BAND INFORMATION RECONSTRUCTION FROM A SINGLE PHOTO

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abstract:This paper describes a computerized photogrammetry method for obtaining the true size of the objects in the accident scene of a single photo.. In the proposed interpolation methods, the special requirement is that several poles placed along a curve must be included in the photo. There is no extra field measurement necessary and any adjustment introduced in the computational process. Graphical display is involved, which allows the user to view the whole image of his input information, as well as his operation process. A case study using results obtained from this method and then compared to the actual objects' measurements is illustrated.

1. BACKGROUND

Single-image photogrammetry by a non-metric camera is an important technique for reconstruction of the state of an accident's scene, and is still considered a state-of-the-art technique(Smith 1988, Smith 1989, Pepe 1989, Wooly 1991). Single image photogrammetry methods can be classified into two categories, either graphical or non-graphical techniques.

The graphical methods play a very useful role in accident reconstruction photogrammetry because of their ease in application. The requirements of these methods are that the horizontal lines, vanishing points, parallel lines, etc., all be determined in the methods' computational processes, which severely limits their usage.

The non-graphical methods currently include the plane-to-plane transformation method, the camera reverse-projection method, and the analytical camera reverse-projection method （Smith 1988）. Comments on these methods follow :

1.The plane-to-plane transformation method will work for any photograph with the assumption that the target surface is flat, and ignores those problems due to lens distortion, film non-planarity, and errors incurred in the printing process, etc. Obviously, the main advantage of this method is that it is simple and easy to apply; however, the major drawback is that the accuracy in the interpolation computation is usually not good.

2.The camera reverse-projection method will accurately relocate the objects in a photo after the photogrammetry position and pose are determined. Limitations on this method are its tedious and time-consuming process, and the necessity for special camera devices; severe influence on roadway traffic as well as safety is also unavoidable.

3.The analytical camera reverse-projection method will accurately relocate the objects in a photo, and is similar to the camera reverse-projection method. The accuracy when using this method is dependent upon high-order mathematical functions for surface description, and accurately calibrated measured points. It requires a complicated calibration process for the interior and exterior adjustment of a camera, as well as datum points. Consequently, this method makes it difficult to obtain the object's true scales in a photo, and also the interpolation result is unstable, due to the use of high-order mathematical functions.

This paper proposes a simple computerized photogrammetry method which is combined with a graphical operation system. The advantages of using this method are that it requires no field measurements, nor does it require calibration for the camera and its position and pose. It is very efficient in operation, and the use of an interactive graphical operation system helps the user view the whole image of his input information, computational results, as well as the operation process.

2. OPERATING PROCEDURES

The basic idea of this method is that the image length of the objects in a photo is a function of the length of the corresponding objects in the field. If a roadway surface can be represented by a polynominal function form, then this surface in a photo can be described as another polynomial function form which involves those effects such as lens distortion, film non-planarity, camera position and pose inclination, etc. Therefore, if a smooth curve-line exists on a roadway, the relationship between its image length and the associated true length in the field can be described by a mathematical function; if this curve is replaced by a measuring tape, then the above-mentioned relationship can be made obvious. However, at the investigation of a scene, it is not feasible for practical application to put a measuring tape on a roadway surface for this purpose. Thus, a measuring tape is replaced by several poles, as shown in Fig. 1; these poles stand erect along a curve, and each has arms of the same fixed length along X, Y, and Z directions. By comparing the actual lengths of the arms of these poles and their associated image lengths in a photo, a mathematical description to correlate them for each direction along the curve length can then be generated. Furthermore, as more poles are set along a curve, more precise functional relationships can be achieved.

To avoid using high order-mathematical functions, this paper uses a second order function for the mathematical description in interpolation. Three equations representing the X, Y, and Z directions are introduced in a problem. Then, the coefficients of each established function can be calibrated by the least-square method.

The practical operating procedure of the proposed method can be stated as follows :

1.First, poles are erected along a curve on a roadway surface, as shown in Fig. 1. The three directions of those arms on a pole are pointed to the parallel, perpendicular, and vertical directions to this curve respectively. After the poles are set up, a photo of the scene can be taken from a distance. All arms of the poles should be clearly projected, taking care that

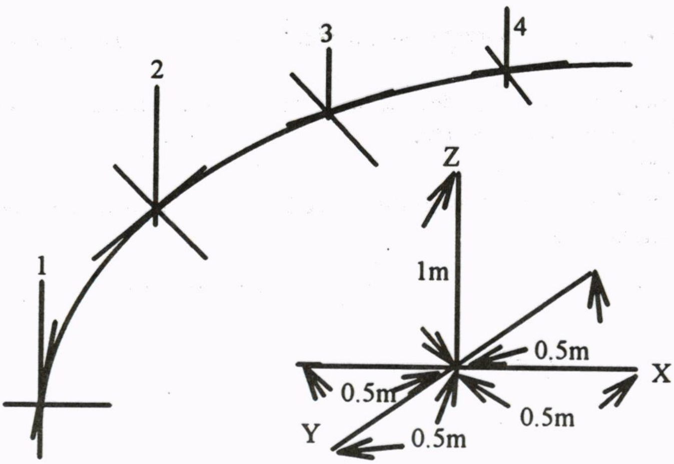

Figure 1 Four poles are set along a curve.

the ones farthest in the picture-plane will be readable for identification.

2.Then, as an image photo is scanned by a scanner, the corresponding positions of the objects in the photo are measured.

3.Finally, the interpolation method is used to correlate the relationship between the measured dimension of the objects in an image and their associated true scales in the field. A detailed description of the interpolation method appears in the following paragraph.

3. INTERPOLATION

Several poles are set along a curve; the relationships between the true dimension of those arms on the poles and their corresponding image scales can be interpolated as functions of the distance along this curve. Furthermore, the true scales of the objects near this curve can be evaluated by using the generated functions. In order to simplify the order of the interpolation functions, three separate functions are introduced to describe the relationship along the three different directions, which are parallel, vertical, and perpendicular to the curve. The following describes the generation of those three functions, respectively.

1.Distance along the curve

Four rulers, each measuring one-meter in length, are set along a curve, as in Fig. 2. A 2nd-order polynomial function is employed to represent the curve in an image as in Eq.(1). The least-square method is used to smooth out possible variations in interpolation.

$$\mathbf{Y = a_0 + a_1 \times X + a_2 \times X^2} \tag{1}$$

where

Y，X:the coordinates of a point in an image plane.

a_0, a_1, a_2:constants.

The image lengths in the photo of those four one-meter rulers can be described as a function along the curve. Eq.(2) represents the relationship of a pixel size of a particular object in a photo and its corresponding actual length in field.

$$\mathbf{Length = b_0 + b_1 \times Si + b_2 \times Si^2} \tag{2}$$

where

Si:the image distance between the starting position of the curve to the particular point in the curve.

Length:the actual distance in the field, which is measured along the curve from the starting point to the specified Si position in an image.

b_0, b_1, b_2: constants.

Again, Eq.(2) is calibrated by using the least-square method with the data collected from the established four rulers in process.

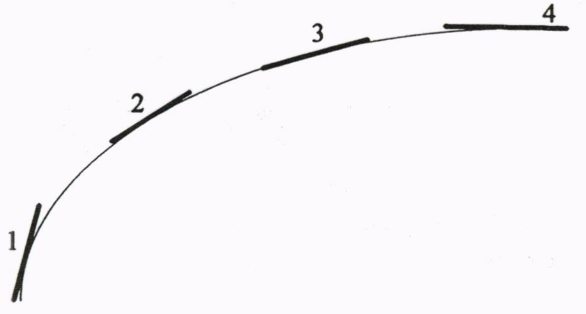

Figure 2 Four rulers are set along a curve.

2.Distance perpendicular to the curve

As in Fig. 3, four rulers are set up, each one-meter in length, set perpendicular to a curve. Then the image length of each ruler can be found, and the information is used to derive the formula in Eq.(3) to represent the relationship of a pixel size in an image and its actual length perpendicular to the curve in the field; this formula is a function of the distance of the curve.

$$\mathbf{Width} = c_0 + c_1 \times Si + c_2 \times Si^2 \qquad (3)$$

where

Width:a point located at the distance Si along the curve; the actual perpendicular distance of this point to the curve corresponds to a pixel size in an image.

c_0, c_1, c_2:constants.

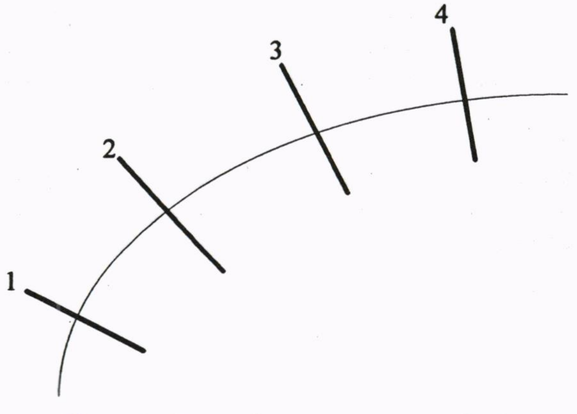

Figure 3 Four rulers are set perpendicular to a curve.

3.Height above a plane

A similar process can be provided to obtain the relationship between a pixel size in an image and its actual height above the curve in field, which is a function of the distance Si along the curve.

$$\text{Height} = d_0 + d_1 \times Si + d_2 \times Si^2 \tag{4}$$

where

Height:the actual height represented by a pixel size in an image at the distance Si along the curve.

d_0, d_1, d_2: constants.

The method proposed in this paper requires having accurate image dimensions for any measured object in a photo. Thus, it is vital that the particular objects in a photo be as clear and large as possible.

4. NEARBY OBJECTS

The previous paragraph shows that the effective scope for the measurements is limited within the area close to the specified curve, represented by several poles. That band information along the curve is the major target for the use of the method proposed here. The following describes the required computation used to interpolate the dimensions of the objects located near the curve.

As in Fig. 4, point I is located near a curve, on which four poles exist, each with one arm perpendicular to the curve. The numbers 1, 2, 3, and 4 represent the pole numbers; AB, CD, EF, and GH represent the arm of each pole perpendicular to the curve. To obtain the true distance from point I to the curve, one must first obtain the J point, which is the perpendicular projection of point I to this curve. The true distance between I and J points in the image can then be computed. The following illustrates the steps taken to determine the image point J:

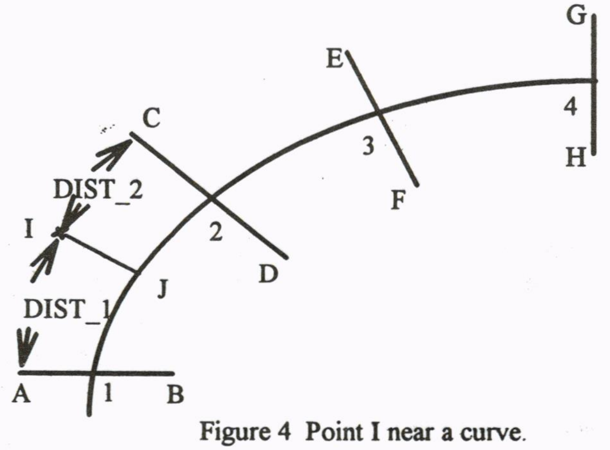

Figure 4 Point I near a curve.

a.Calculate the slopes of those arms of the poles perpendicular to the curve, such as the arms AB, CD, EF, and GH in Fig. 4.

b.Calculate the vertical distances from point I to those arms perpendicular to the curve separately, i.e., the vertical distances between point I to the arms AB, CD, EF, and GH, respectively.

c. Choose the two nearest poles to point I, and calculate the distance between these two poles, or poles 1 and 2 in the case of Fig. 4.
d. Calculate the slope of the line IJ by using Eq. (5).

$$\mathrm{SLOPE\_I} = \frac{\mathrm{SLOPE\_1} \times \mathrm{DIST\_2} + \mathrm{SLOPE\_2} \times \mathrm{DIST\_1}}{\mathrm{DIST\_1} + \mathrm{DIST\_2}} \tag{5}$$

where
SLOPE_I: the slope of the line IJ.
SLOPE_1: the slope of the arm AB in the first nearest pole.
SLOPE_2: the slope of the arm CD in the second nearest pole.
DIST_1: the distance from point I to the first nearest arm (AB).
DIST_2: the distance from point I to the second nearest arm (CD).

As the projection image point J is determined, the height, perpendicular distance, and as well the length of an object can be interpolated. The following describes the methods for such interpolation:

1. Measuring height
Eq. (6) is introduced to measure the height of the bar Ih at the point I, as in Fig. 5; the J point and the distance SJ of this point's curve distance have to be obtained first.

$$\mathrm{TRUE\_HEIGHT} = \mathrm{IMAGE\_HEIGHT} \times (d_0 + d_1 \times Si + d_2 \times Si^2) \tag{6}$$

where
TRUE_HEIGHT: the true height of the bar Ih.
IMAGE_HEIGHT: the image height measured from a photo, which is the number of pixels.
$d_0 + d_1 \times Si + d_2 \times Si^2$: it is Eq. (4)

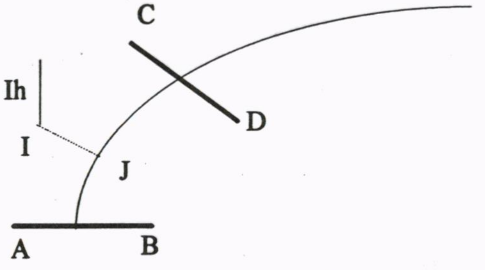

Figure 5 To measure Ih height.

2. Measuring the distance perpendicular to a curve
The Eq.(7) is used to measure the actual distance, IJ, between point I and the curve, as in Fig. 6.

$$\mathrm{DIST\_IJ} = \mathrm{IMAGE\_WIDTH} \times (c_0 + c_1 \times Si + c_2 \times Si^2) \tag{7}$$

where
DIST_IJ: the true distance of the line IJ.
IMAGE_WIDTH: the image distance of the line IJ in a photo, again, it is described by a pixel number.
$c_0 + c_1 \times Si + c_2 \times Si^2$: it is Eq. (3)

3. Measuring the length of an object

The Eq. (8) is provided to evaluate the actual distance of the image length IK, as in Fig. 6.

$$DIK = \sqrt{DJL^2 + (DKL - DIJ)^2} \tag{8}$$

where

DIK:the true distance of the line IK.
DJL:the true distance of the line JL.
DIJ:the true distance of the line IJ.
DKL:the true distance of the line KL.

Some previous equations have to be involved in the computation of the distances DJL, DKL, and DIJ in the Eq. (8).

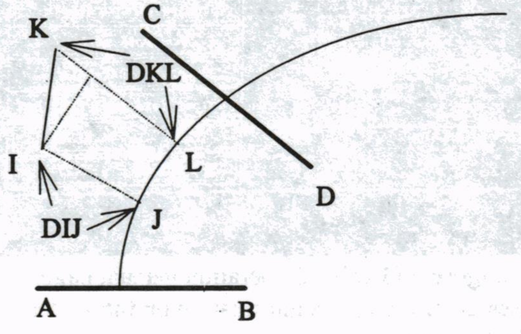

Figure 6 To measure IJ width and IK length.

5. GRAPHICAL OPERATION SYSTEM

An interactive computer graphical system was developed in this study, which enables a user to view and work on the input information. Fig. 7 shows its menu page. The following describes the functions included in this particular system:

Image file name -->:to input existing data from an external file.
Input poles data from file:input those coordinates of the poles from a file.
Input poles data from keyb: input those coordinates of the poles from the keyboard.
MEASUREMENT:picks one of the following four items to specify the particular item for operation.
by keyboard:operates by using the keyboard.
by mouse:operates by using the mouse.
HEIGHT of a speci pt.:to evaluate the height of the specified point.
DISTANCE between 2 pts:to evaluate the distance between two selected points.
DISTANCE of a pt. to curve: to evaluate the distance of a point to the curve.
LENGTH of a speci. curve:to evaluate the length of a specified curve.
Show point coordinate:shows the coordinates of the selected point.
Show grid mesh:displays a grid mesh on the screen.
Generate .DXF file:generates an output file of the image on the screen for the AUTOCAD program.
OUTPUT to -> : specifies an external file name for output.
ZOOM : scales up a part of the image on the screen.
RESET : resets to the original image size on the screen.

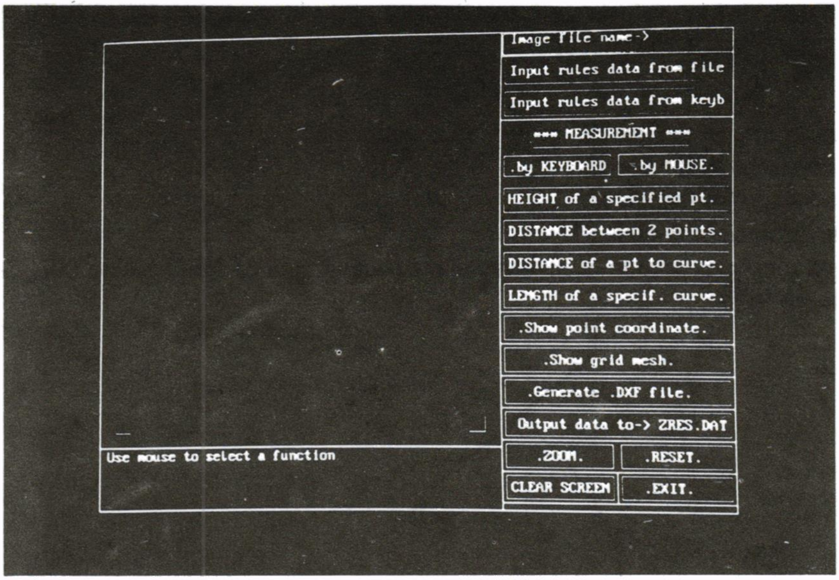

Figure 7 Graphical operation manual page.

CLEAR SCREEN: erases all of the image information on the screen.
EXIT : quits this graphical system.
Fig. 8 illustrates the use of this system to evaluate the true distance between two image points.

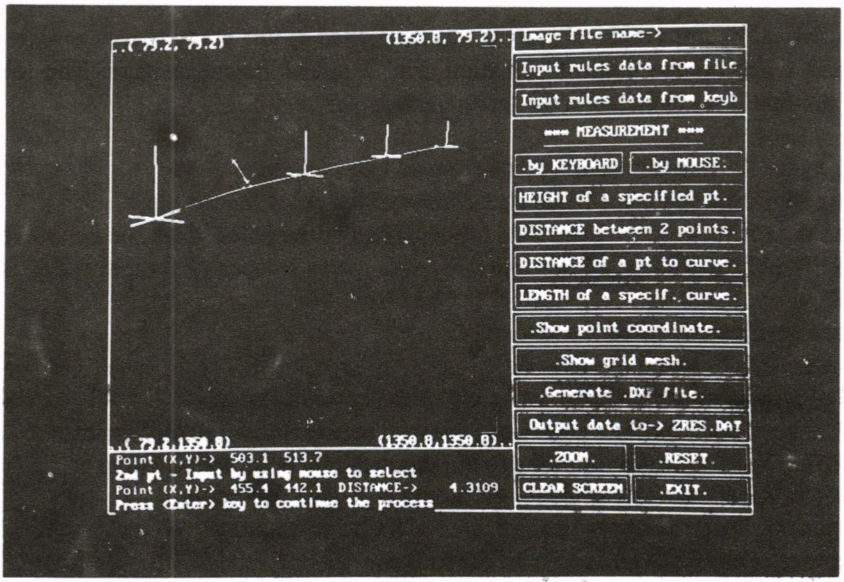

Figure 8 The display of the result.

6.BENCHMARK

Figs. 9 and 10 show the field test used in this paper, in which there are four poles set along the curve of an athletic track. Six boxes are placed near this curve. The distance between any two poles set next to each other is five meters, and the distances from the curve to the boxes are either 50 cm or 20 cm. There are two different sizes of cartons, each one either 42cm (length) by 28.3cm (width) by 28.8cm(height), or 37cm by 23.5cm by 25.7cm. Photos were taken from three different orientations, shown as A, B, and C in Fig. 11. Table 1 shows the comparisons between the measurements taken from the field and from the computational method proposed in this paper. The results of this table show that:

Figure 9 Boxes in field.

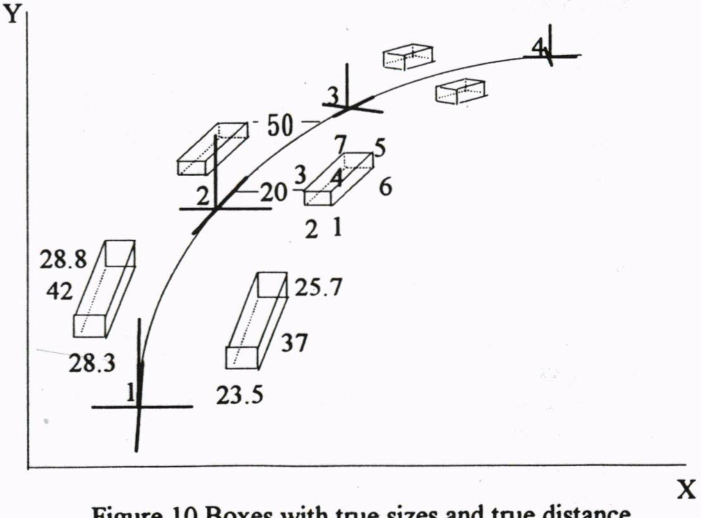

Figure 10 Boxes with true sizes and true distance
from the curve in field.

1.The computed distance between any two poles next to each other along the curve can be achieved with high accuracy, the reasoning being that the computation can use the four poles for calibration. The accuracy is within 11 %.

2.The errors of the computed height of the boxes are within 12%, but the errors of the computed distances from the boxes to the curve may be as high as 28%, due to the difficulty in accurately measuring the sizes of the boxes in a photo which is very small and unclear.

3.The accuracy in computing the sizes of the boxes is not good, in which the errers may be as high as 22.6 %, the reasoning being the same as in the previous statement. Different accuracy can result from using photos taken from different orientations.

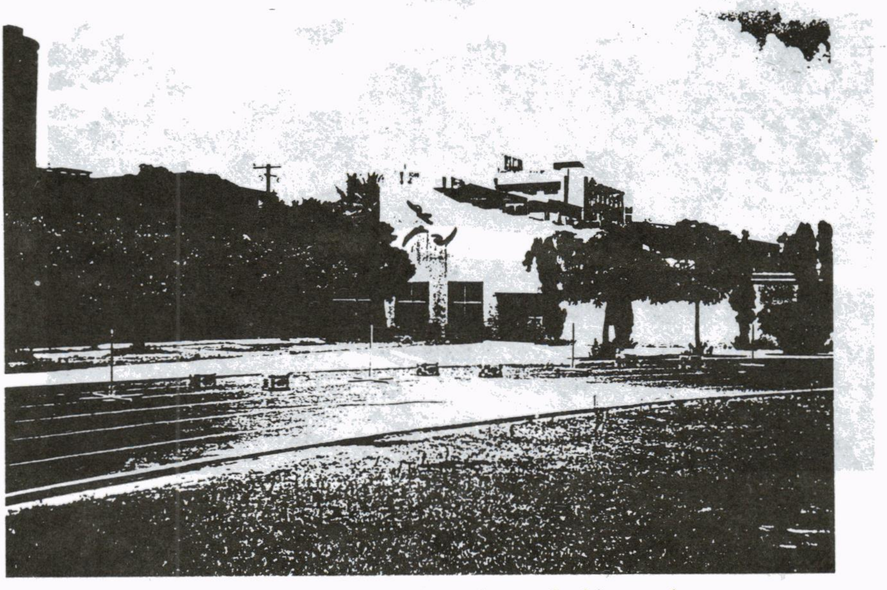

Figure 11 Different orientations of taking a photo.

From the above discussions, it can be seen that the use of different photos taken from different orientations can result in different levels of accuracy. The key point here is that it is vital to have correct information about the image scales of an object in a photo.

7.CONCLUSIONS

This study proposes a close-range photogrammetry method, which is simple in computation while still accurate in evaluating the actual sizes of objects in a single photo. This method is based on the information achieved from the well-calibrated poles set along a curve in a photo; as long as accurate image scales of the arms of the poles can be obtained, the computational results should be good. However, there are two major assumptions imposed on this method, which are :

1.The roadway surface at the scene is smooth, which is usually correct in reality.

2.Correct scales of the arms of the poles in a photo can be obtained, as well as that the image size of a particular object in a photo can be correctly measured. The discussion of

Table 1.Comparisions of the field measurement versus the computational results proposed in this paper.

BOXES											
Item	Point	Angles	POLE1,2[c]			POLE2,3			Pole3,4		
			A	B	C	A	B	C	A	B	C
Height of box (M)	I.O.C.[a] 1,4	Estimated	24.3	25.9	29.1	23.9	24.7	29.3	24.4	25.1	29.0
		Measured	25.7	25.7	28.8	25.7	25.7	28.8	25.7	25.7	28.8
		Error(%)[d]	5.4	0.8	1.0	7.0	3.8	1.7	5.0	2.3	0.7
	O.O.C.[b] 1,4	Estimated	23.1	23.9	27.7	22.7	22.8	27.2	22.6	24.9	27.7
		Measured	25.7	25.7	28.8	25.7	25.7	28.8	25.7	25.7	28.8
		Error(%)	10.0	7.0	3.8	11.7	11.3	5.5	12	3.1	3.8
Length of box (M)	I.O.C. 1,6	Estimated	40.7	40.4	44.0	36.5	43.8	38.1	37.8	40.5	40.7
		Measured	37	37	42	37	37	42	37	37	42
		Error(%)	10.0	9.2	4.8	1.3	18.4	9.3	2.2	9.5	3.1
	O.O.C. 1,6	Estimated	33.1	42.4	43.4	37.3	40.2	41.4	31.1	39.4	38.2
		Measured	37	37	42	37	37	42	37	37	42
		Error(%)	10.5	14.6	3.3	0.8	8.7	1.4	15.9	6.5	9
Width of box (M)	I.O.C. 1,2	Estimated	23.1	24.9	26.6	17.6	27.1	32.9	23.4	25.1	31.1
		Measured	23.5	23.5	28.3	23.5	23.5	28.3	23.5	23.5	28.3
		Error(%)	1.7	6.0	6.0	25.5	15.3	16.3	0.4	6.8	9.9
	O.O.C. 1,2	Estimated	23.0	23.8	31.6	25.3	20.5	32.4	18.2	22.6	23.4
		Measured	23.5	23.5	28.3	23.5	23.5	28.3	23.5	23.5	28.3
		Error(%)	2.1	1.2	11.6	7.6	12.7	14.5	22.6	3.8	17.3
Distance from the curve (M)	I.O.C. 2	Estimated	15.5	19.9	20.3	21.5	24.7	17.3	16.4	2.1	24.3
		Measured	20	20	20	20	20	20	20	20	20
		Error(%)	22.5	0.5	1.5	7.5	23.5	13.5	18	10.5	21.5
	O.O.C. 1	Estimated	36.0	46	52	54.1	36.8	57.3	41.8	45.1	58.1
		Measured	50	50	50	50	50	50	50	50	50
		Error(%)	28.0	8.0	4.0	8.2	26.4	14.6	16.4	9.8	16.2
Length of curve(M)		Estimated	4.87	5.45	4.78	5.01	5.52	4.89	4.88	5.54	4.47
		Measured	5	5	5	5	5	5	5	5	5
		Error(%)	2.6	9	4.4	0.2	10.4	2.2	2.4	10.8	5.2

note:[a]I.O.C.:inside of the curve

[b]O.O.C.:outside of the curve

[c]Pole1,2:between pole1 and pole2

[d]Error(%): (| Measured-Estimated | ／Measured) $\times 100$

the previous paragraph demonstrates that most errors result from incorrect input, especiall as the image size of a specific object in a photo is sometimes too small to be read accurately.

The method proposed here has proved to be accurate, as well as simple in operation and application. Obviously, if two or more curves can be set along a surface, then the scope of the measurements of the proposed method will not be limited to a band area along a curve, and rather can be easily extended to the whole range in a photo, in which case the accuracy in computational result will be further improved.

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