ENVIRONMENTAL DATA SCIENCE SESSION

MAPPING FOREST INFRASTRUCTURE – COMPARING DIFFERENT DATA ACQUISITION TECHNIQUES

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Abstract:

Forest resource information usually change over time, what is monitored by forest inventories using different methods. Forest infrastructures, such like roads, hydrographic network, other linear facilities are relatively stable in time. Nevertheless, conventional forest inventories in Lithuania map forest infrastructures every time the survey of forest resources takes place. Assuming, that different and rapidly developing forest stand inventory techniques are applied each time, there are significant changes in location of forest infrastructures observed. Repeated inventories of such objects usually assume increased inventory costs and introduce significant disorder when aiming for permanent forest management. This study investigates the opportunities of different data acquisition techniques for mapping relatively stable over time forest infrastructure objects. We compare classification and geometric accuracies of forest infrastructures achieved using (i) ground geodetic survey, (ii) available from state maintained geo-referenced background database, which has been created using interpretation of aerial images, (iii) extracted from 3D airborne laser scanning point clouds and (iv) very high-resolution World-View-1 satellite images. The key finding is that costly and time-consuming ground data collection approaches may be successfully substituted by remote sensing based data collection, which delivers compatible data contents for significantly lower costs.

Keywords:

remote sensing, forest infrastructure, mapping, accuracy.

1. INTRODUCTION

Forest of Lithuania, which cover more than 2 million ha, contribute significantly to the economy of country, thus, their management planning needs to base on timely and accurate inventory data. All state forests in Lithuania have been inventoried at least once in the 19th century and one of peculiarities of forest management planning was the division of forest tracts into usually rectangular blocks. Maps at a scale 1:5000 were produced since the 1930's, since the stand-wise forest inventories became routine procedures repeated on the same area approximately every decade, of course, disturbed by historical factors of the 20th century [1; 2]. After restoration of independency in 1990, Lithuania issued a Law of geodesy and cartography in 2001 [3].

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This legal act set detailed requirements for surveying and mapping, as well for developing GIS databases [4]. In 2004, the first version of georeferenced cadastre database GDB10LT was developed, which was considered as a mandatory dataset to develop all thematic GIS datasets, including the database originating from stand-wise forest inventories. Nevertheless, GIS in Lithuanian stand-wise forest inventories was introduced nearly a decade before the country-wide general-use datasets were created. This resulted in numerous overlaps and mismatches of the same features. More, the GDB10LT did not cover all information needed for stand-wise forest inventories and the Forest State Cadastre (FSC). All geographic data in FSC database are stored in state coordinate system LKS-94 [5]. Following the requirements for SFC database, the accuracy of clearly identifiable features, such as intersection points of roads, drainage canals, etc. may not exceed 5 m [6]. Even though there were formal requirements to update the FSC database permanently registering all changes due to silvicultural activities, in fact the solution used was to replace all information in the areas, where the stand-wise forest inventories took place, usually every 10 years [6]. Thus, it was soon realized, that the position of by-definition stable object in the forest, like the block lines, road infrastructures or hydrographic network changes with the stand-wise forest inventories [4]. In 2013, a project was carried-out to test the use of GPS technology to create accurately field surveyed forest geodetic network [7]. The methodology was tested and approved on 2014 and the product was named as the forest geo-reference background [8; 9]. There were set high quality requirements for field survey, however, it was also soon realised that development of forest geo-reference background is rather costly affair. Thus, the question was asked, what is the accuracy of forest geo-reference background and whether there are more economically sound alternatives to get the same product. General requirements for geospatial positioning accuracy are well known since 1998. [10]

The first validations of the forest geo-reference background indicated, that the accuracy of intersection points of forest block lines were surveyed with accuracies on X axis ± 3.1 m and ± 2.59 m on Y axis [11]. More detailed study was carried out in 2017 [4], which concluded, that the most accurate data was achieved on the block line intersection points and due the good forest block line condition and an appropriate choice of surveying techniques. The recommendation given was to carry out survey during the leafless forest condition in a mixed deciduous-coniferous stands [4]. Testing of alternative solutions to get the same product with lower costs was rather episodic. Nevertheless, there are numerous opportunities to facilitate the development of forest geo-reference background utilising alternative solutions. In this study, we will focus on the potential of remotely sensed data to identify the same object, which are usually field surveyed to create the forest geo-reference background. As such solution may serve e.g. orthophotos, built on materials of aerial photography used in Lithuanian stand-wise forest inventory which possibilities to acquire the georeferenced information are detailed presented in 1996 [12]. Potential of high resolution (sub-meter) satellite images is also proven, as the information from usually used in stand-wise forest inventories in the areas where the aerial photos are not possible to acquire (e.g. over flight-restricted areas, near country borders with Russia and Belarus). Finally, airborne laser scanning techniques are coming to Lithuanian stand-wise forest inventory, too. [13]

The aim of study described in this paper was to investigate the opportunities of different data acquisition techniques for mapping relatively stable over time forest infrastructure objects. We compare classification and geometric accuracies of forest infrastructures achieved using (i) ground geodetic survey, (ii) available from state maintained geo-referenced background database, which has been created using interpretation of aerial images, (iii) extracted from 3D airborne laser scanning point clouds and (iv) very high-resolution WorldView-1 satellite images.

2. MATERIAL AND METHODS

The study was conducted in Dubrava forest in central Lithuania and its neighbourhood (Fig.1). Total area under focus was about 20000 ha.

Fig. 1. Location of the study area

We compare the classification and geometric accuracies of four data sources to map forest infrastructures within the frames of stand-wise forest inventories. The data sources are:

1. Information, contained in forest geo-reference background (hereafter, FGB), which is created using the requirements of Specifications for forest management planning [14]. According to the Specifications, the FGB contains the information on relatively stable over time natural or human created objects in the forest, such like roads (≥4 m wide), linear hydrographic features (≥3 m wide), railways, other technological linear objects (≥4 m wide) and lines used to build forest blocks. The FGB is developed using ground survey methods by field measurements of points where the linear FGB objects intersect, as well as points where the block lines change their azimuth. The version of FGB used for our tests was developed in winter season of 2012-2013 by State company Lithuanian Forest Inventory and Management Planning Institute (LFIMPI) using Leica Smart station 1200 equipment, achieving positional accuracies of measured points inside 15 cm.
2. Information which is contained in a spatial dataset of Geo-reference data cadastre for Lithuania (hereafter GRPK), which is available from geoportal.lt. This data set is aimed to record stable over time natural and anthropogenic origin land surface objects, related to the locations of water features, land covers, transport and communication infrastructures, elevations, location names, etc. This data set is permanently updated, usually using mono interpretation of orthophotos and is supposed to fit mapping standards at a scale 1:10000. For this study, we used version of GRPK downloaded 4-3-2020.
3. A geo-database, developed following the requirements for FGB, but conducting the measurements in 3D point cloud created using data from airborne laser scanning (hereafter, ALS) instead of field survey. Study area was scanned using ALTM3100 instrument from 1500 m altitude and 70 kHz pulse frequency or shooting density 1 point per m^2 (resulting in more than 2 responses per square meter) in summer of 2008. Features contained in FGB were interpreted using RGB visualizations based on the ALS point height percentiles: R – 90%, G – 60% and B – 30%. To support the interpretation, 3D visualizations of point clouds were also used.
4. A geo-data base of forest infrastructures based on the international cartographic standard MGCP, developed within the frames of MySustainableForest project by GMV AEROSPACE AND DEFENCE SA (hereafter, MSF). It is created by interpretation of Worldview-1 satellite images from 23-3-2019, aiming for feature representation at a scale 1:5000 and feature extraction – 1:2000. The thematic categories of the dataset are hydrography and waterways, transportation network, populated places, enclosures, industrial and energy objects and land cover.

Three types of points were identified independently on intersections of linear features, contained in all four data sources mentioned above: (i) intersections of forest block lines, (ii) intersections of forest block lines and roads and (iii) intersections of forest block lines and linear hydrographic features. Assuming formal requirement to use the FGB data set in stand-wise forest inventories, we considered it as the reference data set. All other data sets were considered as an alternative to create the FGB. So, we estimated geometric accuracies of points identified using other three datasets, comparing their cartesian coordinates with the ones achieved from FGB. Approaches established by Federal Geographic Data Committee of USA in National Standard for Spatial Data Accuracy [10] were used to compare the datasets. Horizontal accuracy was evaluated using root mean square errors for x and y coordinates:

$$RMSE_x = \sqrt{\sum\left(x_{data,i} - x_{FGB,i}\right)^2 / n} \quad (1)$$

$$RMSE_y = \sqrt{\sum\left(y_{data,i} - y_{FGB,i}\right)^2 / n} \quad (2)$$

Where: $x_{data,i}$ and $y_{data,i}$ are the coordinates of the ***i*** point in the dataset being evaluated;

xFGB,i and *yFGB*,i are the coordinates of the ***i*** point in the FGB dataset.

Horizontal error (*HE*) at point ***i*** is:

$$HE = \sqrt{\left(x_{data,i} - x_{FGB,i}\right)^2 + \left(y_{data,i} - y_{FGB,i}\right)^2} \quad (3)$$

Horizontal root mean square error $RMSE_r$ is:

$$RMSE_r = \sqrt{RMSE\frac{2}{x} + RMSE\frac{2}{y}} \quad (4)$$

As the $RMSE_{min}/RMSE_{max}$ were in the range of 0.6 and 1.0, we calculated the circular standard error (at 39.35% confidence) as 0.5×($RMSE_x$+$RMSE_y$), and, accepting that the errors were normally distributed and independent, calculated the accuracy value:

$$Accuracy_r : 2.4477 \times 0.5 \times \left(RMSE_x + RMSE_y\right) \quad (5)$$

To evaluate clustering effects of errors, we calculated Global Moran's I statistic for point-wise horizontal accuracies. ArcGIS and MS Excel were used to process the data and elaborate the illustrations.

3. RESULTS AND DISCUSSION

There were 262 points located as the check points on the FGB, 84 representing the intersections of forest block lines, 108 – intersections of forest block lines and roads and 71 – intersections of forest block lines and linear hydrographic features. However, 79%, 58% and 73% of points identified on FGB, were located and identified on GRPK, respectively. Usually, the forest block lines were missing in the GRPK, due to specifics of nomenclature of GRPK. Only 38%, 34% and 23% of points were identified using intersection points of linear features, extracted from ALS data. Also, should be noted, that not the whole study area was covered by ALS data, and, similarly to the previous case, only block lines, which were clearly detectable, were used. 76%, 71% and 58% of points extracted using forest infrastructures based on Worldview-1 satellite images (MSF), were mapped. In all cases, the percentage of identified points would increase if using also virtual lines prolonging available linear features were used. However, we did not apply such approach because of the primary objective to evaluate geometrical accuracies of available intersection points.

Relatively largest horizontal accuracies were achieved using the GRPK as the source for constructing the database, which emulates the FGB (Fig. 2 and Table 1.). Nevertheless, the accuracies were below the requirements for mapping stable over time forest infrastructures. The lowest accuracies were achieved using ALS data as the input. Bearing in mind, that positional accuracies of points in the cloud were potentially more accurate than the accuracy of orthophotos to build the GRPK and MSF datasets, we explained this by imperfections in the methods, used to extract linear features in the ALS point clouds. If considering only GRPK and MSF dataset only, that the most problematic features to detect were the intersections of forest block lines and the roads, while the most precisely detected ones were the intersections of forest block lines and linear water features.

This contradicts a bit with our previous finding, that the hydrographic elements are the most difficult to identify on the image-based orthophotos in Lithuanian stand-wise forest inventories [8].

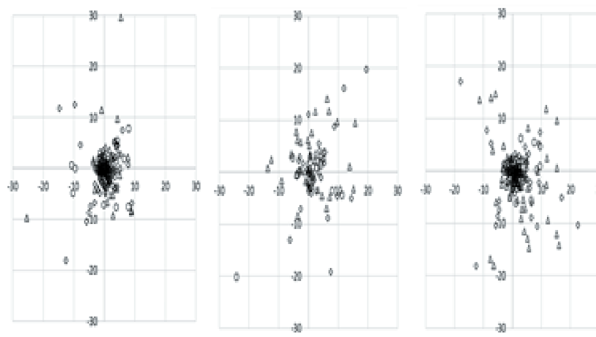

Fig.2. Magnitude (in meters) of horizontal errors of check points, depending on the input data source; a) GRPK, b) ALS, c) MSF. ◊ - block lines, Δ - block line x road, o - block line x linear water feature

Type of intersection	Number of points	$RMSE_x$	$RMSE_y$	$RMSE_r$	Circular standard error	$Accuracy_r$
Spatial dataset of Geo-reference data cadastre for Lithuania (GRPK)						
Block lines	66	3.921	4.502	5.970	4.212	10.31
Block line x road	63	4.297	5.264	6.795	4.780	11.70
Block line x linear water body	52	3.473	2.818	4.472	3.145	7.669
All	181	3.937	4.395	5.900	4.166	10.20
Forest infrastructures, created by interpretation airborne laser scanning 3D point cloud (ALS)						
Block lines	32	6.243	7.350	9.643	6.440	15.76
Block line x road	37	6.431	5.611	8.535	6.021	14.74
Block line x linear water body	16	7.512	5.481	9.299	6.500	15.90
All	85	6.580	6.301	9.110	6.440	15.76
Forest infrastructures, created by interpretation of Worldview-1 images (MSF)						
Block lines	64	5.929	5.017	7.767	5.473	13.40

Block line x road	77	5.645	6.190	8.378	5.918	14.49
Block line x linear water body	41	3.330	2.492	4.160	2.911	7.126
All	182	5.323	5.144	7.403	5.234	12.811

Table1. Potential accuracy of identification of stable point-features in the forest, using different dataset as the input, all check points

Horizontal accuracies of all points extracted from the GRPK and MSF dataset, exhibit statistically significant clustering patterns (Fig.2). Visually, relatively poorer identification is towards the edges of forest tracts.

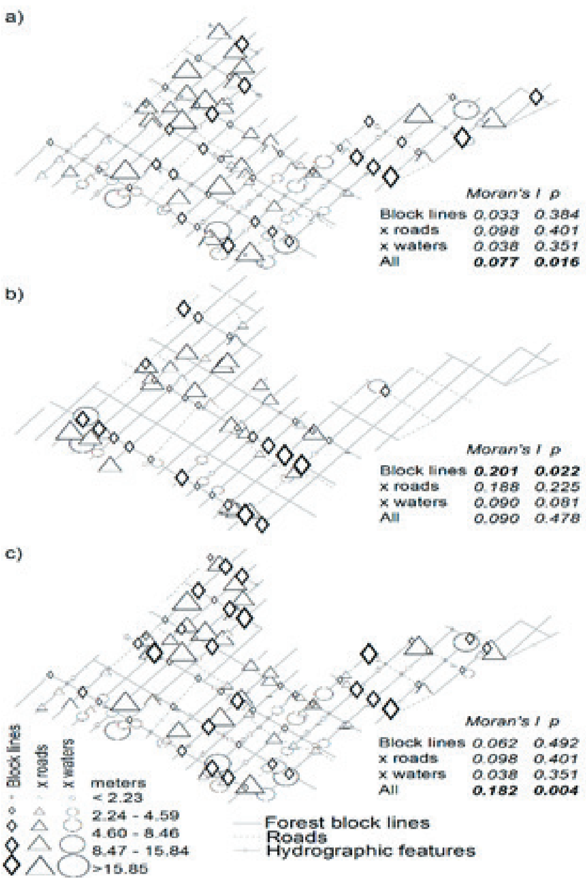

Fig. 2. Spatial pattern of horizontal errors, depending on the input data source; a)GRPK, b) ALS, c) MSF

All the above findings assume that the FGB dataset is free from errors. However, the identification of crossroads in the specifications for FGB development [8] deviates from the practices used in photogrammetry. Also, it is very difficult to explain rather bit horizontal errors for some check points. Thus, we considered 5% of points with largest horizontal errors as outliers and removed from the calculations.

Another mandatory condition for the check point to be considered as an outlier were large horizontal errors (>10 m) on at least two data sources evaluated. Should be noted, that only intersections of forest block lines and block lines and roads were assigned to the outliers, i.e. never the intersections of block lines and water streams. After removed outliers, the accuracies improved notably (Table 2), suggesting that the GRPK may be used to build FGB, i.e. accuracies required in stand-wise forest inventory specifications are achieved without expensive field survey. Accuracies also improved for the MSF case, too, however, not for the ALS.

Type of intersection	Number of points	$RMSE_x$	$RMSE_y$	$RMSE_r$	Circular standard error	$Accuracy_r$
Spatial dataset of Geo-reference data cadastre for Lithuania (GRPK)						
Block lines	62	3.367	3.284	4.704	3.326	8.140
Block line x road	58	2.391	3.298	4.074	2.845	6.963
Block line x linear water body	52	3.473	2.818	4.472	3.145	7.669
All	172	3.108	3.155	4.429	3.132	7.666
Forest infrastructures, created by interpretation airborne laser scanning 3D point cloud (ALS)						
Block lines	31	6.342	7.459	9.791	6.901	16.89
Block line x road	33	6.021	4.699	7.637	5.360	13.12
Block line x linear water body	16	7.512	5.481	9.299	6.500	15.90
All	80	6.467	6.056	8.860	6.262	15.33
Forest infrastructures, created by interpretation of Worldview-1 images (MSF)						
Block lines	60	5.389	4.230	6.850	4.809	11.77
Block line x road	71	4.790	5.938	7.629	5.364	13.13
Block line x linear water body	41	3.330	2.492	4.160	2.911	7.126
All	172	4.716	4.720	6.672	4.718	11.55

Table 2. Potential accuracy of identification of stable point-features in the forest, using different dataset as the input, with 5% outliers removed

4. CONCLUSIONS AND RECOMMENDATIONS

- Costly and time-consuming ground data collection to build the forest georeferenced background, which is mandatory to build GIS databases in Lithuanian stand-wise forest inventories, may be supported by using information available from Geo-reference data cadastre for Lithuania.
- Forest infrastructures, extracted from Worldview-1 satellite images, may not substitute neither the field survey nor the Geo-reference data cadastre for Lithuania, however, they may contribute to validating and improving the forest georeferenced background.

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