3D MODELING AND GIS ANALYSIS FOR AERODROME FOREST OBSTACLE MONITORING

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ABSTRACT:

The article discusses methods for constructing and using digital photogrammetric and cartographic models as a basis for growing tree height control and plantation planning in aerodrome areas. Forests or gardens in the take-off and landing flight areas, exceeding special limitation surfaces, are dangerous obstacles and intended to cut down. Tree and bush vegetation should be under periodic monitoring because of their growth. The research was aimed to determine the maximum permissible obstacle height and tree age when it reaches the obstacle limitation surface altitude. For these purposes, it is proposed to use geospatial modeling and geoinformation analysis methods. As a basis for geospatial models, remote sensing optical stereo images were used. The allowable height is calculated as a difference between 3D obstacle limitation surface and the earth surface altitude values. The article presents the study results for a Belarus climatic zone, where the tree species predictive age in reaching the maximum permissible height is calculated. The main goal of the technology is to manage the aerodrome forest plantation growth without further labor-intensive monitoring, while ensuring the safety of aircraft flights.

1. INTRODUCTION

Aerodromes and airports are often located in areas densely covered with forest or park vegetation (Belarus, Germany, Estonia etc.). Trees in the aircraft take-off and landing area that exceed the special obstacle limitation surfaces (OLS) are hazardous flight obstruction. According to international aviation safety rules (ICAO Annex 14, 2018), vegetation in such aerodrome areas should be removed or reduced in height to a level not exceeding the lowest limitation surface (Figure 1).

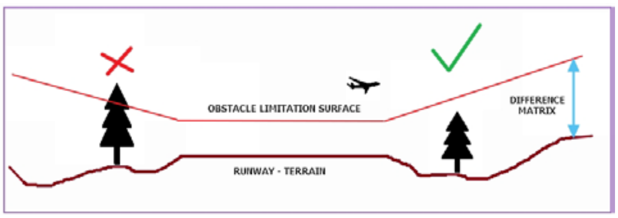

Figure 1. Permissible tree height according to obstacle limitation surface (OLS)

The forest obstacles monitoring, assessment and removing procedures must be carried out every 3-5 years and that is a laborious and expensive processes (Mitsevich and Zhukovskaya, 2018). Regular observations only reveal the presence of vegetation obstacles, which annually increase. In areas where forest vegetation has been eliminated, it is necessary to grow new plantations in order to avoid uncontrolled tree or bush overgrowth, which would also need to be eliminated when certain heights are reached.

As a scientific paper review reveals, the aerodrome obstacle identification and collision risk assessment have been carried out on satellite and UAS imagery, lidar and radar sensor's data. Presented survey methods demonstrate their advantages and mostly suggest the existing obstacle measuring technics. So, to observe the dynamics of vegetation obstacle changes for a Spain aerodrome, a spatial-temporal analysis on radar and GNSS data was conducted (Contreras-Alonso et al., 2020). Risk analysis study of the obstacle limitation surfaces using air traffic radar information was performed for Canada aerodromes (Sandaradura, 2015). There is an example of plant height measurements on different-time digital terrain models (Gomez et al., 2015). For airports in Mexico, observation of the obstacle objects was based on stereoscopic viewing of printed images (Prado et al., 2012). The study of tree growth rate by the lidar data point cloud was conducted for Finland area coniferous trees (Yu at al., 2005).

The current research considers the problems of aerodrome flight safety, forested area monitoring and re-afforestation planning. It is obvious, that tree growth rate depends on the climate and soil conditions, species, age and canopy density. At the aerodrome Minsk-2 area, forest under 60 years old grows at average 40 cm per year but the tree species growth differs significantly. Based on the reference values, it is possible to calculate the coniferous and deciduous stands permissible age in order to predict when a plantation reaches a certain height. The proposed solution is mathematical and cartographic modeling based on the geospatial data.

2. METHOD

To build digital cartographic models of permissible forest heights in the aerodrome area, the methods of 3D modeling, correlation and regression analysis are used. The result visualization demonstrates geocoded contours (isolines) with maximum tree age and forest class values assigned.

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By the aviation rules (ICAO Annex 14, 2018), the vertical accuracy of the aerodrome obstacle survey is 3.0m. To ensure that the total error of modeling does not exceed this value, the choice of survey has to take into account the image resolution, the accuracy of geolocation, and the errors in building and filtering a digital terrain model (DTM).

For DTM data extraction, it is proposed to use a stereo model as an optimal source of bare earth level and aerodrome object spatial parameters (Mitsevich, 2020). Airborne or satellite-based optical scanner imagery with a pixel size of 0.3-0.5m is suited for a continuous stereo model. The advantages of the scanner optical images are the high accuracy of the initial data, the minimal numbers of ground control points and the seamless stereo visualization.

The OLS parameters have general construction rules (ICAO Annex 14, 2018), but are unique for each aerodrome in terms of location, direction and configuration. They can be built on aerodrome parameters directly in a stereo model or imported into the model.

To determine the maximum allowable obstacle heights at each point, the difference matrix between OLS and DTM models is created. To get the difference matrix point cloud (or regular digital network), the earth surface altitude is subtracted from the OLS altitude at the same point (Figure 2).

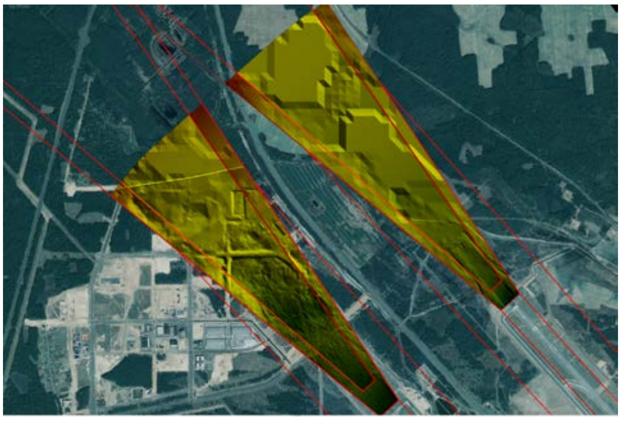

Figure 2. The difference matrix between OLS and DTM

To clarify the visualization, isolines with equal heights are drawn on the difference matrix with a given step that does not exceed the vertical accuracy of obstacle determining (Figure 3).

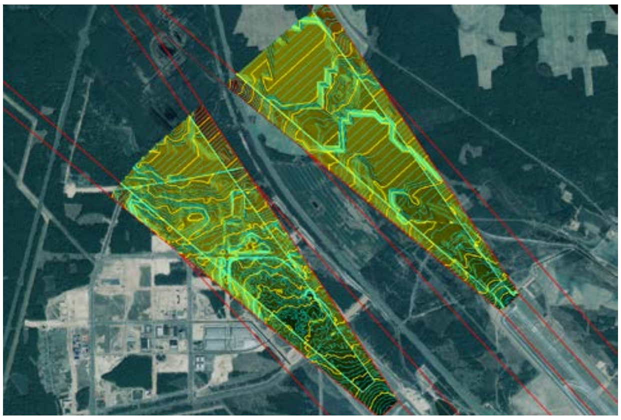

Figure 3. The difference matrix isolines

The forest stand age when it reaches the maximum permissible height is calculated by regression analysis. As the initial data for modeling the tree height and age relationship, normal yield tables of the forest stands are used.

The most widespread in the studied area forest formations are investigated. For all analyzed species, the relationship between age and height is most accurately estimated by a third-degree polynomial (1):

$$y_{tree} = ax^3+bx^2+cx+d, \qquad (1)$$

where y_{tree} = tree species maximum age
x = maximum permissible height
a, b, c, d = equation coefficients

For a regression model, the coefficient of determination R^2 is about 99%. So, every isoline would be assigned the tree age with a very precise value (Figure 4).

H, m	Age, y.o.
9,2	20
14,2	30
18,5	40
22,0	50
24,9	60
27,3	70
29,4	80
31,0	90
32,4	100
33,6	110
34,5	120

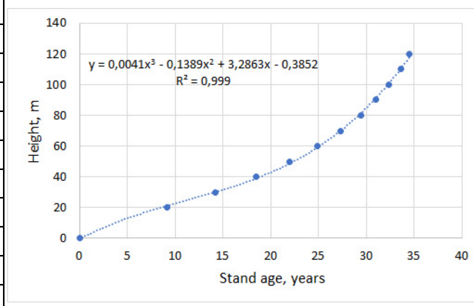

Figure 4. Correlation between spruce stand height and age

For better perception obtained data are ranked in ascending order and are colored from red (the lowest and fastest growing trees) to blue (not increasing in height) (Figure 5).

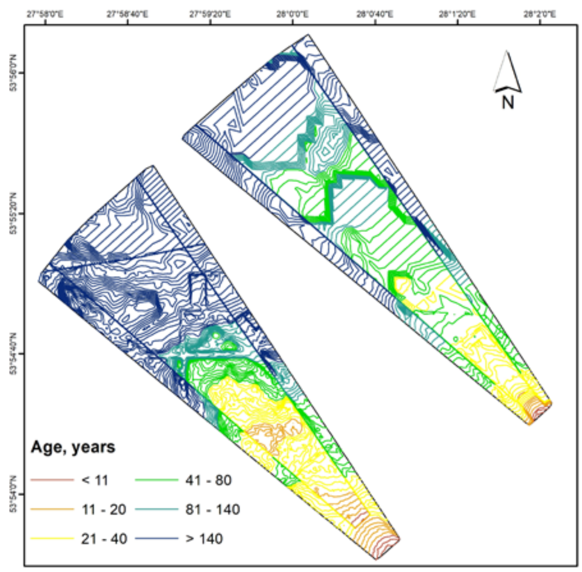

Figure 5. Age of spruce in reaching the maximum permissible height with the color ranking

3. EXPERIMENT

The study experiment was carried out for the Minsk-2 two runway take-off and landing areas. The airborne scanner ADS-100 (Leica, Switzerland), 0.3m per pix, and the remote sensing scanner Pleiades-1B (Airbus DS, France), 0.5m per pix stereo images were used as a photogrammetric basis. The georeferencing (exterior orientation elements) for aerial scanner images was implemented in flight by GNSS and inertial navigational data. The Pleiades-1B stereo images were provided by ground control points with 0.05-0.10m accuracy. The Digital Photogrammetric Workstation PHOTOMOD (PHOTOMOD Development Team, 2021) modules for the aerial triangulation and difference matrix extraction were used. The ArcGIS (ESRI) instruments were implemented for calculations, tree height-age analysis and visualization.

As a source of the tree growth rate for Belarus bioclimate zones, the forest management reference book (Kulagin at al., 2019) was used. Pine, spruce, birch and black alder forest formations are investigated as they are most widespread in the studied area. According to the reference tables, pine formations occupy 41% within the oak and dark coniferous forest geobotanical subzone, spruce formations - 16 %, birch formations - 21 % and black alder formations - 6 % of the forested area. The data on the maximum attainable heights for each tree species were analyzed.

For the research area, the following models were built:
1) Stereo model of the aerodrome area;
2) Digital terrain model (DTM);
3) Dense model of aerodrome obstacle limitation surfaces (OLS);
4) Difference matrix between OLS and DTM;
5) Mathematical and cartographic models of the forest stand permissible height and age.

Dense digital models of aerodrome obstacle surfaces were created from vector OLS models calculated according to the aerodrome Minsk-2 category (Mitsevich, 2020). The DTM was built up on the filtered and manually checked point cloud. The difference matrix between OLS and DTM models was created as a regular digital elevation model. Contours were formed on the difference matrix. The isoline step section was chosen 1.0m (Figure 6).

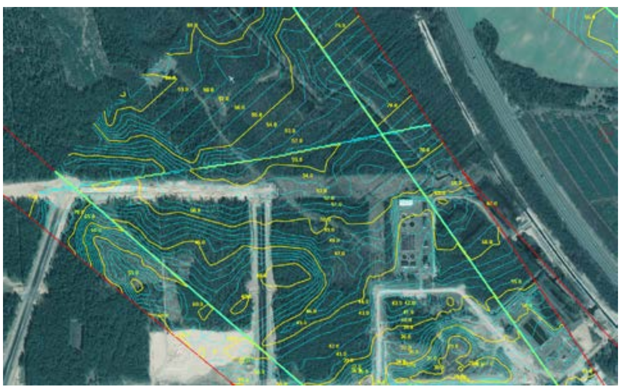

Figure 6. Permissible obstacle height contours with 1.0m step section

Further, the model with contours was used as a basis for geoinformation analysis and modeling. The regression analysis method for calculating of the forest stand age when trees reach the maximum permissible height was used. Such attributes as the age of pine, spruce, birch and black alder stands were added to isolines feature dataset. The attributive fields were filled in automatically using the ArcGIS Field Calculator and regression equations calculated for each analyzed tree species (2-5):

$$y_{pine} = 0.003x^3 - 0.0821x^2 + 2.547x - 0.1523; \quad (2)$$

$$y_{spruce} = 0.0041x^3 - 0.1389x^2 + 3.2863x - 0.3852; \quad (3)$$

$$y_{birch} = 0.0043x^3 - 0.1228x^2 + 2.1315x - 0.3245; \quad (4)$$

$$y_{black\ alder} = 0.0029x^3 - 0.0334x^2 + 1.2577x - 0.2484, \quad (5)$$

where y = tree species maximum age
x = maximum permissible height

The isolines with maximum permissible heights were assigned the attributes of maximum allowable age.

When analyzing models of deciduous (birch, black alder) and coniferous (pine, spruce) species, it can be seen that birch and black alder stands have slightly higher growth rate. And as a result, in some areas they reach the permissible height earlier (Figure 7, 8).

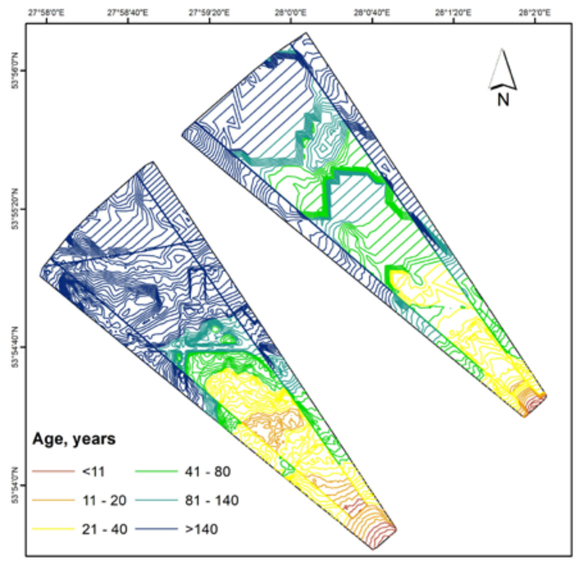

Figure 7. Age of the pine forest in reaching the maximum permissible height

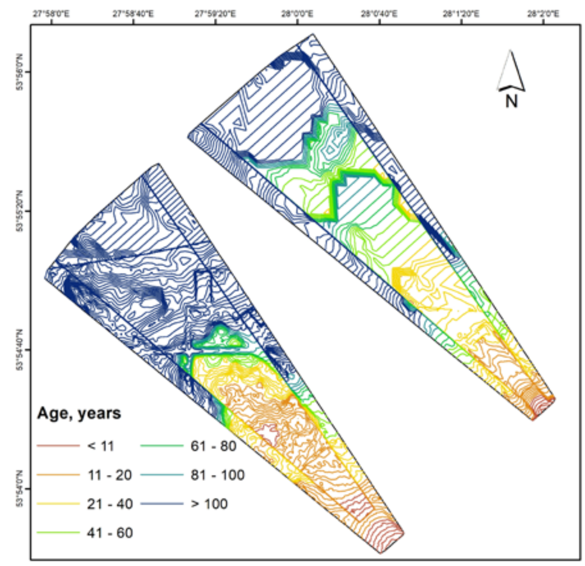

Figure 8. Age of the birch forest in reaching the maximum permissible height

The models show that birch in the first 10 years grows much faster than pine plantations.

4. RESULTS AND DISCUSSION

On aerodrome areas densely covered with forest stands, constant monitoring and elimination of plantation, which are vertical obstacles, are required. The methods of 3D digital cartographic modeling and geospatial analysis is proposed for predicting of the forest plantation height.

As a basis for the geospatial models, the stereo scanner imagery, terrain and aerodrome obstacle limitation surface models were used. The difference matrix of permissible heights was extracted from DTM and OLS models and converted to three-dimension regular step contours. To model the correlation between the different tree height and age, regression analysis for each forest stand species was used.

When comparing models, it can be seen that conifers grow in height more slowly than deciduous ones. Therefore, for aerodrome areas with significant height restrictions in the take-off and landing OLS, it is necessary to choose tree species with a low growth rate, or to grow seedlings.

Following the forest reference book (Kulagin at al., 2019), in areas with temperate climate (Belarus, Poland, Germany, Baltic countries), the maximum tree height is 37.3m (pine) and the tree no longer grows. Therefore, where the isoline height exceeds 38.0m, any forest stands can grow without restrictions and the need for monitoring. But in climatic zones with other tree species (palms, sequoias), it is necessary to take into account their local growth rates and maximum heights.

On the obtained models, it is possible to determine the forest age classes which also help to define the boundaries of the territory, where there is no need to monitor the height, and, consequently, the age of forest (Figure 9, 10).

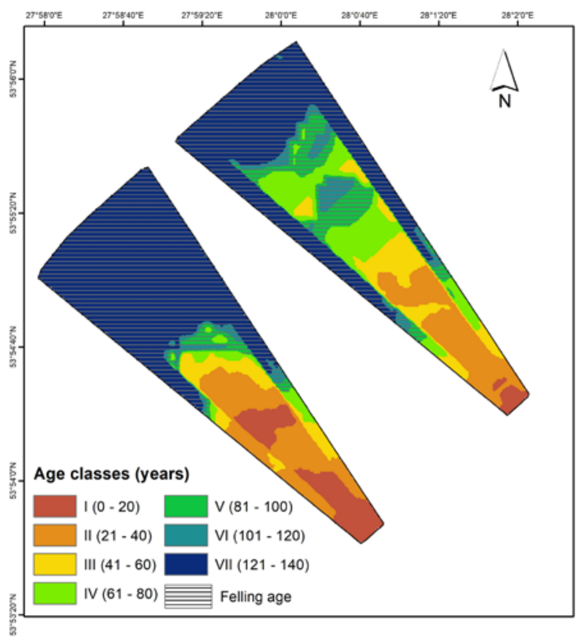

Figure 9. The pine forest age classes

It is important for forest management to achieve the maximum productive (felling) age of the tree. The model illustrates the location, where the coniferous forest can reach the felling age (more than 80 years). The V-VII age classes occupy about 60% of the research territory.

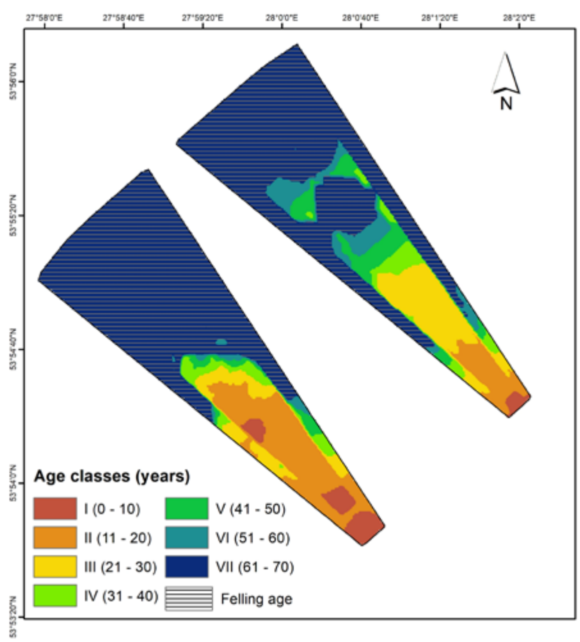

Figure 10. The birch forest age classes

According to the Figure 10, for the deciduous species the felling age is VII age class occupies about 63% of the area, and the of trees is above 60 years.

Thus, at the aerodrome areas, with the geospatial models of permissible tree obstacle height and age, the problems of forest planning, periodic deforestation and re-afforestation can be solved while ensuring flight safety.

The technology also can be useful for many tasks of near aerodrome territory land management (construction of power lines, bridges, road network etc.).

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