Automated processing of unmanned aerial vehicles images based on conceptual modeling of objective tasks

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Abstract. In this article, the authors proposed a methodology for processing images of unmanned aerial vehicles, based on the conceptual modeling of objective tasks, which allows to increase the accuracy of decoding of forest resources due to the unified description of the conceptual model of the process. The approach is based on a hierarchical structural representation of the process of decrypting the image. The result of the application of the method is the determination of individual contours of tree crowns. The developed method involves the use of the watershed many times for each contour, which made it possible to determine the contours of each tree and at the same time not to miss trees with small crowns. Using the error matrix and the formula for calculating the Kappa Cohen index, the reliability of thematic decryption was evaluated. The developed methodology allowed to improve the identification of objects by 18.6%.

1. Introduction

Information on forest reserves is created and updated to meet the information needs [1] in various fields, from environmental monitoring and public administration of the territory to calculating the economic benefits of logging. For this purpose, forest taxation is carried out as part of forest management and forest conservation work, which is one of the main tasks in forestry.

Updating information on the attributes of forest vegetation objects using remote sensing data is described in many studies of Russian and foreign scientists [2-4]. Most studies consider obtaining information on forest stands from data from satellite images of medium and high resolution. Insufficient spatial resolution of images is an obstacle to obtaining more detailed data on forest objects. In turn, aerial photography of the territories, providing more detailed data, is economically unreasonable to satisfy the informational need about the forest.

To date, alternative methods have been described for obtaining and updating data on objects of forest territories [5,6]. A frequently used and cost-effective source for obtaining attributive information about forest objects is unmanned aerial vehicles (UAV) images [7]. Processing aerial photographs to obtain the necessary parameters of trees from the point of view of forest inventory is a laborious and lengthy process, and therefore expensive. Therefore, the development of methods and algorithms for the automated processing of UAV images in order to obtain attributive information about trees with their subsequent use by specialists in practice is relevant.

To assess the stock of wood in the forest area as an economic indicator of the territory, counting the number of trees by clearly identifying the contours of the crowns is significant. The existing solutions
to this problem do not provide sufficient accuracy in the allocation of crown boundaries [8,9]. In this study, we consider the automated processing of UAV images in order to isolate tree contours based on segmentation by the watershed method and its expansion based on markers. This method has been described relatively recently [10,11] and is still mainly used for recognition of contours on medical images [12,13], studies of the microscopic structure of organic materials [14,15].

The aim of this study is to increase the accuracy of highlighting the contours of tree crowns in highly detailed images from UAVs, which will automatically calculate the wood supply per hectare of forest. One of the problems solved in the work is the separation of the contour outlining densely spaced crowns as a whole. The methodology proposed by the authors for distinguishing tree crown contours improves the watershed method by using conceptual modeling of objective problems.

2. Experimental part

2.1. Characteristics of equipment for shooting and obtained data

As an experimental site for creating UAV images of the forest territory, the Federal State Institution “Northern Forestry Research Institute dendrological garden acted”.

The shooting was carried out by an unmanned aerial vehicle DJI Phantom on a universal GoPro camera with a resolution of 12 megapixels. The standard lens was replaced on the camera with a specialized lens that cuts red light and transmits near infrared.

An experimental survey of the forest territory was carried out at an altitude of 200 meters above the ground. This is the maximum height at which tree crowns can be recognized. The spatial resolution of the obtained images is about 5 × 5 cm.

Before using the obtained images for decryption, it is necessary to eliminate the distortions caused by perspective. To do this, cropping and stitching of UAV images was carried out. One of the resulting image transformations is presented in figure 1.

![Image](image.png)

**Figure 1.** UAV image obtained as a result of cropping and stitching.

The experimental plot is a part of the territory of the arboretum of the Northern Forestry Research Institute of the Arkhangelsk Region. Spruce forests occupy the largest part of the territory (49%), pine forests are half as much (27%), 22% are occupied by birch forests, and 1% aspen trees. The share of
underrepresented species: larch, fir, cedar, alder, willow in the aggregate is 1% of the area covered by forest.

Forest taxation can also be carried out by land, conducting a continuous count, in which each tree is evaluated. But in large areas this method is impossible due to the complexity. Therefore, much attention is currently being paid to improving the algorithms for decrypting images of forest areas.

2.2. Conceptual model development

The technique of conceptual modeling of objective problems [16] allows you to control the logic of solving problems and reduces the number of errors at the implementation stage. This is possible due to strict formalization, the construction of a clear hierarchy of actions and visual ways of presenting information (tables, diagrams). Also, this technique is effective in solving problems in the team. Domain experts compose an algorithm for solving the problem, and programmers who are not even familiar with the domain will be able to implement this algorithm in matrix code on a matrix diagram.

These advantages make the conceptual modeling theory relevant for use in the development of methods and information systems for automated processing of UAV images.

Using the standard method of segmentation by a watershed will not give sufficient quality of interpretation. Depending on the parameters that are set, the result will be either generalized (many crowns will be grouped and counted as one tree) or excessively fragmented (because of the internal shadows, the crown of one tree will be counted as several, as well as small crowns of trees will not be detected at all) [17]. Therefore, it was decided to apply the watershed method in several stages:

1) determination of the contours of the general area of tree crowns;
2) the partition of these areas into the contours of single trees.

At the first stage, markers for the watershed are determined by filtering local maxima.

In a second step, markers will be determined by applying an adaptive threshold based on the average. Such markers can be narrowed. In thin places during narrowing, the markers are torn, forming several from one. But with a small narrowing, it will not be possible to ungroup the crowns, and with a large one, small crowns will be lost. To avoid this, the second stage will be repeated for each contour separately with an increase in the narrowing coefficient until the markers disappear completely. With each such passage, the contour that has been ungrouped will be removed from consideration, and new ones will be added.

In the course of the work, model representations for objective tasks were compiled:

- “Primary definition of contours”;
- "Secondary definition of contours";
- “Ungrouping of contours” (an intermediate task responsible for the cyclical solution of the problem “Secondary determination of contours” for each circuit separately).

During development, these model representations were used to write the corresponding functions of the program.

The result of conceptual modeling is the formation of a matrix diagram that reflects the representation of the task “Primary determination of contours” as a whole. It is presented in figure 2. For elementary actions, their role is replaced by the sign: “+” for the argument, “.” for the default argument, “*” for the function. The matrix contains the following notation “[“- sequence header, “]” - last action of the sequence, “{“- loop title, “}” - end of loop, “!” - cycle body, “$” - loop function, “?” - switch header, “/” - switch alternative, “#” - switch function.

The matrix diagram allows you to visually show the relationship of objective actions (rows) with parameters (columns). Designations at the intersections of rows and columns give ideas about the structures: sequences, cycles, conditions, input and output parameters of the function. The matrix diagram allows you to control the correctness of the sequence of actions. For example, if a parameter has an opening bracket (the beginning of a sequence or cycle), then it must have a closing bracket (end of a sequence or cycle), which is located on the lower line. According to the matrix diagram, it is easier to program the task, since the basic structures and sequence of actions are already defined.
2.3. Methodology
As a basis for the development of a technique for automated processing of UAV images, we selected the methods of the watershed and filtering of local maxima. The watershed method can give a good result if correctly selected markers. These markers can be obtained by filtering local maxima. When shooting densely populated forests in the daytime, the illuminated crown tops of trees, that is, their centers, will have the greatest brightness.

As a result, the developed technique consists of a primary definition of the contours and their further ungrouping, which includes a secondary definition of the contours.

The initial definition of the contours consists of the following sequence of actions:
1) image preprocessing (translation in grayscale, Gaussian blur);
2) the formation of markers (applying a threshold value, calculating the Euclidean distance transformation, determining local maxima);
3) application of the watershed method;
4) extraction and approximation of all circuits.
The ungrouping of the contours is performed for each contour obtained during the initial determination. It consists of the following sequence of actions:

1) setting the initial coefficient of narrowing;
2) cutting out the area inside the contour from the original image;
3) secondary circuit definition;
4) if the separation has occurred, then the resulting contours replace the original;
5) repeating steps 2-4, increasing the narrowing coefficient, until the secondary definition of the contour ceases to find contours.

The secondary definition of the contours consists of the following sequence of actions:

1) image preprocessing (color mixing, grayscale conversion);
2) the formation of markers (applying a threshold value, expanding an image, calculating the Euclidean distance conversion, applying an adaptive threshold based on the average value, narrowing the image, removing noise);
3) application of the watershed method;
4) extraction and approximation of all circuits.

Figure 3 shows the steps for ungrouping a circuit.

Figure 3. (a) an example of an input image of a single circuit, (b) an example of a threshold of a fixed level, (c) an example of expanding a picture, (d) an example of a normalized Euclidean distance transformation, (e) an example of an adaptive threshold based on an average value, (f) an example of narrowing a picture, (g) an example of the result of work watershed algorithm.

To develop a module that automates the process of extracting tree crowns in a UAV image, the Python programming language was chosen, since it has compact syntax and many libraries (including for working with computer vision and geospatial data). To visualize the results of the module, the geographic information system QGIS (QGIS it's a name for free and open source Geographic Information System) was used with the module to assess the reliability of decryption. The result of the module is shown in figure 4.
3. Evaluation of the results

The aim of the work is to increase the reliability of the interpretation of UAV images due to the development of automated processing techniques. This technique is based on the watershed method, so a comparison is made with it.

To evaluate the quality of splitting the image into trees and the rest of the area, the decryption error matrix is used. The error matrix is based on a comparison of the control (reference) identification result with the result obtained using the developed technique. The matrix allows you to take into account not only the classification error for each class, but the errors associated with incorrect classification. The evaluation process includes:

- creating a matrix, the dimension of which is determined by the number of classes, by comparing the reference pixels with those classified on the image;
- calculation of statistical accuracy estimates in percentage terms, based on the results of comparisons recorded in the matrix [18].

There are currently no ready-made solutions for the automated processing of UAV images, therefore, there are no high-resolution image decryption results, including for the dendrological garden of the Northern Federal Research Institute of Forestry, which were used for testing on the territory. A Shapefile was created for which all the crowns of the trees in the image were manually circled. This file is the benchmark for evaluating the reliability of thematic decryption.

The error matrix can be built using the plugin "Accuracy Assessment" for the QGIS system. But before using it, it is necessary to pre-process the research data. There are three SHP format files: standard, results obtained by standard watershed methods and developed methodology. They need to be rasterized with the built-in QGIS tool, preserving the pixel dimensions of the original image, because for evaluation you need to compare the pixels, and Shapefile is a vector format. And then, using the module "Accuracy Assessment", select the standard and layer for comparison. The error matrix is saved in CSV form. The decryption results are presented in table 1.
Table 1. Decryption Error Matrix.

| Reference data | Total | Decryption results | Standard watershed method | Developed methodology |
|----------------|-------|-------------------|---------------------------|-----------------------|
|                |       | The trees         | The rest of the area      | Confidence indicator  |
| The trees      | 220029| 160378            | 59651                     | 72.9                  |
| The rest of the area | 155367| 11258             | 144109                    | 92.8                  |
| Total          | 375396| 171636            | 203760                    | 81.1                  |

The trees 220029 160378 59651 72.9 178279 41750 81.0
The rest of the area 155367 11258 144109 92.8 8228 147139 94.7
Total 375396 171636 203760 81.1 186507 188889 86.7

The decryption confidence indicators given in the error matrix may be random. To take this fact into account, when summarizing the results, the Kappa Cohen index is used, which corrects for chance. To calculate it, you need to know the number of random results, which is calculated by the formula (1).

\[ q = \frac{\sum n_i n_r}{N} \]  

where \( q \) – number of random results; \( n_i \) – the number of random results in the columns of the error matrix; \( n_r \) – the number of true results in the rows of the error matrix; \( N \) – total number of pixels;

\[ q_1 = \frac{171636 \cdot 220029 + 203760 \cdot 155367}{375396} = 184931; \]
\[ q_2 = \frac{186507 \cdot 220029 + 188889 \cdot 155367}{375396} = 187493. \]

The Kappa Cohen index is calculated by the formula (2).

\[ k = \frac{d - q}{N - q} \]  

where \( k \) – Kappa Cohen index; \( d \) – the number of cases the correct result; \( q \) – number of random results; \( N \) – total number of pixels;

\[ k_1 = \frac{(160378 + 144109) - 184931}{375396 - 184931} = 0.628; \]
\[ k_2 = \frac{(178279 - 147139) - 187493}{375396 - 187493} = 0.734. \]

The classification reliability indicator in the given example by the standard method of the watershed is 62.8%, and by the developed method - 73.4%. The developed technique for the automated processing of UAV images made it possible to increase the reliability of thematic decryption by 10.6%. Of the 113 trees shown in the image, 59 (52.2%) were correctly determined using the standard watershed method, and 80 (70.8%) were correctly determined by the developed method. The main problem of the standard method is that it defines large trees with inner shadows as a group of several. The developed methodology allowed to improve the identification of objects by 18.6%.

4. Conclusion

The proposed approach to the automated processing of UAV images through the application of the theory of conceptual modeling of objective tasks makes it possible to uniformly present both the information and functional components of the model of the image decryption process. A unified way of describing a set of tasks reduces decryption errors associated with the human factor. The results obtained exceed the result achieved by the original method of the watershed during image processing due to the hierarchical structure of its application described in the conceptual model of the problem.

The reliability of thematic decryption by the developed technique was estimated using the error matrix and the Kappa Cohen index calculation formula. Compared to the standard watershed method
with markers, the new technique increased the reliability of thematic decryption by 10.6% in the Kappa Cohen index. Also, an assessment of the quality of identification of each tree established that the developed methodology improved the identification of objects by 18.6%.

The developed system can be used by organizations in the forest industry.

The introduction of development for forest resources accounting will allow: to reduce costs by reducing the staff of employees involved in this task; increase the accuracy of the solution due to the lack of human factor; reduce the time to solve the problem.

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