

Comparison of Accuracy of UAV Aerials and Ground Measurements in the Curonian Spit Dunes

Algimantas ČESNULEVIČIUS, Artūras BAUTRĖNAS,
Linus BEVAINIS, Neringa MAČIULEVIČIŪTĖ-TURLIENĖ

Institute of geosciences, faculty of Chemistry and Geosciences, Vilnius University,
M.K.Čiurlionio str.21, Vilnius, LT – 03101, Lithuania

algimantas.cesnulevicius@gf.vu.lt; arturas.bautrenas@gf.vu.lt;
linas.bevainis@gf.vu.lt; neringa.maciuleviciute@gf.vu.lt

Abstract. Various detailed means are taken to stabilize the dune surface. One of them is the creation of sand traps, which reduce the amount of sand transmissions. Therefore, it is desirable to develop a methodology that will help evaluate the effectiveness of sand traps. The topographic measurements of dune harm the sand surface and cannot be often – twice a year, when 2–3 months would be a better interval. For detailed monitoring an aerial photogrammetry and automated granulometry method is developing for less invasive measurements. For dune surface analysis were applied topographic mapping and UAV aerial images. These commonly used methods allowed of evaluation the accuracy of photogrammetric methods for the analysis of aeolian processes in dunes and will allow for precise evaluation of changes by doing minimal harm to the surface of the dunes.

Introduction

Detailed measurements of the dunes are carried out for many years to assess the impact of various meteorological and natural phenomena on unstable terrain surfaces. At the end of the twentieth century, large numbers of dunes visitors have exacerbated this problem. Various methods are taken to stabilize the surface in the Curonian Spit. One of them is the creation of barriers (sand traps) to reduce the amount of transmissions. Therefore, it is desirable to develop a methodology that will help evaluate the effectiveness of sand traps for surface stabilisation.

Every time when dune surface is measured, harm is done to the sand surface. If traditional methods are applied, measurements cannot be often – twice a year, when 2–3 months would be a better interval. For detailed monitoring and evaluation of impact of protection measures, an aerial photogrammetry and automated granulometry method is developing for less invasive measurements. This method will allow for precise evaluation of changes by doing minimal harm to the surface of the dune.

An important task is to select the most appropriate methodology for accurate estimation of surface changes. Three methods were parallelly applied for precise evaluation of the dune surface changing: topographic mapping, aerial photogrammetry

and granulometric sand research. Topographical research and aerial photogrammetry are the most commonly used methods that allowed evaluate the accuracy of photogrammetric methods for the analysis and modelling of aeolian processes in dunes. The novelty of the proposed method is to combine them with microscopic photography of surface sand fractions. We believe that this method will allow for precise evaluation of changes by doing minimal harm to the surface of the dune.

The use of unmanned aerial vehicles allows for fast and inexpensive ways to explore the ground surface and to identify objects of interest (Turner et al., 2012, Whitehead et al., 2014 a, 2014 b). On the other hand, the research on assessing precision of aero-images of unmanned aerial vehicles has been scarce (Shahbazi et al., 2015). The accuracy of aero-images received with the help of unmanned aerial vehicles (UAV) can be affected by a big number of factors such as flight altitude, photo camera image quality, UAV route designing, methods of georeferencing and others. An appropriate design of UAV route ensures cruise attitude and constant aero-image coverage of the whole territory. An appropriate flight project and a high-quality photo camera result in efficiency in photogrammetric processing of images. The tested and broadly applied mathematical and photogrammetric algorithms of image processing simplify further investigations. The problems occur designing a 3D model of the territory captured in aero-images. The initial 3D model is created in the conditional coordinate system, which is later linked to the officially used coordinate system. Two variants are employed to connect the coordinates: direct graphical connection of the object position in the aero-image to the coordinate system (less precise) or linking GPS measurements of fixed objects and coordinates of aero-images. The accuracy of vertical positioning of given points is a highly important factor designing 3D relief models that are used for identification, analysis and mapping of surface changes.

The recent research studies (Benassi et al., 2017; Forlani et al., 2018; Hugenholtz et al., 2013, 2016; Shahbazi et al., 2015; Turner et al., 2012, Ruzgienė et al., 2015; Sužiedelytė-Visockienė et al., 2016) have shown that aiming at high accuracy of vertical positioning of objects, it is not enough to use Global Navigation Satellite System (GNSS) only and Ground Control Points (GCP) has to be applied as well. Such a combined technique allows designing a more accurate digital relief model (DRM), where precision of vertical positioning of points equals 0.7 cm.

Applying UAV photo-images for dune research is complicated by two factors: herbaceous vegetation and temporary snow cover. The height of dunes grass significantly varies during the different year seasons. At summer end the height of the grass stems reaches 15-30 cm (bushgrass, *Calamagrostis epigejos*); 40 - 60 cm (lyme grass, *Leymus arenarius*) and 50 - 100 cm (marram grass, *Ammophila arenaria*) compared to early spring.

The methods of narrow-spectral and surface thermal analysis are applied for the analysis of structural diversity of vegetation cover on the basis of UAV aero-images (Laliberte, Rango, 2009; Berni et al., 2009, Baluja et al., 2012, Bellvert et al., 2013, Chisholm et al., 2013, Huesca et al., 2013, Knoth et al., 2013, Lebourgeois et al., 2008; Malthus and Madeira, 1993; Zarco-Tejada et al., 2001; Adams et al., 1999; Zhang et al., 2001).

The research studies mainly focus on the influence of big ligneous plants on mapping of surface elements, whereas the impact of low herbaceous vegetation on low forms of relief has not been exhaustively researched so far (Kaneko and Nohara, 2014; Salami et al., 2014).

During the winter, the temporary snow cover significantly changes the morphometric parameters of the surface. It is thin on the windward slopes of the dunes, and sometimes it was blown-out away. Meanwhile, the thick layers of snow (0.8 - 1.2 m) are covered in the windward slopes, hollows and depression. This situation complicates the comparison of UAV photo-images taken during the summer and winter.

Research object and methods

The researches were carried out in two areas of main dune-ridges of the Curonian Spit: Nagliai cognitive path and Parnidis dune (Fig. 1). There is a fee for visiting the Nagliai cognitive path, which slightly limits the number of visitors. The dune of Parnidis is close to the Nida settlement, there is a road to it and its visit is not limited. The research was conducted in different seasons of 2017, 2018 and 2019 years.

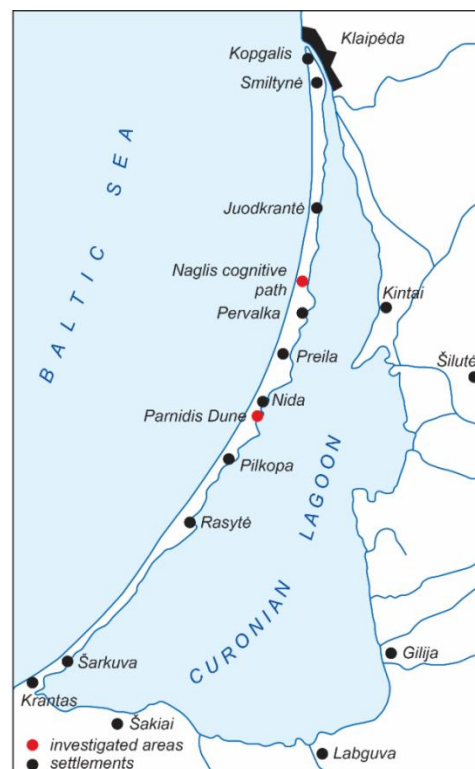


Fig. 1. Investigated area in Curonian Spit.

Surface geodetic measurements and UAV aerial images were used to assess meso-rank surface changes. Changes of micro-rank surface changes and microstructure were evaluated using an automated method of recording sand granulometry. The accuracy of

the meso-rank surface changes was assessed by comparing the maps, which created based on ground-based geodetic measurements and the UAV aerial images.

The surface was mapped by isoline methods in maps. The interpolation between fixed points was based on the Delaunay triangulation principle (Fang and Piegl, 1992). In department of Cartography and Geoinformatics Vilnius University was created software (author Dr. Artūras Baurėnas) for calculating isolines point position. The program is conventionally referred to as “Circle_3p” (Fig. 2).

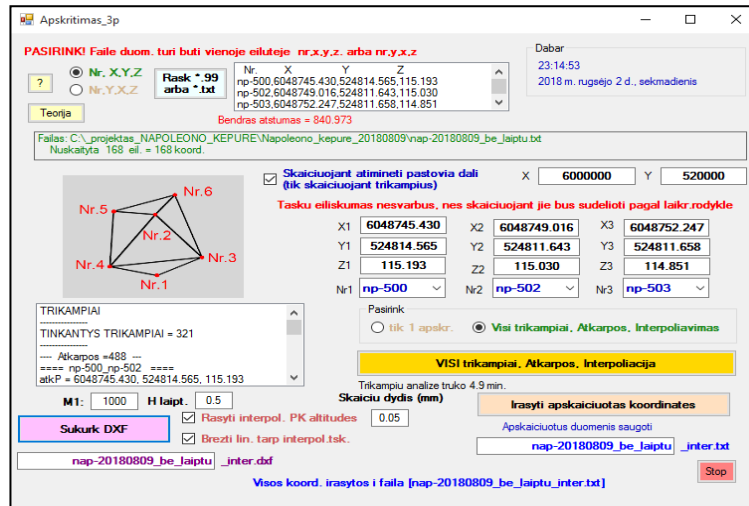


Fig. 2. The application (task) of the management window of the software program “Circle_3p”.

The Delaunay triangulation is a connection of dots on a dot plane to make up triangles, so that there are no single points left within the circle. For example, there are four points, among which only the triangles must be selected, so that vertices of those triangles can be used to draw circles, which will correspond to the principles of Delaunay triangulation.

Among these points (theoretically), 4 triangles can be drawn: 1-4-3, 4-2-1, 1-2-3 and 1-4-2. It needs to be checked which of them comply with the Delaunay principles and which do not meet them.

It is obvious that the triangles 1-4-3 and 4-2-3 are not suitable because they fall into the drawn circles: in the first case, point 2, and the second case - point 1. Therefore, the only correct option for interpolation, its interconnection between triangles 1-2-3 and 1-4-2, because no outsider points end up in the defined circles (Fig. 3).

Selection of point pairs. Obviously, application of the Delaunay triangulation for the selected 179 measurement points is a complex geometric and mathematical problem that would be very difficult to perform “manually” and computer software is required to perform this task. There are many available programs, which perform division of the point pairs into triangles. However, aiming at the accuracy of the conducted interpolations and their comparison on the basis of this particular topographic photograph, they are not very appropriate because of the unknown algorithm they apply.

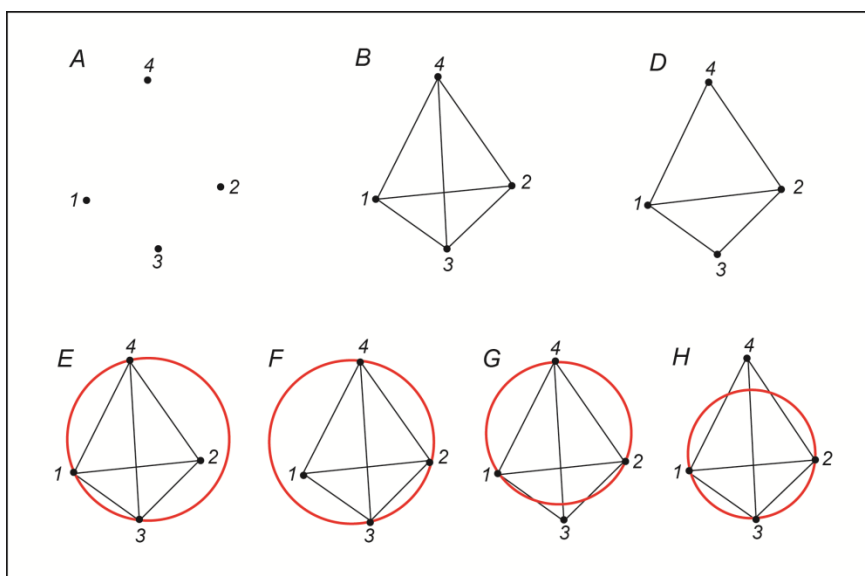


Fig. 3. The points between which interpolation should be performed and the possible arrangements to combine points of triangles.

Principle of program operation. After selecting a set of points (in these topographic photographs 179 points were selected), the program starts checking all the possible points to combine triangles. The coordinates of the centre of the circle are calculated when the vertices of a chosen triangle are drawn through the centre of the circle (Fig. 4), following the formulas 1-3.

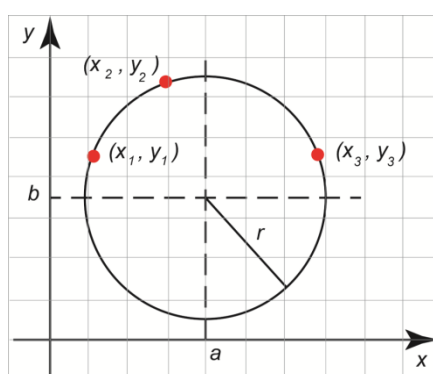


Fig. 4. The calculation of the circle drawn through the centre of the three point coordinates and its radius. Here $x_1, y_1, x_2, y_2, x_3, y_3$ are point coordinates, x, y are coordinates of calculated centre of the circle and r is radius of the circle.

$$x = \frac{(x_1^2 + y_1^2)(y_2 - y_3) + (x_2^2 + y_2^2)(y_3 - y_1) + (x_3^2 + y_3^2)(y_1 - y_2)}{2(x_1(y_2 - y_3) - y_1(x_2 - x_3) + x_2y_3 - x_3y_2)} \quad (1)$$

$$y = \frac{(x_1^2 + y_1^2)(x_3 - x_2) + (x_2^2 + y_2^2)(x_1 - x_3) + (x_3^2 + y_3^2)(x_2 - x_1)}{2(x_1(y_2 - y_3) - y_1(x_2 - x_3) + x_2y_3 - x_3y_2)} \quad (2)$$

$$r = \sqrt{(x - x_1)^2 + (y - y_1)^2} \quad (3)$$

After the calculation of the coordinates of circle centre, the main condition of the Delaunay triangulation is checked, i.e. if any outsider falls into the defined circle. If this condition is not met, then another triangular connection option is checked. This condition is continuously verified until all the appropriate triangles are selected, and only then interpolation is done between the heights of these triangles with a selected horizontal step (e.g. 0.5 m) (see: Fig. 5).

For example:

The points X_1 and X_2 are 24 and 24.5 m respectively (if horizontal step is 0.5 m), because these numbers are between $H_A = 23.72$ and $H_B = 24.64$ (formulas 4-7).

$$X_1 = \frac{(H_{X_1} - H_A)}{(H_B - H_A)} \times L \quad (4)$$

$$X_2 = \frac{(H_{X_2} - H_A)}{(H_B - H_A)} \times L \quad (5)$$

$$X_1 = \frac{(24.00 - 23.72)}{(24.64 - 23.72)} \times 200.64 = 61.06 \quad (6)$$

$$X_2 = \frac{(24.50 - 23.72)}{(24.64 - 23.72)} \times 200.64 = 170.11 \quad (7)$$

Knowing the distances between horizontals, the coordinates of these points are calculated and these points are plotted accordingly.

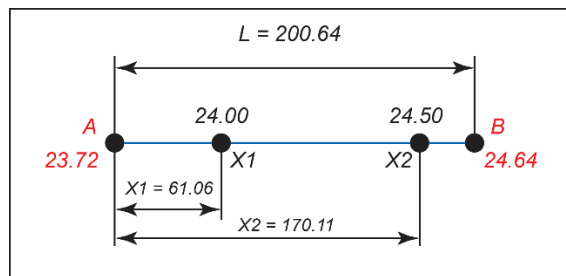


Fig. 5. The calculation of distances to isolines.

Drawing of a topographic plan. Firstly, the Delaunay triangulation (Fig. 6.) was completed among selected topographic points using the program “Circle_3p”. This allowed triangles to be selected, among which interpolation of the triangle vertices was performed.

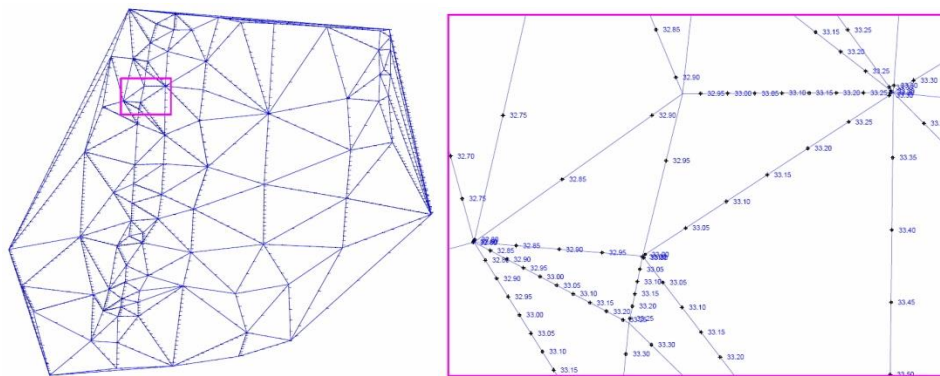


Fig. 6. The Delaunay triangulation among the selected topographic points using the program “Circle_3p”.

Among these triangle vertices, horizontal interpolation was performed in the LAS07 height system using a selected step of 0.5 m (Fig. 7). The coordinates of 1676 extra points, plotted as horizontals, were calculated during the interpolation.

The interpolation points were uploaded to TopoPlan (AutoCAD 2016). The horizontals were plotted using the "Spline" function (Fig. 8).

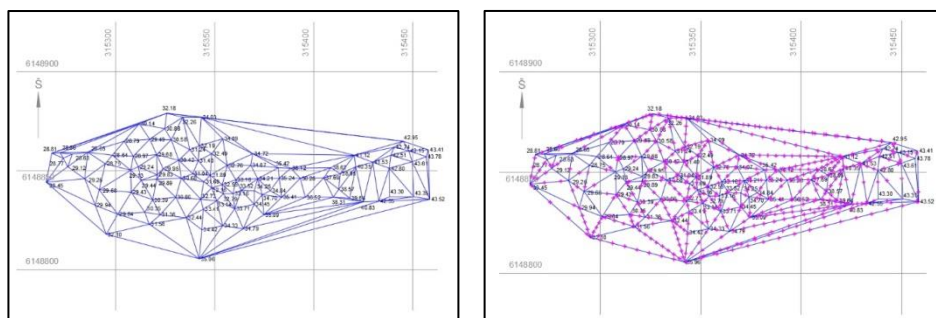


Fig. 7. The interpolation among the vertices of selected triangles in research area.

The random error distribution depends on the accuracy of the object identification therefore the graph consists of taking the errors in absolute size in mm.

The error analysis shows that they increase significantly when the orientation marks are fewer than 5, even for those objects that are visible in the 3D model. Therefore, it can be argued that in order to maintain the accuracy of measurements, there should be at least 5 orientation marks. It has been noticed that the error rate is influenced not only by the vegetation but also by the experience and thoroughness of the operator measuring the 3D model. As the precision of the well-known objects is practically unchanged (from 10 to 5 marks), it can be argued that the 3D model will be created with the maximum accuracy 5 GCPs and well-visible coordinated objects will be used (Table 1 and 2).

Table 1. The object errors when a 3D model is made on the basis of 10 marks.

Absolute error size (mm)			
Point No.	X	Y	Z
np-28.81	54	77	74
np-29.26	8	12	28
np-32.10	15	14	24
np-30.86	98	45	44
np-34.03	32	43	69
np-35.42	42	80	41
np-33.16	14	13	32
np-36.28	34	23	33
np-43.52	5	11	24
np-41.53	40	30	44

Table 2. The comparison of absolute errors in different numbers of marks for precision calculation, mm.

Point No.	3 marks			4 marks			5 marks			7 marks		
	x	y	z	x	y	z	x	y	z	x	y	z
np-28.81	402	608	514	309	194	263	56	80	51	48	70	73
np-29.26	86	105	56	36	42	42	11	12	26	10	9	19
np-32.10	175	193	64	78	14	10	15	8	25	13	16	26
np-30.86	95	145	574	48	33	254	95	56	57	88	39	49
np-34.03	954	657	1419	692	170	164	48	46	52	37	38	55
np-35.42	400	492	194	387	308	406	45	84	48	43	78	47
np-33.16	102	266	88	56	32	39	16	11	28	11	15	29
np-36.28	729	371	803	524	498	527	35	25	31	30	28	27
np-43.52	109	145	188	64	75	84	17	14	26	9	16	22
np-41.53	701	398	239	471	480	341	42	32	46	45	33	43

A comparison of ground surveying and unmanned aerial photography was made in winter of 2018 year. season was made. Snow cover and its varying thickness have a significant impact on the accuracy of aerial imagery of UAF images photogrammetric

interpretation. The UAV images fixed not the real surface of the dunes, but the snow cover, which has quite a different thickness. Comparison of the ground-based geodetic survey plan and the UAV aerial imagery shows that the largest mismatch in isoline position are at the foot of the meso-rang relief forms where are the largest snow accumulations (Fig. 12).

One of the possible the obstacle for correct position of isolines drawn from the UAV images was snow on the dune slopes (Fig 9 B). The problem is that the snow is giving reflection, and the photogrammetric software is not able to properly incorporate the key points in UAV images (in some places). As the result the maximal spatial mismatch of isolines seeks about 3 meters (2.88 m) and average mean squared deviation is about $\pm 1,25$ (maximal ± 2.05 m)(Fig. 10 and 11, Table 3). The measurements are strongly influenced by the snow on the surface of the dunes.

More over there is no stable objects which could be used as GCP's in dunes. As the result it could cause the isolines mismatches results (Fig. 11). The results of previous research showed that 5 GCP's is a strong argument for the better precision and the surface covered by grass.

Table 3. Comparison of the relief isolines position (UAV's and precision ground measurements data)

Slope with a thick snow cover (Winter 2018)									
Mismatches of isolines position, m	Mean squared deviation, $ \Delta $	Mismatches of isolines position, m	Mean squared deviation, $ \Delta $	Mismatches of isolines position, m	Mean squared deviation, $ \Delta $	Mismatches of isolines position, m	Mean squared deviation, $ \Delta $	Mismatches of isolines position, m	Mean squared deviation, $ \Delta $
A - A		B - B		C - C		D - D		H - H	
0.30	0.227	2.88	2.052	2.05	1.483	0.00	0.31	0.00	0.61
1.16	0.632	0.93	0.102	0.61	0.043	0.36	0.05	0.37	0.24
1.04	0.513	1.32	0.492	1.30	0.733	0.50	0.19	0.98	0.37
0.58	0.053	1.19	0.362	0.39	0.177	0.15	0.16	0.71	0.10
0.20	0.327	0.03	0.478	0.00	0.567	0.51	0.20	0.35	0.26
0.53	0.003	0.24	0.588	0.89	0.323	0.17	0.14	1.02	0.41
0.55	0.023	0.50	0.328	0.29	0.277	0.49	0.18	0.84	0.23
0.39	0.063	0.36	0.468	0.23	0.337	0.14	0.17		
0.63	0.103	0.00	0.828	0.43	0.137	0.47	0.16		
0.64	0.113			0.35	0.217	0.31	0.00		
0.11	0.110			0.17	0.397				
				0.10	0.467				
Total	0.653		1.899		1.488		0.493		0.839

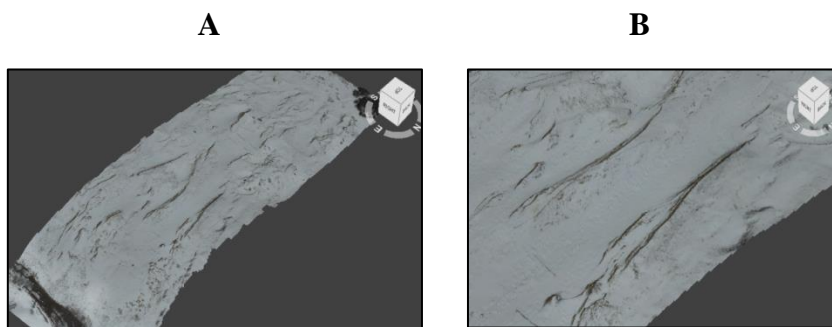


Fig. 9. Fragments of blowin dunes: A – without snow cover, B – with snow cover.

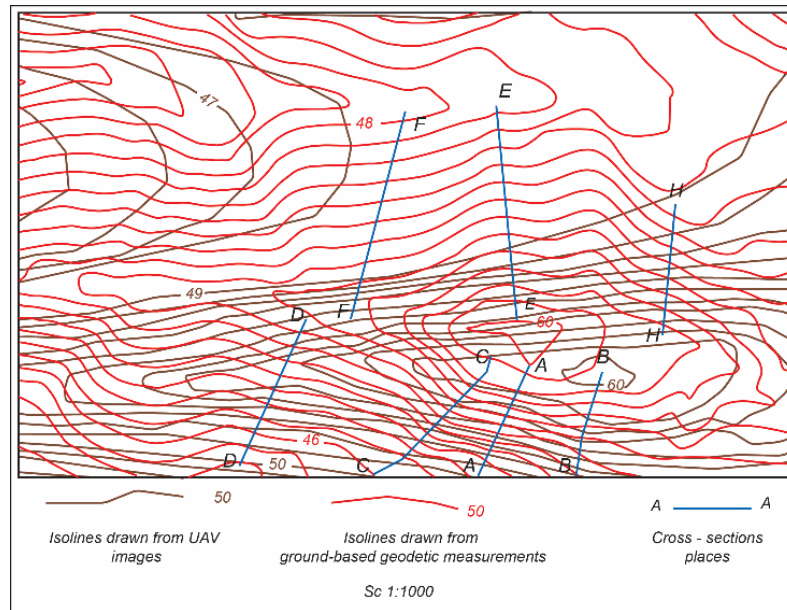


Fig. 10 Comparison of mismatches of relief isolines position drawn from UAV images and from ground-based measurements data in winter time.

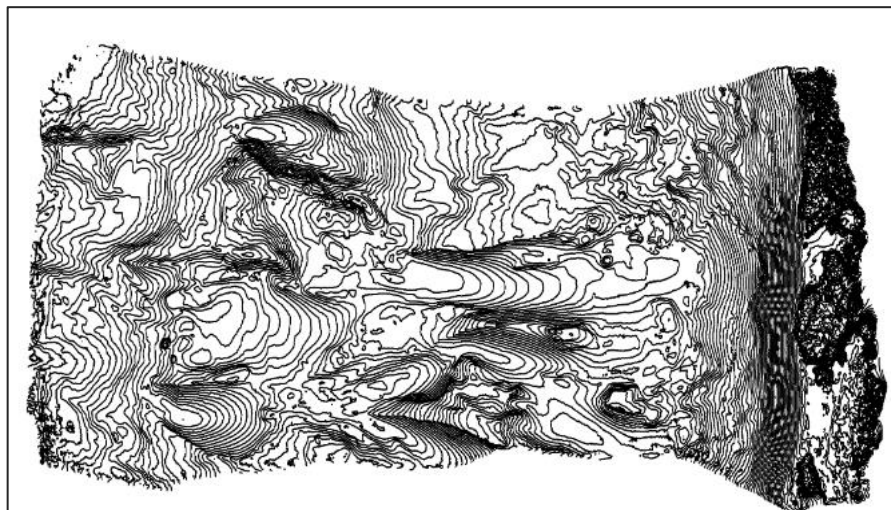


Fig 11. The shape of isolines drawn by photogrammetric software „Pixprocessing“.

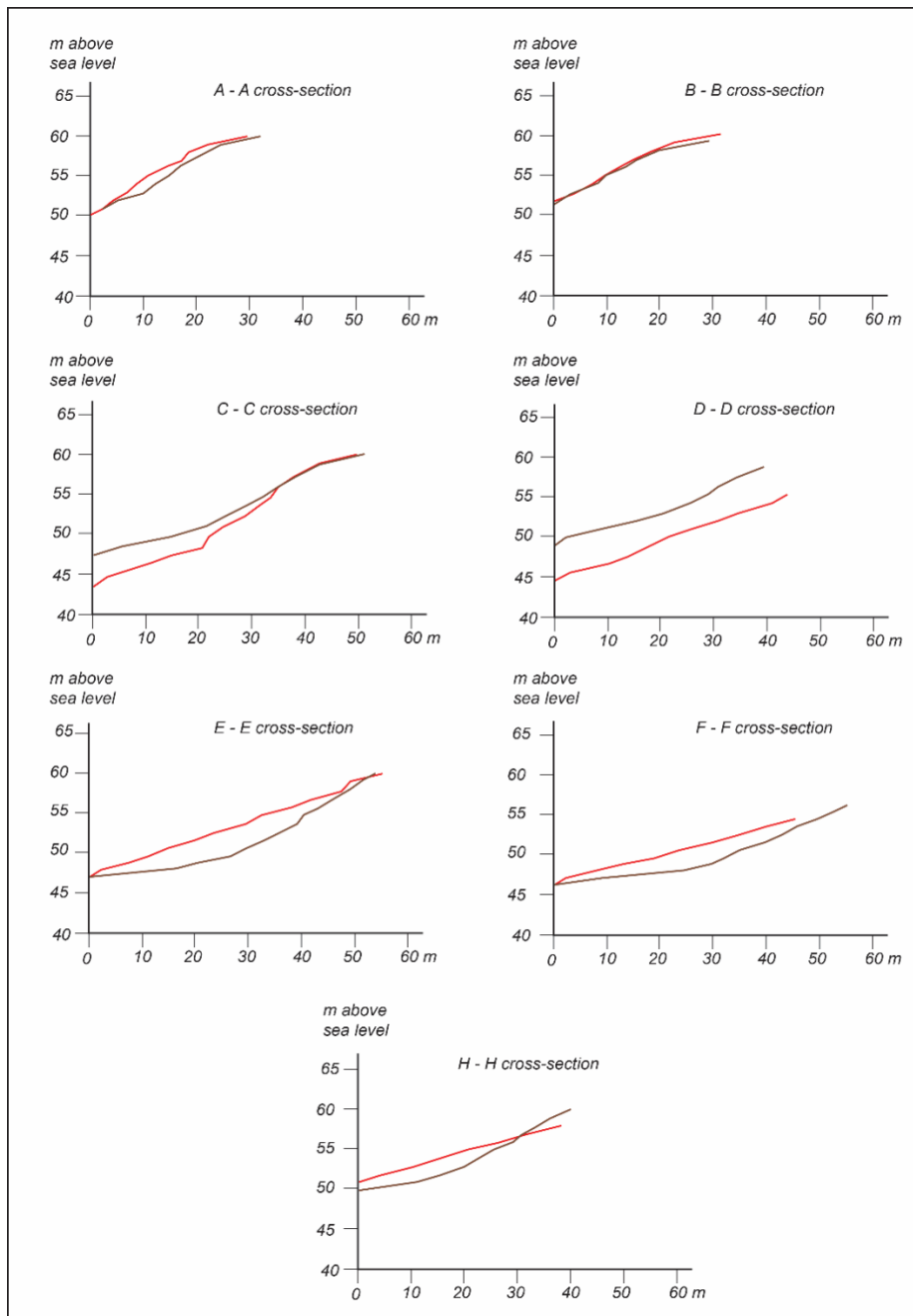


Fig. 12. Comparison of mismatch of relief cross-section drawn from UAV images and from ground-based geodetic measurements data in winter time. Places of cross-section are shown in Fig. 10.

Conclusions

1. Evaluation of accuracy of the created orthophotographic model shows that difference between the co-ordinates of control points on the surface of the sand dune measured by Trimble GPS and co-ordinates estimated from the orthophotographic model differ not more than $\pm 4\text{--}6$ cm. That allows asserting that in the future the number of measured markers necessary for a topographic map can be reduced 2–3 times.

2. The comparison of the results of the geodetic measurements and the UAV images, showed that the best overlaps of surface microform isolines are in steep slopes. On the flat surface microform variance makes up 0.7–1.0 meters. This is due to the rare density of the interpolation points calculated by the program “Circle_3p”. The variance of the isolines at the foot of the dune reaches 0.45–0.7 m and 0.95–1.35 m (in high grass patches). The study has shown that external factors have a significant influence on the identification of the surface microforms.

3. The research related to the GCPs position shows that 5 GCPs arranged at the edges and the centre of the object give the best accuracy compared to other variations. The best results of aerial photographs are obtained even when the shortest distance between GCPs points does not exceed 20 m.

4. The efficiency of automated points height interpolation of ground-based measurements is improved by the computer program “Circle_3p” created by in Department of Cartography and Geoinformatics Vilnius University (author: Dr. Artūras Baurėnas). The operation of the program is based on the classical Delaunay method and ensures a consistent systemic selection of points. The use of “Circle_3p” for the analysis of aerial photographs of the Curonian Spit dunes has shown that the program needs to be improved by adding the elements for correction of the isolines.

5. The snow is giving reflection, and the photogrammetric software is not able to properly identify the key points in UAV images (in some places). As the result the average mean squared deviation is about 1,25.

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Authors' information

Algimantas Česnulevičius – Dr. Habil., Professor. Head of the Department of Cartography and Geoinformatics.

Author and co-author of 5 monographs, 6 textbooks and 180 articles.

Member of the editorial board of scientific journals:

Geology. Geography (Lithuanian Academy of Sciences),
Geodesy and Cartography (Vilnius Gediminas Technical University),
Polish Cartographical Review (Polish Geographical Society),
Baltica (Lithuanian Academy of Sciences).

Scientific interests: geomorphologic processes, thematic mapping, history of cartography, UAV and remote sensing.

Artūras Baurėnas – Dr., Associated professor.

Author and co-author of 2 text-books, about 50 scientific articles.

Scientific interests: geomorphologic processes, thematic mapping, UAV and remote sensing.

Linas Bevainis – Dr., Assistant.

Co-author of 1 text-book and about 20 scientific articles.

Scientific interest: UAV and remote sensing.

Neringa Mačiulevičiūtė – Turlienė – Ph.D student.

Co-author of 5 scientific articles.

Scientific interest: geomorphologic processes, thematic mapping.