A New Approach to Estimate Lens Distortion on the Camera

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Abstract: Lens distortion is a thorny problem in extracting data by using recorded videos. The method to calibrate lens distortion is often divided into two classes, total calibration and nonmetric calibration. The paper proposed a new approach based on the total calibration in order to estimate the distortion of lens system in DJI Phantom 4 Pro's camera. In accordance with the theory that a light passes through the center of the stop is the least bending light, the degree of distortion can be calculated by comparison the location of distortion points with the middle-center position. The results showed that image distortion does not affect the data obtained from the device in simulating traffic data. At the focal point F/7.1, the largest and smallest aberration values are -3.4% and -0.2% respectively. These values demonstrate that lens distortion of the device have a negligible impact to the accuracy of the extracted data.

Keywords: Lens distortion, Barrel distortion, Estimation, Fish-eye effect, UAV, DJI Phantom 4 Pro.

1. INTRODUCTION

1.1 Lens Distortion

Digital image processing technology has been widely applying in transportation field for monitoring traffic status. In the context of rapid development of intelligent transport, the traffic monitoring depends strongly on the quality of record videos. Hence, the precision of image has attracted more and more attention.

In technical side, the pre-process step for collected videos has to deal with two main issues that are lens distortion and image stabilization. Accurate camera calibration of an imaging device is extremely importance, especially in various applications which involve quantitative measurements. The vibration effect, which is the main issue of stabilizing image, has been minimized by a component named gimbal and stabilizing algorithms in software. Gimbal provides a steady platform for setting the camera. The stabilizing utilizes artificial intelligent and machine learning technique to reduce the negative shaking effect. While the stabilizing image have been minimized by both hardware component and software solution, the lens distortion is an innate hardware problem of lens. Software solution has been the only possible solution so far.

Peatross and Ware (2017) defined lens distortion, other names are fish-eye effect or radial distortion, as a visual aberration that the magnification of a photo varies depending on the distance to the center of a photo. In other words, the photo is stretched or compressed as it approaches the edges of the frame, as stated by Dobbert (2013). As the field of view becomes larger or smaller, the magnification from center to corner of a photo also changes much faster. Peatross and Ware (2017) stated that there are two common types of distortion, “barrel” and “pincushion” as expose in Figure 1(b) and Figure 1(c). Barrel distortion is observed if the magnification decreases as the distance from the center increase. The image, therefore, is compressed at its corners. On the other hands, when the magnification increases from the center outwards, it called pincushion distortion. The effect results that a straight line out of optical axis of the object is imaged as a curve not a straight line any more.

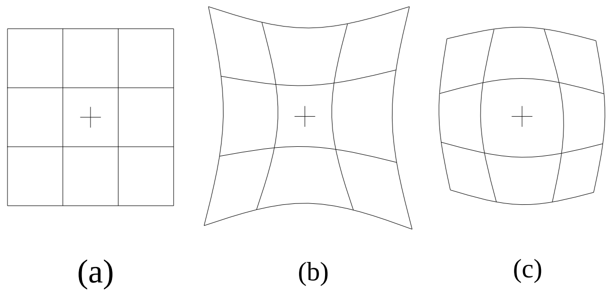

Figure 1. Distortion category, (a) normal object, (b) pincushion distortion, (c) barrel distortion (source Dereniak and Dereniak (2008))

Dereniak and Dereniak (2008) explained the cause of lens distortion is that position of aperture stop and the lens in the image space, as showed in Figure 2. When the aperture stop is in front of the lens, image is distorted in barrel manner. In the opposite, when the aperture stop stands in back of the lens, pincushion distortion is formed. cc mentioned that beside the distance of aperture stop, aperture size also contributes to the magnitude of distortion. This factor is represented in the value of focal ratio, which determines the field of view size. Focal ratio also is called in other names, f-number, f-ratio, f-stop, or relative aperture. When aperture size becomes larger, the magnification from center to corner of a photo also changes much faster, the more severity of distortion results in photo.

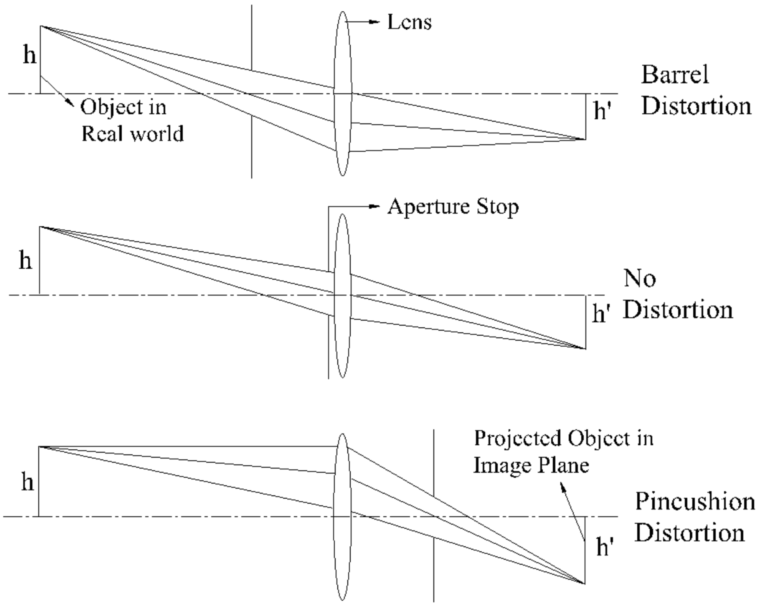

Figure 2. Stop positions causes lens distortion

This paper has been organized into four sections. Section 1 introduces lens distortion definition and the employed device, UAV Phantom 4 Pro, in the study. Section 2 reviews some of the methods used to calibrate lens distortion and emphasizes on applying the method. The calibration procedure and its results are presented in Section 3. The paper conclusion is finally drawn in Section 4.

1.2 UAV Phantom 4 Pro

Like other UAV devices used today, Phantom 4 pro device has wide variety of application fields. The free-site-selection constraint, high height above the ground level, and top-view give its opportunity for applying in transportation. The advanced method has some pros and cons as following discussion. It has three advantages compared to conventional method, standstill cam-recorder, for example Kanagaraj *et al.* (2013); Vlahogianni (2014).

Firstly, this method is independent from the high building, which is a thorny constraint of preceding research. Since flying vehicle unties restriction of camera setting position, the researchers are free in choosing survey site. It offers an opportunity to reach the previous unfavorable locations, which have no high place to set the camera or high-risk for researcher. Secondly, the adjustable flying height resolves the covered area issue. With the same field of view, higher flying height gives wider covered area. However, the same video resolution for the wider area leads to the video's details matter. Owing to the modern camera sensor technology, video resolutions is improved dramatically, up to 4K quality. That helps to ensure the detail in recorded videos for the large area. Thus, the size of site is not a problem at all. The third advantage related to the accuracy of extracted information from the video. In transportation research, videos of survey site are often exploited for traffic flow characteristics, for example speed, density, traffic flow, and travel time to name a few. The top-view of UAV camera eliminates close sight effect in video. This point is essential in increase the accuracy in data extraction.

Despite of various advantages, some drawbacks are still remained. The limited recording duration is the biggest drawbacks. Due to the battery capacity, the device has to land to replace battery after a period of time, around 20 minutes for the conducting device. The recorded videos are not continuous in long duration. Others are dynamic position, engine vibration, shake due to strong wind. The researchers, who want to utilize this modern methodology, need to address all mentioned problems. The paper shows lately a remedy to these problems.

Due to these above advantages, the UAV is employed to record the traffic data in the research project. The recorded videos are lately extracted positions of vehicles by time series using the semi-manual data extractor software. The accuracy of the vehicle's positions on videos is the main concern. Thus, the estimation of lens distortion effect on videos carrying a significant meaning in ensuring precision of data. The key finding of the study is measuring the lens distortion effect on the record videos. The experimenter could make a conclusion that the videos require image correction or the distortion on videos is negligible. The Phantom 4 Pro is a specific device that the data collection team employed. Other lens system can also apply the following method for estimate lens distortion.

2. METHODOLOGY

A few studies on distortion calibration have been carried out, and Wang *et al.* (2008) stated that the method to calibrate lens distortion fall into two classes, total calibration and nonmetric calibration. The total distortion, including studies of Fang *et al.* (2013), Zhang (2008), Shah and Aggarwal (1994), Wang *et al.* (2009), is calculated by equation for group of lens. It is sophisticated and is to require deeply insight into the design of the lens' system. Ahmed and Farag (2005) points out that the combination of distortion parameters and other intrinsic and extrinsic parameter sometimes leads to errors in the obtained results. It is one of the disadvantages of this method. Sagawa *et al.* (2005) mentioned that the error becomes large at the points that are far from the optical center.

On the other hand, the nonmetric approach estimate distortion from user’s perspective, not relying on any calibration object of known structure. It takes advantage of geometric invariants of some image features, e.g., straight lines, vanishing points, or the image of a sphere. This class method relies on the fact that a straight line remains a straight line in perspective projecting process if and only if there is no lens distortion. Stein (2002) described a new method for lens distortion calibration using point correspondences in multiple views without the need to know either the 3D location of the points or the camera location. Using only two or three images of the same objects at multiple views, the distortion parameters could be derived reasonably. This method is useful but complicated for the distortion estimation. Sagawa *et al.* (2005) proposed another novel method for calibrating lens distortion by projecting dense markers. This method maps the relationships between distorted and undistorted points onto the display coordinate. By using the photo of structured light on plat display, the distortion is mapped for entire photo frame. This manner is akin to proposed method in the paper in the conducting experiment.

In addition, Ahmed and Farag (2005) discovered two new distortion measures. The first one based on the sum of slope differences between tangents at two neighbor points of a line. The second one based on the image gradients. This approach is a fast, closed-form solutions to estimate the distortion coefficients. However, the evaluation of distortion image on the user perspective was not mentioned. Valkenburg and Innovation (2015) announced a method based on the principle that straight lines remain straight under perspective projection, in the spirit of the analytic plumb line technique. These above methods have a limitation that complicated procedure and calculation. For the quick estimation of distortion, they show their demerits in terms of requirements and calculation speed.

Shah and Aggarwal (1994) presented simple and effective procedure in order to correct the fish-eye effect and to calibrate the accuracy of corrected image. The supporting theory is that three data points in a straight line should result in a straight line in the image plane. The comparison of fixed length value in real world and from the corrected image is represented for accuracy level. The maximum calibrated errors of corrected image in both vertical and horizontal direction is mentioned as 1.6%. All the camera, which uses lens system, are facing lens distortion issue. Based on quality or efficient solution that lens distortion is cut off.

Thus, the paper uses the unique method similar manner to Shah and Aggarwal (1994) in order to estimate the distortion of lens system in DJI Phantom 4 Pro. The image deformation is computed on both horizontal and vertical direction. Instead of calculating based on pixel, the series of distorted pixels, a fixed line segment, are employed to calculate the magnitude of image distortion.

The proposed method has several pros and cons as the following. While the other methods rely on the sophisticated empirical calculation and requires the thorough understanding of lens system, the proposed method is practical and straightforward. The experiment is conducting directly on the device. It does not require complicated and expensive equipment. In addition, the procedure is also uncomplicated and repeatable. No training course is requisite for the experimenter. Nevertheless, its drawback is that the error is contributed by many factors, lens distortion of the camera, flatness of target sheet plane, print system error, and human error. Even though lens distortion is dominant, others are inevitable in conducting experiment.

3. EXPERIMENT AND RESULTS

3.1 Procedure

The paper uses the unique method similar manner to Shah and Aggarwal (1994) in order to estimate the distortion of lens system in DJI Phantom 4 Pro. The procedure is presented in this section as following. The first step is designing and printing sheet in A0 paper size, 841×1189mm. The sheet, which is used as a target for camera shot, includes parallel horizontal and vertical crossing lines, as in Figure 3. The distances between these lines are fixed value, 0.01meters. In the second step, the target sheet is pasted on flat and vertical surface, the wall for example. The importance is to ensure the flat and vertical of the paper on the wall. The third step is setting up the DJI Phantom 4 Pro in a tripod to satisfy the constraint that the center of camera has the same height with the center of target sheet. To ensure the parallel between the sensor of camera and the target sheet plane, several test shots and careful adjustment is required. In fourth step, the whole sheet is shot in a range of preset focal ratio. The photo resolution is set as same as recording value, 3840×2160pixels, 4K quality.

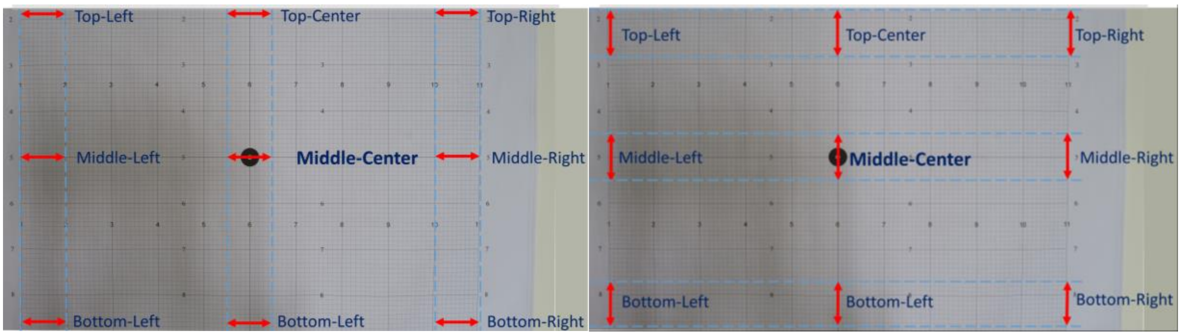

Figure 3. Horizontal and vertical measurement from the target sheet

These photos are lately processed in Adobe Photoshop software. For each focal ratio value, the length of a fixed segment, 0.1meters, at nine spread positions in these photos are measured in pixel. The different in length is an indication for the degree of lens distortion. Dobbert (2013) stated that a light passes through the center of the stop is the least bending light. It means that the length at the middle-center position is not affected by lens distortion Therefore the study compares the length in middle-center position with the other positions in both horizontal and vertical direction. Figure 3 depicts the measuring position and direction in taken photos of the plaid sheet. The variation of the number of pixels of the fixed line segment between two positions is the error cause by distortion as in the following formula,

$$error = \frac{l_i - l_{middle\_center}}{l_{middle\_center}} \times 100\% \quad (1)$$

where,

l_i : the number of pixels of the line segment at position i

l_{middle_center} : the number of pixels of the line segment at position middle-center

3.2 Results

From the process of following the steps above when applying to the Phantom 4 Pro device, the following results with the focal ration F/7.1 are obtained when the camera is set to record the results at an intersection as Table 1 and Table 2. The results show that all of the values are negative and tend to become larger in the corner of the sheet, the farthest position from the center. That matches with the theoretical explanation of barrel distortion. The largest values of horizontal and vertical approach are -3.4% and -2.7% respectively. Both of them are in the same corner of the target sheet. These errors are included, lens distortion of the camera, flatness of target sheet plane, print system error, and human error. Among them, lens distortion contributes the highest proportion of total error.

Table 1. Measurement of lens distortion in horizontal at focal ratio F/7.1

	Length of segment (pixel)			**Error compare with the Middle-Center**		
	Left	**Center**	**Right**	**Left**	**Center**	**Right**
Top	408	411	406	-1.0%	-0.2%	-1.5%
Middle	398	412	400	-3.4%	-	-2.9%
Bottom	408	411	398	-1.0%	-0.2%	***-3.4%***

Table 2. Measurement of lens distortion in vertical at focal ratio F/7.1

	Length of segment (pixel)			**Error compare with the Middle-Center**		
	Left	**Center**	**Right**	**Left**	**Center**	**Right**
Top	408	406	411	-1.2%	-1.7%	-0.5%
Middle	407	413	411	-1.5%	-	-0.5%
Bottom	408	412	402	-1.2%	-0.2%	***-2.7%***

In order calibrate the camera, the distortion is estimated under entire range of focal ratio of the camera, from F/2.8 to F/11.0. Each ratio value is estimated in the same process of the F/7.1. The summary result of lens distortion measurement is showed in Table 3. As in the result, even though there is some noise, the smaller value of focal ratio still results the higher error. From F/2.8 to F/11.0, the average errors gradually decrease. That matches with the optics theory, the smaller the focal ratio the more severe the fish eye effect in video. The focal ratio F/2.8 has the highest error and too far to other ratios. From F/5.0 to F/11.0, the maximum value is -4.1%, which are not high compared with calibrated error of corrected image, 1.6%, mentioned by Shah and Aggarwal (1994) This largest estimated value is also acceptable for the data extraction. From the result of maximum error, the paper suggests that future data collection should set the focal ratio from F/5.0 to F/11.0 in UAV Phantom 4 Pro in order to downsize the lens distortion impact.

Table 3. Summary error of lens distortion measurement in range of focal ratio

	F/2.8	**F/5.0**	**F/7.1**	**F/9.0**	**F/11.0**
Average error in vertical (%)	-1.6	-1.0	-1.0	-0.7	-0.9
Maximum error in vertical (%)	-6.8	-2.7	-2.7	-1.9	-2.2
Average error in horizontal (%)	-0.7	-1.7	-1.6	-1.7	-1.6
Maximum error in horizontal (%)	-4.3	-4.1	-3.4	-4.1	-3.4

4. CONCLUSION

In this paper, a comprehensive approach to estimate lens distortion in the camera is presented. The method is based on the theory that a light passes through the center of the stop is the least bending light, the calibrated error value of corrected image in both vertical and horizontal is measured. The Phantom 4 pro device is applied to calculate lens distortion effect on recorded video. The results showed that lens distortion has a negligible repercussion of the videos. At the focal point F/7.1, the largest and smallest aberration values are -3.4% and -0.2% respectively. The suggestion for future data collection process is to set the focal ratio from F/5.0 to F/11.0

The paper still has several following limitations. Firstly, though the observed error is contributed mainly by lens distortion, the proportion of other factors was not stated. Secondly, the lens distortion estimation only is taken into consider. The image correction part is not mentioned due to the focus of this paper. The future study should consider these limitations and apply the method for more lens systems.

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