Automatic Interior Orientation of Aerial Photographs with Model-free Condition

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ABSTRACT

This paper proposes an approach of automatically calculating the center location of fiducial marks up to sub-pixel accuracy with model-free condition. The conceptual model, composed of two assumptions, about general geometric property of fiducial area and fiducial mark is established. The proposed approach is primarily based on the strategy of calculating the center of symmetry and is composed of three steps of processing: (a) determining horizontal center of fiducial area, (b) locating center of a fiducial mark, and, (c) finally calculating the exact center up to sub-pixel accuracy. Evaluation with respect to RMK style marks and RC style ones shows that the proposed approach can be evaluated as robust one. However there are several images which can't be analyzed by the proposed approach.

Keywords : Fiducial Mark, Interior Orientation, Photogrammetry

1. Introduction

Aerial photographs taken by an aerial camera or a metric camera are calibrated generally by following the procedure of interior orientation, relative orientation, and absolute orientation before they are processed for extracting precise geographic information of ground. Interior orientation, a process of transforming the image coordinate into the photo coordinate, is concerned with the determination of a set of parameters, such as the calibrated and equivalent focal lengths, lens distortion, principal point, camera resolution, and focal plane flatness. Among those parameters, the location of the principal point, representing the geometric center of photograph, is calculated from the location of fiducial marks which is typically located in four corners and/or four sides of the photograph. Where, a fiducial mark is composed of several geometric primitives such as lines, circles and/or a point [1][2].

Automatic identification and determination of the precide center location of a fiducial mark can be challenging researches in developing an advanced Digital Photogrammetric Workstations (DPWs). For the automatic identification of fiducial marks, there have been several previous researches such as binary cross correlation, modified Hough transformation [3], least-square template matching [2], and attribute-based mathematical morphology [4]. However there have been restrictions such as the requirement of a priori knowledge of the precise geometric shape or the rasterized image model database of the mark.

In our previous researches [5][6], a new approach based on the radiometric and geometric analysis of a fiducial mark has been proposed. Where, the candidate region of the mark is isolated by applying a binarization process and mathematical morphology, and then the center location up to unit pixel accuracy is obtained by applying $\nabla^2 G$ (Laplacian of Gaussian) filtering and a symmetry enhancement filtering.

Although the proposed approach includes a meaningful advantage that it doesn't require exact geometric model of the mark in calculating the center location, there has

been restrictions, as well, that it can be applicable to RC style fiducial marks only and that the sub-pixel location can't be obtained.

In this paper, a revised approach which relies only on geometric analysis is proposed. For developing a revised approach, a conceptual model of the fiducial area and the fiducial mark is proposed. Based on the model, it is proposed a way of identifying the center location of a mark without a priori information of any style of fiducial marks. A way of calculating the center location up to sub-pixel accuracy is proposed, as well.

Section 2 discusses the conceptual model and strategy in analyzing fiducial area and fiducial mark. Identification of location of a fiducial mark and calculation of the exact center up to sub-pixel location is discussed in Section 3 and Section 4. Finally, Section 5 concludes this paper.

2. Conceptual model and strategy

2.1 Conceptual model

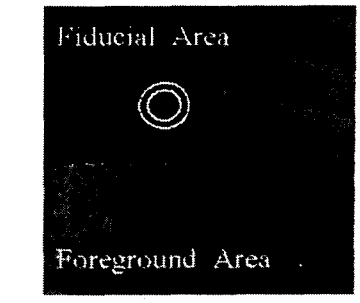
As has been proposed in our previous researches [5][6], the strategy for identifying a fiducial mark can be based on a radiometric and geometric model of the mark, and appropriate way of analysis can be implemented on the strategy.

In this paper, we will propose a revised approach based on a conceptual model of the fiducial area and the fiducial mark which defines geometric characteristics of those objects. The model is based on the following assumptions:

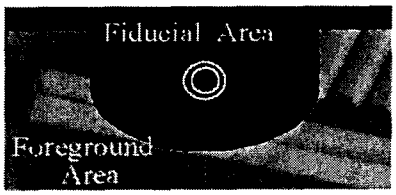
① The whole geometric characteristics of a fiducial mark is generally symmetric with respect to any axis which passes center location of the mark.

② The fiducial area is symmetric with respect to certain axis, and which axis always passes center location of the mark.

Figure 1 shows a simulated image of typical fiducial mark, fiducial area and foreground area, where the symmetric axis of fiducial area is appeared as dotted line.



(a) Corner area



(b) Center area

Fig. 1: Conceptual model of fiducial marks

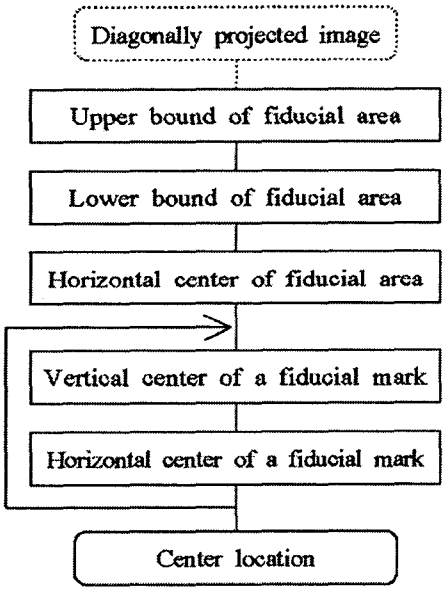


Fig. 2: Procedure of calculating the center location of a fiducial mark

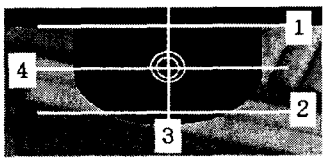


Fig. 3: Order of finding the center location of a mark

2.2 Strategy

The strategy in calculating the center location of a fiducial mark is based on two assumptions explained in the above. Since it is assumed that the fiducial area is

symmetric with respect to certain axis which passes the center location of a fiducial mark, the approximate location of center of a mark can be determined by finding the axis of symmetry of fiducial area.

Figure 2 and figure 3 shows proposed procedure of calculating the center location of a fiducial mark, and the serial order of finding the location, respectively. The upper bound and lower bound of fiducial area is determined by analyzing the accumulated profile of vertical edge of input image. Then the horizontal center of fiducial area is determined by analyzing the accumulated profile of horizontal edge of input image existing within the upper and lower bounds. Finally, the location of vertical center and horizontal center of a fiducial mark is determined by successively applying three geometric filters : simplified $\nabla^2 G$ filtering, symmetry enhancement filtering, and band rejection filtering. Exact location of the center of a fiducial mark is refined iteratively until it reaches a given threshold.

Since the symmetry axis of corner area exists in the diagonal direction, as is shown in figure 1, diagonal projection of input image is performed before applying the proposed procedure. Figure 4 shows diagonal projection of corner area.

3. Identification of fiducial marks

3.1 Horizontal center of fiducial area

Identification of a fiducial mark and determination of center location of fiducial marks have been implemented based on the procedure as is proposed in figure 2. Upper and lower bounds of fiducial area is determined by analyzing the accumulated profile of vertically calculated edge of input image.

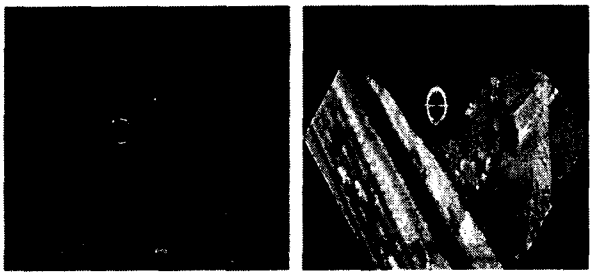
The accumulated profile of vertical edge is calculated by the following equation.

$$I1 = \int_{p1}^{p2} |I0(x, y-d) - I0(x, y+d)| \qquad (1)$$

where I0 denotes input image, I1 resultant image, and p1 and p2 interval of accumulation.

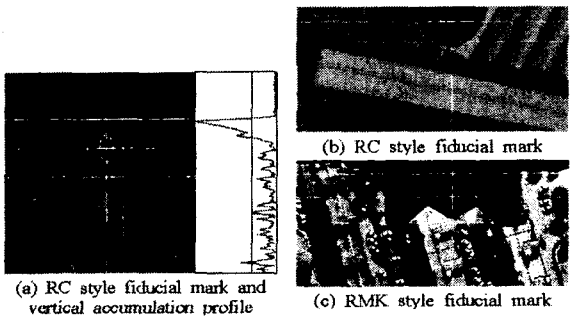
The upper bound is determined using the accumulated profile and a given threshold, as is shown in figure 5(a), where the threshold is determined by analyzing variations of the accumulated profile. Approximate horizontal center of fiducial mark is determined by analyzing horizontally accumulated profile of edge image, where the accumulation is done for a given interval defined below the upper bound. A similar way of processing used for the determination of upper bound is performed for the approximate horizontal center and its neighbor. Then lower bound of fiducial area is determined.

Horizontal center of fiducial area is refined by analyzing the accumulated profile of horizontally calculated edge image. The center is determined by finding medium location of left and right bounds, where the bounds are determined by using a given threshold.



(a) Original image (b) Projected image

Fig. 4: Diagonal projection of corner area



(a) RC style fiducial mark and vertical accumulation profile (b) RC style fiducial mark (c) RMK style fiducial mark

Fig. 5: Calculation of the center location of a mark

3.2 Center location of a fiducial mark

The center location of a mark is determined by successively applying three filters : simplified $\nabla^2 G$ filtering, symmetry enhancement filtering, and band rejection filtering. As is $\nabla^2 G$ filtering generates zero-crossing of input image [7], simplified one generates zero-crossing as well. However simplified $\nabla^2 G$ filtering is much faster then the original one because box filtering technique[8] can be applicable when the simplified $\nabla^2 G$ filtering is concerned [6].

The simplified $\nabla^2 G$ filtering is defined by the following equation:

$$I2 = \frac{1}{N_{R2}} \int_{R2} I0 - \frac{1}{N_{R1}} \int_{R1} I0 \qquad (2)$$

where N_{R1} and N_{R2} denote number of pixels of simplified $\nabla^2 G$ convolution kernel defined in figure 6(a).

Symmetry enhancement filtering is useful in detecting reflective center of symmetry [5][6]. The filtering through Y- and X-axis is defined by the following equation:

$$I3_y = \int |I0_{S1} - I0_{S2}| \qquad (3)$$

$$I3_x = \int_{T1} |I0_{T1} - I0_{T2}| \qquad (4)$$

where S1 and S2 denote region of vertically symmetric convolution kernel defined in figure 6(b), and T1 and T2 that of horizontally symmetric one defined in figure 6(c).

Band rejection filtering is useful in detecting sudden variation of a given signal, and is defined by the following equation :

$$I4 = \left| I0 - \frac{1}{N} \int I0 \right| \qquad (5)$$

Figure 7 shows proposed procedure of calculating the center of symmetry. Firstly, $\nabla^2 G$ filtering is applied with respect to some neighborhood of horizontal center of fiducial area which is already determined in previous step of processing. After symmetry enhancement filtering through Y-axis is applied, the resultant image is converted into 1D signal by calculating accumulated

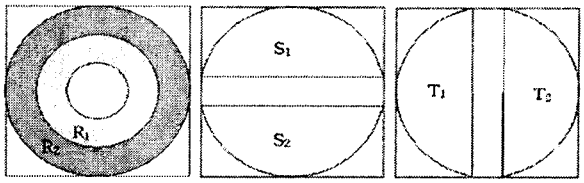


Fig. 6: Convolution kernel used for (a) $\nabla 2G$ filtering, (b) vertically symmetry filtering, and (c) horizontal symmetry filtering

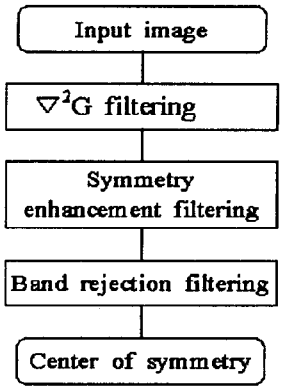
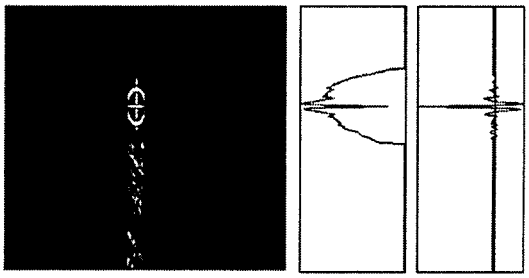
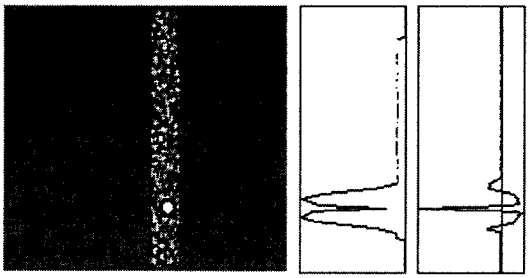


Fig. 7: Procedure of calculating the center of symmetry



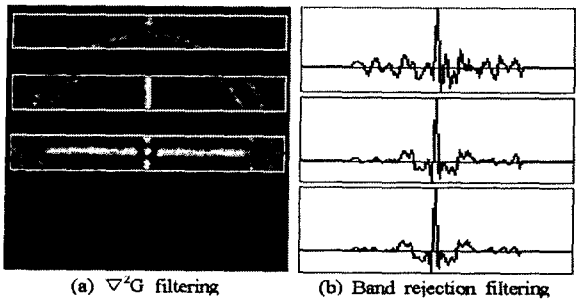
(a) $\nabla^2 G$ filtering, (b) Symmetry enhancement filtering, (c) Band rejection filtering

Fig. 8: Calculated result of center location w.r.t the RC style fiducial mark



(a) $\nabla^2 G$ filtering, (b) Symmetry enhancement filtering, (b) Band rejection filtering

Fig. 9: Calculated result of center location w.r.t the RMK style fiducial mark



(a) $\nabla^2 G$ filtering (b) Band rejection filtering

Fig. 10: Stability of calculating the center of symmetry

profile. Finally, for determining the center location of a fiducial mark calculated in Y-axis, band rejection filtering is applied with respect to the resultant signal.

Figure 8 and figure 9 shows calculated result of center location, in Y-axis, with respect to RC style and RMK style of fiducial mark, respectively. Maximum peak appeared in figure 8(c) and figure 9(c) corresponds to the location of maximum symmetry of the target object, and which means the center location of each fiducial mark calculated in Y-axis. This is because the location of maximum symmetry, that is the center of symmetry, means the center location of a fiducial mark by the assumption ① of the proposed conceptual model.

This process of determining center location by three successive filtering is repeated iteratively once in vertical direction and once in horizontal direction. This repeating process stops when positional difference by iteration becomes smaller than a given threshold.

Figure 10 shows stability of the proposed approach in calculating center location of a fiducial mark. Figure 10(a) shows $\nabla^2 G$ filtered result of three substantial part of a fiducial mark, and figure 10(b) shows result of band rejection filtering. It can be acknowledged that three peak location of signal, that is the center of symmetry of each substantial part, is coincident each other. This might mean that the proposed way of three successive filtering can provide reliable results even when there are small defections within a fiducial mark.

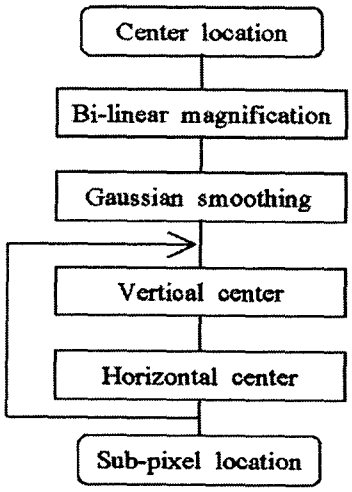
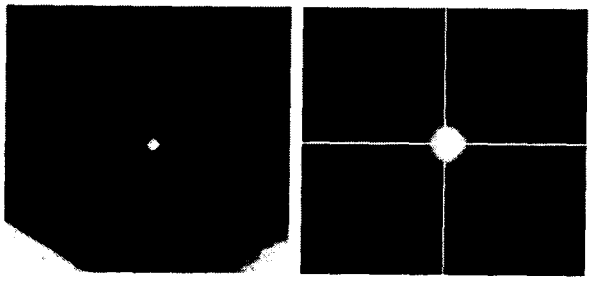
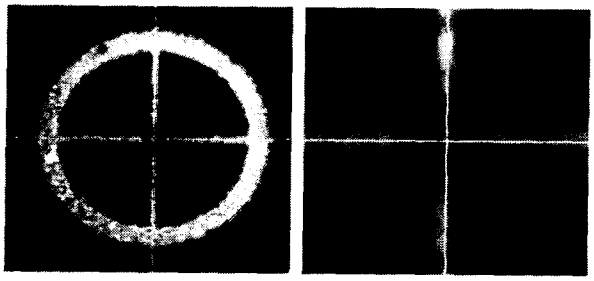


Fig. 11: Procedure of calculating the sub-pixel location



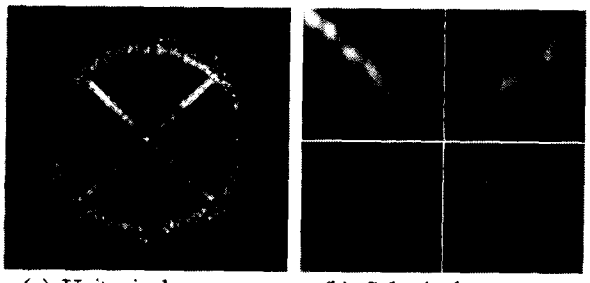
(a) Unit pixel accuracy (b) Sub-pixel accuracy

Fig. 12: Calculated center location of the RMK style fiducial mark existing on center area



(a) Unit pixel accuracy (b) Sub-pixel accuracy

Fig. 13: Calculated center location of the RC style fiducial mark existing on center area



(a) Unit pixel accuracy (b) Sub-pixel accuracy

Fig. 14: Calculated center location of the RC style fiducial mark existing on corner area

4. Sub-pixel location

Since the center location of a fiducial mark is determined at unit pixel accuracy, it is necessary to determine sub-pixel location of center for reliable performance of interior orientation.

Partial image containing a neighborhood of previously determined center location is extracted from the original image and is enlarged for calculating sub-pixel location.

As is shown in figure 11, partial image is enlarged by applying bi-linear interpolation and is smoothed by applying Gaussian smoothing filter. Then the same way of processing done by applying three successive filters explained in previous session is applied with respect to the enlarged image. This stops when positional variation by iteration becomes smaller then a given threshold.

Three results of center location of a fiducial mark calculated up to sub-pixel accuracy is shown in figure 12, figure 13 and figure 14, respectively. As can be seen in these figures, the proposed approach can be evaluated as robust one.

5. Conclusions

We have proposed an approach of automatically calculating the center location of fiducial marks up to sub-pixel accuracy with model-free condition. The conceptual model, proposed in this paper, is composed of two assumptions about general geometric property of fiducial area and fiducial mark. The symmetric center line of fiducial area is determined by analyzing geometric characteristics and symmetric property of image which contains fiducial area. Center location of a fiducial mark up to unit pixel accuracy is determined by successively applying three filters : $\nabla^2 G$ filtering, symmetry enhancement filtering, and band rejection filtering. Sub-pixel location of center of the mark is determined by applying bi-linear magnification, Gaussian smoothing, and those three filters.

Experiments with respect to RMK style marks and RC style ones, which is not appeared in this paper, show that the proposed approach can be evaluated as robust one. However there are several images which can't be analyzed by the proposed approach.

Further research should be imposed on developing more reliable and robust methodology by introducing a hybrid concept of merging the proposed approach and the conventional one such as template based cross correlation and/or feature-based matching.

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