Investigation on the positional accuracy of 3D models generated by the Pix4Dcatch app synchronized with the viDoc® RTK rover for iPad

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1 Introduction

RTK (Real-Time Kinematic) is a technique used to increase the accuracy of GNSS positions using a fixed base station, that wirelessly sends out correctional data to a moving receiver. GNSS refers to a constellation of satellites providing signals from space that transmits position and timing data. The receivers then use this data to determine their location as shown in fig. 1.
An RTK technique requires two receivers: A stationary "base station" with a known location, and a mobile "rover". In this study, we will be referring to the base station as a “mountpoint”. The communication between the mountpoint and the rover is carried out through an NTRIP service. An NTRIP service is used in areas with strong 3G/LTE cellular coverage and a vast network of NTRIP mount points nearby.
Lightweight RTK options are an integral part of many professional drones today. Studies inves-

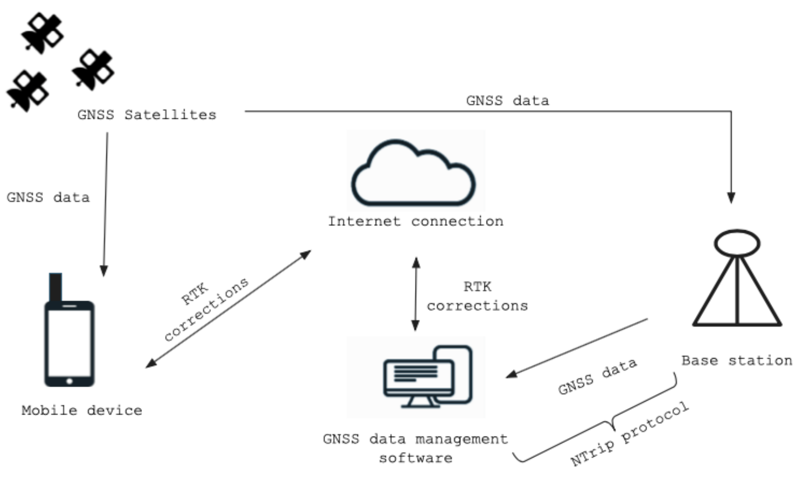

Figure 1: RTK device operation.

tigating the absolute accuracy of photogrammetric deliverables generated with RTK and to a large extent conclude that the collection of Ground Control Points (GCPs), the traditional way to georeference image blocks, do not substantially increase the accuracy. Knowledge of accurate camera positions determined by the GNSS receiver allows users to achieve global accuracy on the ground in the range of 2-3 pixels. This requires good quality images with sufficient overlap, precise synchronization of the employed hardware components and robust processing software. In drone image datasets the image center accuracy as provided by the RTK device is mostly constant, since the visibility of the local network is not blocked by buildings. The RTK rover used in this test is very similar to what can be found today on drones. An important difference is the varying positional accuracy due to limited satellite visibility or multipath effects on the GNSS signal. It is therefore important to detect these variations in accuracy and assign each image with realistic position accuracy.

The goal of this white paper is to investigate the absolute accuracy of photogrammetry deliverables achieved by using the viDoc RTK rover synchronized with the mobile image acquisition software: Pix4Dcatch. In this study, we have also conducted experiments in areas with limited satellite visibility in order to validate the robustness of the solution in sub-optimal conditions.

2 Method

Before starting a capture using Pix4Dcatch+viDoc RTK rover, it is necessary to correctly attach the rover to the mobile device where Pix4Dcatch is installed.

2.1 Installation of the viDoc RTK rover

Pix4Dcatch+RTK is supported on the iPhone12 Pro, iPhone12 Pro Max, and the iPad Pro 11 inch. The rover is composed of two main parts (see fig. 2 left): the antenna and the receiver. The metal case is specifically designed to protect internal components from environmental conditions, impact, and electronic interference. It can fit different iPad models thanks to a sliding part on the bottom, as shown in fig. 2 right.

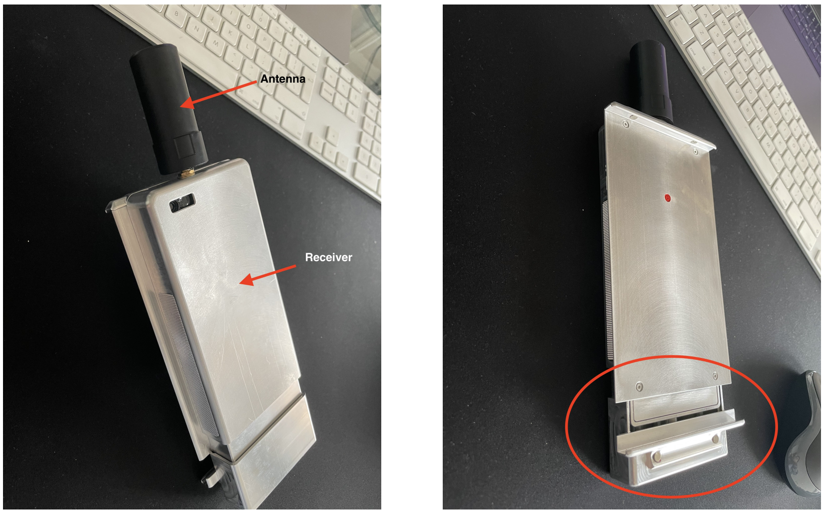

Figure 2: The viDoc RTK rover for iPad - left: The two main components (antenna, receiver) are indicated with the red arrows. Right: Adaptable RTK rover for iPads.

The offset between the antenna and the camera is precisely known and accounted for during the data acquisition. In order to have this offset applied, the rover must be mounted on the center of the iPad, as shown in fig. 3. The RTK rover is equipped with two small magnets that easily align with the iPad's magnets and help in positioning it to the centre (fig. 4).

Figure 3: Correct positioning of the viDoc RTK rover with the iPad.

Figure 4: Left: The small magnets on the viDoc RTK rover (indicated by the red arrows). Right: Position of the iPad's magnets.

Figure 5: Power button located on the side of the RTK device.

2.2 Connecting the viDoc RTK rover to Pix4Dcatch

The viDoc RTK rover needs to be mounted to an iPad where the Pix4Dcatch app is to be used for image acquisition. Mount the viDoc RTK rover to the mobile device. Turn on the rover with a single long press. The green light on the rover indicates that it is turned on, as shown in fig. 5. Open the device settings and turn on the Bluetooth and start Pix4Dcatch. In the top-left corner of the screen, select the signal indicator and select viDoc RTK via Bluetooth. In the RTK Device Settings dialog, select the viDoc RTK rover under Available Bluetooth Devices, enter the NTRIP details and select Connect (fig. 6). When the connection is established, select Choose mountpoint and select the preferred mountpoint and select save. A successful connection to the NTRIP service is indicated with a green RTK icon.

Once connected to the RTK rover, the capture screen of the app will display the horizontal and

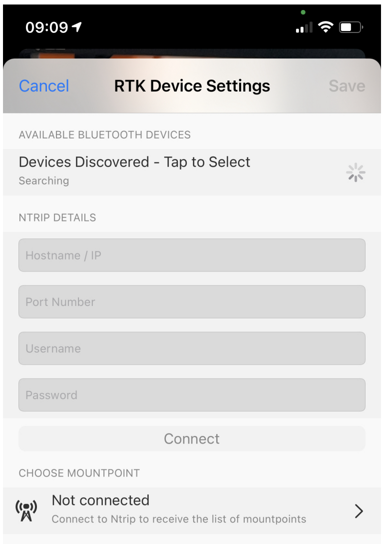

Figure 6: The RTK device settings dialog in the Pix4Dcatch to establish a connection to the NTRIP service

Figure 7: The capture screen of Pix4Dcatch displays the real-time accuracy once connected to the RTK rover.

vertical accuracy in real-time (fig. 7).

2.3 Obtaining an optimal capture in the work-site

While using Pix4Dcatch+viDoc to capture a dataset, ensure that you are standing in an open air with good internet connection. In order to have a good quality signal, the antenna must be unobstructed and pointing upwards. Avoid underground captures, captures near buildings, trees, or under bridges, in order to have unhindered access to the satellites. These factors can affect the signal as shown in fig. 8.

Usually, a few seconds are required to arrive at an RTK fix of 0.01 m. Once an RTK fix is

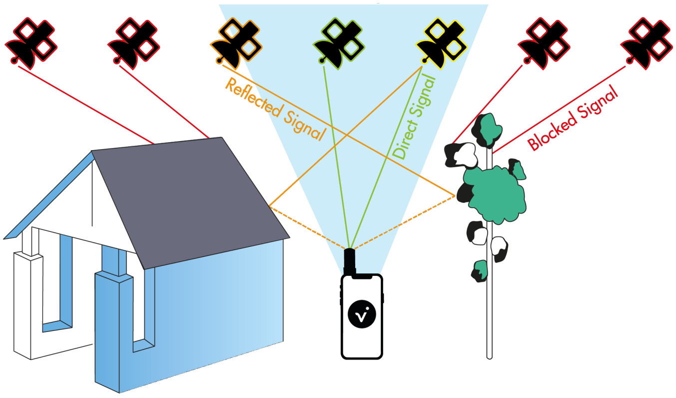

Figure 8: Buildings or trees can reduce the access of the RTK rover to optimal number of satellites and thus impacting accuracy.

achieved, wait 3 s before starting capture.
During the capture, keep an eye on the accuracy: if it decreases (above 0.02 m), please stay stationary until the accuracy becomes 0.01 m again, then continue data collection. Ensure to walk slowly and steadily during capture.

Figure 9: The Javad Triumph-LS receiver was used to measure the positions of checkpoints.

3 Experiments

To test the absolute accuracy of Pix4Dcatch+viDoc we conducted several experiments, all based on a similar setup:

- Acquired datasets using Pix4Dcatch+viDoc in areas where control points had been collected. The control points were visually identifiable in the datasets. The images are automatically georeferenced by the RTK rover.
- Processed the datasets using Pix4Dmapper desktop software
- Marked the control points as checkpoints inside Pix4Dmapper
- Documented the accuracy of each checkpoint

We measured the control points with the Javad Triumph-LS GNSS receiver (fig. 9) connected in real-time to the Swiss GNSS correction service: Swipos. Each point was measured statically in a 2 min interval with 1 Hz recording rate. These measurements resulted in the absolute accuracy of 1 cm horizontally and 1.5 cm vertically.

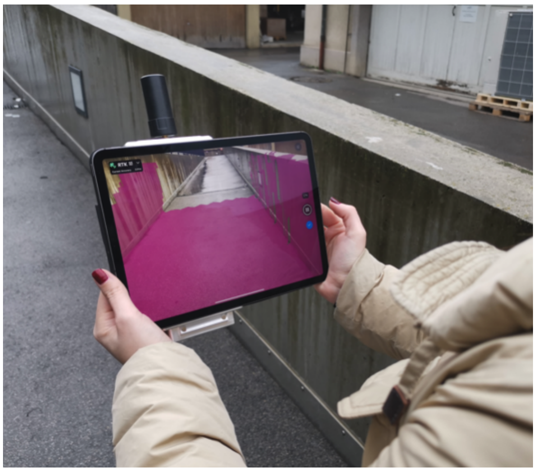

Figure 10: Acquisition of the Pix4D office dataset with the Pix4Dcatch+viDoc.

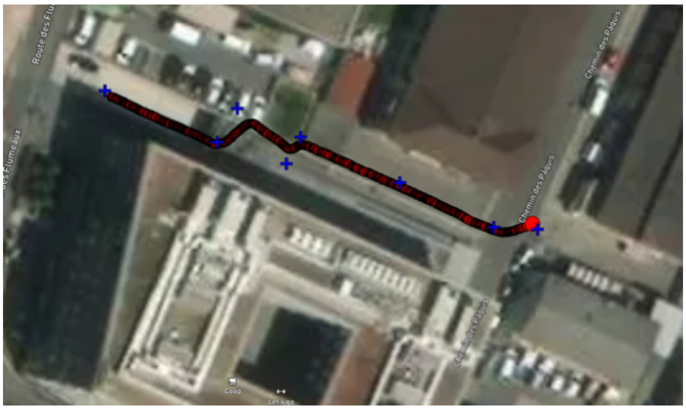

Figure 11: Pix4D office dataset with Pix4Dcatch+viDoc acquired image positions (red dots) and independently measured control points (blue cross).

3.1 Pix4D Office

The test site of the Pix4D office dataset had 8 independently measured points from which 7 are visible in the dataset. The location is characterized by relatively high buildings and the validation GCP's are close to those buildings.

About 600 images have been captured with Pix4Dcatch (see fig. 10) and processed in Pix4Dmapper with the 3D models template processing option (fig. 11 and fig. 12). After importing and measuring the checkpoints inside the images, Pix4Dmapper does present global accuracy as the RMS error of the check points. Those are shown in fig. 13 and indicate an xyz RMS error that is under 5 cm in all dimensions.

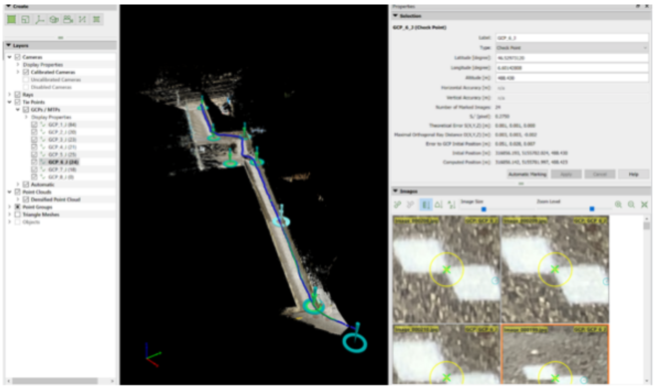

Figure 12: The Pix4D office dataset was processed using Pix4Dmapper.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		0.062	0.024	-0.006	0.457	84 / 84
GCP_2_J		0.009	0.020	-0.030	0.897	20 / 20
GCP_3_J		0.038	0.088	0.003	0.618	23 / 23
GCP_4_J		0.021	0.006	-0.048	0.936	21 / 21
GCP_5_J		0.034	0.038	0.024	0.877	25 / 25
GCP_6_J		0.051	0.028	0.007	0.635	24 / 24
GCP_7_J		0.077	-0.018	0.089	0.670	18 / 18
Mean [m]		0.041621	0.026443	0.005549		
Sigma [m]		0.021751	0.030130	0.040764		
RMS Error [m]		0.046962	0.040088	0.041140		

Figure 13: Checkpoint accuracy for Pix4D office dataset.

3.2 Park Scene

The scene is relatively small with 7 check points. Pix4Dcatch automatically extracted about 450 images and the point cloud can be seen in fig. 14. On average we observe a Ground Sampling Distance of around 1 mm and the RMS error of all check points is in the order of 2-3 cm as shown in fig. 15.

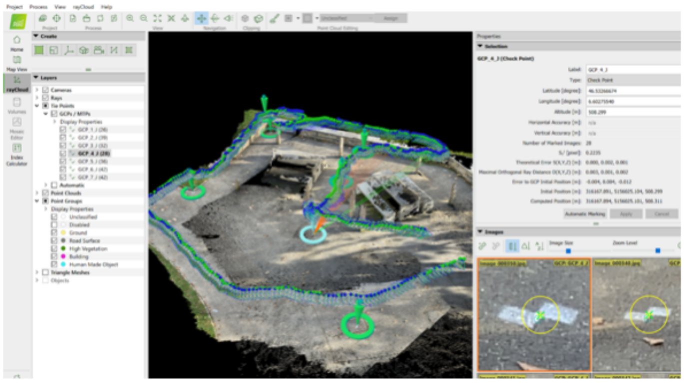

Figure 14: Pix4Dmapper screenshot of the park scene.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		-0.006	0.026	-0.002	0.754	26 / 26
GCP_2_J		0.000	0.030	-0.002	0.969	39 / 39
GCP_3_J		-0.017	0.017	-0.020	0.937	32 / 32
GCP_4_J		-0.004	0.004	-0.012	0.551	28 / 28
GCP_5_J		0.012	0.008	0.024	1.043	36 / 36
GCP_6_J		0.026	-0.014	0.044	0.822	42 / 42
GCP_7_J		-0.014	-0.016	-0.029	0.897	42 / 42
Mean [m]		-0.000285	0.007759	0.000586		
Sigma [m]		0.013818	0.016699	0.023587		
RMS Error [m]		0.013820	0.018414	0.023594		

Figure 15: Check point statistics for the park scene.

3.3 Vaudoise Arena, Prilly

The test site Vaudoise Arena has 16 independently measured GCPs from which are 14 visible in the dataset. The location is characterized by open space, without big buildings. On the path, a tunnel's presence (see fig. 16) impacts both horizontal and vertical accuracy drastically, passing from 1 to 35 cm, see fig. 17.

Figure 16: The tunnel on the Vaudoise area.

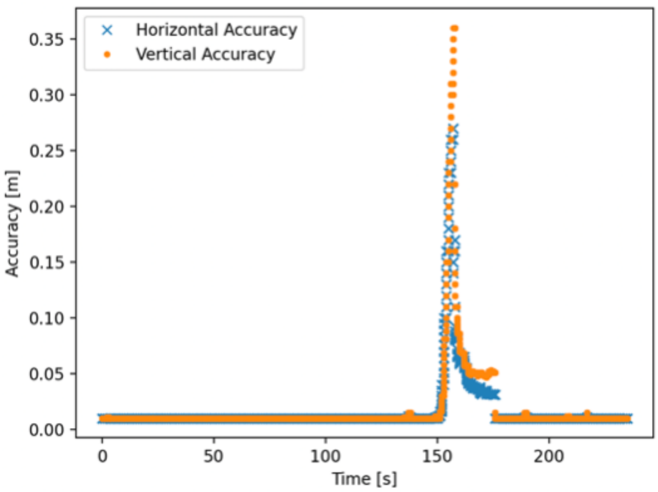

Figure 17: The tunnel's effect on the horizontal and vertical accuracy.

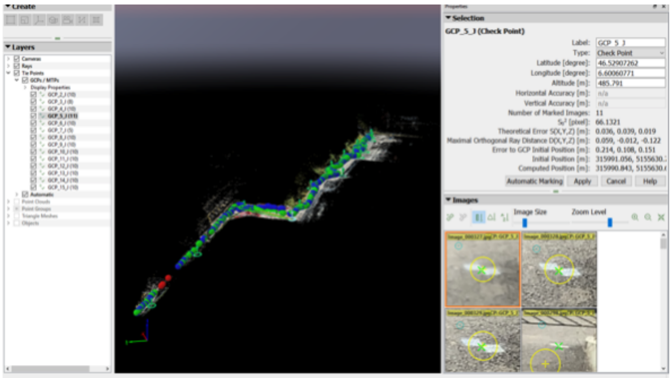

Figure 18: Pix4Dmapper screenshot for Vaudoise Arena dataset.

Check Point Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_2_J		-0.006	-0.024	-0.024	0.961	10 / 10
GCP_3_J		0.003	0.061	-0.036	0.563	8 / 8
GCP_4_J		0.053	-0.006	-0.065	1.223	10 / 10
GCP_5_J		0.213	0.103	0.145	0.456	11 / 11
GCP_6_J		-0.004	0.059	-0.052	1.473	10 / 10
GCP_7_J		0.002	0.062	-0.038	0.622	5 / 5
GCP_8_J		-0.003	0.062	-0.038	0.992	10 / 10
GCP_9_J		0.034	0.053	-0.040	0.555	10 / 10
GCP_10_J		0.031	0.047	-0.038	0.758	10 / 10
GCP_11_J		0.023	0.016	-0.061	0.968	10 / 10
GCP_12_J		0.038	-0.014	-0.055	1.084	10 / 10
GCP_13_J		0.020	0.051	-0.051	1.163	10 / 10
GCP_14_J		0.025	0.052	-0.051	1.084	10 / 10
GCP_15_J		0.030	0.053	-0.045	0.925	10 / 10
Mean [m]		0.032736	0.041114	-0.032086		
Sigma [m]		0.052816	0.033815	0.050345		
RMS Error [m]		0.062139	0.053233	0.059700		

Figure 19: Check points accuracy for Vaudoise Arena dataset.

About 1160 images have been captured with Pix4Dcatch and processed in Pix4Dmapper with the 3D models template processing option (fig. 18). After importing and measuring the check points inside the images, Pix4Dmapper does present global accuracy as the RMS error of the check points. Those are shown in fig. 19 and indicate a xyz RMS error that is around 6 cm in all dimensions.

4 Repeatability of tests

In order to test the reliability of the device, the three datasets were acquired on different days.

4.1 Pix4D Office

The mapper accuracy is shown in fig. 20, fig. 21, and fig. 22, for the Pix4D office at 02-02-2021, 09-03-2021, and 16-03-2021, respectively.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		0.062	0.024	-0.006	0.457	84 / 84
GCP_2_J		0.009	0.020	-0.030	0.897	20 / 20
GCP_3_J		0.038	0.088	0.003	0.618	23 / 23
GCP_4_J		0.021	0.006	-0.048	0.936	21 / 21
GCP_5_J		0.034	0.038	0.024	0.877	25 / 25
GCP_6_J		0.051	0.028	0.007	0.635	24 / 24
GCP_7_J		0.077	-0.018	0.089	0.670	18 / 18
Mean [m]		0.041621	0.026443	0.005549		
Sigma [m]		0.021751	0.030130	0.040764		
RMS Error [m]		0.046962	0.040088	0.041140		

Figure 20: Accuracy for the Pix4D office site at 02-02-2021

GCP_1_J		-0.152	-0.097	-0.065	1.514	8 / 8
GCP_2_J		-0.013	0.024	-0.084	1.078	8 / 8
GCP_3_J		0.001	0.036	-0.042	0.675	8 / 8
GCP_5_J		-0.009	0.013	-0.006	1.462	8 / 8
GCP_6_J		-0.017	0.001	-0.003	1.352	8 / 8
GCP_7_J		-0.016	0.007	-0.024	1.382	8 / 8
Mean [m]		-0.034222	-0.002424	-0.037425		
Sigma [m]		0.053080	0.043628	0.029618		
RMS Error [m]		0.063156	0.043695	0.047727		

Figure 21: Accuracy for the Pix4D office site at 09-03-2021

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		0.024	0.014	-0.024	3.121	2 / 2
GCP_2_J		0.016	0.014	-0.016	1.781	4 / 4
GCP_3_J		0.049	-0.091	-0.100	2.330	4 / 5
GCP_4_J		-0.077	-0.016	0.009	0.811	5 / 5
GCP_5_J		-0.033	-0.108	-0.057	2.225	4 / 4
GCP_6_J		-0.075	-0.045	-0.023	0.976	3 / 3
GCP_7_J		-0.016	0.018	-0.021	2.139	3 / 3
GCP_8_J		-0.003	0.024	-0.052	1.443	4 / 4
Mean [m]		-0.014463	-0.023619	-0.035486		
Sigma [m]		0.042500	0.048723	0.031269		
RMS Error [m]		0.044894	0.054146	0.047297		

Figure 22: Accuracy for the Pix4D office site at 16-03-2021

Looking at the final results (Tab:1), Pix4Dcatch + viDoc® RTK achieves an average accuracy of around 5 cm. The results are good considering that the site is really close to big buildings that can affect the signal's quality.

Table 1: Accuracy results for the Pix4D office site

	x-RMS [m]	y-RMS [m]	z-RMS [m]
Pix4D office (02-02-2021)	0.047	0.040	0.041
Pix4D office (09-03-2021)	0.063	0.044	0.048
Pix4D office (16-03-2021)	0.045	0.045	0.047
	0.052	0.043	0.045

4.2 Vaudoise Arena, Prilly

The Pix4Dmapper accuracy is shown in fig. 23, fig. 24, and fig. 25, for the Vaudoise Arena site at 02-11-2020, 09-03-2021, and 16-03-2021, respectively.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_2_J		-0.006	-0.024	-0.024	0.961	10 / 10
GCP_3_J		0.003	0.061	-0.036	0.563	8 / 8
GCP_4_J		0.053	-0.006	-0.065	1.223	10 / 10
GCP_5_J		0.213	0.103	0.145	0.456	11 / 11
GCP_6_J		-0.004	0.059	-0.052	1.473	10 / 10
GCP_7_J		0.002	0.062	-0.038	0.622	5 / 5
GCP_8_J		-0.003	0.062	-0.038	0.992	10 / 10
GCP_9_J		0.034	0.053	-0.040	0.555	10 / 10
GCP_10_J		0.031	0.047	-0.038	0.758	10 / 10
GCP_11_J		0.023	0.016	-0.061	0.968	10 / 10
GCP_12_J		0.038	-0.014	-0.055	1.084	10 / 10
GCP_13_J		0.020	0.051	-0.051	1.163	10 / 10
GCP_14_J		0.025	0.052	-0.051	1.084	10 / 10
GCP_15_J		0.030	0.053	-0.045	0.925	10 / 10
Mean [m]		0.032736	0.041114	-0.032086		
Sigma [m]		0.052816	0.033815	0.050345		
RMS Error [m]		0.062139	0.053233	0.059700		

Figure 23: Accuracy for the Vaudoise Arena site at 02-11-2020

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_2_J		0.007	-0.012	-0.031	1.719	8 / 8
GCP_3_J		0.010	-0.005	-0.053	1.138	8 / 8
GCP_4_J		0.012	-0.005	-0.065	1.417	8 / 8
GCP_5_J		-0.003	-0.018	-0.027	1.073	8 / 8
GCP_6_J		-0.010	-0.006	-0.036	1.748	8 / 8
GCP_7_J		0.000	-0.004	-0.037	1.190	8 / 8
GCP_9_J		-0.019	-0.006	-0.036	1.169	8 / 8
GCP_10_J		-0.024	-0.010	-0.037	1.205	8 / 8
GCP_11_J		-0.019	-0.003	-0.030	2.399	8 / 8
Mean [m]		-0.005253	-0.007702	-0.039137		
Sigma [m]		0.012657	0.004495	0.011532		
RMS Error [m]		0.013704	0.008918	0.040801		

Figure 24: Accuracy for the Vaudoise Arena site at 09-03-2021

For the Vauidose Arena site (tab:2), the average accuracy achieved during the test was around 3 cm. On this site, the accuracy is always affected by the tunnel presence that decreases the accuracy to around 40 cm for some meters during the capture.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_2_J		-0.007	0.005	-0.050	1.388	5 / 5
GCP_3_J		-0.003	-0.011	-0.024	1.072	5 / 5
GCP_4_J		0.026	-0.011	-0.027	1.101	4 / 4
GCP_5_J		0.105	-0.037	-0.072	3.158	3 / 4
GCP_6_J		0.011	-0.003	-0.024	2.004	4 / 4
GCP_7_J		-0.009	-0.011	-0.034	2.091	5 / 5
GCP_9_J		-0.008	-0.016	-0.043	1.346	4 / 4
GCP_10_J		-0.026	-0.018	-0.033	3.051	3 / 3
GCP_11_J		-0.021	-0.025	-0.033	1.310	3 / 3
GCP_14_J		-0.003	-0.032	-0.036	1.097	3 / 3
GCP_15_J		-0.013	-0.015	-0.032	0.790	3 / 3
Mean [m]		0.004614	-0.015799	-0.037094		
Sigma [m]		0.034426	0.011485	0.013235		
RMS Error [m]		0.034734	0.019533	0.039385		

Figure 25: Accuracy for the Vaudoise Arena site at 16-03-2021

Table 2: Accuracy results for the Vaudoise Arena site

	x-RMS [m]	y-RMS [m]	z-RMS [m]
Vaudoise Arena (02-11-2020)	0.062	0.053	0.060
Vaudoise Arena (09-03-2021)	0.014	0.001	0.041
Vaudoise Arena (16-03-2021)	0.035	0.020	0.039
	0.037	0.025	0.047

4.3 Park Scene

The Pix4Dmapper accuracy is shown in fig. 26 and fig. 27 for the Park site at 02-11-2020 and 16-03-2021, respectively.The best results were achieved in the park site, where, thanks to the open space, it was possible to achieve an average of 2 cm of accuracy (tab:3).

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		-0.006	0.026	-0.002	0.754	26 / 26
GCP_2_J		0.000	0.030	-0.002	0.969	39 / 39
GCP_3_J		-0.017	0.017	-0.020	0.937	32 / 32
GCP_4_J		-0.004	0.004	-0.012	0.551	28 / 28
GCP_5_J		0.012	0.008	0.024	1.043	36 / 36
GCP_6_J		0.026	-0.014	0.044	0.822	42 / 42
GCP_7_J		-0.014	-0.016	-0.029	0.897	42 / 42
Mean [m]		-0.000285	0.007759	0.000586		
Sigma [m]		0.013818	0.016699	0.023587		
RMS Error [m]		0.013820	0.018414	0.023594		

Figure 26: Accuracy for the Sicpa site at 02-11-2020

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP_1_J		-0.028	0.014	-0.025	2.017	4 / 4
GCP_2_J		-0.024	0.020	-0.017	0.510	3 / 3
GCP_3_J		-0.011	-0.013	-0.016	2.078	2 / 2
GCP_4_J		-0.027	-0.046	-0.020	1.261	3 / 3
GCP_5_J		-0.017	-0.067	0.035	1.460	3 / 3
GCP_6_J		-0.008	-0.002	0.037	1.712	4 / 4
GCP_7_J		0.016	-0.001	-0.054	2.404	3 / 3
Mean [m]		-0.014223	-0.013697	-0.008684		
Sigma [m]		0.014236	0.029389	0.030586		
RMS Error [m]		0.020123	0.032424	0.031795		

Figure 27: Accuracy for the Sicpa site at 16-03-2021

Table 3: Accuracy results for the Park site

	x-RMS [m]	y-RMS [m]	z-RMS [m]
Park site (02-11-2020)	0.014	0.018	0.024
Park site (16-03-2021)	0.020	0.033	0.032
	0.014	0.026	0.032

5 Conclusion

In this paper we have conducted accuracy investigations on three different test sites, each of which have been repeated several times on different days. The processing and accuracy assessment was done in Pix4Dmapper using checkpoints. The experiments show RMS errors between 1 and 6 cm, with an approximate median of 3 to 4 cm. Notably, this is also the case when part of the survey area contains regions with poor satellite visibility (a tunnel as in Vaudoise Arena in fig. 19). In this case, the lower accuracy positions from the GNSS receiver are improved by interpolating with the relative positions from Augmented Reality (AR).
The highly accurate ground-based 3D models generated by the Pix4Dcatch+viDoc RTK rover used in combination with Pix4D cloud or desktop photogrammetry software has potential applications in the creation of digital twins in the construction, utility, inspection or surveying industry. In particular, this solution could be used for underground utility mapping (such as underground networks of water, gas, fiber-optic, electricity), volume calculation of small stockpiles or mapping of road infrastructure. The low price point in comparison with traditional RTK rovers, the ease of use and the high accuracy obtained, make the Pix4Dcatch+viDoc RTK rover an optimal solution for any professional seeking to create digital twins of their work-site.