Solution of the problem of superposing image and digital map for detection of new objects

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Abstract. The problem of superposing the map of the terrain with the image of the terrain is considered. The image of the terrain may be represented in different frequency bands. Further analysis of the results of collation the digital map with the image of the appropriate terrain is described. Also the approach to detection of differences between information represented on the digital map and information of the image of the appropriate area is offered. The algorithm for calculating the values of brightness of the converted image area on the original picture is offered. The calculation is based on using information about the navigation parameters and information according to arranged bench marks. For solving the posed problem the experiments were performed. The results of the experiments are shown in this paper. The presented algorithms are applicable to the ground complex of remote sensing data to assess differences between resulting images and accurate geopositional data. They are also suitable for detecting new objects in the image, based on the analysis of the matching the digital map and the image of corresponding locality.

1. Introduction
Currently, obtaining images of a terrain by different systems is not a problem: there are available the digital maps built sufficiently detail. However, if we have a fairly accurate map of a particular area and the image of this area, the task can be formed which is linked with discovering new objects in the region described by given map. These might be objects that were previously unknown. Let we have the map of certain area on the one hand and the images of this area made in different frequency bands. An important task may be formulated as follows: to do analysis by superposing them and to find out the differences. To improve the reliability of the results, the image of the area which has been obtained by various sensors may also be superposed with each other. The sensors may be operating on different physical principles or images can be received at different times. Also the following task is solved: to estimate various ways to superpose the obtained images [1, 2]. They may be the fragments of the images which are represented in different spectral ranges regarding the digital local map.

2. Mathematical description of the problem
In practice, the images of the same object or area obtained at different times or by different sensors can differ considerably from one another and from the digital local maps (DLM). Hence several important problems appear. They are the problem of superposing, problem of pegging and problem of precise mutual geometric correction and brightness correction. The solving of these problems should be the base for the subsequent joint analysis. In any case, this requires the establishment of the correspondence between the elements of the original images. It results in need to allocate support points in the image. In other words, they are so called bench mark or conjugate points. Pegging
pictures on coordinates with accompanied simultaneous geometric correction [3,4,5] can be accomplished on using these conjugate points. Pegging may be done on the navigation parameters and using search algorithms that establish a correspondence between elements of images. Let us consider ways of superposing images from the DLM. Since the earth surface image can be obtained at a range of hundreds of kilometers it is necessary to consider the influence of the earth's sphericity [6] as it is shown and demonstrated on Fig.1. As was shown in [7], the angle of the center of the frame - $\gamma$, slant range to the center of the frame DLM and flight height of carrier ($H$) are linked each to other with expression (1), where $D_{CF}$ denotes the center of the frame and $R_E$ is the Earth's radius of the refraction, it is equal to 8,400 km. (1):

$$\sin(\gamma) = \frac{H}{D_{CF}} + \frac{D_{CF}}{2R_E}$$

Thus, the height of the carrier with respect to the center of the frame is given, according to [8], by expression (2):

$$H_c = D_{CF} \sin(\gamma) = D_{CF} \left( \frac{H}{D_{CF}} + \frac{D_{CF}}{2R_E} \right) = H + \frac{D_{CF}^2}{2R_E}$$

The value of the belittling of the point corresponding to the center of the frame [8] may be calculated by formula (3).

$$\Delta H = \frac{D_{CF}^2}{2R_E}$$

Influence of the sphericity of the Earth must be considered when calculating the center of the view area position specified on the MSC, as well as when recalculating area image from one coordinate system to another to display on the monitor.

3. The algorithm for calculating the brightness values of the converted image on the base of navigation parameters
Let we have a rectangular image, which was received in the coordinates "slant range - azimuth". The offered algorithm is reduced to the transformation of this rectangular picture into the polar coordinate system, taking into account the sphericity of the Earth. In this coordinate system, the starting point of the coordinate system corresponds to the position of the carrier and the angular position of the element of image is counted relatively the north [9,10]. As the result of transformation, the image conversion from the Cartesian coordinate system to the polar the image on the screen is formed as the sector represented in Fig.2. To make the conversion for each screen pixel $(r, c)$ the point on the earth's surface with the coordinates $(x, y)$ is calculated and is associated with this pixel. For this point on the earth's surface the corresponding slant range and azimuth of targets are calculated. Based on the calculated value of the azimuth and slant range corresponding values of the number of the strobe and number of the azimuth reference number are calculated.

![Figure 1. Influence of the sphericity of the Earth.](image-url)
A strobe is time interval in the monitor’s reamer to monitor, control, or post-processing. The calculation [11,12,13] is made as the following sequence of steps.

Step 1. The pixel’s number is counted from the upper right corner. The position, which corresponds to it on the ground, may be calculated according to formulas (4) and (5).

\[
X_{\text{car}} = X_I + \frac{zM}{100} \left( r - \frac{N_X}{2} \right), \quad r \in \left[ 1; N_X \right]
\]

\[
Y_{\text{car}} = Y_I + \frac{zM}{100} \left( c - \frac{N_Y}{2} \right), \quad c \in \left[ 1; N_Y \right]
\]

Step 2. On the basis of current coordinates of the position the current horizontal distance to the point is calculated [17] by using formulas (6) and (7):

\[
D_{\text{car}}^2 = (X_{\text{car}} - X_C)^2 + (Y_{\text{car}} - Y_C)^2
\]

\[
D_{\text{car}} = \sqrt{D_{\text{horcar}}^2 + H^2 + \frac{D_{\text{horcar}}^2}{4R_E^2} \left( \frac{R_E}{R_E - H} \right)}
\]

The angular position of a point in the imaging sector counting from the left corner of the image is equal to the result of (8).

\[
AZ_{\text{car}} = \arctg \frac{2(x, y)}{2} - AZ_I + \frac{\Delta AZ_T}{2}
\]

Step 3. The value of image reference corresponding to the current point is calculated according to the formulas (9) and (10) [14].

\[
N_D = \frac{D_{\text{car}} - D_I}{\Delta D} + \frac{N_{CN}}{2}
\]

\[
N_\phi = \frac{AZ_{\text{car}}}{\Delta AZ_T} N_{AZ}
\]

In formulas (9) and (10) \(X_I\) and \(Y_I\) are values of the coordinates of the center of the selected area to form an image in the cartographic coordinates. In the above formulas, the following notations are used:

- \(X_C, Y_C\) – coordinates of a carrier in a plane of rectangular coordinates in meters;
- \(Z_I\) – the azimuth of targeting relatively the direction of the north;
- \(D_I\) – slant range of targeting until the image center of the frame;
- \(H\) – the height of the flight the carrier relative to the surface of the Earth;
- \(N_X, N_Y\) – the dimensions of the image area of cartographical information displayed in pixels;
- \(Z\) – resolution of the indicator.
- $\Delta D$ – image resolution of the range;
- $N_{CN}$ – the number of the channels of the range;
- $N_{AZ}$ – counts the number of images in azimuth;
- $\Delta AZ_T$ – the size of viewing area in azimuth;
- $M_{DLM}$ – the scale of display the map.

If the number of reference on the range or azimuth is outside the existing image values there no image is at the given local point. In this case this pixel is set to 0 [15]. Since the calculated values of the respective sample images are real numbers, the resulted transformed coordinates do not fall mostly in the discrete lattice sites. Therefore, to determine the brightness of the image at the given point of the screen it is necessary to make the appropriate interpolation values in the array "slant range - azimuth" by one of the existing methods [16].

4. The algorithm for calculating the brightness values of the converted image on the base of bench marks

The placement of reference points is carried out manually by the operator. Example of arrangement bench marks is shown in Fig. 3. Consistently placing the appropriate bench marks in the DLM are $(X_{RI1}, Y_{RI1})$. On the image of the area they are represented as $(X_{B}, Y_{B})$, so we get arrays of coordinates of bench marks [7]. Let we have $k$ conjugate points which are placed on the image. On the basis of $k$-spaced conjugate points vectors of coordinates of reference points for local area are formed represented by expressions (11) and (12) [9, 17].

$$X_{RI}=\begin{pmatrix} X_{RI1} \\ X_{RI2} \\ \vdots \\ X_{RIk} \end{pmatrix}$$

(11)

$$Y_{RI}=\begin{pmatrix} Y_{RI1} \\ Y_{RI2} \\ \vdots \\ Y_{RIk} \end{pmatrix}$$

(12)

Also a special matrix of bench marks of the DLM is formed as it is shown in expression (13).

$$H = \begin{pmatrix} 1 & x_1 & y_1 & x_1^2 & x_1y_1 & y_1^2 \\ 1 & x_2 & y_2 & x_2^2 & x_2y_2 & y_2^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_k & y_k & x_k^2 & x_ky_k & y_k^2 \end{pmatrix}$$

(13)

Thus the placement of reference points and formation of the vector coordinates of the image points of the terrain and formation of the matrix of the points of DLM are finished. Thereafter a calculation of the corresponding point of the image for each screen pixel by the formulas (14), (15) is performed [20,21].

$$N_D = a_0 + a_1r + a_2c + a_3r^2 + a_4rc + a_5c^2$$

(14)

$$N_\phi = b_0 + b_1r + b_2c + b_3r^2 + b_4rc + b_5c^2$$

(15)

Figure 3. Example of arrangement bench marks.
The transformation parameters are the polynomial coefficients as represented in expressions (16):

\[
A = [a_0, a_1, \ldots, a_i]^T \quad B = [b_0, b_1, \ldots, b_i]^T
\]  

They are calculated according to formulas (17), where the superscript T denotes transposition of matrix.

\[
A = (H^T H)^{-1} H^T X_{ni}, \quad B = (H^T H)^{-1} H^T Y_{ni}
\]  

Similarly, the image conversion algorithm for navigation settings to obtain the integer values of samples, an interpolation of image samples is necessary to do [18,19].

5. Experimental results

The case of superposing the converted image area in a given coordinate system with a choice of transparency [20,21] is considered. It was performed by using two described algorithms. When superposing the converted image of the area and the DLM, the operator may choose the level of transparency of image layers, it is equal to \( \alpha \). The level of transparency of image layers may be ranged from 0 to 1. The value 0 means fully transparent, when only DLM is available. The value 1 means fully opaque, when only the image area is available. Fig. 4 shows the examples of the superposition of DLM and the local image of the image of the same area with different transparency on the base of navigation parameters. Selection of the transparency coefficient is often complicated by the fact that when superposing each of the layers prevents to the image of other layer [22,23,24]. When transparency of the image is greater, DLM significantly interferes with perception. Low transparency is hampered analysis of DLM. This mode is appropriate particularly in the review of terrains when a detailed, thorough analysis of objects is not required. In this case, the entire object structure and is displayed and there is a possibility to analyze the entire image. Consider overlay vector layers of DLM onto converted bitmap of areas by the algorithm calculating the brightness values of image on the base of placed bench marks. In this case, the image appears opaque, and above it layers of the electronic map are presented.

Fig. 5 shows cases overlay maps in the image of the area. On the right frame on Fig. 5 some of the layers, preventing analysis of the image, are not displayed. Thus, it can be argued that for superposing the image of a local area and DLM using of the algorithm for calculating brightness values of the converted image on the original image on the navigation parameters is permissible for cases when a detailed clarification of the location of objects is not required. For specification position of the image of area on the DLM it is better to apply the algorithm for calculating the brightness values of the converted image on the original image on the base of placed bench marks.

\[\text{Figure 4. Examples of superposing DLM and the image with different coefficients of transparency: a) } \alpha = 0.7; \quad \text{b) } \alpha = 0.8; \quad \text{c) } \alpha = 0.9.\]
6. Conclusion

For high-quality superposing images obtained by various means of observation with map and among themselves it is necessary to eliminate linear and non-linear distortions of the images associated with the features of the systems functioning. To eliminate the distortions it is advisable to use a polynomial transformation, the parameters of which are formed on the basis of current navigation parameters and characteristics of observing systems.

In the calculation of the image transformation parameters obtained at considerable distances (tens hundreds of kilometers), it is necessary to take into account the sphericity of the Earth. Influence of the sphericity of the Earth must be considered when calculating the position of the center of the view area specified on the DLM, as well as in recalculating image from one coordinate system to another when displaying on the monitor. The transformation parameters by placing the conjugate points by an operator and run on the basis of their additional polynomial transformations may be updated. This gives opportunity to do analysis of superposing digital maps and information given by observing systems.

7. References

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