ADVANCES IN GEOMATICS

VOLUME 02 • ISSUE 02 • OCTOBER 2024
e-ISSN: 3023-4980

ORIGINAL ARTICLE

Submission: 01/07/2024
Accepted: 12/10/2024

DRONE PHOTOGRAMMETRIC ACCURACY CHANGE WITH FLYING HEIGHT

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ABSTRACT

A perception among photogrammetrists is that as the flying height increases, accuracy decreases as well. To investigate this intuition, two separate flights are flown. For the first flight, the UAV data are collected at 60, 90 and 120 m. For the second flight the data are collected at 54, 73 and 121 m. To analyze the data sets, Trimble Inpho and Pix4D are used. For the results, standard deviations and Root Mean Square Error (RMSE) values are compared. Results showed that Pix4D had consistently lower and almost constant RMSE and standard deviation values across flights, while Inpho's RMSE and standard deviation increased linearly with height in Project A and non-linearly in Project B. The observed variations between the software remain unclear, and limited Pix4D documentation hinders result interpretation, indicating a need for further research.

Keywords: Photogrammetry, UAV, Trimble Inpho, Pix4D, Aerotriangulation.

Cited As:

Berber, M. M., Munjy, R., & Meme, K. (2024). Drone photogrammetric accuracy change with flying height, Advances in Geomatics, 2(2), 49-58. https://doi.org/10.5281/zenodo.14555243

INTRODUCTION

While evaluating errors in photogrammetry, it is assumed that blunders and systematic errors are removed, and we are only left with random errors. Some of the error sources in digital photogrammetry are (Wolf et al., 2014): errors in photographic measurements, e.g., photo coordinates, errors in ground control, and GNSS errors. It is obvious that these errors will be apparent in the images. Thus, to quantify the errors in terms of precision and accuracy, after digitizing the ground control points and processing the data using a bundle block adjustment, standard deviation and Root Mean Square Error (RMSE) are calculated. In order to have meaningful statistics, currently American Society for Photogrammetry and Remote Sensing (ASPRS) standards 2023 (ASPRS, 2023) require that at least 30 check points must be used.

ASPRS 2023 outlines that RMSE is calculates as:

$$RMSE_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{i(map)} - x_{i(surveyed)})^2} \tag{1}$$

where $x_{i(map)}$ is the coordinate in the specified direction of the i^th^ checkpoint in the data set, $x_{i(surveyed)}$ is the coordinate in the specified direction of the i^th^ checkpoint in the independent source of higher accuracy, n is the number of checkpoints tested, and i is an integer ranging from 1 to n. Mean Errors in X, Y, and Z are computed as:

$$\bar{e} = \frac{1}{n}\sum_{i=1}^{n} e_i \tag{2}$$

where e_i is the i^th^ error in the specified direction, n is the number of checkpoints tested, i is an integer ranging from 1 to n. Sample Standard Deviation is computed as:

$$s_x = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{3}$$

where x_i is the i^th^ error in the specified direction, is the mean error in the specified direction, n is the number of checkpoints tested, i is an integer ranging from 1 to n.

Although Eqs. (1) and (3) seem similar, these two statistics are conceptually quite different. Because RMSE is dispersion around a true value, it is a measure of accuracy. In contrast, because standard deviation is dispersion around the observation set's own mean, it is a measure of precision. This means that standard deviation is used to measure the precision and RMSE is used to measure the accuracy of an observation set (Meyer, 2012).

In this study, two projects, Project A (flights at 60, 90 and 120 m) and Project B (flights at 54, 73 and 121 m), were carried out. Images produced by these flights were processed using Trimble Inpho (version: 7.1.0.50413) and Pix4D (version: 4.5.6) and standard deviations, RMSE, mean, maximum, minimum and range values are calculated, the results are tabulated, and the graphics are prepared for visual comparisons.

1. TEST SITE AND FLIGHT

Two photogrammetry campaigns were flown over the San Joaquin Experimental Range (SJER) located in Fresno County, California in the foothills of the Sierra Nevada Mountain range located about 32 km north of the California State University, Fresno campus. There were 81 control points (see Fig. 1) laid out in a 9-by-9 grid spaced approximately 40 m apart throughout a 320 m by 320 m area. The terrain of the area is rolling hills with sparse vegetation, structures and roads. The control point flight targets were designed to be circular, black and white, and measured about 47 cm in diameter (see Fig. 2). These control points were surveyed to 1 cm horizontal and 0.3 cm vertical accuracies, both at one sigma confidence level.

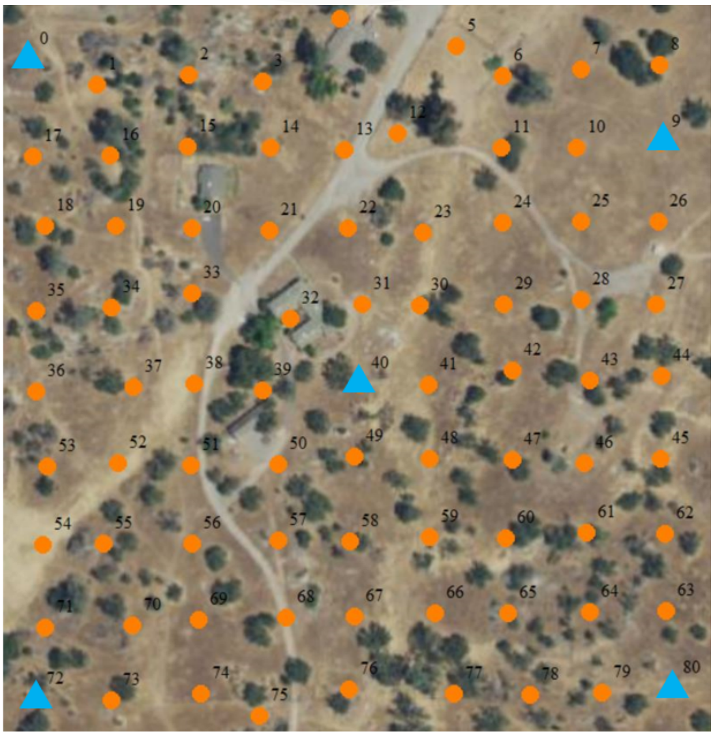

Figure 1. Control points established at the project site (image is prepared using GlobalMapper)

Figure 2. Ground target image

For Project A the aircraft platform used was a Phantom 4 RTK UAV, a vertical-take-off-and-landing platform with a quad rotor. The camera model was FC6310R, with a focal length of 8.8 mm, pixel size of 2.4 microns, and an electronic/global shutter. As can be seen in Table 1, three data sets are used in this study. Additionally, 65-75% side/forward overlap is maintained throughout the survey.

Table 1. Flights used with Project A (m)

Flying height above ground level	Number of photo-graphs
60	947
90	485
120	296

For Project B, the aircraft platform used was a senseFly eBee, a fixed wing drone with a low-noise, brushless, electric motor. The camera model was SODA, with a focal length of 10.6 mm, pixel size of 2.4 microns, and an electronic/global shutter. Table 2 shows the flying height and number of photographs generated for the second flight.

Table 2. Flights used with Project B (m)

Flying height above ground level	Number of photo-graphs
54	300
73	243
121	171

Five points (0, 9, 40, 72 and 80) are used as control points. These 5 control points are identified with a blue triangle in Fig. 1. The remaining points are used as check points for the results explained in the following section.

For Inpho, standard deviations of GNSS positions were 0.06 m for horizontal coordinates and 0.09 m for vertical coordinates i.e., they are for the positions of the camera stations (determined by the onboard GNSS hardware). IMU rotations were set to 0.0008 degrees for all three coordinates. Standard deviations of image points were 0.0012 mm and standard deviations of object points were 0.03 m which are for the coordinates of the ground control points. The same parameters for GNSS, IMU and control points are entered into Pix4D software to be consistent with processing parameters. To compute self-calibration parameters in Inpho, a 12-parameter option is chosen.

2. RESULTS

Although RMSE, Standard Deviation, Mean Error, Maximum Error, Minimum Error and Range values are tabulated in Tables 3-6, for the analyses of the results we are going to focus only on RMSE and Standard Deviation. Therefore, only RMSE and Standard Deviation graphics are portrayed in Figures 3 and 4.

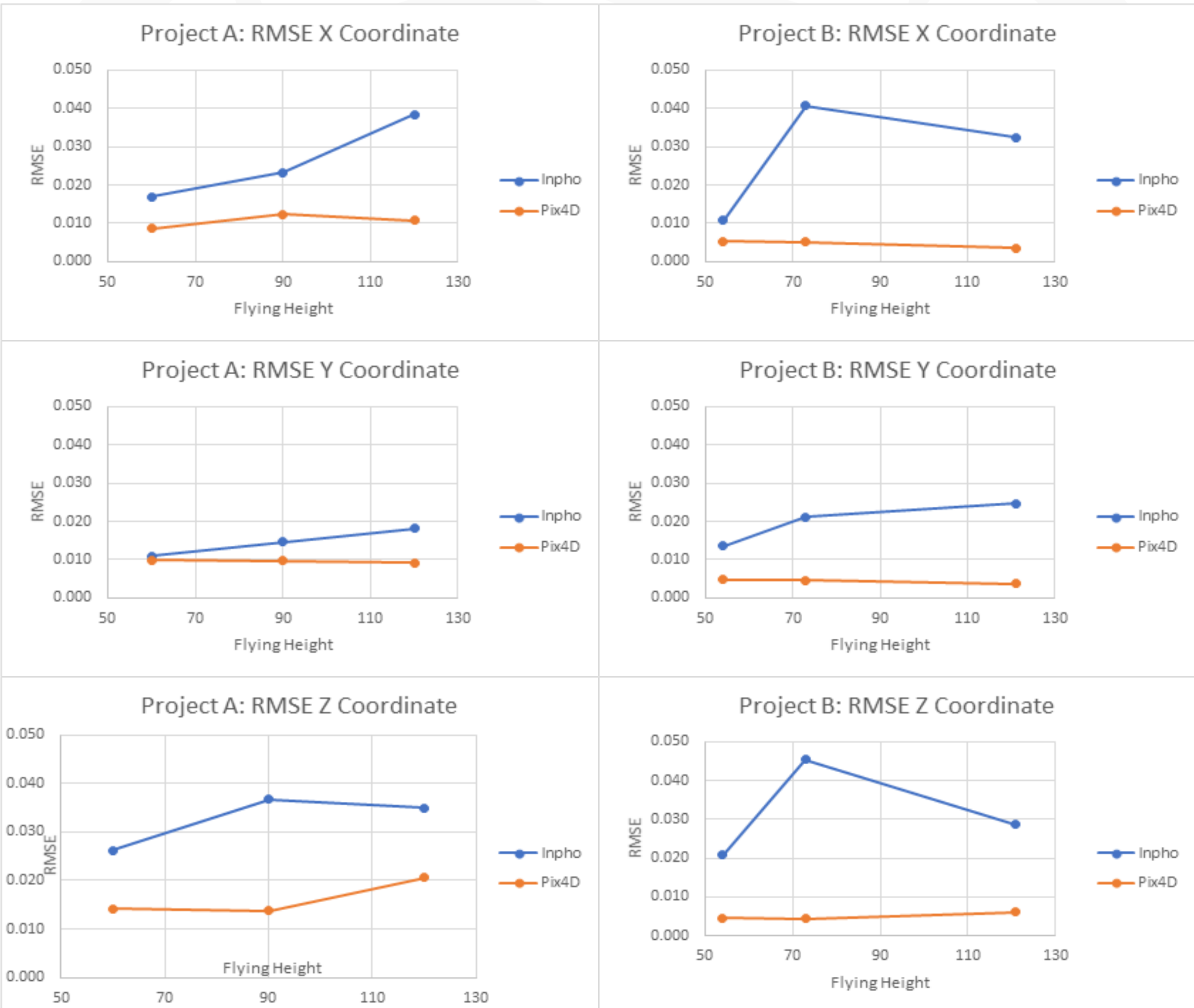

Figure 3. RMSE results for both Projects A (left) and B (right). All units are in meters.

Table 3. Project A, Inpho results (m)

	RMSE			Std. Dev.			Mean Error			Max Error			Min Error			Range		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
60	0.017	0.011	0.026	0.017	0.010	0.025	-0.003	0.005	-0.009	0.040	0.021	0.048	-0.029	-0.014	-0.046	0.069	0.035	0.094
90	0.023	0.015	0.037	0.024	0.012	0.031	0.002	0.009	-0.020	0.066	0.024	0.062	-0.038	-0.020	-0.082	0.104	0.044	0.144
120	0.038	0.018	0.035	0.038	0.018	0.033	-0.010	0.000	0.012	0.053	0.029	0.086	-0.082	-0.037	-0.042	0.135	0.066	0.128

Table 4. Project A, Pix4D results (m)

	RMSE			Std. Dev.			Mean Error			Max Error			Min Error			Range		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
60	0.009	0.010	0.014	0.009	0.008	0.014	0.000	0.006	-0.003	0.020	0.019	0.034	-0.018	-0.013	-0.033	0.039	0.031	0.067
90	0.012	0.010	0.014	0.012	0.009	0.012	0.005	0.004	0.007	0.031	0.026	0.031	-0.017	-0.016	-0.018	0.048	0.042	0.049
120	0.011	0.009	0.021	0.011	0.009	0.021	0.002	0.002	0.000	0.023	0.021	0.097	-0.020	-0.023	-0.024	0.043	0.044	0.120

Table 5. Project B, Inpho results (m)

	RMSE			Std. Dev.			Mean Error			Max Error			Min Error			Range		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
54	0.011	0.014	0.021	0.010	0.014	0.019	-0.003	0.002	-0.008	0.021	0.038	0.035	-0.023	-0.034	-0.052	0.045	0.072	0.086
73	0.041	0.021	0.045	0.041	0.021	0.039	-0.006	-0.002	0.024	0.109	0.050	0.087	-0.086	-0.049	-0.071	0.195	0.099	0.158
121	0.032	0.025	0.029	0.032	0.025	0.019	-0.004	0.000	-0.022	0.058	0.052	0.026	-0.066	-0.057	-0.058	0.124	0.109	0.084

Table 6. Project B, Pix4D results (m)

	RMSE			Std. Dev.			Mean Error			Max Error			Min Error			Range		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
54	0.005	0.005	0.005	0.005	0.005	0.004	0.000	-0.001	0.002	0.017	0.010	0.011	-0.012	-0.015	-0.008	0.029	0.025	0.019
73	0.005	0.005	0.004	0.005	0.005	0.004	0.001	0.000	0.002	0.012	0.010	0.012	-0.011	-0.012	-0.011	0.023	0.022	0.023
121	0.003	0.004	0.006	0.003	0.004	0.006	0.000	0.000	-0.002	0.011	0.008	0.015	-0.010	-0.011	-0.013	0.021	0.020	0.029

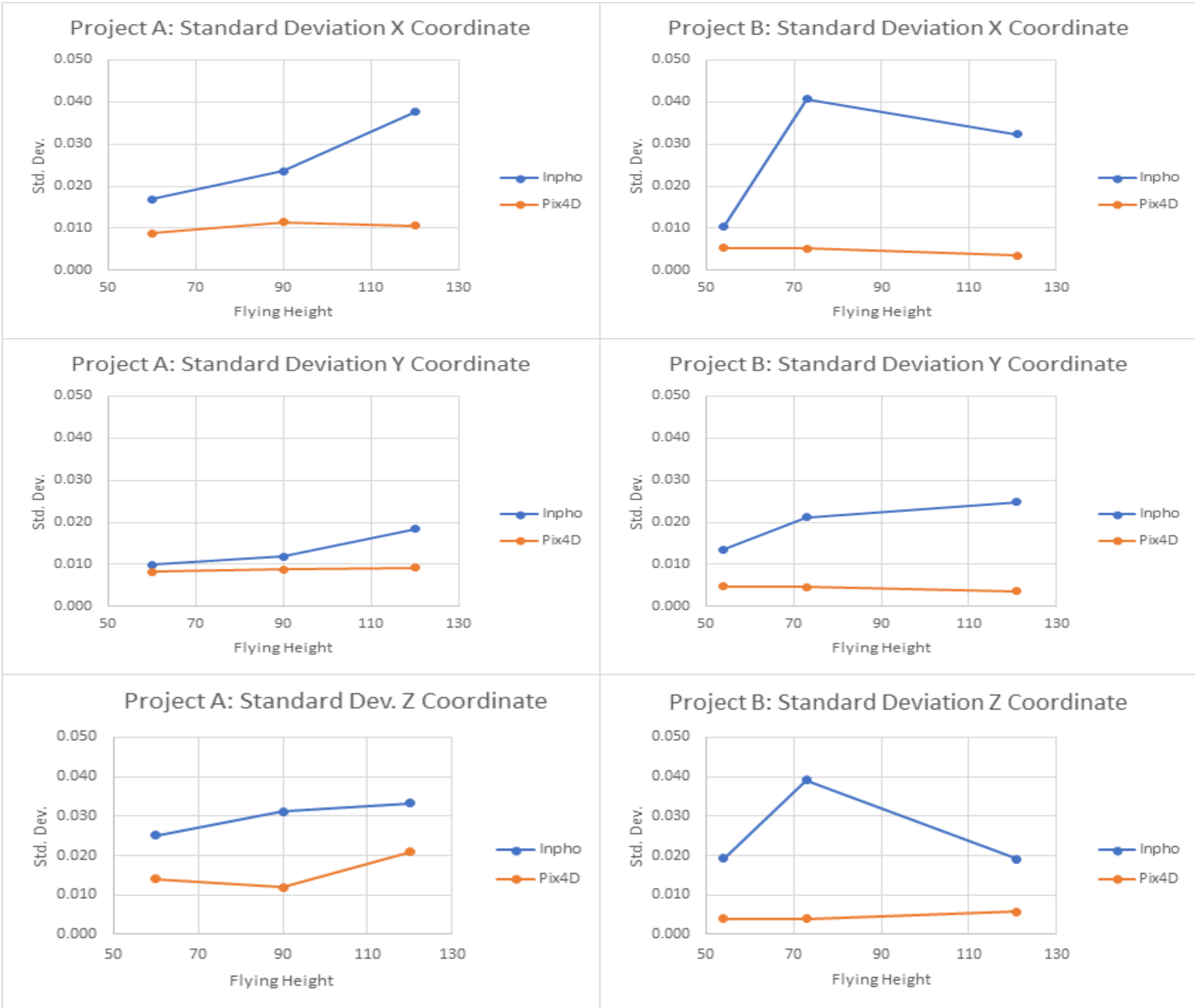

Figure 4. Standard deviation results for both Projects A (left) and B (right). All units are in meters.

To facilitate further comparison, statistical information is compiled in Tables 7 and 8. The number of photos in Table 7 slightly differs from that in Table 8 because Inpho generates strips and omits some photos during the transition between strips. In Table 7, the average number of match points per photo increases with the flying height. Whereas, this trend is not observed in Table 8, where there is no consistency in the average number of match points per photo. Additionally, neither Table 7 nor Table 8 shows consistency regarding the total number of points per flight. Therefore, further research is required to understand the reasons behind these erratic results in both tables. Moreover, to illustrate flying height against average number of match points per photo, Fig. 5 is prepared.

Table 7. Inpho results (m)

	Flying height	Number of Strips	Number of photos	Average number of match points per photo	Total number of points per flight
	60	24	923	238	219,674
Project A	90	22	467	248	115,816
	120	16	282	273	76,986
	54	21	298	45	13,410
Project B	73	17	241	109	26,269
	121	11	171	113	19,323

Table 8. Pix4D results (m)

	Flying height	Number of photos	Average number of match points per photo	Total number of points per flight
	60	947	73603	69,702,041
Project A	90	485	72476	35,150,860
	120	296	66985	19,827,560
	54	300	19481	5,844,300
Project B	73	243	37730	9,168,390
	121	171	41658	7,123,518

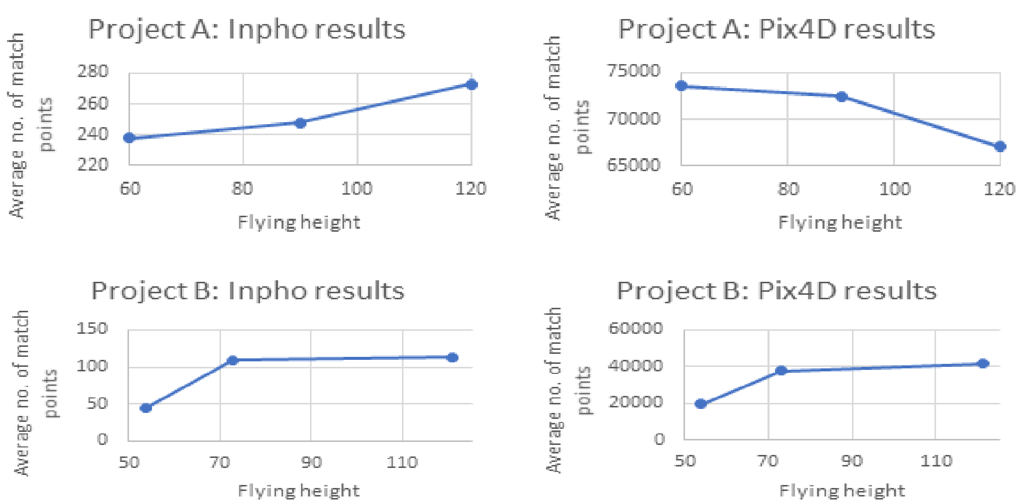

Figure 5. Flying height against average number of match points per photo. Projects A results are shown with graphics in the first row and Projects B results are depicted in the second row. Left column graphics display Inpho results and right column graphics show Pix4D results.

Based on the results of Project A, we found that:

RMSE or standard deviation plots for Pix4D show lower values than for Inpho.

RMSE in Pix4D is almost constant and does not change with flying height.

Inpho RMSE appears to show an approximate linear relationship with flying height.

In terms of standard deviation, Pix4D results are almost constant and Inpho results show nearly linear change.

Based on the results of Project B, we found that:

RMSE or standard deviation plots for Pix4D show lower values than for Inpho.

RMSE in Pix4D is almost constant and does not change with flying height.

Inpho RMSE does show non-linear change with flying height.

In terms of standard deviation, Pix4D results are almost constant and Inpho results show non-linear change.

Final summary: The results of Projects A and B demonstrate that Pix4D consistently outperforms Inpho in terms of RMSE and standard deviation values, showing lower and nearly constant values across various flying heights. For Project A, Inpho's RMSE and standard deviation increase linearly with flying height, whereas Project B displays a non-linear pattern. These findings suggest that Pix4D provides more stable accuracy metrics across different heights, while Inpho's performance varies significantly based on altitude.

DISCUSSIONS AND CONCLUSIONS

In order to investigate whether accuracy varies with the flying height, two photogrammetry campaigns are flown. For Project A, the UAV data are collected at 60, 90 and 120 m. For Project B, the data are collected at 54, 73 and 121 m. To analyze the data sets, Trimble Inpho and Pix4D software are utilized. Based on the results we found that Pix4D RMSE and Standard Deviation (X, Y and Z) graphics show lower values than Inpho. RMSE in Pix4D is almost constant and does not change with flying height. Inpho RMSE shows linear change with flying height with Project A, whereas, with Project B, Inpho RMSE shows non-linear change with flying height. In terms of standard deviations, Pix4D results are almost constant and Inpho results show linear change with Project A; whereas, with Project B, Pix4D results are almost constant and Inpho results show non-linear change. Consequently, the reasons for the variation in values between the two software programs are not well understood. Moreover, the limited documentation available for Pix4D complicates the interpretation of the results. As such, further research is necessary to unveil the reasons behind the results.

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