (std)	**0.0281 (0.0156)**	**0.0291 (0.0190)**	**0.0351 (0.0201)**

4.7 Case 7 - Half of the GCPs

4.7.1 Using the image position

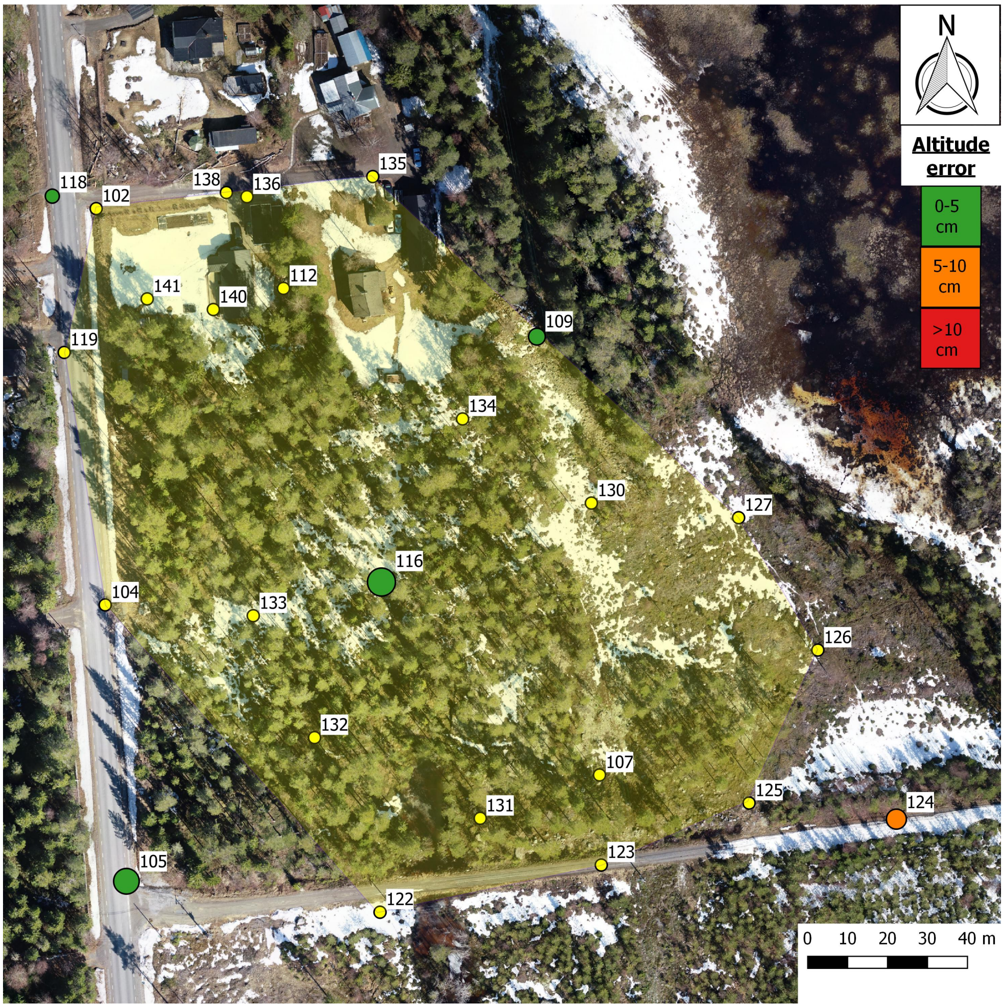


Figure 13 – A map of the GCPs (yellow dots) in the set of "Half of the GCPs" when the image position is used, along with their covered area (22 754 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 14 – Errors for the five control points when the GCPs are spread according to case 7 (Half of the GCPs). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0359	-0.0323	0.0125
109	-0.0074	0.0170	0.0341
116	0.0126	-0.0683	0.0207
118	-0.0084	0.0019	-0.0173
124	0.0329	-0.0069	-0.0589
Mean absolute value (std)	**0.0194 (0.0138)**	**0.0253 (0.0267)**	**0.0287 (0.0187)**

4.7.2 Without the use of the image position

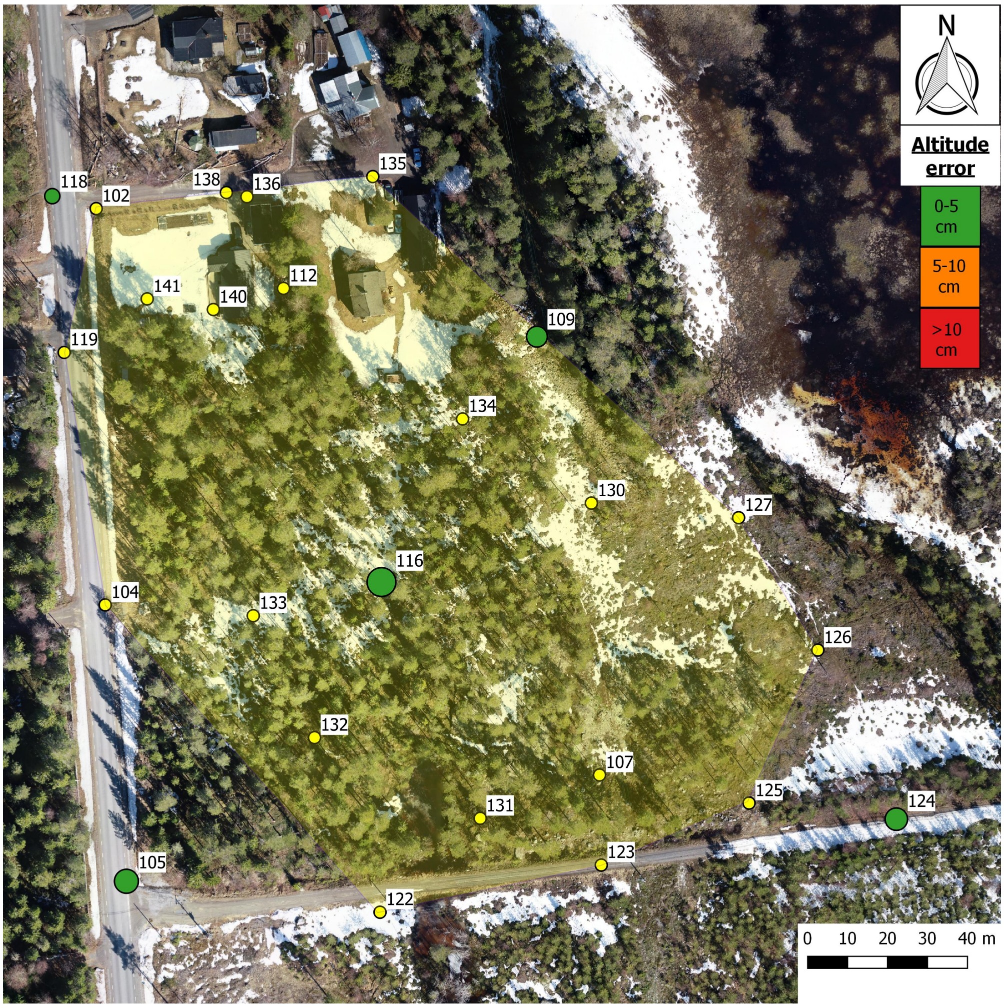


Figure 14 – A map of the GCPs (yellow dots) in the set of "Half of the GCPs" when the image position is not used, along with their covered area (22 754 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 15 – Errors for the five control points when the GCPs are spread according to case 7 (Half of the GCPs). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0293	-0.0300	0.0158
109	-0.0119	0.0115	0.0303
116	0.0146	-0.0703	-0.0022
118	-0.0126	0.0031	-0.0097
124	0.0386	-0.0131	-0.0260
Mean absolute value (std)	**0.0214 (0.0120)**	**0.0256 (0.0268)**	**0.0168 (0.0115)**

4.8 Case 8 - All ground control points

4.8.1 Using the image position

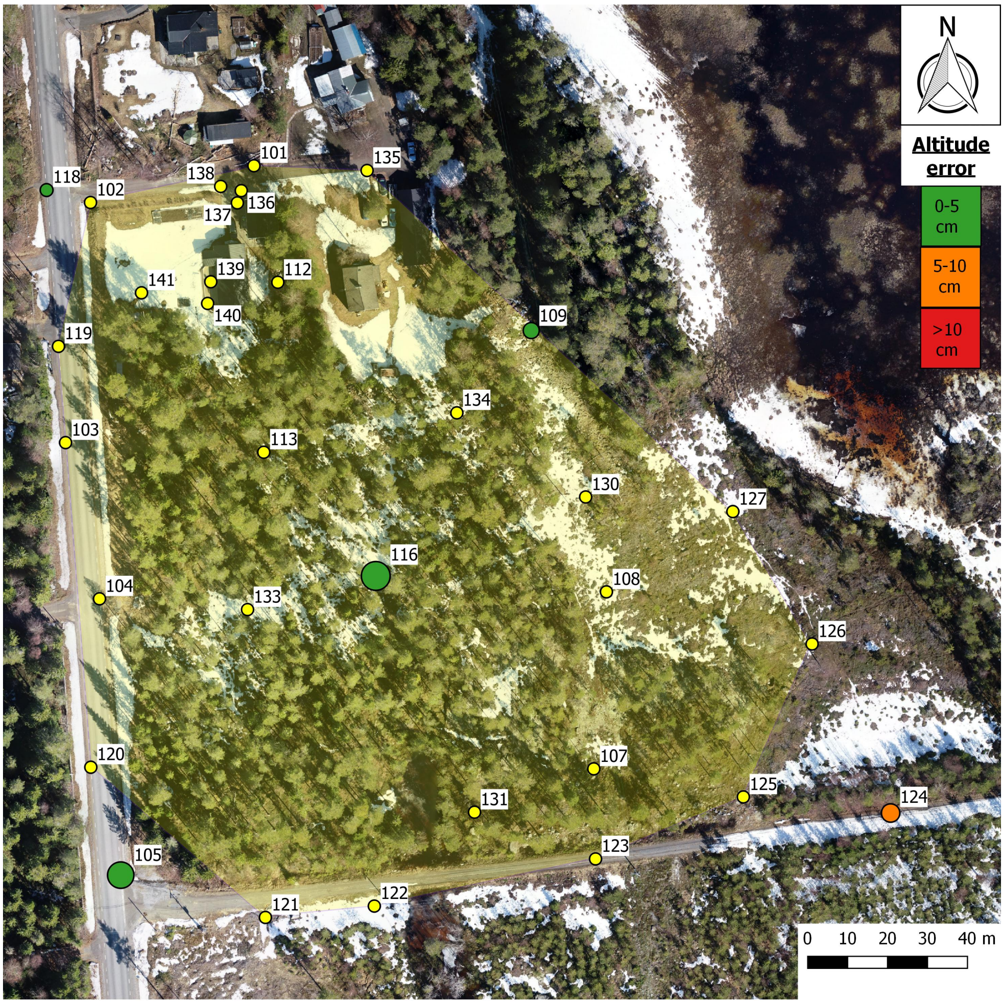


Figure 15 – A map of the GCPs (yellow dots) in the set of "All GCPs" when the image position is used, along with their covered area (22 754 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the color represent the error in Altitude as the scale on the map shows.

Table 16 – Errors for the five control points when the GCPs are spread according to case 8 (All GCPs). Using the image positions.

Control point	Easting error (m)	Northing error (m)	Altitude error (m)
105	-0.0360	-0.0368	0.0090
109	-0.0041	0.0169	0.0290
116	0.0142	-0.0701	0.0153
118	-0.0044	-0.0005	-0.0260
124	0.0332	-0.0067	-0.0631
Mean absolute value (std)	**0.0184 (0.0154)**	**0.0262 (0.0281)**	**0.0285 (0.0210)**

4.8.2 Without the use of the image position

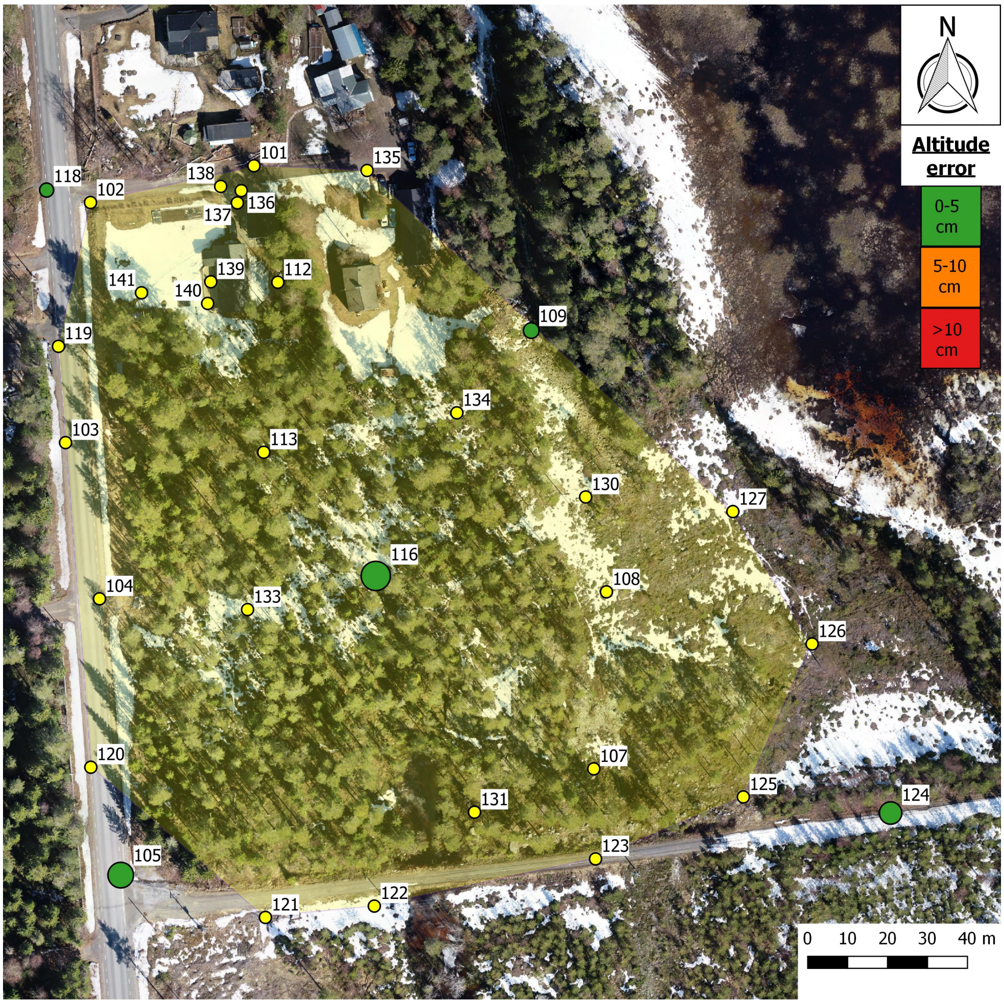


Figure 16 – A map of the GCPs (yellow dots) in the set of "All GCPs" when the image position is not used, along with their covered area (22 754 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 17 – Errors for the five control points when the GCPs are spread according to case 8 (All GCPs). Not using the image positions.

Control point	Easting error (m)	Northing error (m)	Altitude error (m)
105	-0.0339	-0.0351	0.0282
109	-0.0061	0.0123	0.0223
116	0.0160	-0.0716	-0.0030
118	-0.0077	0.0016	-0.0154
124	0.0390	-0.0130	-0.0312
Mean absolute value (std)	**0.0205 (0.0151)**	**0.0267 (0.0279)**	**0.0200 (0.0113)**

4.9 Case 9 - Outer edge

4.9.1 Using the image position

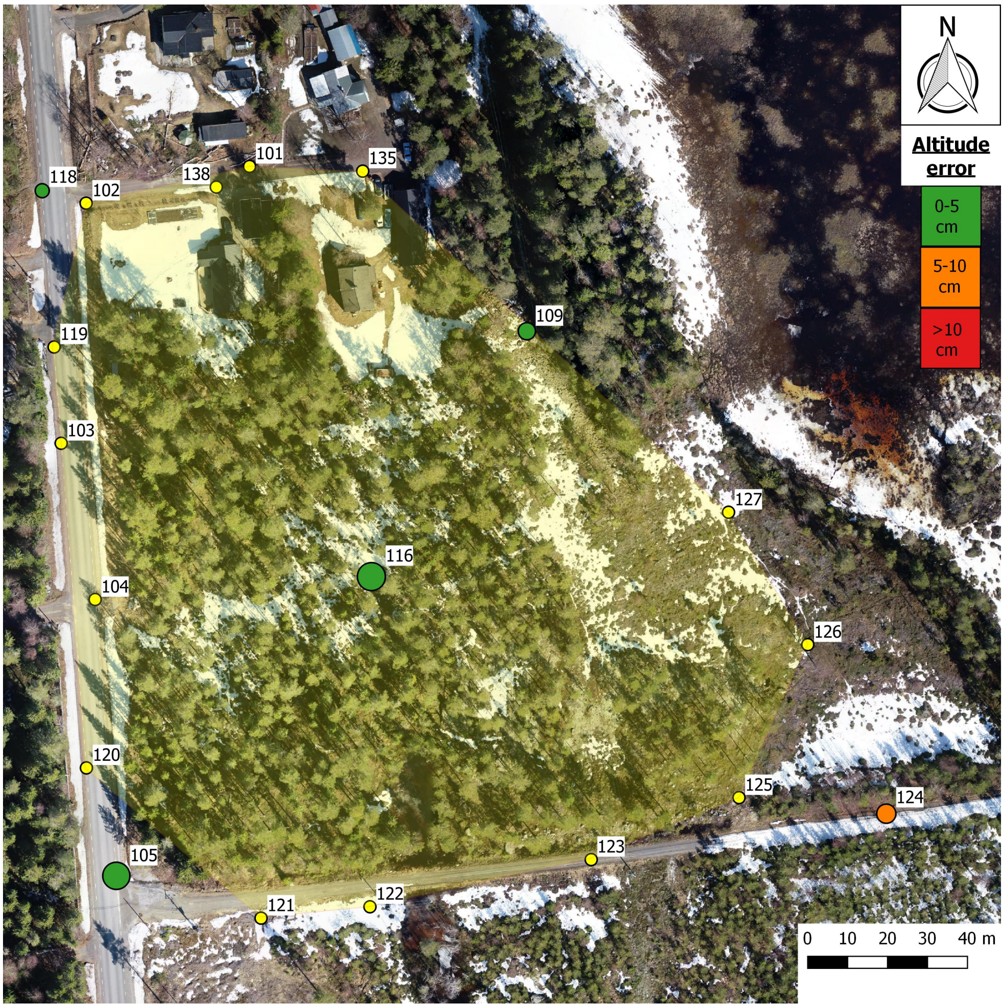


Figure 17 – A map of the GCPs (yellow dots) in the set of "Outer edge" when the image position is used, along with their covered area (25 266 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 18 – Errors for the five control points when the GCPs are spread according to case 9 (Outer edge). Using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0391	-0.0364	0.0148
109	-0.0080	0.0178	0.0326
116	0.0106	-0.0694	0.0196
118	-0.0084	0.0013	-0.0190
124	0.0294	-0.0068	-0.0618
Mean absolute value (std)	**0.0191 (0.0143)**	**0.0263 (0.0276)**	**0.0296 (0.0192)**

4.9.2 Without the use of the image position

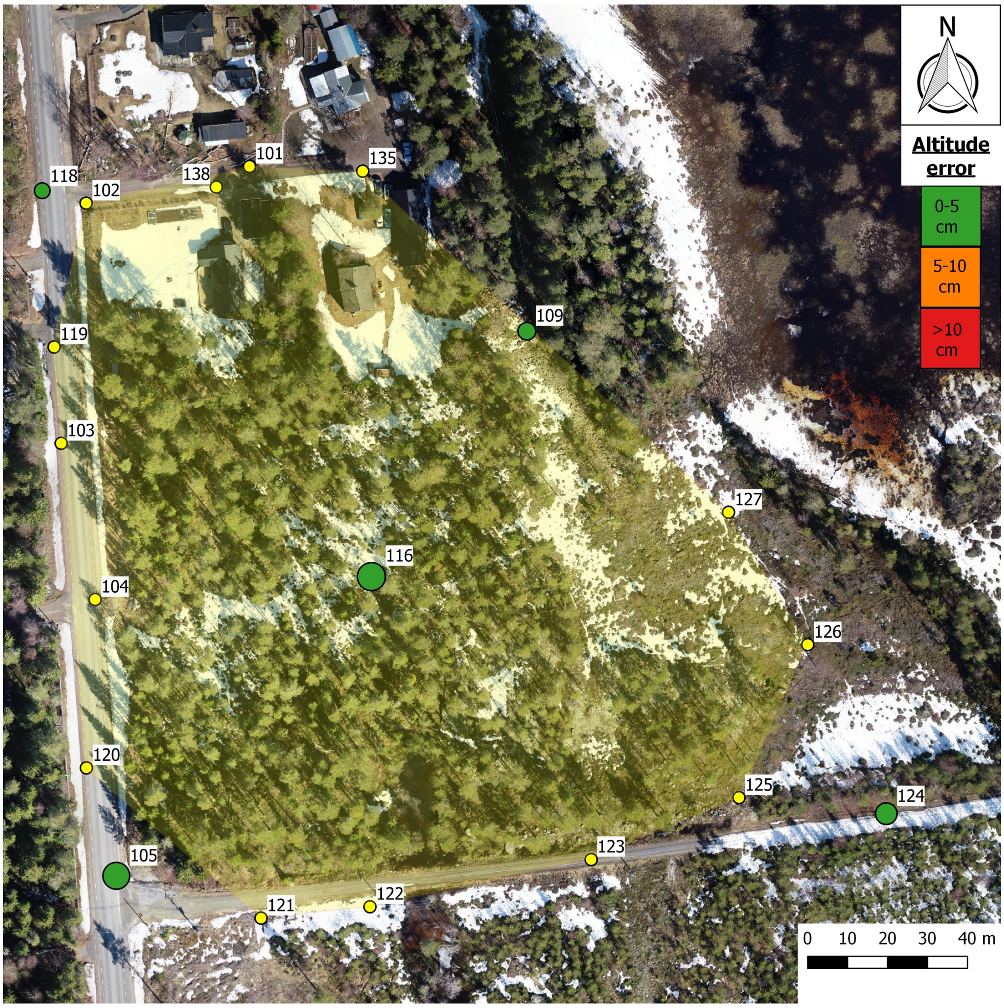


Figure 18 – A map of the GCPs (yellow dots) in the set of "Outer edge" when the image position is not used, along with their covered area (25 266 m^2) and the CPs. The size of the CPs represent the combined error in Easting and Northing while the colour represent the error in Altitude as the scale on the map shows.

Table 19 – Errors for the five control points when the GCPs are spread according to case 9 (Outer edge). Not using the image positions.

Control point	Easting error [m]	Northing error [m]	Altitude error [m]
105	-0.0385	-0.0348	0.0454
109	-0.0144	0.0136	-0.0112
116	0.0095	-0.0704	-0.0488
118	-0.0140	0.0032	0.0031
124	0.0344	-0.0148	0.0237
Mean absolute value (std)	**0.0222 (0.0133)**	**0.0274 (0.0266)**	**0.0264 (0.0203)**

5 Discussion

To further investigate the performance of the DJI Phantom 4 RTK we create a figure containing the mean errors of the five control points for each case examined in section 4.

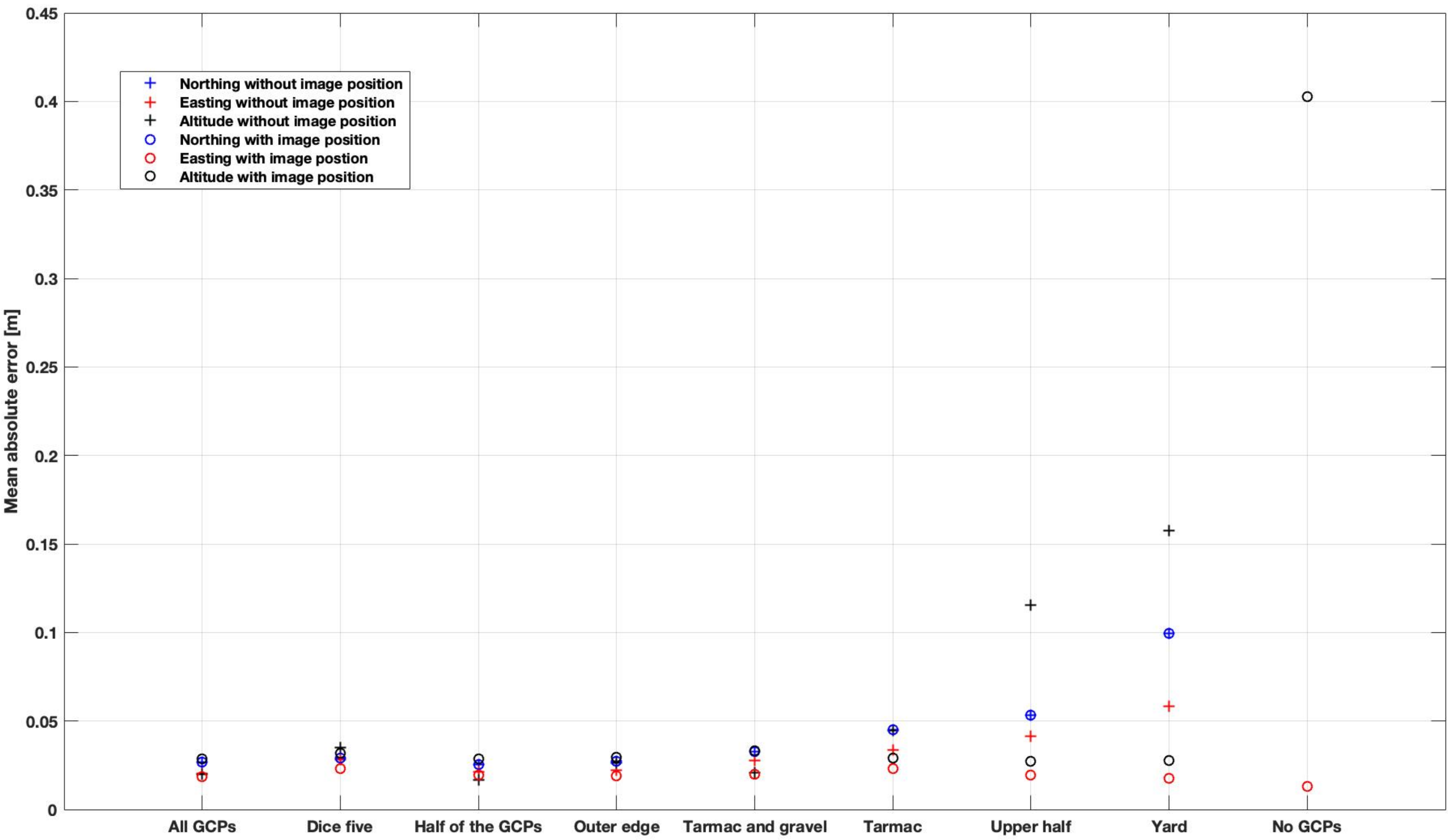
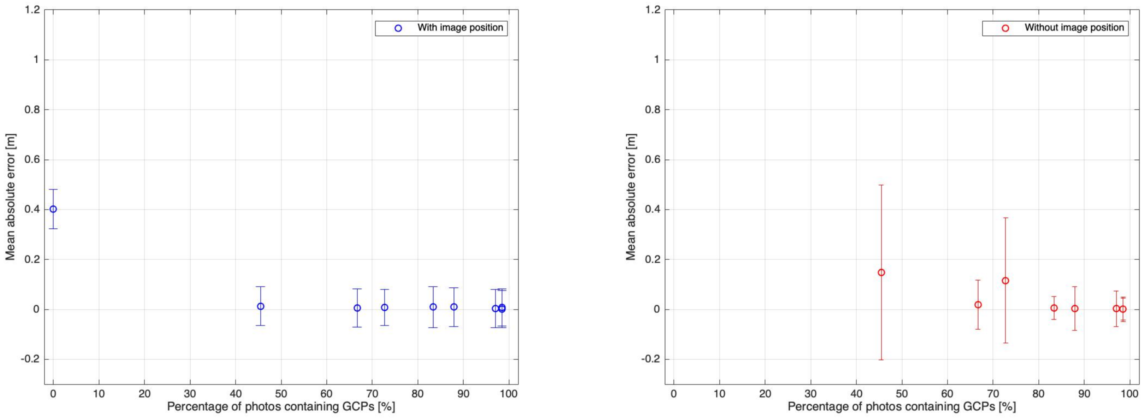


Figure 19 – Showing the mean errors of the controlpoints in the directions northing, easting and altitude for each case in section 4 results.

By analysing figure 19 one can see that the when using the cases *tarmac, upper half, and yard* the performance seems to decrease when not using the image positions. This makes sense since fewer images will be corrected from the GCPs. However by using the image position and the RTK sensor the images can be further corrected and one can see that only using the GCPs in case 9 (Yard) will be sufficient for the errors to remain small. This suggests that by using the DJI Phantom 4 RTK the number and the spread of GCPs is of less importance. Still when using only the image positions and no GCPs the error in altitude will be far to significant.

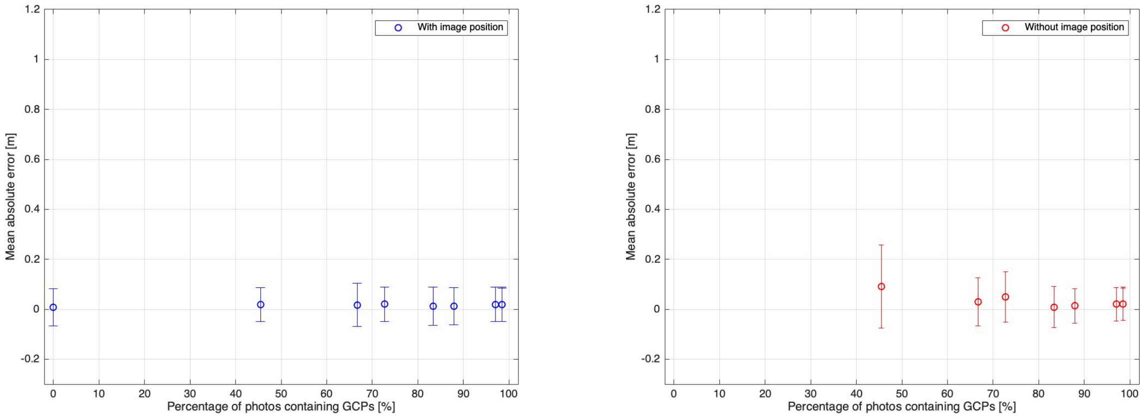
To try and evaluate the overall performance in each case, the errors from tables 3 - 19 were used to find average errors and their 95% confidence bands. These plots are presented in figures 20 - 22. Note that in figures 20-22(b), there is no data for when no GCPs were used.



(a) (b)

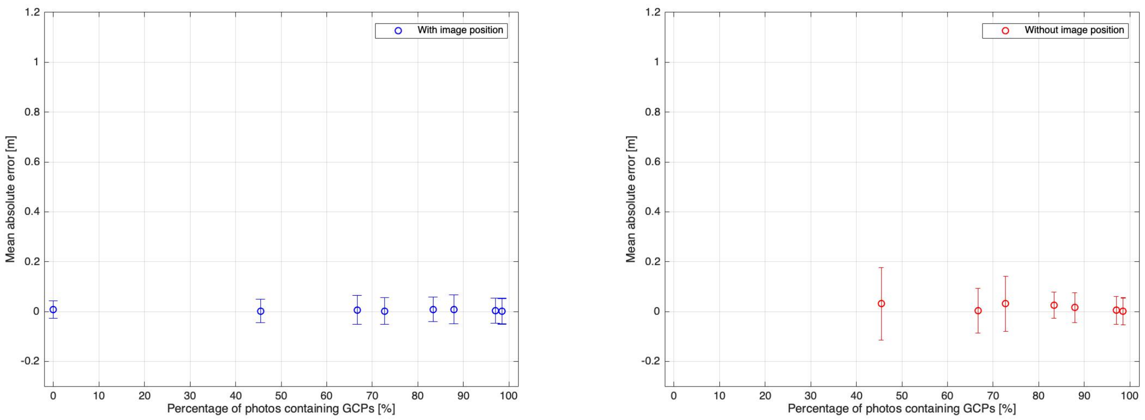
Figure 20 – The error in the measured altititude as a function of the percentage of photos containing GCPs. In (a) the image position is used, in (b) the image position is not used. The errorbars present the 95% confidence band.

Consider the error in altitude. From figure 20(b), when not using the image position there seem to be a trend such that a higher percentage of photos which capture a GCP, the higher the precision will be. This would mean that strategic placement of the GCPs is of higher importance than necessarily using many GCPs. When using the image position, presented in figure 20(a), it is quite noticeable how the accuracy is strongly improved with the introduction of just a few GCPs. By doing a two sample T-test one can with 90 % significance show that there is an improvement when adding the use of the image positions for the cases upper half and yard. In all other cases, the use of GCPs make it such that the addition the image position does not improve the measurement significantly.



(a) (b)

Figure 21 – The error in the measured northing position as a function of the percentage of photos containing GCPs. In (a) the image position is used, in (b) the image position is not used. The errorbars present the 95% confidence band.



(a) (b)

Figure 22 – The error in the measured easting postition as a function of the percentage of photos containing GCPs. In (a) the image position is used, in (b) the image position is not used. The errorbars present the 95% confidence band.

Now consider the horizontal error, presented in figures 21 and 22. A two sample T-test show that there is no significant decrease in the error when adding the use of the image position to the GCPs. One can also interpret this as that the use of the image position performs quite similarly with and without the use of GCPs.

However, to truly make a significant statistical analysis of these 9 cases one would need to do the same flight several times to get a bigger basis of data for each control point. Since these results are based on a single flight, there might sources of error which influences the results in ways that are difficult to quantify.

6 Conclusion

In conclusion the DJI phantom 4 RTK performs with a mean error of less than 10 cm in the plane and 50 cm in altitude without any ground support. According to this study, if one wish to further decrease the error one should use at least some configurations of GCPs similar to the cases yard or upper half. This would result in a mean error of less than 5 cm in all directions.

References

[1] Mulakala, Jay. 2019. *Measurement accuracy of the DJI Phantom 4 RTK photogrametry*. Drone deploy.

[2] http://www.rslab.se/agisoft-photoscan-pro/ (2019-06-06)