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DOCUMENTATION OF HIKING TRAILS AND WOODEN AREAS USING UNMANNED AERIAL VEHICLES (UAV) IN TATRA NATIONAL PARK

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Abstract

The research described in this article was conducted in the Tatra National Park in Poland, which is considered as one of the most-visited national parks in Europe. The exceptional popularity of this place is responsible for intensification of morphogenetic processes, resulting in the development of numerous forms of erosion. This article presents the outcomes of the research whose purpose was to verify the usability of unmanned aerial vehicles to check the condition of hiking trails and forests in alpine areas. An octocopter equipped with a non-metric camera was used for measurements. The paper sketches the methodology of data acquisition in harsh conditions and demanding locations of hiking trails on steep Tatra slopes. The paper also describes stages that lead to elaboration of basic photogrammetric products relying on SfM (Structure from Motion) technique. Finally, it shows the applicability of the prepared products to the evaluation of erosion along hiking trails, and to the study of plant succession or tree stand condition in the area located next to hiking trails.

Keywords: UAV, documentation, hiking trails, forests

INTRODUCTION

Unmanned aerial vehicles (UAV) used to obtain spatial data have recently become increasingly popular. The most common sensors installed on UAV are non-metric cameras. However, devices equipped with infrared cameras, multi-spectral cameras or LIDAR scanners are becoming more and more common (Berni *et al.* 2009, Wallace *et al*. 2012, Chiara *et al*. 2017). Depending on the type of the flying unit, the UAV enables to perform measurements over the areas ranging from a few acres to several square kilometres (d'Oleire-Oltmanns *et al*. 2012, Eltner *et al*. 2013, Hackney and Clayton 2015). It is worth noting that this new and very popular method of spatial data acquisition ensures the required measurement accuracy. Ground sampling distance (GSD) is of crucial importance here. It depends mainly on the flight altitude and the camera sensors and lenses used to take measurements. The second important aspect is to provide the final products in a form of georeferenced data. Currently, mainly ground control points measured with classical surveying methods are used for this purpose. There are also other solutions such as the use of point coordinates obtained from other sources, for example, from satellite images (d'Oleire-Oltmanns *et al*. 2012). Georeferencing can be also supplied directly by measuring exact coordinates of images projection centres. Such solutions are typically used in situations when the unmanned aerial vehicle is fitted with a satellite receiver, which determines the UAV position in real time, and with the Inertial Navigation System *(*INS) (Colomina and Molina 2014, Benassi *et al*. 2017).

Another factor affecting the accuracy of results obtained from the UAV data is topography of the area which is the subject of this research. Varied terrain, lack of possibility to indicate break-lines in some software or interpolation errors affect accuracy of Digital Surface Model (DSM) generated from UAV images. This in turn has an influence on the accuracy of the orthophotomap based on this DSM. In the areas where landscape is not very diversified (flat areas) the accuracy of the final products approximates 2-3 GSD (Eltner *et al*. 2013, Barry *et al*. 2013, Hlotov *et al*. 2015). However, according to our best knowledge, no studies have been conducted so far to determine the accuracy of UAV-based photogrammetric products in areas with larger height differences. The relative height differences of the area being subject to the tests described in this article are up to 1000 m.

The photogrammetric methods are one of the most popular sources of data used in work related to forest administration. They started to be used in 1887 when first photogrammetric photographs were taken with a camera lifted by a balloon. The photographs were later used for settling a forest (Hildebrandt 1987). Around 1890 first successful attempts of using terrestrial photogrammetry for mapping forest stands were made (Wodera 1948). A significant breakthrough in the development of photogrammetry for the needs of the analysis of forest stands came along with the development of plane aviation. One of the first photogrammetric flights used by forestry took place in Bavaria in 1924 (Spellmann 1984).

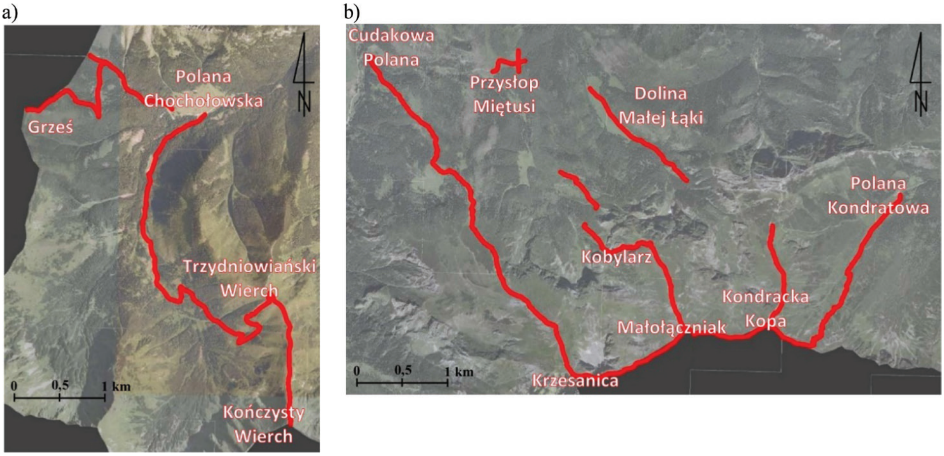
Currently, in majority of cases, the laser scanning measurements are performed concurrently with taking aerial photos. It is particularly crucial for densely wooded areas where the tree branches make it impossible to take photos from the level of the ground. Aerial laser scanning provides accurate information related to forests in vast areas. However, it is often insufficient to define the condition or features of individual trees. Therefore, terrestrial laser scanning is a better method of estimating the condition of a forest stand, especially the density of afforestation (Wencel 2008). It should be mentioned that laser scanning is one of the most expensive methods of assessing the current state of land cover and land forms. On the other hand, the scale of aerial photographs might not be sufficient for the needs of identification of individual tree tops. In the case of using UAV units this problem is minimised by the adequate selection of parameters of the mission, which allows for obtaining high resolution up to 1 cm.

The most important aim of the research described in this article was to document selected linear hiking trails in alpine areas. The current state of the trails was established using the photogrammetric method (unmanned aircraft vehicle). The data obtained, after comparing them with archive data, comprise valuable information which enables for example to examine the trails erosion degree, the progress of forest succession and the impact of anthropogenic denudation on tree line changes.

MATERIAL AND METHODS

The research described in this article was conducted in the Tatra National Park (abbr. TNP), which is situated in the southern part of Poland. The Tatras comprise the only alpine area in Poland. Due to outstanding natural features of this area, the national park was founded here in 1955. It is one of the largest national parks in Poland with the total area of 21197 ha (TNP 2017).

The hiking trails in the Western Tatras were used as case studies to verify whether it is possible to use unmanned aerial vehicles to evaluate erosion in the alpine areas, and to study plant succession or tree stand condition in the area located next to hiking trails. In total, about 27 kilometres of hiking trails were measured (Figure 1), which constitutes about 10% of all trails in the Tatra National Park. It is worth noting that the relative height differences of the area being subject to the tests described in this article are up to 1000 m.



Source: Own study based on www.geoportal.gov.pl

Figure 1. Hiking trails in the Western Tatras which are the subject of this research

Measurements were carried out in August and September 2016. They included acquisition of nadir images of trails from the board of unmanned aerial vehicle along with georeference information. The device used for measurements was the multicopter manufactured by the DJI company, model S1000+,fitted with Sony Alfa A7R camera with Sony Zeiss Sonnar T* FE 35 mm F2,8 ZA lens, with gimbal stabilisation.

Field surveys with unmanned aerial vehicles were preceded by drawing up UAV flight plans adjusted to the study area, considering height differences along the trail. For each section flight missions were planned in two parallel strips also parallel to the trail axis. In this way 37 missions were planned with length ranging from 0.7 km to 3.2 km. and the estimated GSD of 15 mm in non-forested areas and 20 mm in the areas covered with high trees.

The scope of preparatory works also covered the project of the photogrammetric control points distribution (control points and check points) along the UAV flight routes and indications of the optimal take-off and landing sites. During the field works, before each planned UAV flight, it was necessary to set out, mark and measure coordinates of control and check points in the area covered by the flight mission. The points were measured with RTN and RTK GNSS. In total, 537 points were measured in the planar coordinate system PL-2000/7 (PL-ETRF2000) and Krondstat86 height system (PL-KRON86-NH) based on the levelling quasi geoid PL-geoid-2011. The accuracy of obtained coordinates is at the level of 2-3 cm.

The UAV flights supplied blocks of digital images which were processed using photogrammetric methods in Agisoft PhotoScan Professional software.

The first step was to initially align images. At this stage, the images were uploaded to the software and were given the initial orientation by adding approximate coordinates of images projection centres.. After images had been initially aligned, control points and check points were indicated on the individual images. This was preceded by uploading coordinates of the terrestrial photogrammetric control to the software. Each marker was indicated on all the photos where it was visible. In total, 7 111 images were used.

With the block of photographs prepared in such a way for each mission, the initial alignment commenced. At this stage, some points of the photogrammetric control worked as control points and the others as check points, which made it possible to evaluate the project accuracy. The block of photographs was aligned and at the same time the camera calibration parameters were determined. In this process the following values were determined: the principal distance (c), the location of the principal point (c_x and c_y) and distortion parameters (k_1, k_2, k_3, and p_1 and p_2). As a result of alignment, root mean square errors of control points and check points were obtained (Table 1). Then, the final alignment (optimization) of blocks of photographs was performed. This process involved all points of the photogrammetric control (both control points and check points). Mean values for these parameters calculated for all the missions are: m_x = 30 mm, m_y = 30 mm and m_h = 32 mm, which corresponds to the error of the horizontal point position m_{xy} = 42 mm and the error of spatial position m_{xyh} = 53 mm. These are the values which only indicate the possible accuracies of the products created. Detailed assessment of the accuracy of the obtained materials is subject to a separate publication. It is worth noting that the maximum errors m_{xyh} for control points and check points were over 100 mm and were obtained for Kobylarzowy Żleb. This is a particularly difficult area because of the significant height difference exceeding 300 m on the trail section of about 500 m. For other areas the analysed parameter did not exceed 50 mm.

Table 1. The initial and final root mean square errors of the photogrammetric control (own study).

Parameters		m_x **[mm]**	m_y **[mm]**	m_h **[mm]**	m_{xy} **[mm]**	m_{xyh} **[mm]**
Initial errors	control points	24	24	22	34	41
	check points	29	24	42	38	55
Final errors		30	30	32	42	53

The next step was to create a dense point cloud with the method of dense matching. As a result, a total of 7 854 760 000 points were generated in all missions.

RESULTS AND DISCUSSION

One of the main aims of the research was to determine the erosion of hiking trails. To this end, point clouds obtained from UAV were compared with archive data from airborne laser scanning (ALS) for the whole study area. It must be emphasised that data from ALS comes from 2012. On the basis of the results of these analyses, differential raster maps were generated which allow visual assessment of the degree and reasons for erosive phenomena. It has to be remembered, though, that the aerial laser scanning archive data is characterised by far lower spatial resolution and therefore some spatial objects, such as route beds, boulders, erosion craters, could have been generalized. Additionally, thie lower data spatial accuracy can lead to a constant shift in reference to actual data.

The analyses were performed using CloudCompare software. For the numeric calculations to be improved, the data from UAV flights was subject to resampling with a minimum distance between points set at 3 cm. In this way, the number of points to be analysed was considerably reduced while the reliability of the analyses undertaken did not decrease. The ALS data was imported in two versions:

- the first one included all classes of points and therefore represented land forms along with the land cover (DSM ALS);
- the second one included only points classified as ground points, which represent land forms solely (DTM ALS).

Subsequently, for the results of comparison to be as reliable as possible, TIN (Triangulated Irregular Network) models were prepared for ALS data. It enabled to calculate distances between the clouds of points along normal vectors to the generated triangles and therefore the information was obtained about the direction of changes in the land form (decrease/increase). Moreover, the influence of the survey data density on the accuracy of determined distances was eliminated.

As a result of the analyses, for each point from the set gained from UAV a value of deviation between DSM and/or DTM was obtained which derives from the comparison of archive data and that of the actual state. However, because browsing the point data results requires appropriate software as well as a lot of RAM, the results obtained were presented as a raster dataset which enables convenient browsing of materials in the GIS environment. To this end, based on UAV clouds and calculated differences, rasters with a resolution of 5 cm were generated.

Considering the characteristics of the compared data, the proper interpretation of the obtained maps of differences should consist in locating local disturbances of differences and comparing them with the image on the high-resolution orthophotomap. It enables to establish what causes these variations and to note whether they are related to measurements errors (e.g. people on the trail during measurements).

Below, several hypothetical study areas are presented. They illustrate possible interpretations of the acquired materials. In all of the examples shown below the same colour scale has been used (Figure 2d). It must be emphasised that data from ALS was treated as referential data, and therefore negative values (blue ones) prove the decrease within the period between measurement series, whereas positive values (red ones) prove the increase (accumulation) or the occurrence of objects in the UAV data that do not occur in the ALS data.

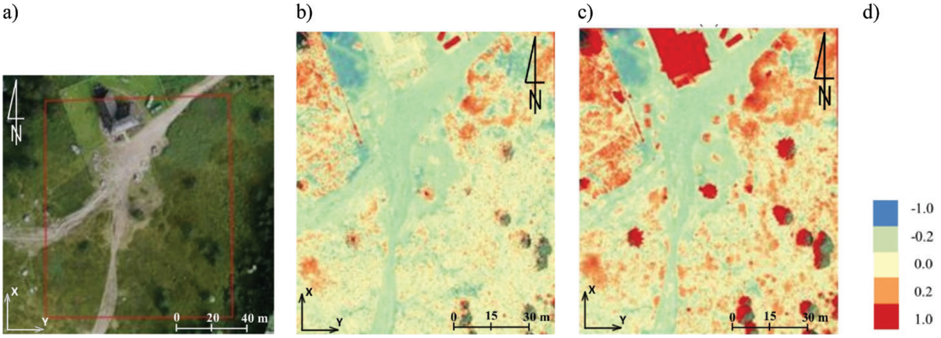


Figure 2. The mountain shelter in Hala Kondratowa:
a) the study area, b) the results of comparison of DSM UAV – DSM ALS,
c) the results of comparison of DSM UAV – DTM ALS, d) colour scale (the units given in [m])

In the area presented in Figure 2a, on the basis of differences between DSM UAV and DTM ALS identified for the roofing of the mountain shelter (Figure 2b), a relative accuracy of both sets of data can be calculated. Assuming that between the measurement periods the roof of the shelter was not subject to any displacements, this accuracy oscillates between – 20 cm and +10 cm. Another aspect which can be observed in the discussed example are the places marked with a distinct orange-red colour which, in the case of the DSM UAV – DSM ALS comparison, prove the increase in vegetation. However, this increase can depend on the period in which measurements were taken. In case of the DSM UAV – DTM ALS comparison, it proves the occurrence of medium and high vegetation (Figure 2c).

When analysing the trail area, one may notice immediately the trail bed and small relative differences of colours, which indicate erosion (more blue ones) or accumulation (light yellow-orange ones). However, in the above-mentioned area such changes are insignificant.

Another comparison area was the yellow trail in the area of Jaworzynka-Siodłowa Perć (Figure 3) which shows how the collected materials can be interpreted. In the images presented below, the following changes occurring on the trail can be observed:

- violet line – places of increased erosion,
- yellow line – places of accumulation,
- green line – errors in measurement data resulting from the presence of people on the trail during the measurement.

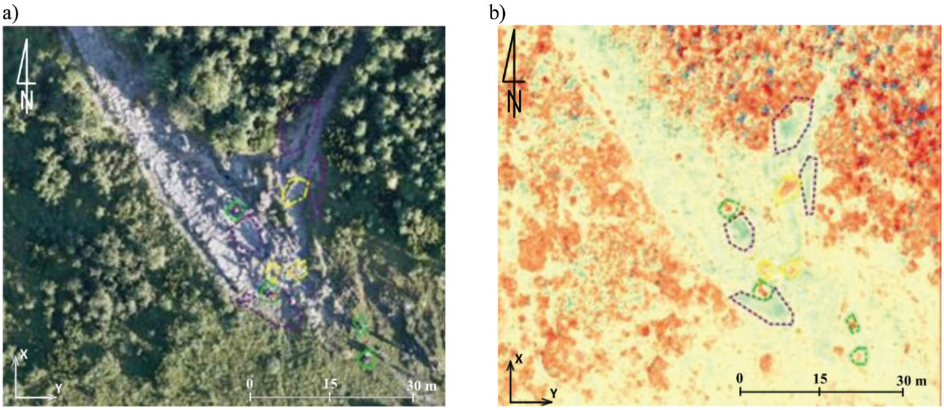


Figure 3. The yellow trail in the area of Jaworzynka-Siodłowa Perć: a) ortophotomap, b) the results of comparison of DSM UAV – DSM ALS

The materials produced during the study can be used for analyses concerning the land cover such as monitoring the anthropogenic changes of the environment or the extraction of tree tops (Wallace 2013). Data collected with the UAV allowed for making an orthophotomosaic of GSD size ranging from 1.5 cm to 2.0 cm. The archive product for the study area is characterized by a GSD at least five times larger. During the study materials of ten centimetres resolution were used for the eastern areas of the study and twenty-five centimetres for the western part (Figure 4). The radiometric quality of the archive products should also be taken into account (Figure 5). A comparison between the orthophotomap made on the basis of UAV-based materials and the aerial orthophotomap is presented in Figures 4 and 5.

UAV-based orthophotomap allows not only to survey hiking trails, but also to inspect wooded and bushed areas located in the immediate vicinity of footpaths. An exemplary analysis what percentage of all trees are healthy trees, partially dry trees and completely dry trees were carried out in the study. The test fields most affected by the phenomenon of trees death were selected: a fragment of the yellow/blue hiking trail from the Chochołowska Polana to Grześ peak

(350 m long), and three sections of the yellow hiking trail from the Chochołowska Polana to Jarząbcza Dolina with lengths of 350 m, 220 m and 520 m.

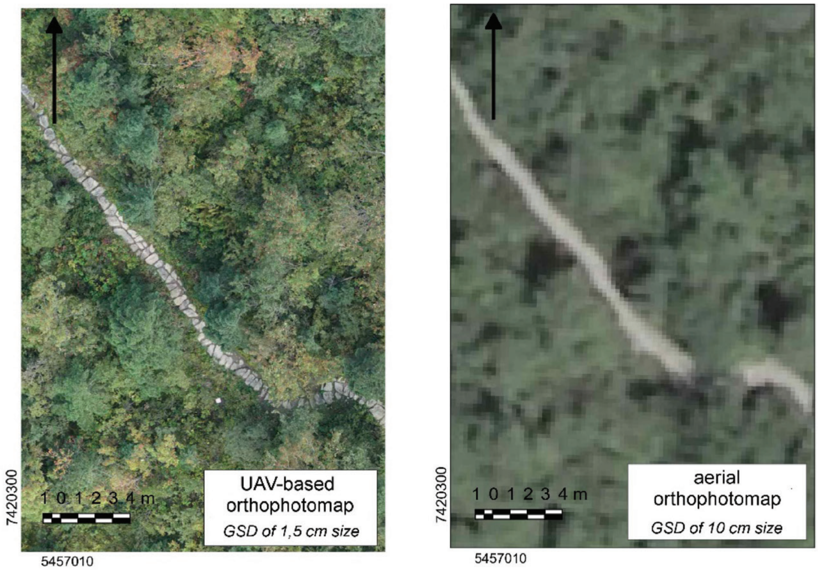


Figure 4. Comparison of geometric resolution of orthophotomaps

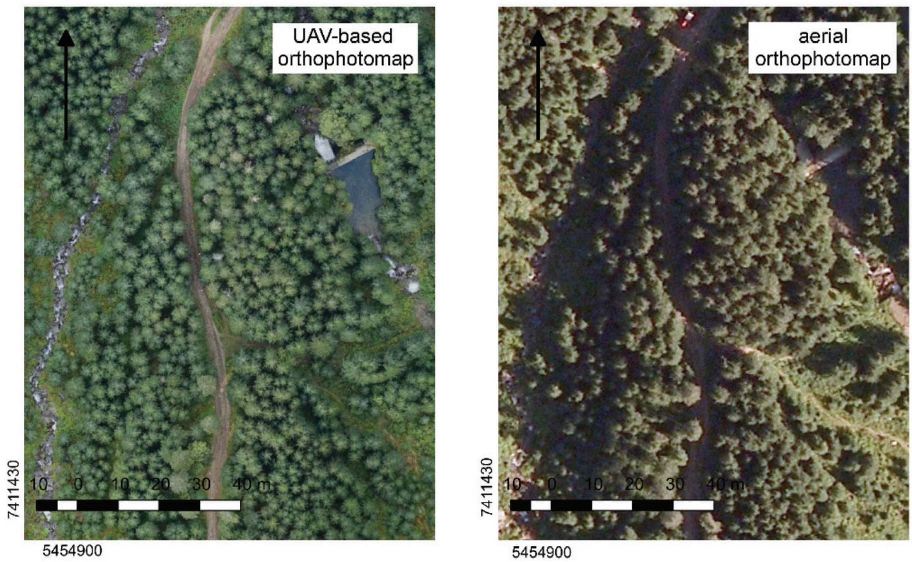


Figure 5. Comparison of radiometric quality of orthophotomaps

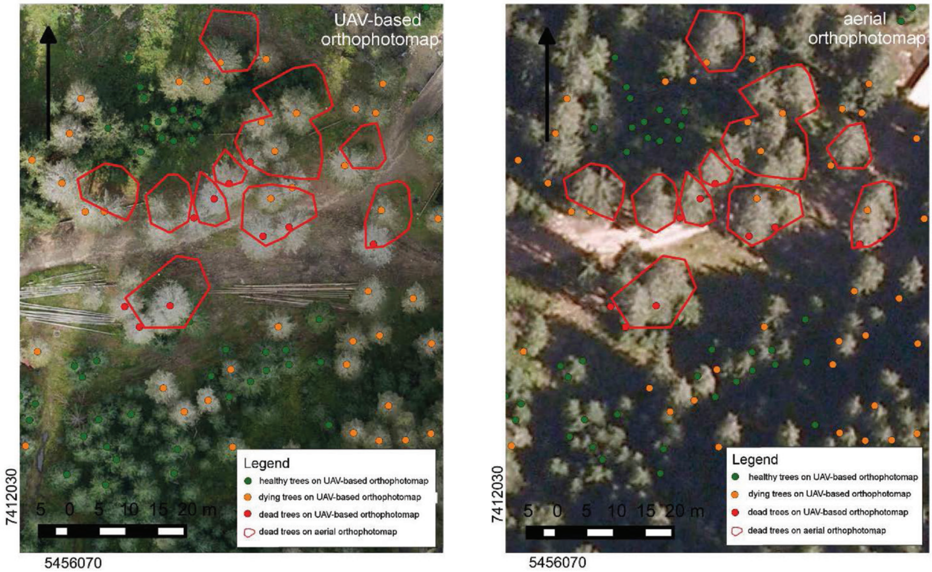


Figure 6. Vectorization of trees in the control area

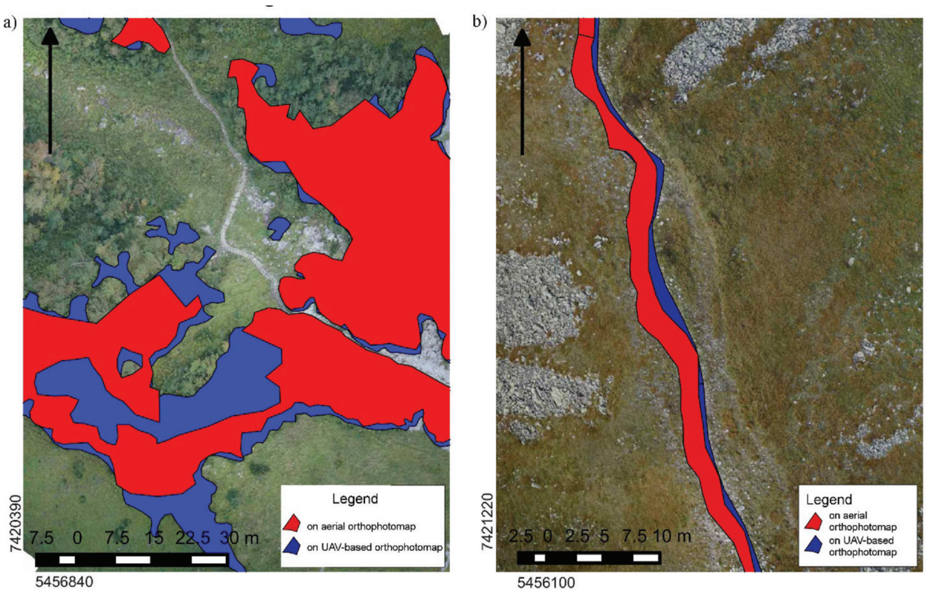


Figure 7. The areas occupied by: a) dwarf mountain pines, b) hiking trail

The study was carried out within twenty-five metres of the route boundary, however dead and dying trees were marked also outside the designated zone. The assimilation apparatus defect was used as a tree classification criterion. If the assimilation system of the tree was defective:

- less than 10% – the plant was considered healthy,
- between 10% and 90% – the plant was considered to be dying,
- larger than 90% – the plant was considered dead.

In the study area, for the current state (2016), healthy trees account for 74% of all trees, trees with partially dry branches for 25% and dead trees for 1%. For archive data (2009 or 2013), due to the resolution of the archives, it was not possible to indicate individual trees (healthy, dying or dead), therefore groups of trees with a different colour were marked. Examples of the analyses carried out are shown in Figure 6.

In addition, radial shifts of groups of trees vectorized on the archival orthophotomap are noticeable. This phenomenon is related to the fact that the UAV-based products are based on the DSM, which makes the crowns of trees orthorectified. True orthophomaps allow for better identification of plants in the field. The archive materials are based on the DTM, as a result of which coordinates of all the land cover elements are incorrect.

The part of the study area was also vectorised in order to determine the basic geometric parameters characterising hiking trails, areas occupied by dwarf mountain pines and trees. Six vector layers were prepared, drawing three groups of objects on the current orthophotomap and the same three groups of objects on the archive orthophotomap. The test area was 7.2 km long. It consisted of:

- 2.1 km of the blue hiking trail from Kobylarz to Małołączniak,
- 2.2 km of the yellow hiking trail from the Chochołowska Polana to Jarząbcza Dolina,
- 2.9 km of the yellow/blue hiking trail from the Chochołowska Polana to Grześ peak.

An area within 25 m from the border of the trails was studied. Figure 7 shows examples of the analyses carried out. It is worth noting that because of the differences in GSD comparing current and archive materials is impossible or incorrect in several places.

The work has shown how the area of linear hiking trails has changed. In the analyzed area, as a result of comparison of orthophotomaps from archive and current measurements, it was found that in the period between 2009/2013 and 2016 the total surface area of the trails increased by almost 10%. It is worth pointing out that in the case of products with different accuracy it is only an estimated value. In forest areas, the increase in hiking trails area did not exceed 6%. An analysis of the average width of the trail was also carried out, sampling it on the test fields every fifty meters. The results are presented in Table 2.

Table 2. The average width of the trail in 2009/2013 and 2016 (own study).

The width of the trail	on UAV-based ortho-photomap, 2016 year	on aerial orthophotomap, 2009/2013 year
in forest area	1.2 m	1.1 m
in area covered by dwarf mountain pines	2.6 m	2.3 m
in open area	3.4 m	2.9 m

The data presented in the form of a high-resolution orthophotomap allow for the supervised and unsupervised classification aimed at obtaining the land cover maps. One of the methods supporting the identification of objects is decorrelation stretching based on the PCA (Principal Component Analysis). The application of the histogram decorrelation stretching facilitated identification of trees that succumb to diseases or atrophy (Figure 8). The sole analysis of components allows for the separation of tree tops. Decorrelation stretching enables efficient processing of large amounts of data and it does not take much time. Artificial neuron networks also give good results in the EHR (Extremely High Resolution) classification.

a) b)

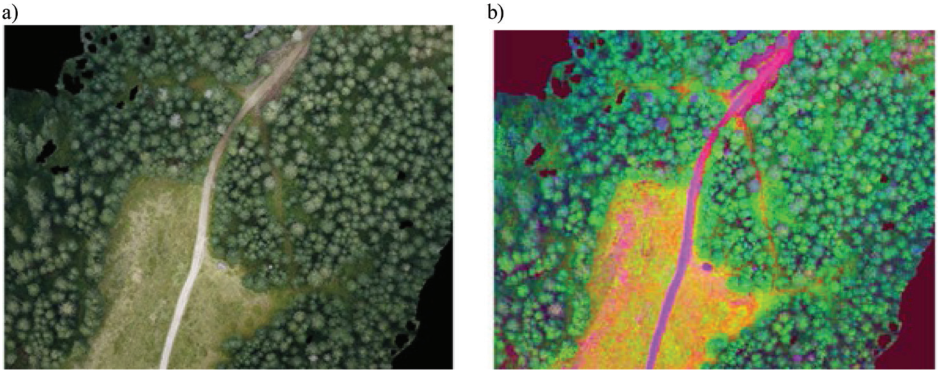


Figure 8. a) A sample of the orthophotomap with the tourist trail between Dolina Chochołowska and Trzydniowiański Wierch b) Decorrelation stretching conducted on the basis of the analysis of the main components

In addition to quantitative analyses, numerous qualitative analyses can be carried out on the basis of archive materials and current data. Figure 9 shows an example of the damage detected due to winds in the Chochołowska Dolina or the effects of The Community Forestry activities in this area. In both cases, the same area was presented on a map completed under this research (Figure 9a) and an aerial map from 2009 (Figure 9b).

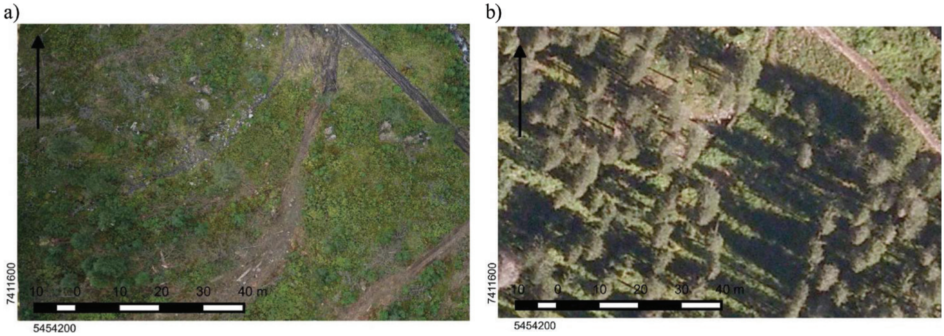


Figure 9. Orthophotomap of the Chochołowska Dolina fragment made in: a) 2016; b) 2009.

CONCLUSIONS

This article presents the outcomes of the research whose purpose was to verify the usability of unmanned aerial vehicles to check the condition of hiking trails and forests in alpine areas. It should be noted that the presented results are from the first measurement series and TNP does not have archive data for the test area of comparable quality to the products made during this study. For this reason, the available materials, which are characterized by lower accuracy and resolution than point clouds, orthophotomaps and DSM, based on data collected from UAV, were used as reference data. This situation affects the quality of the analyses. It should be emphasized that this problem will not occur during the implementation and development of subsequent series of measurements for the studied area.

It should also be mentioned that aerial laser scanning, as a method of comparison, is one of the most expensive methods of assessing the current state of land cover and land forms. Considering the data stored in the generally accessible public data bases, it has to be remembered that the time in which the data was collected might not correlate with the timing assumptions of the conducted project. Therefore, the potential of unmanned aerial vehicles, as a much cheaper solution, needs to be noted as these devices can supply information about the measured area in the chosen time, provided that weather conditions are favourable.

The area in which the research was conducted is demanding and imposes the necessity of precise planning of the UAV mission as well as positioning control points with regard to a great number of factors. At this stage it is particularly important to focus on the land forms and forest cover.

Basic products resulting from UAV flights (clouds of points, DTM, orthophotomosaics) make a valuable source material for advanced spatial analyses. The comparison of data from various measurement periods makes it possible to assess the erosion along hiking trails as well as to study land cover changes, particularly the floral succession in the immediate vicinity of hiking trails. The work shows how the area of hiking trails has changed. It should be added that the vectorization of the boundary of the area occupied by a hiking trail, dwarf mountain pines or forest is always burdened with misinterpretation. Therefore, such analyses should be carried out on an ad hoc basis, at the time of the need, by one person. However, the application of various methods of digital analysis of images allows for automatic detection of phenomena and relations which are invisible for an observer, since such a detection method is more efficient than manual data processing.

It should be noted that the presented studies do not exhaust the potential of analyses or their interpretations. Additionally, it is worth emphasizing that the most effective method would be to compare the data of similar accuracy and resolution parameters conducted in a similar period of the year. Therefore, it seems justifiable to conduct further measurements using the UAV in the following years.

It should also be mentioned that aerial laser scanning, as a method of comparison, is one of the most expensive methods of assessing the current state of land cover and land forms. Considering the data stored in the generally accessible public data bases, it has to be remembered that the time in which the data was collected might not correlate with the timing assumptions of the conducted project. Therefore, the potential of unmanned aerial vehicles, as a much cheaper solution, needs to be noted as these devices can supply information about the measured area in the chosen time, provided that weather conditions are favourable.

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