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Thickness of Glass Effect on the Accuracy of Photogrammetric Measurements

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Abstract: ***Accuracy is an important term in photogrammetric science. It is affected by several factors, which depend on the nature of the object and its circumstance. One of these factors is that the displacement of the object points image, which can be caused by light ray refraction. It is well known that if a light ray passes from one medium (e.g. air) through another medium (e.g. glass), which has parallel surfaces, it will refract through the second medium and emerge from the first medium parallel to its direction with displacement of its original way. In photogrammetric works, such properties cause inaccurate measurements due to displacement of the object's point's position in the images. The light ray refraction makes the object points appear in another position in the image, which cause direct effect in the photogrammetric measurements accuracy. Some photogrammetric applications need to be photographed from in front of a glass. In such cases, the glass thickness will affect the accuracy of photogrammetric measurements. In photogrammetric works, the term accuracy has a big role in 2D and 3D measurements. It is therefore important to investigate to which level the glass thickness will affect photogrammetric measurements. The aim of this research was to study the effect of glass thickness in the accuracy of 3D photogrammetric measurements.***

Keywords: close range photogrammetry, accuracy, glass, 3D measurement, refraction

1. Introduction

It is well known that close range photogrammetry has a lot of applications in several different fields. Some of these applications require high or certain accuracy. Some others are restricted by their own position and/or circumstance, which put them under a certain conditions, which may affect the photogrammetric measurements' accuracy. Examples of this are applications where objects need to be photographed from in front of a glass, such as antiques, mummies, small monuments, Jewries, etc. The glass in front of these objects causes the light ray to displace from its original path. This displacement depends on some factors and affects the accuracy of the measurements.

There has been a lot of research into photogrammetric measurements' accuracy, for example, [8] conducted an accuracy investigation into a low cost 3D-measurement tool for architectural and archaeological applications. [4] studied the effect of the images' resolution on the accuracy of 3D measurements in digital close range photogrammetry. [5] has done some research into Islamic art accuracy by using digital close-range photogrammetry. More research articles can be found through the references of the above studies.

Some researchers have previously looked at light ray refraction in photogrammetric studies; so called "2-media photogrammetry" (from air into water, etc.). [10] demonstrated that a critical problem in hydraulics is accurate measurement of fluvial that is involved in the 2-media photogrammetry.

This study will focus on the effect of the glass thickness on the photogrammetric measurements' accuracy. In the next sections, a brief description of the light ray refraction and the accuracy will be presented.

Light Ray Refraction

The term refraction is the bending of a light ray when it crosses the boundary between two different materials, as from air into water. This change in direction is due to a change in speed. Light travels fastest in a vacuum and slows down upon entering matter. Its speed in air is almost the same as its speed in space, but it travels only 3/4 as fast in water and only 2/3 as fast in glass. The refractive index of a substance is the ratio of the speed of light in space (or in air) to its speed in the substance. This ratio is always greater than one.

When a beam of light enters a pane of glass perpendicular to the surface, it slows down, and its wavelength in the glass becomes shorter in the same proportion. The frequency remains the same. On emerging from the glass, the light speeds up again, the wavelength returning to its former size.

When a light ray strikes the glass at some other angle, it changes direction as well as speed. Inside the glass, the ray bends toward the perpendicular or normal. If the two sides of the glass are parallel, the light will return to its original direction when it leaves the glass, even though it has been displaced in its passage. If the two sides of the glass are not parallel, as in the case of a prism or a lens, the ray emerges in a new direction (Note access Internet Site [12].

The amount of the light ray deflection of its original direction depends on the second medium refraction coefficient, the incidence angle, and the glass thickness. Figure (1) shows light ray refraction through the second media.

The law of refraction is mentioned in the books of physics and on the Internet sites, such as Optics site (Optics Internet Site [13]).

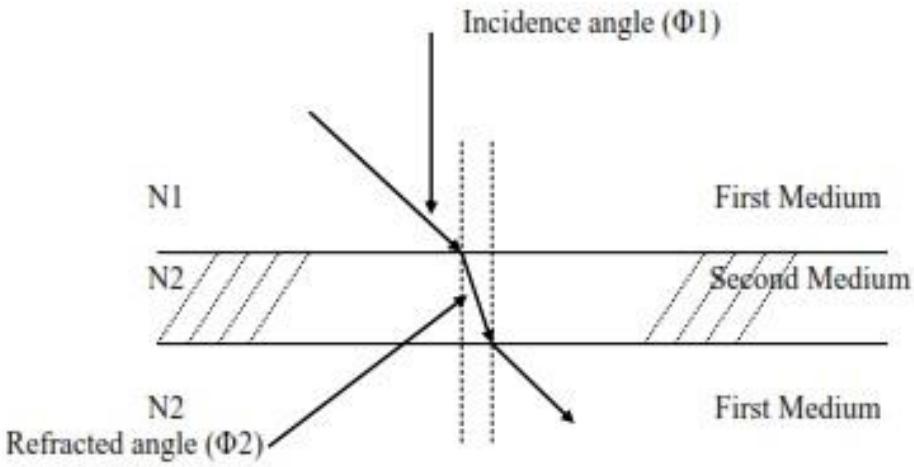

Figure 1: Light ray refraction through a second medium

Accuracy

Accuracy is an important element in the world of measurements, as it has been defined in several textbooks and articles. As an example, [6] defined accuracy as the degree of conformity or closeness of a measurement to the true value. They stated that accuracy includes not only the effects of random errors, but also any bias due to incorrect systematic errors. If there is no bias, the standard deviation can be used as a measure of accuracy.

[2] defined accuracy as the degree of conformity with a standard ("The Truth"). He mentioned that accuracy relates to the quality of the result, and is distinguished from precision, which relates to the quality of the operation by which the result is obtained.

[11] defined accuracy as the degree to which information on a map or in a digital database matches true or accepted values. Accuracy is an issue pertaining to the quality of data and number of errors contained in a dataset or map.

[2] wrote that accuracy has only one measurement: conformity with the truth. One or more of the following defines the truth in measurement science:

- An adopted physical or other standard (on distance, weight, volume, time, etc.).
- Geometric law.
- A system decided as correct by some recognized authority.

In the theory of errors of measurements, the term accuracy is traditionally used for a concept that measures the closeness of derived estimated or predicated data to reality [3].

Accuracy can be evaluated by using one of the following two methods [9]:

1) Check measurements
2) The accuracy predictor.

In the first method, the photogrammetric results are compared with the results obtained from a more accurate measuring procedure. The accuracy predictor is a theoretical way to evaluate a system using its main parameters.

[7] agreed with [9] for the first method and mentioned "If check points are available in the object space, the root-mean-square (RMS) error of photogrammetrically determined target point co-ordinates can be used as an accuracy measure".

Photogrammetry often estimates the accuracy of a method by controlled experiments, where the photogrammetrically determined co-ordinates are compared with so called given co-ordinates that have accuracy that considerably higher than that of the method to be checked [3].

2. The Research Idea

In some Photogrammetric applications, it is necessary to take photos from in front of a glass since the object lies behind it. As mentioned previously, the light ray is displaced from its original path as it goes through a glass due to refraction through the glass. As a result of this displacement, the accuracy of the 3D photogrammetric measurements are affected as the object's points will be in another position in the image than that if there was no glass. The displacement of the light ray depends on three factors, which are:

a) Glass thickness.
b) Incident angle.
c) Glass properties.

In this paper, the first factor will be studied to find out the effect of the glass thickness on the 3D photogrammetric measurements. Figure (2) shows the effect of the light displacement on the object points' co-ordinates.

3. Theoretical Problem

To investigate the theoretical effect of glass thickness on the points' space co-ordinates, a theoretical solved problem for such case will be presented. Assume the following (see fig. (2)):

X is the horizontal axis, Y is vertical axis, and Z is perpendicular to the image plan.

T = glass thickness

Dp = Original point distance from the glass.
Do = Observed point distance from the glass.
$\Phi1$ = The incidence angle.
$\Phi2$ = The refracted angle.
Δt = The deviation of the ray.
ΔZ = The error in Z direction.
N1 = First medium refraction coefficient.
N2 = Second medium refraction coefficient.
L = The refracted ray length between the glass surfaces.

$$\Phi2 = Sin^{-1}((N1/N2)*Sin(\Phi1)) \quad (1)$$

$$L = T/Cos(\Phi2) \quad (2)$$

$$\Delta t = L * Sin(\Phi1 - \Phi2)$$

$$\Delta t = T * Sin(\Phi1 - \Phi2)/Cos(\Phi2) \quad (3)$$

$$\Delta Z = \Delta t/Sin(\Phi1) \quad (4)$$

$$\Delta Z = T * Sin(\Phi1 - \Phi2) / (Sin(\Phi1)Cos(\Phi2)) \quad (5)$$

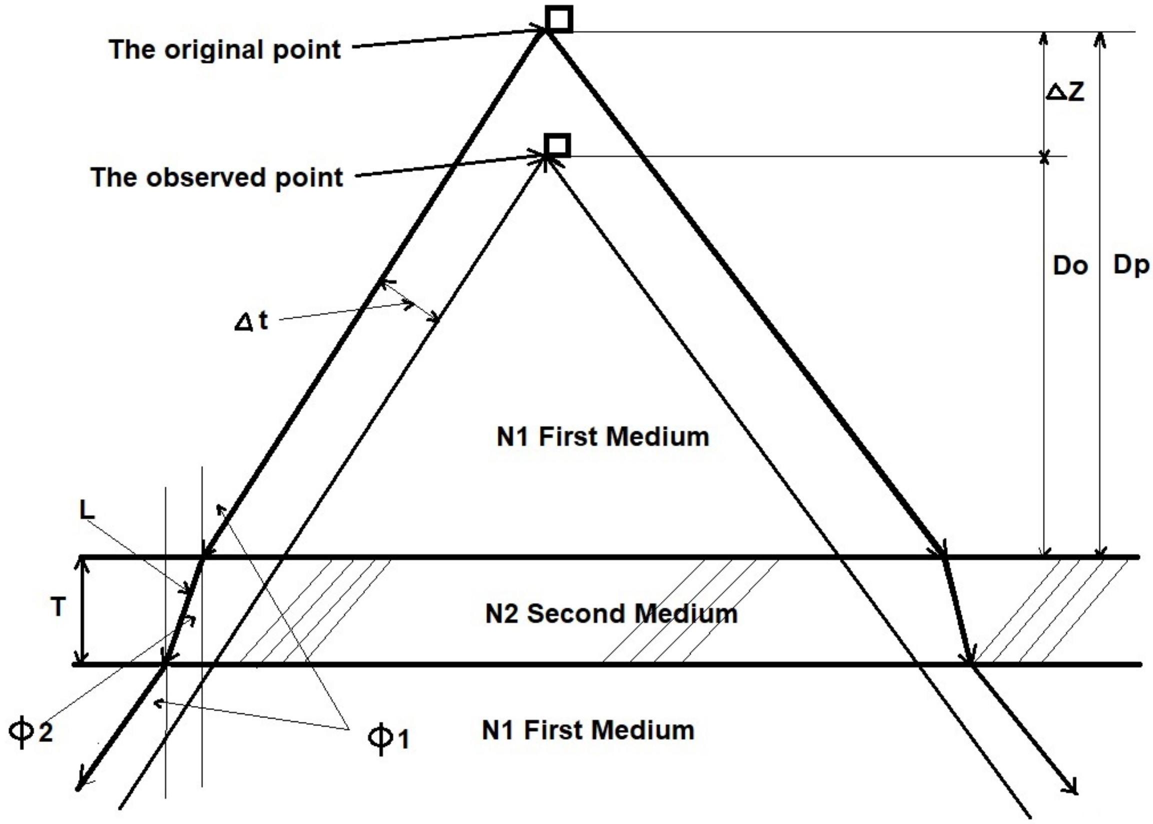

Figure 2: The effect of the glass on the object points' co-ordinates

Equation (5) proofs that when T increases, the error in Z direction increases. If the side cameras are in a symmetric position around the center, there will not be any error in X direction co-ordinate. If the side camera positions are not in the same level of the test field center in the Y direction, there will be some error in the Y direction co-ordinate. Also, the errors are affected by the incidence angle, as this angle increases so does the error.

If we assume T = 4 mm, $\Phi1 = 30^o$, N1 =1, and N2 = 1.03, then

According to equation (1):
$\Phi2 = 29.04110043^o$,
$\Phi1 - \Phi2 = 0.958899573^o$

According to equation (3): Δt = 0.0766 mm
According to equation (4): ΔZ = 0.153 mm

Table (1) shows the theoretical effect of glass thickness on the Z direction co-ordinate according to the above equations.

Table 1: Theoretical effect of glass thickness on the Z co-ordinates

Glass Thickness	Error in Z direction
2 mm	0.077 mm
3 mm	0.115 mm
4 mm	0.153 mm
6 mm	0.230 mm

4. Experimental Studies

An experimental investigation was conducted to investigate the effect of glass thickness on the 3D photogrammetric accuracy of objects lying behind glass. In the next section, a brief description of the tools used in this study will be presented.

4.1 The Camera

An Olympus digital camera C-2/D-230 was used in this investigation. The camera had a 5.5 mm focal lens. The camera took photos at four different resolutions. 1600 x 1200 was used in this investigation.

4.2 The Glass

Standard high quality Pilkington Optifloat clear glass manufactured by the float process was used. Four different thickness of glass were used - 2,3,4, and 6 mm. Physical properties of the glass are shown in Table (2).

Table 2: Properties of the used glass

Glass	Performance Code		Light				Energy							S, UV	
I	W/m^{2}K	%	%	%	%	%	-	%	%	%	%	-	-	-	-	%
	U	LT	Tel	LT	LRo	Lri	Ra	ET	ER	EA	TET	SSC	LSC	TSC	S	UV
2mm	5.9	91	88	91	8	8	99	87	8	5	88	1.00	0.01	1.01	1.3	69
3mm	5.8	90	87	90	8	8	99	85	8	7	87	0.98	0.02	1.00	1.3	64
4mm	5.8	90	85	90	8	8	99	82	7	11	85	0.94	0.04	0.98	1.6	59
6mm	5.7	89	82	89	8	8	98	79	7	14	82	0.91	0.03	0.94	1.09	53

4.3 The Test Field

A test field consisting of 72 points with heights varying from zero to 15 cm was constructed. The points were marked on a wood board and on the center point of the top of wood posts. They were arranged in rows and columns with 5 cm spacing. The points were marked as a cross on a piece of paper and glued on their selected places. Figure (3) shows the used test field.

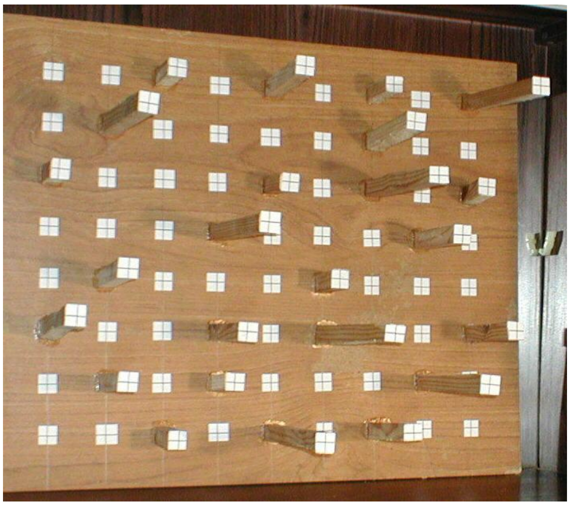

Figure 3: The test field

5. The Research Plan

Four different thickness of glass were used in this investigation, 2, 3, 4, and 6 mm. Three photos were taken for each case to fulfill the condition to determine the 3D co-ordinates for the software, one from the front, one from the left and one from the right. Figure (4) shows the camera configuration. To determine the accuracy of the points' co-ordinates, the test field space co-ordinates must be obtained. As there is no available way to take measurements for the points' space co-ordinate, three additional photos were taken for the test field without any glass in front of the test field, to obtain the test field space co-ordinates photogrammetrically. To calculate the accuracy of the test field space co-ordinates, a direct measurement using steel tape between 10 points on the board was performed and compared with the photogrammetric measurements. An additional test was done to find out the effect of using combined glass (two glass plates were put together instead of one). Two glass plates were used; each of 3 mm thickness, giving a total thickness of 6 mm.

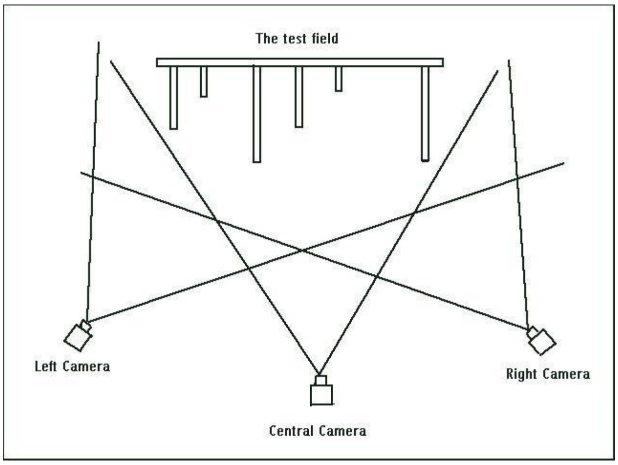

Figure 4: The camera configuration

6. The Results

The test field space co-ordinates were obtained by comparing some lengths on the board with those measured photogrammetrically. The standard deviation was 0.8 mm, which meant a 1/2500 relative accuracy. This is considered a good accuracy according to Hanke K. and Ebrahim M, 1997.

The test field space co-ordinates were obtained for each case (glass thickness) and compared with that obtained when there was no glass. The standard deviations were calculated and tabulated as accuracy measurement. Table (3) shows these standard deviations for X, Y and Z direction according to each glass thickness. Figure (5) shows the relation between the glass thickness and the accuracy in the three directions.

Table 3: The space co-ordinates accuracy according to the glass thickness

Glass Thickness	Standard Deviations (mm)		
	X	Y	Z
2 mm	0.31	0.38	1.4
3 mm	0.37	0.495	1.55
4 mm	0.31	0.32	1.32
6 mm	0.34	0.28	1.33
Combined 6 mm (3 + 3)	0.6	0.62	1.88

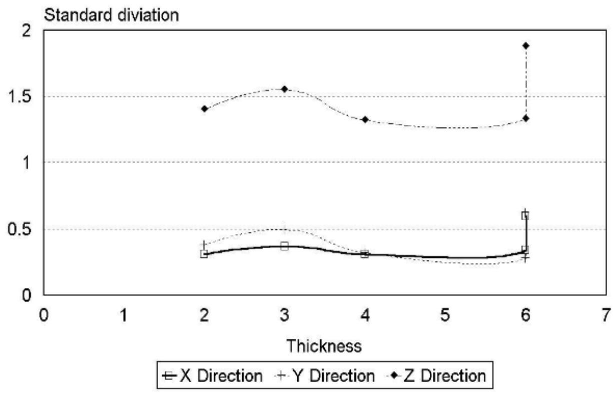

Figure 5: The relation between the glass thickness and the accuracy.

7. Analysis

The above experimental results support the theoretical results. Figure (5) shows that the effect of glass thickness in both X and Y directions is low and that glass thickness does not affect the accuracy and that was clear in the theoretical problem. The result of the experiment is derived from the asymmetry of the left and right camera position around the test field center.

The accuracy in the Z direction is weaker than in the X and Y direction as it has been proved theoretically that the glass thickness affects accuracy mainly in the Z direction.

It is noted from the results that the effect of the glass thickness does not have a trend in Z direction as seen in the theoretical results. This comes from the camera position, which didn't fixed in positions in all cases since the camera was an amateur camera carried by hand. As stated above (equation, 5) the incidence angle affects the accuracy as well. So the difference in the camera position will affect the incidence angle, which affects the accuracy itself. X and Y direction relations have no trend because the glass thickness has no significant effect on the accuracy of these two directions.

In the combined glass case, it was noted that the error is larger compared with the same thickness as one unit (6 mm). This result may come from some other refraction in the light ray through the two-glued surfaces.

Although the glass thickness affects the accuracy in Z direction, it is not large. The accuracy is still good and can be used in some applications, as the accuracy is about 1.5 mm, which translates to 1/1400 as a relative accuracy.

8. Conclusion

Some photogrammetric applications need to be photographed from in front of a glass as the object lies behind it or in a glass show box. This research studied the effect of the glass thickness on the photogrammetric 3D space co-ordinates. Both theoretical and practical results showed that the glass thickness affected the accuracy especially in the Z direction, but still maintained good accuracy for some applications. The effect of the glass thickness in the other direction (X, Y) occurs if the camera configuration is asymmetric around the object center and is not at the same level as the test field center.

Advice to those who want to have 3D photogrammetric measurement for objects that lie behind a glass is that they must take into account the following points:

1) Try to make the camera in a symmetrical position around the object center, which will neutralize the effect of the glass thickness.
2) Try to make the camera position as close as the 3D measuring requirements to avoid the effect of the incidence angle on the Z direction accuracy.
3) Try to avoid photographing objects behind a glued glass, as the accuracy becomes weaker than the same thickness in one unit.

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