ALGORITHMS OF DIGITAL TARGET LOCATION AND THEIR INVESTIGATIONS

A. Chibunichev

Photogrammetry Departmant of Moscow Instityte of Geodesy, Aerial Surveying and Cartografy
(MIIGAIK). Gorochovsky By-str., 4 ,103064, Moscow, Russia.

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Abstract:

Target image-coordinate measurements are caried out approximatly on an interactive digital stereophotogrammetry workstation by applying the measuring mark in the form of a window wich can change its sizes. This paper deals with the algorithms of processing the windows with a target in the form of a circle, a cross, or a square used to determine pixel coordinates of a target center. These algorithms are based on the corresponding geometrical figures equations. The robust estimation technique is applied to reduce the influence of the noise on the precision of pointing. Extensive investigations have been carried out on digital pointing to circular, cross and square targets in order to determine the influence of quantization level, pixel size, target size, noise (random noise, shade, patch of light) and inclination of image on the precision of pointing.

KEY WORDS: accuracy, algorithm, close-range, digital systems, image matching, investigation, location, target

INTRODUCTION

Most industrial photogrammetric problems are solved using targets of different geometrycal shape (cross, circle ,square, triangl and so on). Algorithms of target image coordinate measurement in digital images are based on determination of the center of the corresponding figure by calculating the gravity center (for exampele, E.M.Mikhail and al.,1984, J.C.Trinder.,1989, K.W.Wong, H.Wei-Hsin,1986). However, these algorithms don't take into account that the image is the central projection of an object, consequently all image points are desplaced because of angle between image and object planes. Therefore, the circle on the object is transformed into an ellipse on the image, the equilateral triangle is transformed into a nonequilateral one and so on. In general, the center of the figure on the image doesn't lay on the same perspective ray with the center of the corresponding figure on the object. Invariances to the projective transformations are, as known, a point and a straight line. Therefore the center of a target on the object appeares on the image in the center of the corresponding figure only for cross and square targets. The target center must be computed as a intersection point of straight lines formeing a cross or of diagonales for a square because in other wise the gravity center will shift.

The values of these displacements (for every type of a target) are approximately iqual to $0.5\mu m$ and $1\mu m$ for $200\mu m$ and $400\mu m$ of target size on digital image (A.Chibunichev,1992). These values were calculated by means of simulation process for $f = 50$mm, angles of inclination = 15°, 35°, 45°, camera format = 5x5mm. For all shapes of targets (triangle, circle, square and cross) the gravity center has been computed which was compared with the corresponding exact positions of the center. If the figure equation is used to compute the center of a cross and a square, their centers coincide exactly with their theoretical position. Thus to locate the target with higher precision (when the angles of the camera inclination with respect to object are large) it is desirable: 1) to use a cross or a square as targets; 2) to make the algorithm of target location as the intersection of straight lines. However, as will be shown later, it is better to use a circle as a target when the angles of the camera inclination are not large.

Algorithm of target location.

Figure 1 shows the processing steps of a semi-automatic target location. This approach has originally been presented in earlier papers (A.Chibunichev,1991, 1992). This algorithm serves for targets in the form of a circle, cross, square and for contour points which can be represented as the point of intersection of the lines.

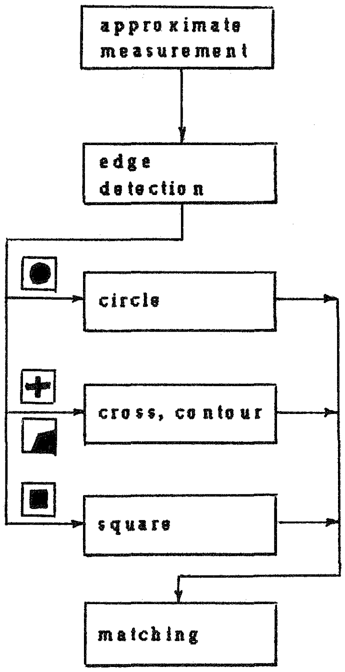

Fig. 1 Block diagram of targets location.

Let's consider each step of this algorithm.

1. Aproximate measurements of targets are carried out applying a well known principle of stereo

observation of digital images on split screen stereoscope system. As far as the acceleration of measurements is concerned the grafical measuring mark in the form of a window. The sizes of window are changed depending on target dimentions of the image. To make measurements one only needs to locate the target into corresponding windows in the right and left images. In this case the measurements are made faster and it is not necessery for observer to have much qualification. If the measured point is not a target the sizes of the mesuring mark should be about 20x20-30x30 pixels of image, because within these limits the obtained precision of matching is optimal, according to D.Rosenholm,1987.

The following processing of images is caried out within the limits of the windows.

2. Edge detection is perfomed here by means of the convolution of the image with a well known Sobel operator. As a result we get the gradient image.

3. The circular target location is based on solution of the equation:

$$(X_i - X_c)^2 + (Y_i - Y_c)^2 - R^2 = 0, \qquad (1)$$

This equation is formed for each pixel i (within the window) the gradient of which is not zero.

The robust technique is applied here to compute the unknown courdenates of center X_c, Y_c and radius R.

In order to reduce the influence of random noise on the precision of pointing and to narrow the target edges (till ±1 pixel) we use the following weight of eq. (1):

$$P_i' = \exp\left(-\left|\frac{G_{max}}{G_i} - 1\right|\right), \qquad (2)$$

where G_{max} is maximum value of gradient in the window; G_i is the gradient value of the pixel i in the window.

To avoid detecting noise (shade, patch of light and so on) as target edges we use robust estimation technique, i.e. the following weight functions are introduced:

$$P_i'' = \left\{ \begin{array}{ll} 1 & \text{if } |V_i| \leqslant 2\mu \\ \exp[-0.1(|V_i|/\mu)^4] & \text{if } |V_i| > 2\mu \text{ and } N \leqslant 3 \\ \exp[-0.1(|V_i|/\mu)^3] & \text{if } |V_i| > 2\mu \text{ and } N > 3 \end{array} \right\} \qquad (3)$$

Here V_i is the descrepance of i equation (1); μ is the standard error of unit weight; N is the number of iteration. The computation is iterated until the required precision is obtained.

4.The cross target location is based on the determination of the target coordinates as a point of intersection of two lines.

The coefficients of line equations are determined using the same principle of a robust estimation technique. Moreover, the pixels are divided into two groups (for each line) applying the directions of its gradients.

The same algorithm is used for determination of coordinates of a contour point which can be represented as a point of intersection of two lines.

5. The square target location is based on the computation of the square center as the point of intersection of diagonals. The needed conditions for the pixels detection which belong to 4 sides of a square are easily obtained from analicis of the gradients directions of pixels. Than the same approach is used for the robust estimation of a line equation.

These algorithms of tagets location in detail can be found in A.Chibunichev (1991,1992).

6. Image matching. First of all it should be said that the algorithms of target location (above-mantioned) solve the pointing problem without image matching. However (as will be shovn below) the matching process permits to improve the precision of determination of paralaxes for cross and square targets as well as for counter points.

The image matching can be done with many methods (M.J.P.M.Lemmens,1988). The least squares matching method (A.Grun, 1985, D.Rosenholm, 1987, Heipke C, 1991) was chosen here because it gives high accuracy potential, high degree of invariance against geometrycal image distortions and relatively simple possibilities for statistical analysis of the results. The disadvantage of this method is a quite high time-consuming. Some recomendations to reduce the computational cost of least square matching are mantioned in A.Chibunichev, 1992.

Investigation of precision of target location

First, let consider the results of extensive studies of the precision of circular target location on digital image (A.Chibunichev, T.Shimshanova, 1992). These investigations have been carried out on the basis of the artificially generated targets with varying characteristics. The simulated process of digitizing was performed for the following pixel sizes 2.8, 6.8, 7.5, 9, 12.5, 17, 19, 23, 27μm,wich correspond to values for real CCD cameras (T.Luhman, 1990). For each pixel size eight different quantization levels (grey scale values) were investigated: $2^1, 2^2, \ldots, 2^8$, which means encoding into 1,2,...8 bits respectively. The target location was carried out 50 times for each pixel size, quantization level and target size (100 and 200 μm). Moreover, the exact position of the target center was changed by a random number up to ±1 pixel for each new digitizing process. The variation in precisions of target pointing (m_ℓ) depending on the quantization level are illustrated in figure 2 for a target zise of 100μm (diameter of circle). The value $m_\ell = \sqrt{m_x^2 + m_y^2}$, where m_x, m_y are standard errors of target center coordinates determination. The pixel sizes are indicated on the left sides of the curves and on the right sides - the ratios of target size/pixel size. Other target size/pixel size ratios were studied, but the precisions of taget location in these cases were approximately similar to those shown in figures 2 and 3.

Figure 3 illustrates the influence of the image random noise on the precision of pointing. It should be pointed out, that the random noise was introduced into the values of the pixels (during the simulated process of digitizing), but prior to quantization . The random noise percentages were ±5% , ±10% , ±15% , ±20% , ±40% which equivalent to ratios K=signal/soise of 20:1, 10:1, 6.7:1, 5:1, 2.5:1. The figure 3 corresponds to the case when a quantization level is equal to 256 (2^8).

The figures 2 and 3 demonstrate that a better precision of target location (near 0.01 pixel size) can be obtained when the quantization level is equal to or greater than 32 (2^5), target sizes are larger than 6*pixel size and the noise is less than 10% (K=1:10).

The similar results were obteined in J.C.Trinder,1989.

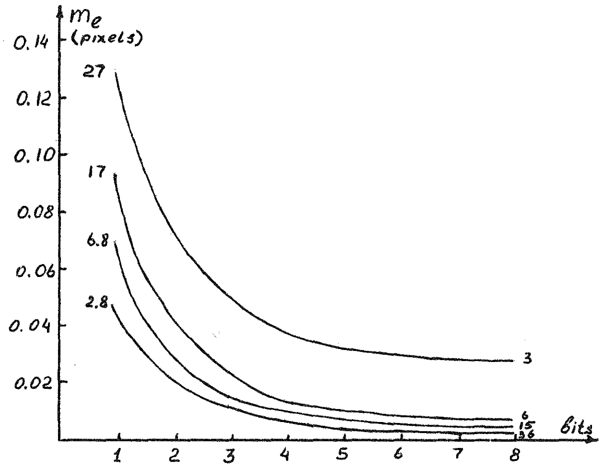

Fig.2 The relation between the precision of a target location and a quantization level.

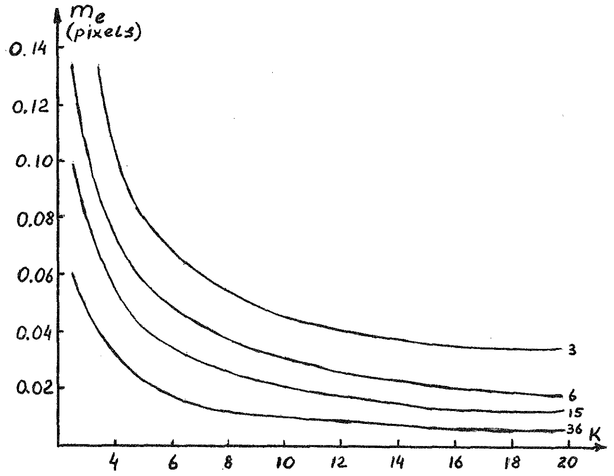

Fig.3 The relation between the precision of a target location and ratios of signal to noise.

In order to test the influence of local noise on the precision of a target pointing the following experiment was perfomed. The initial datas are: window sizes - 42*42 pixels, pixel size - 2.8μm, circular target size - 100μm, quantization level - 256 (2^8), random noise - 10% . The local noise was simulated as square (in the left hand corner of window in figure 4) which have the same grey values of pixels like a target. The sizes of this local noise were changed.

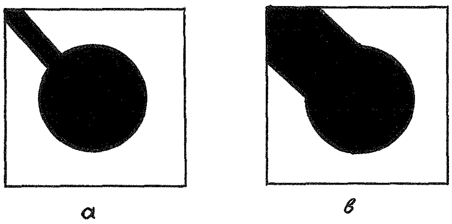

Fig.4 The circular target with the local noise.

The figure 4 shows (schematicly) minimum and maximum sizes of local noise which where approximately 1:40 (fig.4a) and 1:4 (fig.4b) of circle length.

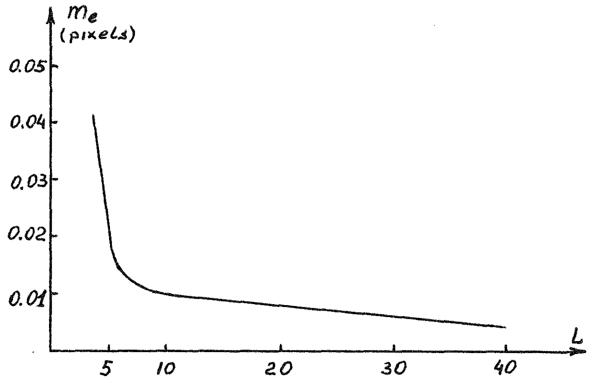

Fig.5 The relation between precision of target location and local noise.

The figure 5 demonstrates the variations in precisions of pointing due to local noise. Here L is the ratio of circle length to arc length which is covered by noise. At the same time (as a comparision) the precision of target pointing without local noise was 0.005 pixel.

The local noise doesn't influence the precision of a target location when L>10. This means that robust algotithm (2,3) is rather effective to suppress noises.

The similar investigations where caried out for cross and square targets.

Table 1 illustrates only some results of cross and square targets location precision (in pixels) as compared with a circular target. The initial datas for tests presented here are as follows: a quantisation level - 32 (2^5), a random noise - 10% , a ratio to target size/ pixel size - 8,15,36. The relationship between the pointing precision and the quantization level, random noise for a cross and a square targets is in many ways similar to that of a circular one.

Table 1. Precision of target pointing (pixels)

Target	K=targ.size/ pix.size		
	8	15	36
circle	0.03	0.02	0.01
cross	0.27	0.08	0.03
square	0.54	0.31	0.20

Table 2. Precision of target matching (pixels)

Target	K=targ.size/ pix.size		
	8	15	36
circle	0.03	0.02	0.01
cross	0.08	0.04	0.02
square	0.17	0.15	0.13

Table 2 illustrates the results of the matching precision for the same targets (with the same characteristics). The image matching technique used here is based on least squares method.

The results of these tables are not necessary to comment. It is better to apply the circular targets in all cases (from the point of view of precision). However, in some cases (when the angles of camera inclination are very large) it is better to use the cross targets.

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