DISTANCE MEASUREMENT FROM DIGITAL PHOTOGRAPH USING 3rd ORDER POLYNOMIAL EQUATION

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ABSTRACT: Position of pole liked objects is normally surveyed using field work since the object size is too small to be identified in aerial photo or satellite image. Field surveying techniques that can be used include: direct GPS survey; using total-station to measure angle and distance from traverse stations; and offset distance measurement from points with known coordinates. Among these, the latest is simplest and requires no expensive or sophisticate equipment. It also provides resulted position with fairly good relative-positional accuracy. Measuring distance in the field is, however, a tedious and time consuming task. This is especially true when it has to be done without modern laser distance measurement instrument which is quite expensive and has limitation in measuring distance to small object likes pole. Moreover, when the distance is measured using tape, objects must be accessible. This research work has therefore aims to investigate the viability of using digital photo taken from normal digital camera to determine the horizontal distance from camera point to object with known size that is presented in that photo. In this study, photos of known height objects were taken at different distances using both compact and SLR digital cameras. The data from those photos were used in modeling the relationship equations based on Lens Equation. The result has, however, shown that proper relationship equation could not be generated and so the object distance. The regression co-efficient analysis has then been used and the relationship equation has been successfully generated in the form of 2nd degree polynomial equation. It is nevertheless noticed that accuracy of the calculated distances varied significantly with the position of object on the photograph and also with how accurate the size of object in the photo is measured.

INTRODUCTION

As a result of the fast and widespread growing of GIS development in Thailand, needs for more detailed and more accurate positional data of real world objects are accentuated in many organizations. One example is the Provincial Electricity Authority (PEA) of Thailand which has just conducted the survey of their distribution network containing nearly 15 million electric poles throughout the whole country. To acquire the position of these pole-liked objects, field surveying work is normally required since the object size is too small to be identified in aerial photo or satellite image. Various field surveying techniques can be used for this task. They include: direct GPS survey; using total-station to measure angle and distance from traverse stations; and offset distance measurement from points with known coordinates. Among these, the latest is simplest and requires no expensive nor sophisticate equipment. It also provides resulted position with fairly good relative-positional accuracy. Measuring offset distance in the field is, however, a tedious and time consuming task. This is especially true when it has to be done without modern laser distance measurement instrument. Despite of its high cost, the use of laser distance measurement equipment with small object likes pole has found to be problematic in some circumstances. And if the distance to be measured using measuring tape or measuring wheel, objects must be accessible. This research work has therefore aims to investigate the viability of using digital photo taken from normal digital camera to determine the horizontal distance from the camera to object with known size that is presented in that photo. In this study, photos of known height objects were taken at different distances using both compact and SLR digital cameras. The data from those photos were used in modeling the relationship equations based on Lens Equation. The result has, however, shown that proper relationship equation could not be generated and so the object distance. The regression co-efficient analysis has then been used and the relationship equation has been successfully generated in the form of 2nd degree polynomial equation.

THEORIES AND RELATED WORKS

Based on the basic principles of the appearance of image through lens (CVI Melles Griot,2011) we can determine the distance between lens and object (or so-called the object distance) from the well-known "Lens Equation" (1) together with the Lens Magnification Equation (2).

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad ; \quad v = \frac{f.u}{u-f} \tag{1}$$

$$m = \frac{i}{O} = \frac{v}{u} \tag{2}$$

when u = object distance, v = photo distance, f = focal length of the lens, m = lens Magnification, i = image size and O = object size

From equation (1) and (2), if we consider that the focal length f is very small comparing to object distance u and replace (u-f) with u, we can then calculate u from equation (3).

$$u = \frac{f.O}{i} \tag{3}$$

In a study of density and distribution of small trees, Kendal (2007) has developed the mathematical calculation based on equation (3) above to determine the size of objects in a photograph. The calculation could also be used to compute the distance from camera to object with known size.

In the field of robot-vision, Wang et al. (2007) has also proposed a novel measuring system based on a single non-metric CCD camera and a laser projector for measuring distance of a remote object. The proposed method with a simple structure and algorithm is claimed to be easily realized by field programmable gate array (FPGA) for use in real-time processes. In the experiments of measuring object distances ranged from 1 to 18 meter using the proposed system, the average error was found to be merely 0.502%.

Despite the existence of various methods for object distances from digital camera mentioned above, the technique is hardly found to be used in practical. This may be because of the complexity of the formula used or the extra equipment required for those proposed methods.

One major question is about getting the accurate focal length of the camera when a specific photo was taken. Since most if not all of compact digital cameras equipped with a zoom lens, the focal length is therefore affected by the zoom level at the exposure. In principle, an accurate value of a fixed zoom lens could be acquired only by the testing procedure in a lab. This is far too problematic for the geospatial data users. So it's come to the question that can we use the focal length value presented in the EXIF or JPEG CDS data attached with the digital photo file? And if not, what could be a simple way to calculate the object distance without focal length value?

TESTING OF DISTANCE MEASUREMENT USING DIGITAL CAMERA

In this research, three digital cameras were used. They are Sony DSC-HX5V; Nikon Coolpix L23; and Canon 40D. Tripods and bubble leveling were used to align the camera to the proper position. The leveling staff were used as the objects in consideration.

A series of photographs of the staff placed at the preset positions were taken by each camera. The staff positions were set to be at 8 to 30 meters and every 2 meters intervals, from camera position. Three alignments of staff positions were conducted. Figure 1 shows a sample of the photo taken while Figure 2 illustrates the three alignments of different preset positions where the staff was placed. The photos were used as the raw data from which the study of different methods and the variation of factors can be conducted.

Figure 1: Sample photo

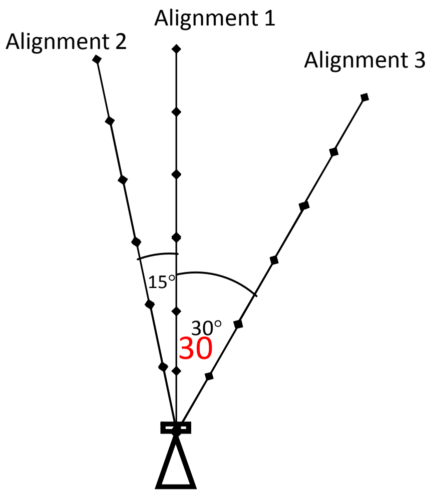

Figure 2: The preset positions of staffs (objects)

In our first test, the objectives were to assess the feasibility of calculating object distance using lens equation which requires focal length value. Testing procedures are as followed:

1. Set up the camera on the tripods with the height of camera of 1.5 meters which is half the length of staff.
2. Place the staff at each preset position as illustrated in Figure 2.
3. Taking photo of staff at every position, each with 3 levels of zoom.
4. For each photo that was taken, measure the dimension of the staff in the photo.
5. Calculate the object distance based on the equation (2) using focal length value from the photo's EXIF information.

RESULTS AND DISCUSSIONS

The test result shows in Table 1. It can be observed that object distances calculated from general lens magnification equation using focal length values from EXIF information have average error of 6.54% and 11.68% with the compact camera and 2.08% with the digital SLR camera. From these error figures, we can conclude that the object distance calculated from the simple lens magnification equation using focal length value from EXIF file cannot be used for distance measurement in geo-information field of works.

Table 1: Average error of object distances calculated from lens equation

Camera	Focal length value (from EXIF info)	Average Error on Object distance
Nikon Coolpix L23	4 mm.	6.54 %
Sony DSC-HX5V	4 mm.	11.68 %
Canon 40D	17 mm.	2.08 %

The data from photographs taken with the Nikon L23 and the Sony HX5V was then re-analyzed using the regression analysis method. In this method, the relationship between the actual object distances and the image dimensions were formulated. At first, we tried using the 2nd order polynomial equation as the trend line. An average R-square of 98.6% was achieved from those 2nd order polynomial trend lines. We then tried using the 3rd order polynomial as the trend line and getting the average figure of 99.6% R-square. Figure 3 illustrates four graphs of the trend lines. Two of them are for the data taken by the Sony HX5V camera and other twos are for the Nikon L23.

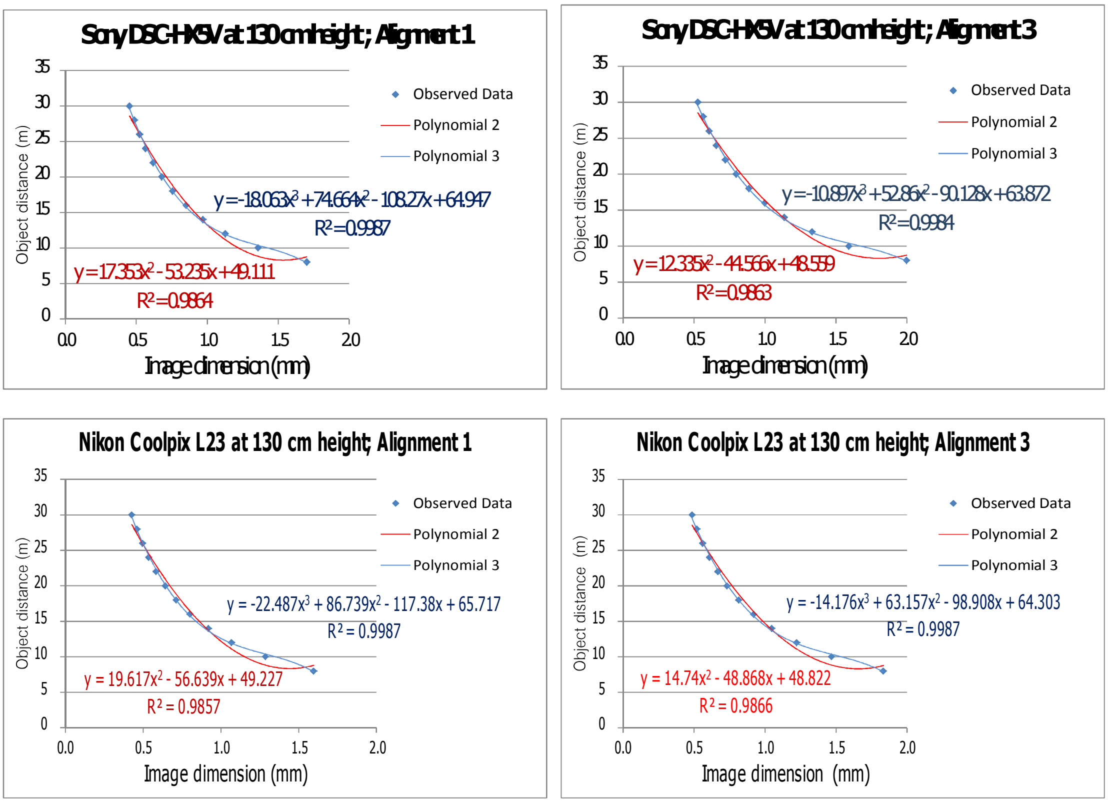

Figure 3: Polynomial equations between object distances and image dimensions

The object distances calculated using the polynomial trend line equations were then assessed by comparing with the corresponding actual object distances. Table 2 demonstrates the RMSE of error in object distance from different methods of calculation.

From Table 2, it can be easily observed that the RMSE of object distances acquired by using 3rd order polynomial equation is significantly smaller. When using the polynomial equation from the data in alignment 1 (center of photo), the error of points along this alignment is only at around 0.25 meters. However, if we use the same polynomial equation with the points in the alignment 3 which mean that the location of object on the photo is deviated horizontally from the photo center, the RMSE becomes much larger at 2.691 and 3.168 for the Nikon and Sony camera respectively.

Table 2: RMSE of Object distances from different methods

Methods used in calculating the object distance	RMSE of alignment 1		RMSE of alignment 3	
	Sony HX5V	Nikon L23	Sony HX5V	Nikon L23
- Lens Magnification equation	2.360 m.	1.776 m.	4.894 m.	13.059 m.
- 2nd order Polynomial equation from alignment 1	0.806 m.	0.825 m.	2.914 m.	2.481 m.
- 3rd order Polynomial equation from alignment 1	0.250 m.	0.246 m.	3.168 m.	2.691 m.
- 2nd order Polynomial equation from alignment 3	-	-	0.809 m.	0.800 m.
- 3rd order Polynomial equation from alignment 3	-	-	0.275 m.	0.251 m.

To study the effect of vertical deviation of object location on the image, the photos taken at different camera height were processed. The result is shown in Table 3. In general, the RMSE obtained from different camera heights are not significantly changed. This could be explained by the fact that the staff, which is the object of interest in this test, is vertically long in shape. Changed in vertical location of the object on the image is considered to be small compared to the image dimension and therefore did not generate significant effect on the results.

Table 3: RMSE of object distances from the photo taken at different camera height

Camera height (m)	RMSE (3rd order Polynomial, Alignment 1)		
	Sony HX5V	Nikon L23	Canon 40D
1.00	0.245	<u>0.239</u>	0.269
1.30	0.250	0.245	1.187
1.50	<u>0.240</u>	0.264	<u>0.235</u>
1.80	0.261	0.262	0.241
2.00	0.263	0.265	0.239

The polynomial equation formulated from the test data was then used in determining distance to other objects with known height. The resulted object distances obtained were found to be very erroneous. This suggests that the polynomial equation can only be used with objects of similar size to the objects used in the equation development process.

CONCLUSIONS & RECOMMENDATIONS

A number of digital cameras both of compact type (Sony and Nikon L23) and SLR type (Canon 40D) were tested in this research as the devise to obtain distance to known size objects. The test was carried out by taking photos of leveling staff positioned at the preset fixed distances from the camera. The image dimension of the staff in each photo was then measured in the computer. Using this image dimension, the object size (staff's length) and the focal length value of the camera (from EXIF information), the object distances can be calculated based on the general lens magnification equation. The error of the object distance obtained from this method was found to be too high and unreliable to be used in most of Geo-information fields of work. A new method of regression analysis was then exercised to directly formulate the relationship between image dimensions and object distances. Test results show that a 3rd order polynomial equation can be used as a good trend line of the relationship. The root mean square error of object distances calculated from this polynomial equation was found to be as small as 0.25 meter. This method could then be considered to be feasible and practical for distance measuring task in many fields of applications. Despite the good test result, the proposed method has also contained quite a few limitations. This method could provide good result only with object with similar size to object used in the polynomial equation formulation processes. The location of object in the image should be horizontally centered which is the alignment of objects' positions in the regression analysis processes.

Considering the potential of this distance measurement technique, further studies should be carried out to verify all of the negative effects and find a way to minimize them. This could be to develop a more universal formula which address those effects as much as they can be. A robust and user friendly program tool should also be developed to ease the users in processing the data, starting from equation formulation step.

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