BINDING AERIAL IMAGES OBTAINED BY AN UNMANNED AIRCRAFT VEHICLE TO OTHER IMAGES AND MAPS

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Abstract: The development of surveillance instruments allows obtaining images of the one and same object or area of earth surface that have been taken at different times and with different sensors. The analysis of such images requires the use of geometric transformation to align them. In the paper the use of affine transformation for synthesized aperture radar (SAR) images aligning and the use of projective transformation to register an image to the coordinate system of a map is studied. Aligning of images to maps allows using a map of the area as a reference image instead an orthoimage of this area.

Key words: spatial transformation of images, affine transformation, image processing, maps.

1. INTRODUCTION

Many deciphering tasks are reduced to the mutual comparison of images that are formed by different sensors. An example of this is the development of remote sensing methods for the control of natural resources and the dynamics of ecosystems (so-called monitoring), which comes down to comparing pictures of the same area that were obtained at different times and or with different sensors. Optical, radar, thermal and other fields are most often used. The sharing of different physical fields requires pre-processing of the respective images, for example, in order to bring the images into one spectral range.

In practice, images of the same object or area obtained at different times or with the different sensors can differ significantly from each other. Hence a number of important binding tasks, as well as accurate mutual geometric correction for subsequent joint analysis. In all cases, this requires a correspondence between the elements of the original image, which is reduced to the separation of the so-called reference (conjugate) points of the images, which can be coordinated images with simultaneous geometric corrections. The points of two pictures are conjugated if they are images at one point of the scene [3]. For example, aerospace monitoring assumes the presence of discrete time observation with a short time interval, and therefore, when the moving camera captures the brightness picture of the observed object in the form of a series of images, this picture is distorted due to changes in perspective and camera position.

The geometry of the corresponding deformations is modeled by projective transformations which form a broader class than transformations of Euclidean geometry, such as lengths and angles in projective geometry are not preserved and parallel lines are not transformed into parallel lines [1]. Restoring the spatial relief of stereo images leads to a problem with identification: establishing the exact coordinates (in points) in accordance with the elements of the stereo image. The solution of this problem consists in separating a pair of reference fragments and estimating the parameters of "divergence" of the respective points, at which the function of geometric transformation can be restored and the surface of the three-dimensional scene (relief) can be estimated [4]. The capture of images on board of an Unmanned Aerial Vehicle (UAV) is inevitably associated with geometric distortions in them. These distortions are due to various factors:

- Perspective of the camera optics;
- Movement of the aircraft;
- Orientation in the space of the aircraft;
- Height and speed of the aircraft;
- Relief of the area;
- Capturing the terrain with various sensors - infrared, video cameras, radars, etc.

In order to be able to compare and match images obtained from different sensors or from the same sensor at different times, it is necessary to make geometric corrections to the images. When it is necessary to align an image to a map, one must align the coordinates of the image with the coordinate system of the map. Since most of these distortions are systematic, sufficiently accurate models can be created [5, 8].

2. APPLYING GEOMETRIC TRANSFORMATIONS TO BIND ONE IMAGE TO ANOTHER AND TO A MAP.

2.1. Binding an image to another image.

Correlation processing is one of the most commonly used methods of image processing and is used in solving the following main tasks:

- Detection of a certain object in the image;
- Determination the position of an object in the image;
- Comparison of relevant sections in two digital images in order to connect them;
- Determination of the position of coordinate markers in the images (reference points, coordinate crosses or intersections of a coordinate grid) for the purpose

of geodetic binding and reference transformation of the image or the vector information obtained from it.

In solving these problems, the choice of the standard is essential. The standard is an object with a characteristic shape, whose gradation characteristics provide good correlation. To ensure this, it is necessary for the standard to provide a narrow correlation function with a pronounced maximum and a good quality ratio - the ratio of maximum to minimum of the correlation function. For this purpose, the standard must have thin lines and not be filled with space and its spatial structure must be good.

In order to solve the mentioned problems, it is necessary to correlate the obtained image to the standard one by means of appropriate geometric transformations before the correlation processing. Various geometric transformations are used to bind the images. The role of geometric transformations is to convert the coordinates of the current image into the coordinate system of the reference image or the map [1]. In geometric transformations, the points (pixels) of the current image are moved so that they stand in the coordinates of their corresponding points (pixels) of the reference image. This is illustrated in fig. 1 with four pairs of points from the current and standard image.

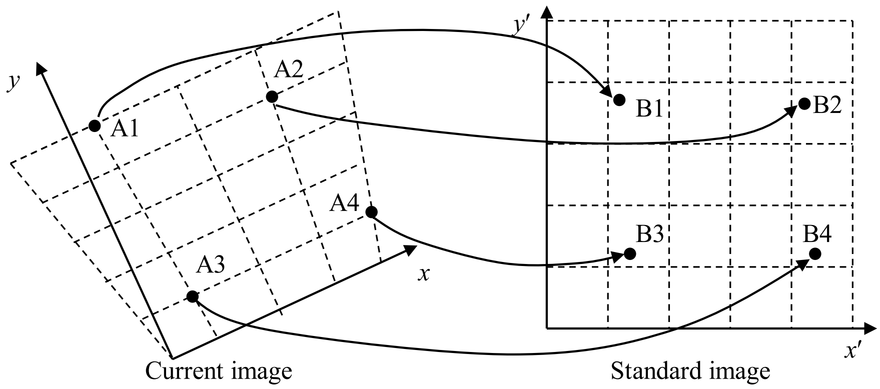


Fig. 1. Principle of geometric transformations

As shown in Fig.1, after the geometric transformation, points A1, A2, A3 and A4 of the current image are displayed at points B1, B2, B3 and B4 in the standard image coordinate system, respectively. As you can see, the images of the points (pixels) of the current image on the reference may not match the pixels of the standard image, which lie at the intersections of the grid. The pairs of corresponding points in the two images (e.g. A1 – B1) are conjugate points and each is an image of the other in the corresponding image.

The coefficients in the equations describing the relationship between the coordinates of the two images are found by selecting several conjugate pairs of points and their coordinates are replaced in the analytical expressions of the equations. Thus a system of new equations is obtained, in which the coefficients are unknown. This system is solved and the coefficients are found. In order to have a solution, the system must have the minimum number of conjugate points such that, after substituting with their coordinates, the number of equations obtained is equal to the number of unknown coefficients. Digital geometric conversion changes not only the geometric position of the pixels in the output image, but also the scale of the output image. One of the problems with these conversions is the discrepancy between the pixels of the reference and the converted image. Different types of interpolations are used to solve it [10].

In geometric transformations, it is necessary to determine pairs of conjugate points. Depending on the chosen geometric transformation, the minimum number of pairs of conjugate points is different. In practice, a larger number of pairs of conjugate points is usually determined and the method of least squares is used to determine the transformation parameters. This allows, at the same time as finding these parameters, to obtain an estimate of the accuracy of the conversion. The basic rules that must be followed when choosing conjugate points are:

- The control points on the standard image must not lie on one line, i.e. they must not be collinear;
- It is best that they cover all edges of the image, but it is desirable if possible to have dots in the middle of the image;
- The coordinates of the points must be determined with high accuracy;
- Do not choose conjugate points that are part of tall buildings or hills;
- A good opportunity to choose points give crossroads and places where tributaries flow into rivers.

For each standard point, the residual error after applying the least squares method is calculated, as well as the total root mean square error. These parameters show the accuracy of the analysis.

In the process of crawling search, the "similarity function" between the images of the standard fragment $\{u_0(\mathbf{x}), \mathbf{x} \in \Gamma_A\}$ and the images of the current (controlled) fragments $\{u(\mathbf{x}), \mathbf{x} \in \Gamma_B\}$ is calculated. The similarity function must be found, which allows to locate the fragment corresponding to the image of the standard fragment with the maximum possible accuracy and reliability, thus fixing the conjugate points of the photos. The mutually corresponding elements of the image of one object in the photos must satisfy the ratio (1):

$$u_0(x,y) = (au(x+k, y+l) + b)rect(x/n, y/n) + \varepsilon(x,y), \tag{1}$$

where are a and b are the parameters of contrast and average illuminance; k, l are parameters of the relative displacement of the sample and its analogue from the controlled image, $\varepsilon(x,y)$ is noise.

The differences between the standard and the current image $u_0(x,y)$ и $u(x,y)$ are due to additive noise and geometric distortions, which are modeled by affine transformation of the image coordinates $u_0(\mathbf{x}) = u(\mathbf{Ax} + \mathbf{t})$, where $\mathbf{x} = (x,y)$,

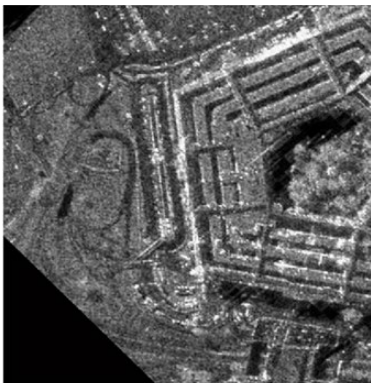
$\mathbf{A}=\alpha\begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}$ is matrix for the relative rotation of the image at an angle θ and α is coefficient of change of scale. The mean peak value of the correlation function of the geometric distortions in the image, normalized to the mean peak value in the absence of distortions, depends on the intensity of the distortions at small angles θ and the magnitude $|1-\alpha|$ and has the form (1):

$$d \approx \sqrt{(1-\alpha)^2+\theta^2}. \qquad (2)$$

Affinity transformation and images matching researches have been performed on synthesized aperture radar (SAR) images, and the conjugate points have been selected interactively [7, 9, 11].

a) current image [13]

b) SAR Image Processing [12]



c) Binding image

Fig. 2 Geometric attachment of images.

Fig. 2 shows two original images which were taken on different dates from different SARs [12, 13]. The binding of the images is done by 5 points with a required minimum of 3 points. The same orientation and location of the objects is shown in Fig. 2b and Fig. 2c. The presence of black fields on the transformed image is due to the fact that in it from the original image (Fig. 2a) remain only those pixels that correspond to objects located on the standard image (Fig. 2b).

Binding images makes it possible to detect objects, determine the position of an object, when its presence is known or at the same time, its presence is determined. As can be seen, the application of affinity transformation gives very good results when attaching images are from SAR. This can be explained by the fact that the SAR is focused simultaneously for all distances and, in fact, all points of the image lie in the focal plane.

The use of linear transformation does not give good results, because the scales on both axes of the images are not the same. This is due to the fact that even if the same azimuth and distance resolution is ensured, the resolution of the image on one axis will depend on the angle between the inclined distance to the point and the plane of the observed terrain.

In optical images, if the altitude is large enough, an affine transformation and even linear transformation can also be used, since then it can be assumed that all points of the image lie in the focal plane. When this condition is not met, it is necessary to use projective transformation, because the parallel lines of the observed terrain will be converted into inclined lines in the image.

2.2. Bind images to a map

When binding an image to a scanned map, the process is same as when binding images. An example of binding an image of an area from the city of Sofia to a map of the same area is shown in fig. 3 [2, 6, 7].

Fig. 3a shows the image of an area of the city of Sofia, formed by Google Earth. In Fig. 3b shows a scanned map of the same area. The difference in the orientation and the scale of the two images is obvious. The binding is performed on four points, using the projective transformation. Fig. 3c shows the image converted and corrected by binomial interpolation. For a clearer comparison of the transformed image and the image of the map, a binary image is formed from the separated contours of the map. The pixels of the contour image have only two values, 1 and 0. This image is superimposed on the converted image. A Laplace filter was used to separate the contours. The imposed images show that the binding was successful. There is an obvious discrepancy between the contours of one section of the map and the image. This is due to an error in making the map.

Successful binding of an image to a scanned map indicates that such maps can be used as standard images instead of orthonormal terrain images. Ordering such images is expensive and not always justified. The map can be used as a standard for geometric attachment of images of the area, taken by various means and equipment.

a) Current image *b) Scanned map*

c) Corrected image *d) Imposed image and map*

Fig. 3 Bind an image to a scanned map.

A special case is when the image is attached to the coordinates on the map. When attaching in this way, the accuracy depends on:

- The spatial resolution of the image;
- The scale / accuracy of the map used;
- The spatial accuracy of the map coordinates must be higher than that of the image - for example, for a spatial resolution of the 10 m, the scale of the map must be at least 1: 20000 and the larger the better.

The maps are made with coordinates, which are taken on the surface of the ellipsoid of the used geodetic coordinate system. The captured image is on the relief above or below the level of the surface of the ellipsoid, which leads to the displacement of objects. The greater the elevation of the objects, the greater the displacement. These displacements are greatest in mountainous areas.

When there is no access to a digital model of the elevation of the captured terrain, only the offset of the control pixels is corrected. This is done before finding the equations for converting the coordinates of the image into real coordinates of the geodetic coordinate system. The height above the reference level must first be set for each control point. Afterwards, the offset of each point on the image is then calculated. Finally, the corrected coordinates of the control pixels on the image are then calculated (the offset in meters divided by the size of one pixel in meters gives the offset in pixels). In order to correct the displacement as much as possible, it is necessary to have:

- Navigation data - the coordinates of the location of the aircraft (usually obtained from GPS) and data on its orientation in space;
- A digital model of the elevation of the captured area;
- Information on the size of the area visible to the camera or SAR;
- Control points for absolute calibration of the location and orientation of the aircraft.

3. CONCLUSION

Geometric distortions that cause geometric errors are due to various sources. These are, distortions due to the input transducers, the curvature of the earth, the relief and the map projection of the resulting (restored) image. The use of affinity image conversion by SAR gives very good results and does not require the use of more complex methods of geometric transformation. Thanks to this transformation, radar images generated at different times and by different aircrafts can be bind. This allows periodic monitoring in an area and, if necessary, an assessment of the damage caused by natural disasters.

When binding images to a map, more accurate information can be obtained about the location of objects. In addition, the maps can be used as a standard image, as a result of which all images of the area can be bound to one coordinate system.

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