The use of unmanned aerial vehicle (UAV) for inventory and assessment of the experimental plantation in Lisino training and experimental forest of Saint-Petersburg State Forest Technical University

A Alekseev¹, Yu Danilov², A Nikiforov¹, M Guzuk² and D Kireev¹

¹ Department of forest inventory, management and GIS, Saint-Petersburg State Forest Technical University, 5 Institutsky per., St. Petersburg 194021, Russian Federation
² Department of soil science and forest plantations, Saint-Petersburg State Forest Technical University, 5 Institutsky per., St. Petersburg 194021, Russian Federation
E-mail: a_s_alekseev@mail.ru

Abstract. In the article results of experimental plantation assessment and inventory made by UAV are presented. Plantation parameters such as the area, the length of the rows with planted trees, number of planted trees and trees heights was assessed both on ground and remotely. The aim of the research was to estimate systematic and random errors of estimations done by remote sensing method. The high resolution aerial photograph of the plantation established by 1997 was done by Geoscan 101 UAV. PhotoScan software was used for photogrammetric treatment of the obtained image. Multilevel special GIS was developed for plantation parameters calculations. As a result of the plantation parameters measurements made by remote sensing and ground method the following systematic and random errors was revealed: row length – systematic error as much as -6.9 meters, random 7.39 meter; trees height – systematic error as much as 0.4 meter, random 1.24 meter; number of trees – no any error.

Taken into account the accuracy of used on UAV GPS positioning device which is as much as ±10 meter and also accuracy of ground measurements which was as much as ±5 meter we may conclude that remotely determined by using UAV plantation parameters are enough accurate and precise.

1. Introduction
Remote sensing use in the forestry has a long history. For the first time in 30th of XX century in the former Soviet Union small-scale aerial photograph was suggested to be used for forest survey purposes by A Novoselsky and G Samoylovich. Since 70th of XX century satellite images also starts to be applied for different forestry related purposes [1, 2]. High resolution aerial photograph from UAV together with special software for photograph treatment including 3D image development offer an additional possibilities for detailed analysis of the forest cover at low cost, in short time and with high accuracy and precision. At the department of forest inventory, management and GIS of Saint-Petersburg State Forest Technical University was developed a special method for tree stand parameters estimations based on high resolution images made by UAV [3]. This method was successfully tested on a number of ground true plots for assessment such a parameters of tree stands as growing stock, mean height, diameter and number of trees per area unit. Survey of forest plantations with the aim of its quantitative parameters estimation may be considered as a next promising step in UAV applications for forestry purposes. Using UAV it is possible to determine the areas on which
forest planting is of need as well as parameters for plantation projection. On already established forest plantations UAV may be of help in estimation of trees survival rate, canopy closure index and plantation ready to be classified as a forest land [4-6]. Also control, documentation and reporting on forest regeneration efficiency may be done much more effective using UAV.

2. Material and methods
Forest plantation established at 1997 on the area of Lisino training and experimental forest of Saint-Petersburg State Forest Technical University located in the settlement Lisino-corpus 60 kilometres to the south from Saint-Petersburg was used as an experimental object [7].

From geomorphologic point of view the Lisino training and experimental forest is situated on Ladoga-Ilmen lake-glacial lowland (the bottom of lake-glacial basin). The height above sea level varies from 20 up to 70 meters. The largest river Lustovka crosses the forest from NW to SE. There are three streams in the forest area: Laguza, Heart and Kastenka. In addition, two channels Kuznetsovsky and Kozhinsky pass through the forest. All of these operate as drainage system for lowland forested area. The topography is flat and undulating. Small flat hills formed by glacial debris are scattered throughout the forest. Formation of Podzol in marsh is the main soil type in Lisino. Other predominant soil types are moor-humus podsolization (20%), podzolic moder humus (18%), marsh soil type (57%), torf-podzolic (2%) and alluvial soils (3%). The soil is slightly acidic, poor with well-developed podzolic humus horizons.

The climate is characterized as moderate, which is influenced by cold air masses coming from the Arctic, and the warmer air mass from the Atlantic. The regional climate is strongly influence by the proximity of the Baltic Sea and Ladoga Lake.

According to the closest weather station Luban maximum recorded temperature of Lisino is 33 °C in July and minimum -40 °C in January. Average annual rainfall is approximately 590 mm. additionally the average wind speed is 3.3 m/s and average relative humidity 80%. The climatic conditions are favorable for growth and development of trees and shrubs. The length of the growing period is approximately 150-160 days.

Norway spruce is the main species for Lisino training and experimental forest occupies 34.5% of total covered by forest area. Second species is Scots pine which takes 28.1% of covered by forest area.

Lisino training and experimental forest of Saint-Petersburg State Forest Technical University is one of the oldest experimental areas for a long time used for research and training and established at 1805 [8-10].

Experimental plantation was established in compartment № 52 of block № 206 on the place of former Norway spruce tree stand with trees of relative density 0.7 and growing stock 130 cubic meters withdrawn by wind at 1996. Ground vegetation on this place was dominated by sorrel and blueberry also presented strawberry, meadowsweet, avens and fireweed, but only in spacing. Soils are weakly podzolic, loamy and humid.

Forest crops were planted in bulk ridges. Tillage was carried out in the summer of 1997 with the excavator with the laying of furrows 0.6 - 0.8 m deep and the filling of ridges on both sides with a width of about 1 m. All the furrows were brought into the stream serve as a water collector.

Norway spruce, Scots pine and Larch trees were planted in 18 rows (Figure 1) using different types and ages of planting material.

To obtain photographic materials used automatic complex for aerial photography Geoscan 101 Pro. The complex includes a ground station, UAV and a collapsible catapult. The ground control station is a portable computer with installed Geoscan Planner software and a modem for communication with the UAV. The UAV is equipped with a digital camera with a storm-slit shutter with a resolution of a light-sensitive matrix of 24 megapixels and a lens of 20 mm.

With the help of UAV, any can obtain aerial photography materials with a spatial resolution of up to 3 cm per pixel. Photogrammetric processing and transformation is performed in AgiSoft PhotoScan Pro software. After processing a series of images we have got ortophotoplan and 3D-models of objects.
The study of experimental forest crops was carried out based on the materials of aerial photography by the unmanned aerial vehicle Geoscan 101 Pro in 2017 from a height of 200 meters with a spatial resolution of 4.47 cm per pixel.

Figure 1. The scheme (a) and orthophotoplan (b) of the rows planted by trees in compartment № 52 of block № 208 of Lisino training and experimental forest.

To determine the location of the experimental site relative to the boundaries of the blocks, as well as to calculate the plantation parameters of interest, a multi-layer specialized GIS was used on the whole territory of the Lisino training and experimental forest [11, 12]. GIS was created using MapInfo Professional 6.0 on the basis of forest inventory and management data on the characteristics of the forest fund as well as topographic maps.

Plantation parameters such as the total area, the length of the rows with planted trees, number of planted trees and trees heights was assessed both on ground and using GIS technology. Determination of the heights of forest crops in the series was carried out using the 3D model created on the studied object. Deviations between plantation parameters such as length of rows, trees heights and numbers of trees survived measured by both approaches was calculated and offer a possibility to assess systematic and random errors of remote measurements.

Systematic and random errors were calculated using the following formula, see equations (1) and (2):

\[
\Delta x = \frac{\sum_{i=1}^{n} (x_r^i - x_g^i)}{n},
\]

there, \(\Delta x\) – systematic error, \(x_g\) – plantation parameter measured on ground, \(x_r\) – plantation parameter measured using remote sensing method, \(n\) – number of measurements.

\[
SD = \frac{\left(\sum_{i=1}^{n} (\Delta x_i - \Delta x)^2\right)^{1/2}}{n-1},
\]

there, \(SD\) – random error, \(\Delta x_i = x_r^i - x_g^i\) - difference in plantation parameter measured on ground and remotely for the case \(i\).

Systematic and random errors was evaluated taken into account the accuracy of used on UAV GPS positioning device which is for horizontal measurements as much as ±10 meter and also accuracy of ground measurements which was as much as ±5 meter.

3. Results and discussion
Remeasurement of plantation parameters on the ground was done in spring 2018 by the staff of the department of soil science and forest cultures and presented in the Table 1.

| № of row part | Length, m | № of row | Number of trees | Mean diameter, sm | height, m |
|---------------|-----------|----------|----------------|------------------|-----------|
|               |           |          | initial | survive |              |           |
| 1             | 75        | 1        | 100     | 59      | 6.9 ±0.23    | 7.8       |
| 2             | 75        | 1        | 100     | 66      | 10.0 ±0.32   | 9.3       |
| 3             | 75        | 1        | 100     | 52      | 11.3 ±0.33   | 9.9       |
| 4             | 75        | 1        | 100     | 53      | 11.2 ±0.36   | 9.8       |
| 5             | 25        | 1        | 60      | 29      | 9.8 ±0.41    | 9.2       |
| 6             | 75        | 1        | 100     | 48      | 10.8 ±0.38   | 9.7       |
| 7             | 33        | 1        | 65      | 30      | 9.8 ±0.41    | 9.2       |
| 8             | 40        | 1        | 82      | 24      | 11.4 ±0.53   | 9.8       |
| 9             | 40        | 1        | 53      | 35      | 14.9±0.49    | 11.1      |
| 10            | 46        | 1        | 99      | 53      | 11.6±0.28    | 10.0      |
| 11            | 190       | 2        | 380     | 153     | 11.2±0.74    | 9.9       |
| 12            | 57        | 1        | 69      | 35      | 14.9±0.50    | 11.0      |
| 13            | 170       | 2        | 340     | 170     | 11.2±0.74    | 9.9       |
| 14            | 40        | 1        | 143     | 48      | 10.5±0.38    | 9.5       |
| 15            | 72        | 2        | 150     | 49      | 12.4±0.55    | 10.3      |
| 16            | 40        | 1        | 91      | 50      | 8.5±0.38     | 8.6       |
| 17            | 72        | 2        | 76      | 32      | 14.0±0.50    | 10.9      |
| 18            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 19            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 20            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 21            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 22            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 23            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 24            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 25            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 26            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 27            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 28            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 29            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 30            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 31            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 32            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 33            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 34            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 35            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 36            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 37            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 38            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 39            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |
| 40            | 40        | 2        | 87      | 25      | 13.8±0.63    | 10.8      |

The results of plantation parameters measurements such as rows parts length and trees heights using remote sensing method in comparison with ground measurements as well as systematic and random errors of remotely done measurements are presented in the Table 2.
Table 2. The results of plantation parameters measurements by remote sensing method and systematic and random errors calculations.

| № of row | № of row part | Length measurement, m | Height measurement, m |
|----------|---------------|-----------------------|-----------------------|
|          |               | ground | remote | deviation | ground | remote | deviation |
| 1        | 1             | 75     | 65     | -10       | 7.8    | 10.6   | 2.8       |
| 2        | 1             | 75     | 65     | -10       | 9.3    | 10.4   | 1.1       |
| 3        | 1             | 75     | 65     | -10       | 9.9    | 12.3   | 2.4       |
| 4        | 1             | 75     | 65     | -10       | 9.8    | 9.5    | -0.3      |
| 5        | 1             | 25     | 27     | 2         | 9.2    | 12.3   | 3.1       |
|          | 2             | 75     | 66     | -9        | 9.7    | 9.8    | 0.1       |
| 6        | 1             | 33     | 31     | -2        | 9.2    | 11.3   | 2.1       |
|          | 2             | 75     | 64     | -11       | 9.6    | 10.9   | 1.3       |
| 7        | 1             | 40     | 31     | -9        | 9.8    | 9.1    | -0.7      |
|          | 2             | 40     | 46     | 6         | 11.1   | 11.9   | 0.8       |
| 8        | 1             | 40     | 27     | -13       | 9.6    | 9.8    | 0.2       |
|          | 2             | 40     | 47     | 7         | 10.7   | 11.1   | 0.4       |
| 9        | 1             | 46     | 40     | -6        | 10     | 9.9    | -0.1      |
|          | 2             | 190    | 167    | -23       | 9.9    | 9.7    | -0.2      |
| 10       | 1             | 57     | 47     | -10       | 11     | 12.4   | 1.4       |
|          | 2             | 170    | 159    | -11       | 9.9    | 9      | -0.9      |
| 11       | 1             | 40     | 30     | -10       | 9.5    | 9.8    | 0.3       |
|          | 2             | 72     | 60     | -12       | 10.3   | 11     | 0.7       |
| 12       | 1             | 40     | 32     | -8        | 8.6    | 6.7    | -1.9      |
|          | 2             | 52     | 49     | -3        | 10.9   | 11.2   | 0.3       |
| 13       | 1             | 40     | 31     | -9        | 9      | 7.4    | -1.6      |
|          | 2             | 54     | 54     | 0         | 10.8   | 10.4   | -0.4      |
| 14       | 1             | 40     | 36     | -4        | 8.9    | 9.4    | 0.5       |
| 15       | 1             | 52     | 44     | -8        | 8.5    | 8.2    | -0.3      |
| 16       | 1             | 56     | 32     | -24       | 10.3   | 10.7   | 0.4       |
|          | 2             | 27     | 31     | 4         | 9.7    | 11.3   | 1.6       |
| 17       | 1             | 18     | 21     | 3         | 10.3   | 9.9    | -0.4      |
|          | 2             | 24     | 14     | -10       | 9.3    | 9.8    | 0.5       |
| 18       | 1             | 32     | 32     | 0         | 9.2    | 7.7    | -1.5      |

| Systematic error | Random error |
|------------------|--------------|
| -6.90            | 7.39         |
| 0.40             | 1.24         |

As it follows from Table 2 the systematic error of the plantation rows length estimation by remote sensing method is as much as -6.9 meter, so lengths measured by this method systematically underestimated but if we take into account the accuracy of GPS for horizontal measurements used on UAV and equal as much as ± 10 meters and also accuracy of ground measurements of ± 5 meters we
may conclude positively about the accuracy of remotely done measurements. Random error of length measurements is as much as 7.39 meter and also fits in the above mentioned limits. So, we may generally conclude that plantation rows lengths measured by remote sensing method using high resolution photograph obtained by UAV are enough accurate and précised.

Remotely measured using 3D model tree heights has systematic error as much as 0.4 meter and random error as much as 1.24 meter these both may be evaluated positively especially taken into account accuracy of height measurement on ground which is as much as ± 1 meter.

Estimation of trees numbers in the rows made by remote sensing method precisely coincides with ground estimations without any errors, both systematic and random error are equal to zero.

4. Conclusion
As a result of conducted research which gives an evidence of the possibility of UAV and related methods use for artificial plantations survey we may derive the following conclusions:

The measurements of plantations parameters by remote sensing method include a number of needed stages such as, first, aerial photography by GeoScan 101 Pro UAV, second, high resolution aerial photograph photogrammetric treatment by AgiSoft Photoscan Pro software to develop the orthophotoplan and 3D model of plantation, third, multilayer GIS development, for example, using MapInfo Professional 6.0 and, fourthly, final measurements of plantation parameters of interest. All this stages needs for high qualified staff, costly equipment and software and may done by special organization, company or university. As a result such a survey will be expensive per area unit and this fact will limit it to the places where survey can’t be done by traditional methods or should be done fast in short time or on large remote areas.

Developed remote sensing method of forest regeneration survey may be applied for control of reforestation after cuttings made by companies. Such a reforestation should be done according to the low in prescribed time limit and with sufficient quality. For monitoring and control of such forestry operations by forest authorities the suggested method may used with high efficiency especially if large areas should be controlled.

5. References
[1] Kulik K and Koshelev A 2017 Methodology for Agroforest and Melioration assessment of protective tree stands using remote sensing data [in Russian – Metodicheskaya osnova agrolesomeliorativnoy otsenki zashitnykh lesnykh nasadjeniy po dannym distantsionnogo monitoringa] Forest Technical Journal [Lesotekhnicheskiy jurnal – in Russian] 3 pp 107–114.
[2] Kurbanov E Vorobyev O Gubayev A Lezhnin S Polevshikova Y and Demisheva E 2014 Four decades of forest research with the use of Landsat images [in Russian – Chetyre desiateletiya issledovaniy lesov po snimkam Landsat] Vestnik of Mari State Technicla University Ser Forest Ecology Nature Management [Vestnik Mariyskogo gosudarstvennogo tekhnicheskogo universiteta Ser Les Ekologiya Prirodopolsovanie – in Russian] 1(21) pp 18-32.
[3] Alekseev A Nikiforov A Mikhailova A and Vagizov M 2016 New method for tree stands parameters determination using high resolution images done by unmanned aerial vehicle [in Russian - Novyy metod opredeleniya taksatsionnykh kharakteristik nasazhdeniy po snimkam sverkhvysokogo razresheniya s bespilotnogo letatelnogo apparata] Proceedings of Saint-Petersburg State Forest Technical Academy [Izvestiya Sankt-Peterburgskoy lesotekhnicheskoy akademii – in Russian] 215 pp 6-18
[4] Rodin A ed 2002 Sylviculture [in Russian – Lesnye Cultury](Moscow: All Russian Research Institute on Forestry and Forestry Mekhanization Publishing) 440 p
[5] Malakhovets P 2012 Sylviculture [in Russian – Lesnye Cultury] (Arkhangelsk: North (Arctic) Federal University Publishing) 222 p
[6] Redko G Merzlenko M and Babich N 2005 Sylviculture [in Russian – Lesnye Cultury](Saint-Petersburg: Saint-Petersburg State Forest Technical Academy Publishing) 556 p
[7] Forestry regulations for Training and Experimental Forest of Leningrad region 2018 [in Russian – Lesokhozyaystvennyy reglament Uchebno-opytynogo lesnichestva Leningradskoy oblasti] http://old.nature.lenobl.ru/Files/file/lhr_uchebno-oputnogo_lesnichestva_2.pdf

[8] Redko G ed 1997 200 Years of Education and Research in Lisino Training and Experimental Forest [in Russian - 200 Let Lesnomu Uchebnomu i Opytnomu Delu v Lisinskem Uchebno-Opytnom Leskhoze](Saint-Petersburg: Saint-Petersburg State Forest Technical Academy Publishing) 356 p

[9] Egorov A and Titov Iu 1997 Flora of Lisino training and experimental forest Text book [in Russian - Flora Lisinskogo uchebno-opytynogo leskhoza Uchebnoye posobiye](Saint-Petersburg: Saint-Petersburg State Forest Technical Academy Publishing) 96 p

[10] Selikhovkin A ed 2009 Lisino 200 years of service to Russian forests [in Russian – Lisino 200 let sluzheniya lesam Rossii](Saint-Petersburg: Saint-Petersburg State Forest Technical Academy Publishing) 224 p

[11] Alekseev A Zayats A and Nikiforov A 2002 Geographical information system of Lisino training and experimental forest [in Russian. Geoinformatsionnaya sistema uchebno-opytynogo leskhoza] Proc. of VI Int. Sci. and Prac. Conf. System Analysis in Design and Management (Saint-Petersburg: Saint-Petersburg State Polytechnical University Publishing) pp 347-349

[12] Nikiforov A 2002 Development of information system for Lisino training and experimental forest using GIS-technologies [in Russian - Razrabotka informatsionnoy sistemy Lisinskogo uchebno-opytynogo laskhoza s primeneniyem GIS-tekhnologiy] Annual scientific conference of Saint-Petersburg State Forest Technical academy for young researches [Sbornik dokladov molodykh uchenykh na ezhegodnoy nauchnoy konferentsii Sankt-Peterburgskoy lesotekhnicheskoj akademii – in Russian] 6 pp 54-59.