Development of methods for automated determination of forest resource parameters using multispectral survey data from unmanned aerial vehicles

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Abstract. One of the most essential renewable resources in the world is the forest. An important issue in the forest industry today is the lack of relevant, reliable and regularly updated information on forest resources. Over the years, this problem has been addressed through labour-intensive field methods. However, in a competitive market and development of high-tech data collection and analysis tools, another issue becomes apparent — the low reliability and detail of the existing remote automated tools of data acquisition on forest resources. The research presented in this article is aimed at addressing this issue. The results of the work built on modern methods and approaches will provide an impetus for the introduction of digital technologies to many business processes of the forest industry.

1. Introduction
The technological cycle in the forest industry involves many steps: from timber harvesting to final production. Forestry processes both in Russia and most foreign countries use a traditional approach to accounting, updating and using information about forest resources. However, in a competitive environment, there is an urgent need to introduce new means of data collection and processing. This is understood by many enterprises of the forest complex through introducing automation and informatization of existing business processes: electronic cartography instead of paper forest plans, support systems for forest machines and much more [1].

Since the inception of forestry, forest stands accounting was carried out in a summarized form. Besides, the fact that forest management was carried out long ago also affects the reliability of data, which are rapidly losing their relevance without regular updating.

Development of technologies for the electric charge accumulation, electronics, emergence of new materials, as well as technical improvement of unmanned aerial vehicles (UAVs), digital cameras and accurate location systems give rise to new means of collecting relevant information on forest resources. However, the listed technical and technological innovations can not bring changes to the existing model of economic activity without the development of effective methods of processing, analysis and interpretation of the obtained highly detailed data [2, 3].
2. Methods and Materials

2.1. Equipment selection
Carrying out scientific research, the necessary technical equipment was used. Air photography was performed using a rotary UAV. Based on the parameters of the selected aircraft, compatible accessories were selected - a suspension and a camera. The brushless three-axis suspension for UAVs allows to compensate for the tilt of the device during flight, imaging exactly in nadir.

The experience of using digital shooting with UAVs in the visible range suggests that different reflectivities are characteristic for different tree species. The study [4] showed that the greatest difference in spectral reflectance of the main forest-forming species is observed in the green (500-600 nm) and near-infrared (700-800 nm) ranges. Therefore, performing digital shooting in these ranges is most appropriate. Hence, in this study, to obtain aerial survey data from UAVs, a specialized digital camera was used, capable of capturing reflected sunlight in the ranges of 400-580 nm and 690-790 nm.

2.2 Territory selection and aerial survey
The territory of the Kholmogorskoje lesnichestvo in the Arkhangelsk region was chosen as an experimental training ground for the research, where 10 circular test sites were selected, 400 m² each, comprising more than 389 individual trees of different ages and species.

This site was chosen for the reason that the stands growing on it are not affected by human activities and natural fires. A variety of species and ages of trees was presented on the site, which is necessary for full testing of the developed approaches and methods.

An experimental survey was performed at heights of 100, 200 and 300 meters above the ground. For the set of used technical means of shooting, the maximum height at which the crowns of trees are distinguishable was 100 meters. Subsequently, the survey was carried out at this height with 50% overlapping frames.

2.3 Method of identification for individual crowns
The study proposes a method for automated tree crown allocation according to aerial survey data obtained from UAVs. The method includes a set of image processing algorithms applied sequentially to the original image.

Figure 1 shows the initial fragment of the image from the UAV, which depicts the forest area; the spatial resolution of the image is 5 centimetres per pixel. The image shows the crowns of trees and inter-crown spaces.

Figure 1. Original UAV image
An ASF filter with a window size of 2 pixels was applied to the image fragment. This image filtering method relates to algorithms for morphological processing of a raster [5]. Using this type of filtering, we have smoothed out the original image and achieved an improvement of the information content of the image while maintaining its topology. The next step was to determine the local maxima of the brightness of the raster.

Subsequently, the watershed segmentation was applied to the image. Using this method, the raster is represented as a three-dimensional surface, the points of which are given by two spatial coordinates, and the brightness level acts as a height.

An application of the segmentation algorithm for watersheds often leads to the effect of excessive segmentation caused by noise and local extrema in the image. This means getting a huge number of areas allocated during segmentation. An excessive segmentation can be so significant that it makes the result virtually worthless.

The approach used to control excessive segmentation is based on the idea of markers [6]. A marker is a connected component that belongs to an image. In our case, the previously selected local brightness maxima of the raster were set as markers. The proposed methodology results in a set of automatically obtained tree crown contours in the forest.

After obtaining the image with the selected contours of the crowns, the vectorization of the obtained contours was carried out with the aim of integration and subsequent processing in the geographic information system. Using the vector layer of the contours of the crowns allows calculating the diameters of the crowns of individual trees and the density of crowns.

The method of allocation of the individual trees’ crowns in highly detailed aerial photographs with UAVs was described by the authors in the study [7] in detail. The result of such processing is shown in figure 2.

Figure 2 Vector layer of the contours of the trees’ crowns superimposed on the original image.

To evaluate the reliability of the method, a test run was performed at test sites with fixation of such parameters as coordinates, height, trunk diameter, and species. A vector cartographic layer was created including all trees defined in the field and their characteristics. This layer was used as a reference for assessing the reliability of the automated method. Using a reference layer, the calculation of correctly identified trees was performed. Reliability was calculated as the percentage of trees correctly identified by the image of their total number at the test sites.

In this example, the total number of trees was 389 pcs, 341 pcs of which were correctly identified from the image. The total reliability of the method was 87.66%.

The main sources of error were the high cohesion of the crowns of several closely standing trees and difficulties in identifying the undergrowth. To address these issues and increase reliability,
experimental work is currently underway on the use of aerial photographs from the spring-autumn leafless period.

2.4. Method of spectral analysis of selected crowns

The main forest-forming species of the taiga zone differ significantly in the level of spectral reflectivity in the green (500-600 nm) and near-infrared (700-800 nm) ranges. The approach used to determine the species composition of stands is based on this property.

The digital image taken by the camera can be represented as a combination of near-infrared, green and blue components (NIR-G-B). This allows calculating the brightness of the pixels in each of the components. The obtained survey data was automatically calibrated taking into account the illumination. The brightness of the pixels was presented in the form of a reflection coefficient, which can take values from the range [0; 1].

The coordinates of trees belonging to the main forest-forming species of the taiga zone – pine, spruce, birch, aspen – were noted on the terrain. For the crown contours of the marked trees, the reflection coefficient was calculated in three components: blue, green, and near-infrared (NIR). Average coefficients for these rocks are presented in table 1.

| Species | Blue  | Green | NIR  |
|---------|-------|-------|------|
| pine    | 0.051 | 0.15  | 0.74 |
| spruce  | 0.052 | 0.132 | 0.67 |
| birch   | 0.06  | 0.3   | 0.95 |
| aspen   | 0.06  | 0.26  | 0.88 |

Since the main forest-forming species have different reflection coefficients in the spectral ranges recorded by the camera, it should be possible to classify the contours selected at the previous stage of the study as trees belonging to the corresponding species.

After calculating the average reflection coefficient for each contour in the test section, we have assigned the value “breed” to each circuit, following the values given in table 1. As a result, we have obtained a map of the species composition of the territory with the species of each tree. In figure 3, pine is marked in orange, spruce – lilac, birch - blue. Thus, the proposed method allows us to determine the reflection coefficient in the blue, green and near-infrared range.

![Figure 3. Contours of trees indicating the species.](image)

To assess the reliability, an approach similar to that described in paragraph 2.3 was used. The reference data for the tree-by-tree conversion of the terrain was compared with the data on the tree.
species obtained using the developed automated method. Of the 389 trees in the reference layer, the breed was correctly interpreted for 355 trees, which corresponds to a reliability of 91.26%.

2.5 System of dependencies between features determined by detailed digital survey data and forest parameters

The methods developed in paragraphs 2.3 and 2.4 for the automated identification of crown contours and interpretation of tree species can certainly make the process of updating forest stand data much more effective. However, the fact that the data on the location and tree species is insufficient to solve practical issues and update forest information is also obvious.

Therefore, when interpreting other parameters from highly detailed aerospace images, it is necessary to take into account the long-term statistical data and dependencies collected by experts in the field of forestry. However, there is a serious problem of integrating this data for automated processing on a computer. One of the solutions can be the application of methods for structuring knowledge about terrain objects, their properties and relationships, along with the developed methods for interpreting objects in digital detailed images from UAVs.

To organize this kind of knowledge in the form of a structure, the use of an ontology apparatus is proposed since this dynamically developing tool allows to visually organize and present knowledge about systems of terrain objects and survey data in the form of a model of "objects, properties, relationships", and flexibly manipulate the knowledge. The strengths of this apparatus also include the possibility of convenient integration of knowledge structures from different subject areas [8, 9].

The ontology-based structural model includes classes (concepts), class properties, relationships, functions.

Classes or concepts is a broad concept that can be represented by any object. A class is an abstract group, may include other classes or subclasses. Classes are a taxonomy - i.e. hierarchy of attachments inside the relation. Each class has properties, for example, name, type, restriction, etc. Subclasses inherit the properties of parent classes. Relationships represent the kind of associations between domain concepts. Most relationships connect two concepts, the so-called binary relation. The most common type of relationship used in all ontologies is the categorization relation, that is, the assignment to a specific category. It allows determining which objects are members of object classes. Functions are a special case of relationships in which the n-th element of a relationship is uniquely determined by the n-1 preceding elements.

The subject area of this work includes:
- territory - we will call it the System of Territory Objects, STO;
- detailed image from UAV of this territory – the System of Objects of a Detailed Image, SODI;
- external data sources – the System of Objects of External Data Sources, SOEDS.

The main classes in STO are forest, soil, water and infrastructure objects.

The Forest class has a nested structure; it includes a subclass of Area (a group of trees), which includes a subclass of Tree.

The Concept ‘Tree’ has the following properties: species (meaning: pine, spruce, birch, aspen), age, height, trunk diameter, crown diameter, trunk volume, the average distance to neighbouring crowns.

STO objects, their properties and relationships are determined by the tasks of forestry, in particular, by identifying the taxation characteristics of the forest.

The main classes in SODI are Point, Line, Polygon.

The classes considered can be represented as a system based on the ontology (figure 4).

The Polygon class has the following properties: spectral (reflection coefficient) and geometric (area, diameter, polygon coordinates, the average distance to neighbouring crowns).

The main class in SOEDS is the Materials of the previous taxation class, represented by maps of the previous forest inventory and a description of them, Bonitet (quality class) and Forest Type.

The developed system displays the relationship between decryption features (SODI objects) and taxation indicators (STO objects).
Figure 4. A system based on the ontology.

In figure 4, the classes are represented by rectangles, the properties of the classes – by circles, the connections between objects are indicated by solid lines with arrows. For example, the Average spectral brightness property of the SODI Polygon class is used to calculate the Species property of the STO Tree class. Functional relationships are indicated by dashed lines.
An example of a functional relationship is the calculation of the diameter of the trunk. This requires data on the diameter of the crown and the average distance between the crowns. Conditionally, the diameter of the crown can be found by the area of the crown (which is quite simply calculated according to the available contours of the crowns in the vector layer).

Based on the fact that the crown has a rounded shape (provided there is no overlap of the crowns), we calculate the diameter of the crown according to the following formula:

\[ D_{cr} = \frac{\sqrt{4S}}{\pi} \]  

(1)

where, \( D_{cr} \) – crown diameter, m; \( S \) – polygon square, \( m^2 \).

The authors conducted a study of the relationship of crown diameter with taxation-decryption indicators of the stand [10]. The result is shown in the following multiple regression equation (1).

\[ D_{1.3} = a + x1 \times H + x2 \times D_{cr} \]

(2)

where, \( D_{1.3} \) – diameter at chest height, cm; \( H \) – tree height, m.

Another example of a functional relationship is the calculation of the trunk volume. Using the previously obtained diameter values at chest height \( D_{1.3} \), it is possible to calculate the volume of tree trunks according to the formula (2):

\[ V = 0.001 \times d_{1.3}^2 \]

(3)

where, \( V \) – trunk volume, \( m^3 \).

To calculate the age and height of the tree, it is necessary to use the data of the growth progress tables \( T \) of the full stands of the North-West of the European part (zones of the northern and middle taiga) [11]. Having determined the tree species from the image (the value of the Average spectral brightness property), we select a table with the corresponding breed. In it, according to Bonitet (quality class), which is determined according to the data of previous taxation materials, and the value of the diameter of the trunk, we will find the Age and Height property.

3. Results and Discussion

3.1. Results

The result of the work is the methodology that allows to reliably identify the contours of individual trees, interpret the diameter of the crown, species, wood stock, age, and the height of the forest stand. The methodology includes the method of identification of individual crowns, the method of spectral analysis of selected crowns, as well as the system of dependencies between the attributes determined by the detailed digital survey and the parameters of forest resources.

The methodology was implemented as a software tool in the Python programming language, which allows automated processing and interpretation of a detailed image from a UAV.

The above results have high practical importance and will be used in the forest industry to update and detail forest accounting materials. The results of the work will contribute to the digital transformation of business processes at the enterprises of the forest complex and become an element in building a digital economy.

3.2. Discussion

The presence of volumetric functionality presented in modern software products designed for thematic processing of remote sensing data often does not guarantee the rapid receipt of accurate and reliable information about the territory. In many cases, the development of specialized methods and algorithms aimed at solving a highly specialized issue is required. The article presents such an example – the method for obtaining data on the stock of forest stands from data from UAV surveys.

The described in the work and similar developments will significantly accelerate the process of thematic interpretation and updating of data on forest resources and improve the reliability of the
information on forests due to the emergence of new means of surveys and new methods of treatment of received space images.

4. Conclusion
The authors of the article described a methodology for updating data on forest resources based on detailed aerial survey data. This methodology can be useful for automating the process of thematic interpretation of orthorectified images with a spatial resolution of 5-10 centimetres per pixel. The experiments presented in the article were carried out on images of closed forests in the north of the European part of Russia.

Future research is expected in the direction of developing algorithms for separating crown complexes into individual crowns, determining the characteristics of the second tier of the forest for even more reliable determination of the parameters of the forest.

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