eBee RTK Accuracy Assessment

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Introduction

The eBee RTK is senseFly's survey-grade mapping drone. This product combines several innovations that senseFly claims render the placement and measurement of ground control points (GCPs) no longer necessary:

- Built-in RTK-capable GNSS antenna
    - o Takes RTK corrections from base station & corrects image geotags in flight
- senseFly's eMotion flight planning software includes:
    - o A post-processing engine that takes RINEX positioning data from the base
    - o A reference station to correct absolute base position
    - o The ability to connect & interpret VRS data
- senseFly's Postflight Terra 3D software (powered by Pix4D)
    - o Constructs orthomosaics & DSMs with high spatial accuracy using advanced photogrammetry[5]

The eBee RTK is supplied with Postflight Terra 3D post-processing software (powered by Pix4D), which can produce high accuracy point clouds, DSMs and orthomosaics.

Glossary

GCP Ground Control Point
A point that has a known 3D position, used for the project's reconstruction.

Verification point (A.K.A check point)
A point that has a known 3D position, used for checking the accuracy of the reconstruction.

Bundle block adjustment
A photogrammetry method that corrects the positions and orientations of the cameras and aims to minimise the total reprojection error with respect to all 3D point and camera parameters.

Orthomosaic
A single, corrected image constructed either from several images taken from different angles, or from several orthophotos. Distortions due to different camera positions, ground curvature and topology are corrected for, so that the image displays accurately in the given map projection.

DSM Digital Surface Model
A 3D digital representation of a surface.

RMSE Root Mean Square Error
A value for error derived from the square root of the sum of the squares of a set of values.
GSD Ground Sampling Distance
The distance measured on the ground between pixel centres in an image or DSM. The smaller the GSD, the higher the spatial resolution of the image. For example, a GSD of 5 cm means that one pixel in the image represents 5cm on the ground.

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[5] *A technique that uses images of the same object taken from different angles to calculate the position of that object in 3D space.*

3 different ways to use the eBee RTK[6]:

VRS (no physical base station required)

Create DSMs and orthomosaics using reference station networks to achieve highly accurate absolute geotags. Useful when you want to benefit from the high absolute accuracy achievable from sophisticated Ntrip networks, or when surveying equipment is unavailable or inconvenient.

Unknown point

Geotag relative to an approximate base station position, then post-process GNSS data to reach high absolute coordinate accuracy. Useful for green-field surveying when no GCPs have been set, when in-field time is limited, or it is impractical to survey beforehand.

Known point

Obtain high absolute coordinate accuracy using your precisely measured base station position as a GCP. Useful when a survey has already been completed and reference points are already marked out. No post-processing is needed to achieve RTK-level geotag accuracy.

senseFly claims:

• The eBee RTK can achieve 3 cm horizontal and 5 cm vertical accuracy

• With an expected level of accuracy of between 1-3x GSD

• Note: these figures depend on the associated base station and/or online RTK correction source specifications (for instance, baseline length or occupation time)

This white paper will attempt to validate these claims by demonstrating the accuracy of the eBee RTK using different flights in different modes.

Methodology

A senseFly team first went out into the field to set out 19 reference points, spread initially over a 0.20 km^2 area of interest. To take these references, they surveyed the zone using a double-frequency GPS/GLONASS receiver taking RTK corrections from swisstopo's Automated GNSS Network for Switzerland (AGNES), whose theoretical accuracy is 5 mm / 10 mm (horizontal / vertical). The majority of the verification points taken were the corners of stable road markings, chosen so that these could also be used for future surveys.

The team flew two different flights using the eBee RTK along with eMotion 2 (version 2.2) for the flight planning and monitoring, and Postflight Terra 3D (version 3.1) for image post-processing. The camera used was the eBee RTK's current default camera, the Canon IXUS 127.

Figure 1: The project's verification points

Accuracy was studied from 2 perspectives:

Point cloud accuracy

The analysis first focused on point cloud accuracy. The point cloud is the first and most precise post-processing output. Each point is defined by three coordinates (X,Y,Z), defined after bundle block adjustment, and Postflight Terra 3D is able to apply textures from the pictures to generate an appealing render.

Point cloud accuracy was calculated using Postflight Terra 3D and its rayCloud Editor, which allows direct visualisation of 2D and 3D errors thanks to its combination of 2D images and the 3D point cloud.

Orthomosaic and DSM quality

An accuracy assessment of the orthomosaic and the DSM was conducted using the same reference points. The quality of both the orthomosaic and the DSM was checked by using ESRI ArcMap 10.1 software to compare the horizontal distances and the vertical offsets between the verification points, computed by Postflight Terra 3D, with the original position of the these points in the field.

Figure 2 and figure 3 illustrate the procedure used, with actual results from the accuracy assessment.

Figure 2: User marks in the rayCloud image sidebar of Postflight Terra 3D:
• Yellow crosses are user marks
• Green crosses are the re-projection of the estimated 3D point
• Blue circles are the estimated position of the point
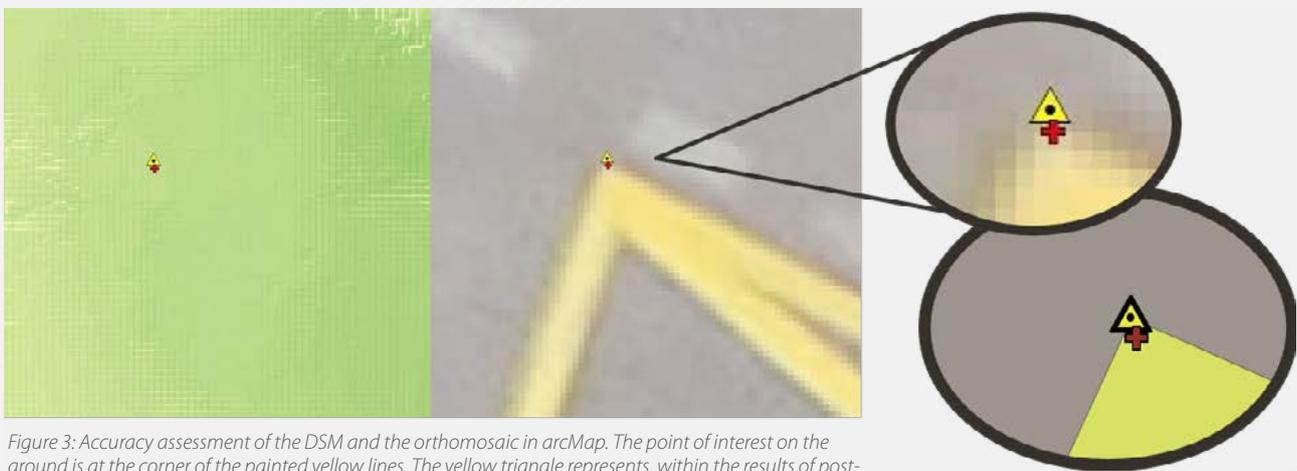
Figure 3: Accuracy assessment of the DSM and the orthomosaic in arcMap. The point of interest on the ground is at the corner of the painted yellow lines. The yellow triangle represents, within the results of post-processing by Postflight Terra 3D, the position of the point that was surveyed with an RTK GPS rover. The red cross appears in this point's measured position (the coordinates output by the GNSS rover).

Two different flights were carried out:

First flight	Second flight
Purpose: to test the maximum accuracy the eBee RTK can achieve.	Purpose: assess the impact of adverse lighting and weather conditions on geotagging accuracy.
RTK corrections using VRS	RTK corrections using VRS
Area of 20 hectares	Area of 20 hectares
GSD 2.5 cm	GSD: 5 cm
Altitude above take-off level : 81 m	Altitude above take-off level: 162 m
Lateral overlap: 80%	Lateral overlap: 80%
Perpendicular flight lines	No perpendicular flight lines
Flight conditions: bright sunny day	Flight conditions: average of 9m/s wind speed and low light conditions
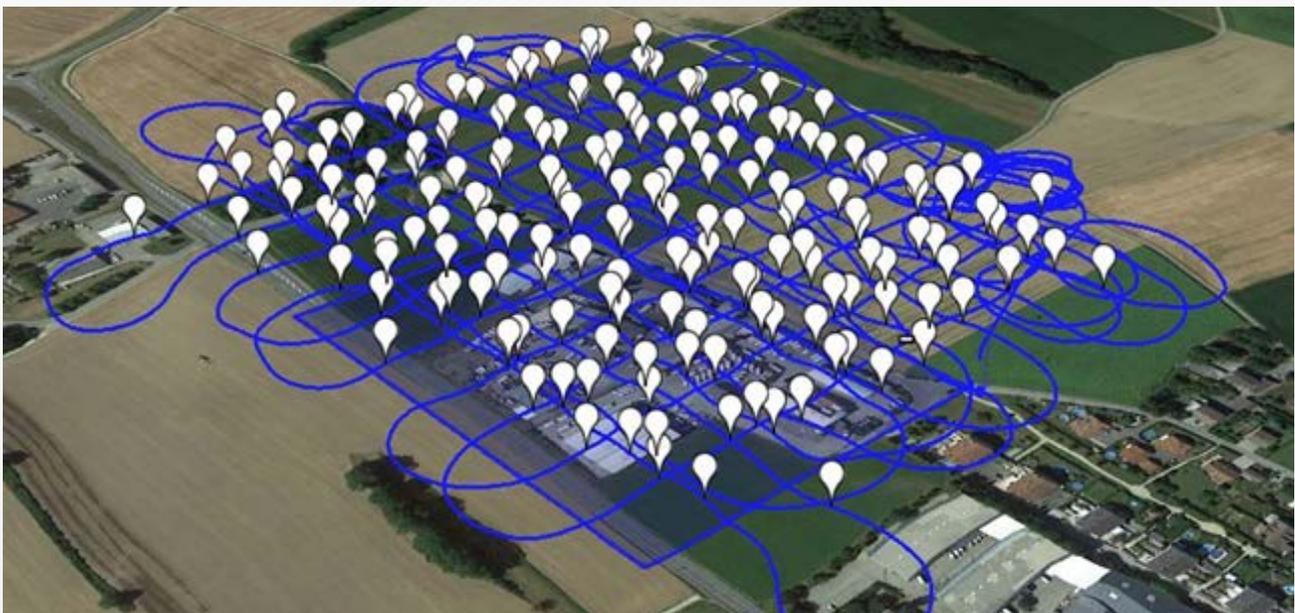
Figure 4: Flight 1's trajectory showing image capture positions

Calculating RMSE

To calculate the accuracy achieved in the different flights, we used the Root Mean Square Error[7]. Root Mean Square Error (RMS error or RMSE) is the standard error measure used in geo-correction. RMSE takes the difference between the observed value and estimated value for each user-defined point, squares it, finds the mean squared value, and then finds the square root of that mean:

$$\text{RMSE X} = \sqrt{\sum((\text{Xdata} - \text{Xcheck})^2)/n} \quad \text{RMSE Y} = \sqrt{\sum((\text{Ydata} - \text{Ycheck})^2)/n}$$

$$\text{RMSE XY} = \sqrt{\sum((\text{RMSE X})^2 + (\text{RMSE Y})^2)} \text{ and RMSE Z} = = \sqrt{\sum((\text{Zdata} - \text{Zcheck})^2)/n}$$

n is the number of points
Xdata is the X coordinate of the dataset
Xcheck is the X coordinate of a reference point

Note: accuracy could have been visualised using the mean error or the standard deviation, but neither of these methods are as sensitive and accurate as the RMSE when used for precise photogrammetric reconstruction.

Results & analysis 1 – verification points in the point cloud

Three different analyses were carried out on the first flight. The table below shows the results (in meters) of the 19 verification points in the point cloud and the final RMSE:

	X (m)	Y (m)	Z (m)
Mean error	0.008	0.001	-0.023
Standard deviation	0.019	0.015	0.021
RMSE	0.020	0.015	**0.031**
RMSE XY	**0.026**		

A copy of this full table is available in the appendix (Table 1).

With a high overlap and high resolution (2.5 cm), we can see that, in these ideal lighting and weather conditions, the eBee RTK can achieve a very high level of accuracy, both horizontally (2.6 cm) and vertically (3.1 cm).

The full table in the appendix highlights the fact that the accuracy of all the points is within the range of 1 to 3 times the GSD. Also, the reprojection error is always under 1 pixel, meaning that the user's manual clicks on pictures were done correctly.

Results & analysis 2 – orthomosaic & DSM accuracy

As mentioned above, testing the orthomosaic and DSM accuracy is also important, since eBee RTK users also use these Postflight Terra 3D outputs to do their work. The table below compares the orthomosaic (for X and Y values) and the DSM (for Z values) with the reference points:

	X (m)	Y (m)	Z (m)
Mean error	0.002	-0.005	-0.023
Standard deviation	0.022	0.023	0.026
RMSE	0.023	0.023	**0.035**
RMSE XY	**0.033**		

A copy of this full table is available in the appendix (Table 2).

As both the DSM and orthomosaic are based on the point cloud, the final accuracy is clearly slightly lower.

Results & analysis 3 – inaccurate geotags

In the event of flight planning oversights in the field, the uplink between the base station and the eBee RTK may be lost for short periods, preventing RTK corrections from reaching eMotion.

To simulate the system's accuracy in these conditions, we edited the GPS positions of 10% of the images obtained during the flight, entering random, incorrect geotags. In this way, we validated Postflight Terra 3D's ability to correct such positions during the bundle block adjustment and camera calibration. The table below shows that even with inaccurate geotags in 10% of the images, the accuracy of the entire dataset is maintained, thanks to the capabilities of Postflight Terra 3D.

	X (m)	Y (m)	Z (m)
Mean error	0.015	-0.001	-0.046
Standard deviation	0.018	0.015	0.016
RMSE	0.023	0.015	**0.048**
RMSE XY	**0.028**		

Results and analysis 4: low light, windy conditions

The second flight, over the same zone, demonstrated that even in windy, low light conditions, the eBee RTK has no difficulty achieving one to three times GSD accuracy, in line with senseFly's claims.

	X (m)	Y (m)	Z (m)
Mean error	-0.045	-0.069	-0.049
Standard deviation	0.019	0.029	0.046
RMSE	0.049	0.075	**0.070**
RMSE XY	**0.089**		

Conclusion

The results are, as expected, within the range of 1 to 3 times the ground sampling distance of each flight, validating senseFly's claims.

Automated photogrammetry is mainly based on image quality, overlap between images and GNSS receiver accuracy. This explains why the eBee RTK is able to achieve its best results of 3 cm horizontal accuracy and a 5 cm vertical accuracy with ideal flight conditions for a camera-based system (bright sunny day, check points well defined on images and no-wind).

Even in less-than-ideal flight conditions, the eBee RTK has proven that it can still reach a high standard of reliability, in line with what you can expect from a standard eBee with ground control points.

Accuracy strongly depends on the quality of the RTK corrections, so users must ensure that the quality of the RTK corrections received matches the level of accuracy they are expecting in their results.

Appendix

Table 1: Point cloud accuracy assessment with Postflight Terra 3D

Geolocation and Ground Control Points

GCP name	Tolerance XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection error [pixel]	Verified/Marked
3D Check Point: 1	0.020/0.020	0.002	0.016	0.015	0.129	13 / 13
3D Check Point: 2	0.020/0.020	0.031	0.013	-0.033	0.156	16 / 16
3D Check Point: 3	0.020/0.020	-0.006	0.013	-0.041	0.235	17 / 17
3D Check Point: 4	0.020/0.020	0.000	-0.023	-0.011	0.138	18 / 18
3D Check Point: 5	0.020/0.020	-0.021	0.014	0.013	0.553	11 / 11
3D Check Point: 6	0.020/0.020	0.022	0.018	-0.033	0.138	14 / 14
3D Check Point: 7	0.020/0.020	0.043	-0.020	-0.021	0.309	15 / 15
3D Check Point: 8	0.020/0.020	0.009	0.001	-0.003	0.133	18 / 18
3D Check Point: 9	0.020/0.020	-0.003	0.013	-0.002	0.148	15 / 15
3D Check Point: 10	0.020/0.020	-0.011	-0.006	-0.039	0.235	16 / 16
3D Check Point: 11	0.020/0.020	0.013	0.002	-0.015	0.183	17 / 17
3D Check Point: 12	0.020/0.020	0.028	-0.015	-0.028	0.313	19 / 19
3D Check Point: 13	0.020/0.020	0.013	0.002	-0.027	0.216	15 / 15
3D Check Point: 14	0.020/0.020	0.009	0.015	0.009	0.240	13 / 13
3D Check Point: 15	0.020/0.020	0.022	0.000	-0.057	0.197	13 / 13
3D Check Point: 16	0.020/0.020	0.011	-0.034	-0.029	0.360	13 / 13
3D Check Point: 17	0.020/0.020	-0.032	-0.023	-0.044	0.255	19 / 19
3D Check Point: 18	0.020/0.020	-0.012	-0.001	-0.043	0.267	13 / 13
3D Check Point: 19	0.020/0.020	0.031	0.006	-0.044	0.183	14 / 14
Mean		0.007923	-0.000480	-0.022832		
Sigma		0.018842	0.015253	0.020591		
RMS error		0.020440	0.015261	0.030745		

Table 2: Orthomosaic and DSM accuracy using ESRI ArcMap 10.1

	Error X (m)	Error Y (m)	Error Z (m)
Check point 1	0.002	0.023	-0.022
Check point 2	0.033	0.014	-0.026
Check point 3	-0.019	0.021	-0.060
Check point 4	-0.033	-0.038	-0.064
Check point 5	-0.017	0.000	-0.030
Check point 6	-0.003	0.000	-0.012
Check point 7	0.053	-0.019	-0.029
Check point 8	0.007	0.017	0.016
Check point 9	-0.009	0.018	0.017
Check point 10	0.015	0.013	-0.020
Check point 11	0.031	0.010	-0.017
Check point 12	0.003	-0.035	-0.047
Check point 13	0.002	-0.034	-0.045
Check point 14	0.008	0.020	0.024
Check point 15	0.010	-0.013	-0.028
Check point 16	0.019	-0.028	-0.028
Check point 17	-0.038	-0.052	-0.056
Check point 18	-0.025	0.000	-0.030
Check point 19	0.008	-0.013	0.024

	X (m)	Y (m)	Z (m)
Mean error	0.002	-0.005	-0.023
Standard deviation	0.022	0.023	0.026
RMSE	0.023	0.023	**0.035**
RMSE XY		**0.033**	