Automated Forest Inventory and Integrated Digitalization of Wood Resources

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Abstract. The article is devoted to solution of the issue of automated forest inventory and digitalization of wood resources by means of technical tools of distance probing of the Earth, methods of analytical decoding of forest canopy indicators and application of information-reference systems of forest taxation normative standards related to complex estimation of wood resources.

1. Introduction

At the present development stage of IT technology, it has become possible to expand characteristics defining foremost a structure of wood resources of each particular forest stand: its commodity-money potential, biological productivity of forest stand according to its biomass fractions, bark, needle-foliation branches and leaves, roots, carbon sequestration and a bio-energetic potential of forest stands in general.

The key element of the automated evaluation and inventory of wood resources is usage of aerial photographs. Nowadays the most advanced technology of forest management fieldworks is a combination of land taxation of stands with analytical decoding of aerial photographs, which reduces labour intensity of land taxation twice, thus increasing labour productivity of an engineer-taxator by half. The most well-known methods of wood distance inventory are air taxation from a plane or a helicopter, cameral decoding of forest canopy based on aerial photographs, lazer taxation of wood from planes, equipped with lidar, space shooting of woods with interpretation of forest canopy based on multiband aerial photographs, thermal shooting of forests [1].

V.I. Arkhipov and his co-authors underline that nowadays there is no highly productive technology of distance inventory of forests in Russia, whereas it is necessary to carry out annual forest inventory on the area of not less than 30 million hectares according to different estimations of experts. Besides, forest inventory by means of land methods does not satisfy information requirements on wood resources on the allocated level in the specified amounts. There is an imperfection of the existing hardware and software means to obtain and process data of distance probing of the Earth, as well as lack of scientific-methodic decisions in order to decode taxation characteristics of stands. To eliminate the said deficiencies, the technology of forest taxation by means of decoding method «From shooting – to the
project» is suggested, which according to its authors increases labour productivity of an engineer-taxator by 2–3 times [2, 3].

It should be mentioned that the suggested technology requires considerable material expenses due to a highly priced equipment, needed for shooting, respective software to process it, as well as high qualification of its executor. The authors outline that the said deficiencies are compensated by a high productivity of works. The suggested technology is reflected in the existing forest management instruction by means of a new decoding method of forest inventory, namely—“Analytical-measurement decoding of stereo photographs” [4].

Research in distance methods of forest inventory is actively implemented abroad. A group of researchers from Croatia have compared results, obtained by means of land method of taxation and by means of aerophotogrammetric survey [5]. It has been noted that the aerophotogrammetric method equals the land method. The most precision is achieved if data obtained at resolution of less than 30 sm/pixel is used. In the later publication of the authors [6] it is stated that there were twice as less mistakes in determination of an average diameter and volume of growing stock based on the survey data with spatial resolution of 10 sm/pixel. Regarding other characteristics of forest stand, such as an average height or a sum of basal area, evaluation precision is approximately similar. Moreover, the authors claim that in both cases understatement of trunks amount and overstatement of an average diameter of forest stands is comparable to the data obtained at field survey. It is related to the fact that outlines of tree crowns, located in the lower part of a canopy, are vaguely seen on the photographs.

A group of researchers from Sweden evaluated a species diversity of forests by means of non-parametric modelling of stands composition according to multispectral aerophotogrammetric data [7]. The authors state that processing methods of multispectral photographs, as well as data availability of stands height and surface topography expand possibilities for automated collection and processing of data. Comparison of data of main taxation characteristics obtained at land and distance measurement points out an acceptable precision of distance methods of forest inventory.

In the work of P. Tompalsky and others [8] it is claimed that despite certain difficulties related to a limited visibility of land surface under dense stands, a digital aerophotogrammetry allows to obtain three-dimension point clouds which is acceptable for evaluation of taxation characteristics of forest stands.

I.V. Tolkach and others [9] completed a comparative estimation of average heights of forest stands, measured in nature with the data obtained by means of aerophotogrammetrical processing upon making a digital model of heights (DMH). A conclusion regarding a high precision of determination of average height of forest stands by a photogrammetric method has been drawn. The authors recommend to use DMH when a forest inventory is carried out in not easily accessible areas, as well as in areas polluted by radionuclides.

Researchers from Norway outline an advisability and a lower cost of works maintenance with aerophotogrammetry compared to an air-lazer scanning (LiDAR). It is pointed out that such type of shooting has a lesser precision but determination of average taxation characteristics in terms of resulting data appears to be quite acceptable. A significant advantage of aerophotogrammetry is getting a side-product as multispectral ortophotomaps, which allow to make automated decoding process of species composition. The authors claim that due to the fact that results of correlation of field measurements and decoding features on decoding fields there arises a possibility of working out evaluation models of taxation characteristics of typical forest stands. It serves as a basis for correction of normative standards of average taxation indicators of forest stands based on aerial shooting. Such approach to forest inventory is called an area-based approach (ABA) [10].

J. Pearse and others [11] specify that height models obtained from sputniks have a lower accuracy upon determination of heights of forest stands, compared with aerial shooting, although they provide a large scale inventory of forests. This statement is quite reasonable and underlines an advantage of application of aviation survey methods than space methods.
K. Fankhauser and others [12] emphasize pilotless aviation systems among aviation means of obtaining aerial photographs, as they provide fast, reliable and reproducible collection of data for processing.

As D.M. Chernikhovsky and others [13] claim that application of distance methods within the framework of scientific and industrial tasks is one of the prioritized directions upon carrying out a wood resources inventory of Russia, which underlines a significance of the mentioned research.

Foreign specialists from Spain, Norway, Austria, Germany and England [14] emphasize an important role of research for forest inventory, evaluation of spatial structure of stands, distribution of trees according to width and dynamics of productivity of forest stands in time. They note a high labour intensity and cost of implementation of land (nature) taxation of forest stands, underlining a necessity to increase amounts of forest inventory works. In order to solve this global problem a scientific community is required to work out a complex of prioritized scientific tasks in the field of distance inventory of forest, applying economically reasonable technologies.

In the publication of D.M. Chernikhovsky and others [15] it is mentioned that application of automated methods of decoding of forests based on materials of aerial shooting is limited, both in massive (continuous) and selective inventory of stands.

Significance and importance of the problem of automated forest inventory is obvious and is specified in normative legal documents, outlining the main directions and principles of branches of the country economy, including forest sector:

1. The Order of the President of the Russian Federation “On Strategy of development of information society in the Russian Federation for 2017–2030”.

2. Decree of the Government of the Russian Federation №1632-p dated 28 June 2017 on approval of the program “Digital economy of the Russian Federation”.

3. List of instructions of the President of the Russian Federation on results of the meeting held on 29 September 2020 regarding issues of development and decriminalization of the forest complex.

The specified documents require the management bodies of the forest complex to implement technological modernization and incorporation of scientific and technical solutions in industry, providing automation of complex evaluation, inventory and usage of wood resources.

The purpose of this work is to use technological platform of a distance probing of the Earth, analytical decoding of forest canopy structure and an automated evaluation of taxation indicators of stands, using IT portal of information-reference systems of forest taxation normative standards (IRSFTS) for a complex evaluation of wood resources.

2. Research methods
The analytical review of the technical solutions, constituting a basis of the technological platform with description of mathematical models and ecological standards of growth, structure and productivity of forest stands, is written in detail in the works [16, 17, 18, 19, 20, 21].

The general scheme of implementation of automated forest inventory of a specific subject of the RF with a complex evaluation of wood resources on forest taxation divisions is shown in figure 1.
Figure 1. General scheme of algorithm of a distance inventory of stands and complex evaluation and inventory of wood resources of the RF subject (V.K. Khlustov 2013).

Contents of the algorithm of a distance inventory of a wood resource complex.
I. Classification division of a territory of the Russian Federation subject:
1. Forest zoning of the RF subject – multidimensional group of forest divisions according to the blocks of indicators:
   - Potential productivity of soils (X1–X4);
   - Climate characteristics (X5–X17);
   - Content of areas occupied by different categories of lands and objects (X18–X28);
   - Content of areas of forest types (X29–X33);
   - Productivity level and canopy density of forest stands of forest types (X34–X39);
2. Object of forest management (economic agent).
3. Landscapes’ map (soil map).

II. Block-scheme of GIS-technologies, aerial shooting and contour and analytical decoding of indicators:
1. Construction of forest cutting area and forest growing conditions: trophotops (X1), gigrotops (X2), land capability (X3);
2. Taxation indicators of forest stands: upper height (X4), density (X5), species composition (X6).
3. Zoning complex of electronic forest taxation normative standards upon forest elements:
   - Block of current actualization of taxation indicators of forest stands and its growth course (U1–U11);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes (U12–U14);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U15–U20);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U21–U23);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U24–U26);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U27–U29);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U30–U32);
   - Block of current actualization and age-specific dynamics of distribution of trees according to depth classes of wood, fuel wood and waste (U33–U35).

4. Description of the algorithm of a distance inventory of a wood resource complex.
   I. Forest zoning of the RF subject – multidimensional group of forest divisions according to the blocks of indicators:
      - Potential productivity of soils (X1–X4);
      - Climate characteristics (X5–X17);
      - Content of areas occupied by different categories of lands and objects (X18–X28);
      - Content of areas of forest types (X29–X33);
      - Productivity level and canopy density of forest stands of forest types (X34–X39);
   II. Object of forest management (economic agent).
   III. Landscapes’ map (soil map).
3) Block of current actualization and age-specific dynamics of trees’ height, volume of trunks and output of coarseness categories of wood, fuel wood and waste (U15–U20);

4) Block of current actualization and age-specific dynamics of distribution of stock and coarseness categories of wood, fuel wood and waste (U21–U25);

5) Block of current actualization and age-specific dynamics of indicators of biological productivity of trees (trunks, branches, bark, needles/leaves, roots) (U26–U30);

6) Block of current actualization and age-specific dynamics of distribution of indicators of biological productivity of trees (trunks, branches, bark, needles/leaves, roots) according to depth classes (U31–U35);

7) Block of current actualization and age-specific dynamics of distribution of carbon distribution (trunks, branches, bark, needles/leaves, roots) according to depth classes (U36–U45);

In the regional scheme of the distance inventory of stands the multi-dimension resource-ecological zoning of the RF subject is implemented, which groups forest divisions according to 39 characteristics. It should be mentioned that such schemes of zoning should regulate appointment of forest procedures, related to ecological factors, structure of lands of the forest fund, structure of forest types, and their productivity. For example, for the territory of the Ryazansky region for 39 resource-ecological indicators six forest districts are credibly outlined (figure 2).

At the next stage an object of forest management is defined, for which it is necessary to carry out works related to distance zoning of the Earth to make automated decoding of forest canopy and evaluate taxation indicators of forest stands required for complex evaluation of wood resources.

![Figure 2. Map-scheme of complex forest zoning of Ryazan region, made according to 39 resource-ecological indicators.](image)

The main technological element of the automated inventory of stands is based on methodical requirements of obtaining of initial data of distance zoning of the Earth, including the following materials:
orthophotomap with resolution 8 (15*) for pixel, color RGB + NIR range with resolution 1m on pixel in a rectangular reference system (for example, WGS84 UTM)
height model of stands in a rectangular reference system with resolution not more than ±1m (grid size for young stock 0,3 m, for maturing forest and mature forest stand 0,5m)
points cloud in the format LAZ (LAS) a rectangular reference system (points density not less than 30 points on square meter)
vector layer of quarters in the same a rectangular reference system.
In order to work out an orthomap and obtaining of a digital model of stands it is required to comply with the indicators of maintenance of aerial shooting, which correspond with photogrammetrical method and method of air-lazer scanning (ALS), specified below.

1. Requirements to indicators of aerial shooting upon photogrammetrical method:
   - Aerial photographs of visible range (RGB) with spatial resolution in the shot center not more than 6 sm for pixel
   - Multispectral photographs of visible range and short range of RGB+NIR with spatial resolution in the shot center not more than 0,1 m per pixel
   - Photography center with precision of evaluation of the center coordinates not more than 0,1 m
   - Characteristics of slabs (longitudinal – 85%, latitudinal – 60%)
   - Requirements to ISO (100–800 units)
   - To do shooting on total cloud coverage or on cloudless days.
2. Requirements to aerial laser scanning indicators and a photogrammetrical method:
   - aerial photographs of visible range (RGB) with spatial resolution in the shot center not more than 12 sm per pixel
   - multispectral photographs of visible range and short range of RGB+NIR with spatial resolution in the shot center not more than 1 m per pixel
   - Photography centers with precision of evaluation of the center coordinates not more than 0,1 m
   - Characteristics of slabs (longitudinal – 75%, latitudinal – 50%)
   - Requirements to ISO (100–800 units)
   - To do shooting on total cloud coverage or on cloudless days.

Indicators of aerial laser scanning:
- density of points of a lazer scanning not less than 1 point per 1 square meter;
- fixation of not less than two reflections;
- precision of planned coordinates of lazer reflection points - 20 cm;
- precision of height coordinates of lazer reflection points - 20 cm.

In order to work out a digital model of stands with identification of forest stands, using aerial laser scanning, it is required to comply with the indicators of maintenance of aerial shooting:
- multispectral photographs of visible range and short range of RGB+NIR with spatial resolution in the shot center not more than 1 m per pixel
- Photography centers with precision of evaluation of the center coordinates not more than 0,1 m
- Characteristics of slabs (longitudinal – 70%, latitudinal – 50%)
- Requirements to ISO (100–800 units)
- To do shooting on total cloud coverage or on cloudless days.

Indicators of aerial laser scanning:
- density of points of a lazer scanning not less than 30 points per 1 square meter;
- fixation of not less than three reflections;
- precision of planned coordinates of lazer reflection points - 20 cm;
- precision of height coordinates of lazer reflection points - 20 sm.
Depending on the chosen technology different tools for obtaining data of distance probing of the Earth are to be applied.

Provided that data on areas from 50 to 200 hectares is to be obtained, the following technical means are used:

Drones of the copter type: DJI Phantom 4 RTK (PPK), and drones of aircraft-type: Geoscan Gemeni, Geoscan 401 and Supercam X6M2 with airborne cameras on the basis of Sony RX1 and onboard geodesic receive unit or other instruments with similar characteristics.

Provided that data on areas from 200 to 5000 hectares is to be obtained, the following technical means are used:

Drones of aircraft-type: Geoscan 101, Supercam 150, Diam 3 airborne cameras on the basis of Sony RX1 and onboard geodesic receiver unit.

Provided that data on areas from 5000 to 25000 hectares is to be obtained, the following technical means are used:

Drones of aircraft-type: Geoscan 201, Supercam 350, Diam 20, Orlan 10 equipped with airborne cameras on the basis of Sony RX1 RM2, ultra-spectral cameras RedEdge-MX and an onboard geodesic receiver unit.

Provided that data on areas more than 25000 hectares is to be obtained, it is advisable to use BBC of sky-borne type: Supercam 450, Diam 20, Orlan 10 and piloted aircrafts.

Then aerial photographs are processed on photogrammetric software, which enables to automatize a process of working out three-dimension models of stands. The said models provide a reliable identification of wood species and allow to determine necessary taxation indicators for automated obtaining of data of complex estimate indicators. Contour (boundary) decoding of an area of stands’ allotment, their species composition of stand is well subject to automation upon multispectral photographs. Resolution of initial data of a distance probing of the Earth determines quality and amount of digital information.

| Spatial resolution of RSD (meter / pixel) | Data obtained upon automated processing of photographs |
|------------------------------------------|------------------------------------------------------|
| 2.5–10                                   | Contour decoding                                     |
| 0.7–2                                    | Contour decoding and decoding composition             |
| 0.3–0.6                                  | Contour decoding and decoding composition, complete canopy, estimation of crowns’ sizes. |
| 0.05–0.15                                | Contour decoding is done not only with regard to its composition, but also with regard to a height of forest stands. Decoding composition is done on the basis of species and taxation characteristics of each tree, sizes and volume form of a crown. |
| VLS                                      | Contour decoding is done not only with regard to its composition, but also with regard to a height of stands. Decoding composition of all layers, including young stands, based on species and taxation characteristics of each tree, sizes and volume form of a crown. |

RSD with resolution 0.05–0.1 m is used for identification of species. Application of technology of neuro networks under such resolution ensures an accurate identification of species composition of stands in 96% of cases.

Identification of height of stands and separate trees is achieved by photogrammetric measurement method as a difference between spot height of an upper part of crown and spot height of land topography at a tree base line. It is also possible to identify tree heights according to data of lazer scanning, but the
saged method is not widely applicable due to a high cost of lidar shooting. At present an automated processing of RSD data with resolution 0.05–0.07 m/pixel allows to obtain spots surface land in dense forest stands with an interval not more than 80 m, work out a horizontal surface and form a height model for further identification of trees and measurement of taxation indicators (figure 3).

![Digital elevation model of vegetation](image)

**Figure 3.** Scheme of formation of height model of stands.

Spatial resolution of RSD data with results’ estimation of an automated decoding of photographs is shown in table 2.

| Spatial resolution of RSD (meter / pixel) | Data obtained upon automation |
|------------------------------------------|------------------------------|
| 2.5–10                                   | Accuracy of a digital model is not sufficient for obtaining trees’ heights. Standard deviation (SD) of data, obtained by means of photographs, compared to factual data equals to 1–40 m. |
| 0.7–2                                    | Accuracy of a digital model is not sufficient for obtaining trees’ heights. SD – 3.5–8 m |
| 0.3–0.6                                  | Obtaining of an average maximum tree height in an allotment. SD – 1–2.5 m |
| 0.05–0.15                                | Obtaining of height of each tree, located in the first layer, and visible trees of the second layer. SD – 0.1–0.3 m |
| VLS with points from 30 thousand square m | Obtaining of height of each tree in all layers. SD – 0.1 m |
An important element of remote sensing data is identification of trees’ crowns. Accuracy of crowns’ segmentation depends on both data resolution and availability of spectral channels for division of species. Depending on quality of working out of a height model of stands it is possible to estimate not only morphometric sizes of trees’ crowns, but also their volume characteristics, for example, insolation surface.

**Table 3.** Possibility to estimate morphometric and volume characteristics of trees' crowns upon different spatial resolution of remote sensing data.

| Spatial resolution of RSD (meter / pixel) | Data obtained upon automation                                      |
|------------------------------------------|-------------------------------------------------------------------|
| 2.5–10                                   | Estimation of crowns of separate trees is not possible             |
| 0.7–2                                    | Estimation of crowns of separate large trees is possible           |
| 0.3–0.6                                  | Estimation of crowns of all trees of the first layer               |
| 0.05–0.15                                | Estimation of morphometric and volume characteristics of trees' crowns of all trees of the first layer and visible trees of the second layer. |
| VLS with points from 30 thousand square m | Estimation of morphometric and volume characteristics of trees' crowns of each tree in each layer. |

Canopy density is estimated more accurately not according to a flat ortophotomap, but according to point cloud of lazer scanning and height models of stands.

**Table 4.** Spatial resolution of remote sensing data and obtained indicators of canopy density in result of automation.

| Spatial resolution of RSD (meter / pixel) | Data obtained upon automation                                      |
|------------------------------------------|-------------------------------------------------------------------|
| 2.5–10                                   | It is not possible to estimate canopy density.                     |
| 0.7–2                                    | It is not possible to estimate canopy density.                     |
| 0.3–0.6                                  | Estimation of canopy density is possible without taking into account a height component. |
| 0.05–0.15                                | Estimation of canopy density is possible at the first layer and the second layer if it is visible. |
| VLS with points from 20 thousand square m | Estimation of canopy density is possible at all layers.           |

The final stage of an automated inventory of stands and complex estimation of wood resources is done with the software: «Information-reference systems of forest taxation normative standards» (IRSFTS). Authors’ certificates on the state registration of computer programs no. 2011615418 dated 12.07.2011 prove an innovation character of the normative-reference system. “Reference system of forest management–taxation standards for inventory of wood resources according to forest elements”, no. 2012613879 dated 25.04.2012 “Automated system of forest management–taxation standards for inventory of wood resources according to forest elements”.

Entry interface of five easily identified indicators of certain forest stands into the program is represented in figure 4. Choosing respective options, a user obtains all required information on all diversity, which increases in time.
Figure 4. Entry interface of data for complex estimation and inventory of wood resources.

It is widely known that according to the existing forest management instruction each forest stand is estimated only upon six indicators in taxation descriptions:
1. availability of layers in wood resources;
2. species composition of each separate layer;
3. relative forest density of each layer;
4. average height of wood species of each layer;
5. average diameter of wood species of each layer;
6. stock of trunk timber according to wood species of each layer.

The specified list of indicators is definitely not sufficient under the present social-economic and industrial-technological conditions, which require a complex estimation of wood resources. It is especially related to productivity of forest stands, estimated only by a non-specific stock of wood resources according to composition of species. The specified indicators in the taxation descriptions do not allow to estimate:
1. commodity-money potential of forest stands (return of categories of wood coarseness and return of separate assortment),
2. biological production of forest stands according to fractions of trees’ phytomass (trunks, bark, branches, needles-leaves, roots),
3. availability of deposit carbon of forest stands according to phytomass fractions,
4. bio-energetic potential of forest stands according to phytomass fractions.

The suggested information-reference system of forest taxation normative standards (IRSFTS) is by far more informative that the existing system of estimation and inventory of wood resources (60 items). Upon usage of the option «Distribution of number of trees according to 10 classes (stages) of depth» a number of indicators increases on yet another order (600 items), which is certified by information represented in separate blocks.

The list of the digital information of the first block is a distribution of taxation indicators of forest elements according to classes (stages) of tree depth in the following order:
1. distribution of number of trees according to classes of tree depth, pieces/hectare;
2. distribution of tree heights according to center classes of tree depth, m;
3. distribution of sums of basal areas according to depth classes of trees, sq.m/ha;
4. distribution of non-specific stock according to depth classes of trees, cubic m/ha;
5. distribution of stock of wood commodity according to depth classes of trees, cubic m/ha;
6. distribution of stock of large timber according to depth classes of trees, cubic m/ha;
7. distribution of stock of mid-level wood according to depth classes of trees, cubic m/ha;
8. distribution of stock of small wood according to depth classes of trees, cubic m/ha;
9. distribution of stock of fuel wood according to depth classes of trees, cubic m/ha;
10. distribution of stock of waste according to depth classes of trees, cubic m/ha;
11. distribution of stock of separate assortments according to depth classes of trees, cubic m/ha;
12. distribution of biomass of trunks according to depth classes of trees, kg/ha;
13. distribution of biomass of bark of tree trunks according to depth class of trees, kg/ha;
14. distribution of biomass of trees’ branches according to depth classes of trees, kg/ha;
15. distribution of biomass of needles (leaves) according to depth classes of trees, kg/ha;
16. distribution of biomass of roots according to depth classes of trees, kg/ha;
17. distribution of carbon mass from tree trunks according to depth classes of trees, kg/ha;
18. distribution of carbon mass from bark of tree trunks according to depth classes of trees, kg/ha;
19. distribution of carbon mass from branches according to depth classes of trees, kg/ha;
20. distribution of carbon mass from needles (leaves) according to depth classes of trees, kg/ha;
21. distribution of carbon mass from roots according to depth classes of trees, kg/ha;
22. distribution of bioenergetic potential of biomass of trunks according to depth classes of trees, Gigajoule/ha;
23. distribution of bio-energetic potential of biomass of bark trunks according to depth classes of trees, Gigajoule/ha;
24. distribution of bio-energetic potential of biomass of branches according to depth classes of trees, Gigajoule/ha;
25. distribution of bio-energetic potential of biomass of needles (leaves) according to depth classes of trees, Gigajoule/ha;
26. distribution of bio-energetic potential of biomass of roots according to depth classes of trees, Gigajoule/ha.

The second block of systems of normative standards represents correlation between trunk volume of trees and categories of wood coarseness with depth of trees according to components of wood species in the following order:
1. correlation between stem volume and trees’ depth, cubic m;
2. correlation between volume of industrial wood with trees’ depth, cubic m;
3. correlation between volume of large wood and trees’ depth, cubic m;
4. correlation between volume of mid-level wood with trees’ depth, cubic m;
5. correlation between volume of small wood with trees’ depth, cubic m;
6. correlation between volume of fuel wood from industrial wood with trees’ depth, cubic m;
7. correlation between volume of waste from industrial wood with trees’ depth, cubic m.

The third block represents a material estimation of forest stands according to components of wood species in the form of:
1. stock of trunk wood, cubic m/ha
2. stock of industrial wood, cubic m/ha
3. stock of large wood, cubic m/ha
4. stock of mid-level wood, cubic m/ha
5. stock of small wood, cubic m/ha
6. stock of fuel wood, cubic m/ha
7. stock of wood waste, cubic m/ha

The fourth block represents commodity-money potential of forest stands in form of monetary evaluation of categories of wood coarseness:
1. monetary evaluation of large wood, Rub./ha;
2. monetary evaluation of mid-level wood, Rub./ha;
3. monetary evaluation of small wood, Rub./ha;
4. monetary evaluation of fuel wood, Rub./ha;

The fifth block represents correlation between biomass fractions of phytomass of trees with trees’ depths:
1. correlation between biomass of trunk wood with trees’ depth, kg;
2. correlation between biomass of bark of trunks with trees’ depth, kg;
3. correlation between biomass of tree branches with trees’ depth, kg;
4. correlation between biomass of needles (leaves) with trees’ depth, kg;
5. correlation between biomass of trees’ roots with trees’ depth, kg;

The sixth block represents biological productivity of forest stands according to phytomass fractions:
1. biomass of trees’ trunks, kg/ha;
2. biomass of bark of trees’ trunks, kg/ha;
3. biomass of trees’ branches, kg/ha;
4. biomass of trees’ leaves, kg/ha;
5. biomass of trees’ roots, kg/ha.

The seventh block represents availability of carbon deposit in forest stands according to phytomass fractions:
1. biomass carbon of trees’ trunks, kg/ha;
2. biomass carbon of bark of trees’ trunks, kg/ha;
3. biomass carbon of trees’ branches, kg/ha;
4. carbon biomass of needles (leaves) of trees, kg/ha;
5. carbon biomass of trees’ roots, kg/ha.

The eighth block represents bio-energetic potential of forest stands according to phytomass fractions:
1. energetic potential of biomass of trees’ trunks, Gigajoule/ha;
2. energetic potential of biomass of bark of trees’ trunks, Gigajoule/ha;
3. energetic potential of biomass of trees’ branches, Gigajoule/ha;
4. energetic potential of biomass of trees’ needles (leaves), Gigajoule/ha;
5. energetic potential of biomass of trees’ roots, Gigajoule/ha.

Figure 5 shows a fragment of table and graphic information presented to a Customer, as well as interpretation of multidimensional patterns and distribution of taxation indicators according to depth classes of trees pursuant to composition of wood species.

Apart from that, IT platform of portal type has been worked out and recommended for implementation. The platform is designed for practical usage by specialists of any level (from forest management bodies, forest users, lessees, employees of scientific and educational institutions of forest science, ecologists and others). The portal interface is represented in figure 6.

All digital information on indicators’ complex, which characterizes wood resources, graphic visualization of distribution of a certain taxation indicator according to trees’ depth pursuant to each separate forest stand, may be presented to a Customer online under the following conditions:
1. Provision to an Executor all materials of aerial shooting in compliance with all technical requirements.
2. Provision to an Executor all data on a certain forest stand:
   - Data on upper forest stand height (H-upper) or middle (H-middle) forest stand height according to layers, m;
   - Data on canopy density or relative density of forest stand (items);
   - Data on a formula of forest stand composition according to layers;
   - Data on density of trees’ positions (items/ha) or an average distance between trees (m) according to layers;
   - Data on age of each forest element (years);
   - Maximum diameter of trees’ crowns according to forest elements (m).
Figure 5. Digital information and graphic visualization of materials of complex evaluation of wood resources according to wood elements (fragments of IRSFTS).

Figure 6. Interface of portal solution of tasks related to a complex estimation of wood resources by software «IRSFTS».

Portal solutions represent a service of calculation of required taxation indicators not at the workplace of a Service Customer, but in online format and on machines and working capacities of an Executor.
Advantages of a portal solution are as follows:
1. A Consumer does not need to have software in a workplace computer (at a forest division, at a lessee and others);
2. A Consumer does not need to upgrade software and apply for technical support;
3. There are minimum requirements to a work place (computer), namely, access to the Internet to form a request and upload data into a service in order to carry out estimation- graphic works;
4. Processing of data and estimation of taxation indicators is done by means of an Executor’s resources;
5. Accuracy of results of forest stands taxation is controlled by an Executor and provided by a targeted application of zone normative standards related to a certain subject of the RF.

Upon carrying out of forest inventory works, using advanced processing methods of aerial shooting materials, accuracy of determination of taxation indicators complies with ocular-estimate method of taxation. Thus, not only increase of accuracy is achieved but also increase in productivity of forest taxation works for 30%, depending on spatial location of forests and structure of forest canopy.

The next important element of an automated digitalization of wood resources is coupe demarcation and taxation of timber cutting areas, evaluation of commodity-money potential of forest stands, subject to cutting.

Pursuant to the existing legislation a lessee is obliged to carry out a photofixation of a cutting area before and after cutting. The suggested technology allows to do as follows:
1. Implement a photofixation of a plot, planned for marking out for cutting;
2. Estimate wood resource condition on a forest plot;
3. Mark out borders of a cutting area by means of cartometry with precision of up to a few centimeters in planned coordinates;
4. Provide an executor with a technological map of cutting operations, exhaustive information on location of a cutting area;
5. Provide a detailed taxation characteristics of a cutting area, estimate quantity and quality condition of a wood resource within borders of a marked cutting area with precision of an enumerative method of forest stands taxation;
6. Provide a customer with an enumerative statement of trees and statement of material-monetary estimation of a cutting area;
7. Provide mapping materials in a form of sketch of a cutting area.

3. Conclusion
1. An automated inventory of forest stands is successfully realized by methods of photogrammetry on aerial photographs of super high resolution and application of IT-portal of regional information-reference systems of forest taxation normative standards related to complex estimation of wood resources.
2. Database on wood resources, obtained by means of application of information-reference systems of forest taxation normative standards, increases data volume, which comply with the respective requirements of the existing forest management instruction by twofold.
3. The recommended technology of an automated inventory allows to surpass productivity of the existing technology for 30% and increase accuracy upon massive taxation of forest stands up to ocular measurement method, and upon inventory of a cutting fund it allows to ensure accuracy, which complies with the existing enumerative method of forest stands taxation (enumeration survey).

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