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Small catchments DEM creation using Unmanned Aerial Vehicles

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Abstract: Digital elevation models (DEM) are an important source of information on the terrain, allowing researchers to evaluate various exogenous processes. The higher the accuracy of DEM the better the level of the work possible. An important source of data for the construction of DEMs are point clouds obtained with terrestrial laser scanning (TLS) and unmanned aerial vehicles (UAV). In this paper, we present the results of constructing a DEM on small catchments using UAVs. Estimation of the UAV DEM showed comparable accuracy with the TLS if real time kinematic Global Positioning System (RTK-GPS) ground control points (GCPs) and check points (CPs) were used. In this case, the main source of errors in the construction of DEMs are the errors in the referencing of survey results.

1. Introduction

In the last decade, there was a trend to increase using of high-performance and high-precision technologies for monitoring erosion processes. In contrast to classical methods of recording erosion and accumulation such as, for example, the runoff method, the benchmark method, etc., new geodetic methods allow calculating the qualitative and quantitative changes in the microrelief by subtracting the extra-high resolution digital elevation models (DEM) from each other. For a long time, such high-performance geodetic instruments were terrestrial laser scanners (TLS), performance of which reached one million points per second [1]. However, despite the high performance and accuracy of scanning systems surveying large areas is very time-consuming. In addition, because of the specifics of taking measurements with ground-based laser scanners the surface scan can contain "shadows" – areas without fixed coordinates, resulting from a lack of direct visibility of the surface by the scanner.

Such limitations of TLS can be overcome using airborne laser scanners, however, the price of this equipment negates the possibility of its use on local catchments [2]. In addition, altitude errors limit the calculation of changes in the relief for different time intervals.

The development and cheapening of the technology of small flying systems coupled with the development of computer vision algorithms, has stepped up the number of works on the construction of digital terrain models using unmanned aerial systems. Such works first appeared at the end of the millennium in 1999 [3]. However, the massive use of this approach began in the second decade of the 21st century when the use of reference points (RP) allowed achieving submetric accuracy of the referencing [4, 5]. Already in 2013, the accuracy of the model reference to the control points obtained with the RTK-GPS receiver (real time kinematic global positioning system) was 0.29 m which, according to the authors [6], is equivalent to the accuracy obtained by scanning systems. Thus, the primary issue in surveying using a UAV is the organization of a precise referencing. In 2015 the achievable accuracy of the model referencing has increased to 0.02 m [7], in 2017 the tendency to increase the accuracy preserved [8].

Also, researchers are interested how accurate the DEM is, for which the DEM obtained with the UAV is often compared with the DEM obtained using the TLS. Recent work shows an average error not exceeding 5 cm [9, 10]. However, such errors are unacceptable when using this approach to study rill and sheet erosion which are the dominant exogenous process on almost the entire area of the arable slopes [11]. The purpose of this work is to develop a methodology for constructing high resolution DEMs using UAVs on the example of small catchments of different landscape zones in the European part of Russia.

2. Study area

The development and approbation of the technique of surveying in small catchments using UAV began in autumn 2016. As the first test site, a small catchment of the gully was located on the right slope of the basin of the river Temev Ruchey (right tributary of the Mesha River). The catchment area is a 500 m long slope composed of deluvial loams on which gray forest soils have formed.

In 2017, the works were carried out on the sites located in the landscape zones (from the forest to the steppe zone) of the basins of the rivers Temev Ruchey (Republic of Tatarstan), Veduga (Voronezh Region) and Medveditsa (Saratov Region). As objects, small catchments of dry valleys with an area of 1-2 km^2 were chosen. The length of the bottoms of the valleys varies from 400 to 1600 m. Also in the basin of the river Veduga of the Voronezh Region with the aim of conducting repeated surveys of rill erosion, which could arise as a result of summer-autumn rains, a catchment area of an agrogenic gully with an area of 0.1 km^2 was chosen. The coordinates of the objects are given in table 1.

Table 1. Study areas coordinates

Object	Longitude	Latitude
Gully catchment, Temev Ruchey River basin	49°39'01.88"E	55°39'17.69"N
Dry valley catchment, Temev Ruchey River basin	49°39'03.44"E	55°38'10.76"N
Gully catchment, Veduga River basin	38°37'17.35"E	51°41'45.50"N
Dry valley catchment, Veduga River basin	38°35'43.82"E	51°45'37.16"N
Dry valley catchment, Medveditsa River basin	45°24'36.95"E	51°50'21.51"N

3. Materials and methods

The work was carried out using an DJI Phantom 4 unmanned aerial vehicle. The UAV in the quadrocopter form factor is equipped with a 12mpx precalibrated camera with a 20 mm focal length in 35 mm equivalent as well as a three-axis active stabilization system. In contrast to the UAV with fixed wings, the form factor of the copter coupled with the stabilization system avoids fuzzy images as well as artifacts.

The survey was carried out in an automatic mode by loading a flight plan into the UAV controller, thus eliminating the human factor as a source of errors. For gully catchments in the basins of the river Temev Ruchey and Veduga, the flight was carried out at a 50 m from the take-off point altitude with 70% longitudinal and transverse overlapping of the images. For the dry valleys catchment the survey was carried out from a 100 m altitude with 70% longitudinal and transverse overlapping of images.

To provide the geodetic control special marks were used representing a 70x70 cm black and white chess pattern [12]. To register the coordinates of the marks a Trimble Geoexplorer 6000 GNSS receiver was used capable of operating in RTK (real time kinematic) mode. As reference, virtual base stations VRNZ and ATKS of the HIVE network respectively located in Voronezh and Atkarsk, as well as the base station of the IGS network, located at the Astronomical Observatory of Kazan Federal University, were used. Removing of the base station from the study area did not exceed 35 km. The data received by the receiver was processed in the RTKLib software where the data was adjusted from the rover and RINEX files of the base station as well as the removal of false points [13].

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4. Results and discussion

The use of photogrammetry makes it possible to achieve the highest performance when working with UAVs. Thus, the average density of the resulting point clouds was 20 points/m^2. At the same time, the coverage area in the catchment area of the Temev Ruchey river basin was 2.33 km^2 (22 million points), 1.6 km^2 at the catchment area of the dry valley (20 million points) and 0.18 km^2 for the of the gully catchment area of the Veduga river basin (11 million points), and 2.77 km^2 for the dry valley catchment of the Medveditsa river basin (60 million points).

To obtain accurate referencing parameters of the model, reference points were used that made it possible to achieve the accuracy of the model referencing not exceeding 2 cm in vertical and 1 cm in the horizontal. Root mean square errors (RMSE) of referencing of control point by the example of the catchment of a dry valley in the basin of the river Veduga are presented in table 2.

Table 2. RMSE of control points

Control points	X (m)	Y (m)	Z (m)
1	-0.0043	0.0063	-0.0029
2	-0.0004	-0.007	0.003
3	0.0023	-0.007	0.0004
4	0.0047	0.003	-0.0002
5	-0.0038	0.0122	-0.017
Total	0.0035	0.007	0.0185

To assess the correctness of the obtained models, the DEM of small watersheds of a gully and dry valley in the basin of the river Temev Ruchey was compared with reference DEM. For a small catchment of the dry valley a DEM obtained from a topographic map with a scale of 1:10000 with an isoline interval of 1 m was used; a model obtained with the Trimble VX ground-based laser scanner (TLS) was used to estimate the model of the gully catchment area. Since the binding of the models obtained with the help of UAVs and with the help of TLS was carried out in the same coordinate system using the same control points, it becomes possible to estimate the quality of DEM by direct subtraction of the tested model from the reference one. As parameters for the assessment we used RMSE systematic error, maximum and minimum error, and the standard mean error as indicators. The results are presented in table 3.

Table 3. Results of UAV and TLS DEMs comparison

Number of points	577528
Systematic error, m	-0.01
RMSE, m	0.03
Minimum error, m	-0.12
Maximum error, m	0.1
Standart mean error, m	0.0002

Thus, using UAVs makes it possible to obtain a DEM comparable in accuracy to TLS DEM. To estimate the DEM obtained by using UAVs on the catchment areas of the dry valley to minimize errors associated with different coordinate systems and altitudes on the topographic map and in the production of DEM, a different approach was applied than that comparing DEMs obtained using UAV and TLS. The residual of slope angles and average lengths of slopes were taken as evaluation criteria. The results are presented in table 4.

Table 4. Results of UAV DEM and DEM obtained from a topographic map comparison

	Slope angles residuals	Average lengths from UAV DEM, m	Average lengths from topographic map DEM, m
Mean	0.097	1378.74	1373.61
Maximum	4	2757.49	2747.22
RMSE.	1.45	669.83	693.86
90% quantile	1.86	2481.74	2472.50
95% quantile	2.91	2619.61	2609.86

Analysis of the statistical indicators allows to state that there are no significant differences between the models obtained using UAV and DEM constructed on a 1:10000 scale topographic map, and all the differences fit the permissible 5%, and for the slope lengths do not exceed 1%. The results of the comparison of the models are confirmed in the studies of other scientists. For example, the same order accuracy (0.08 m) was reached when studying the relief in the basin of the Elbow river (Canada) [14]. The authors conclude that the UAV can achieve such accuracy and resolution which is difficult to achieve with other methods of remote sensing. Even more impressive results were achieved by researchers from Turkey [7]. The accuracy of the model was 0.06 m with a minimum, maximum deviation of altitudes was 0.0081 m and 0.085 m, respectively. Such results look impressive, however, such accuracy was achieved in comparison with GCP when both the real accuracy of the model as well as the estimation of available artifacts of model points is possible only with a continuous comparison of surfaces, which was done by us.

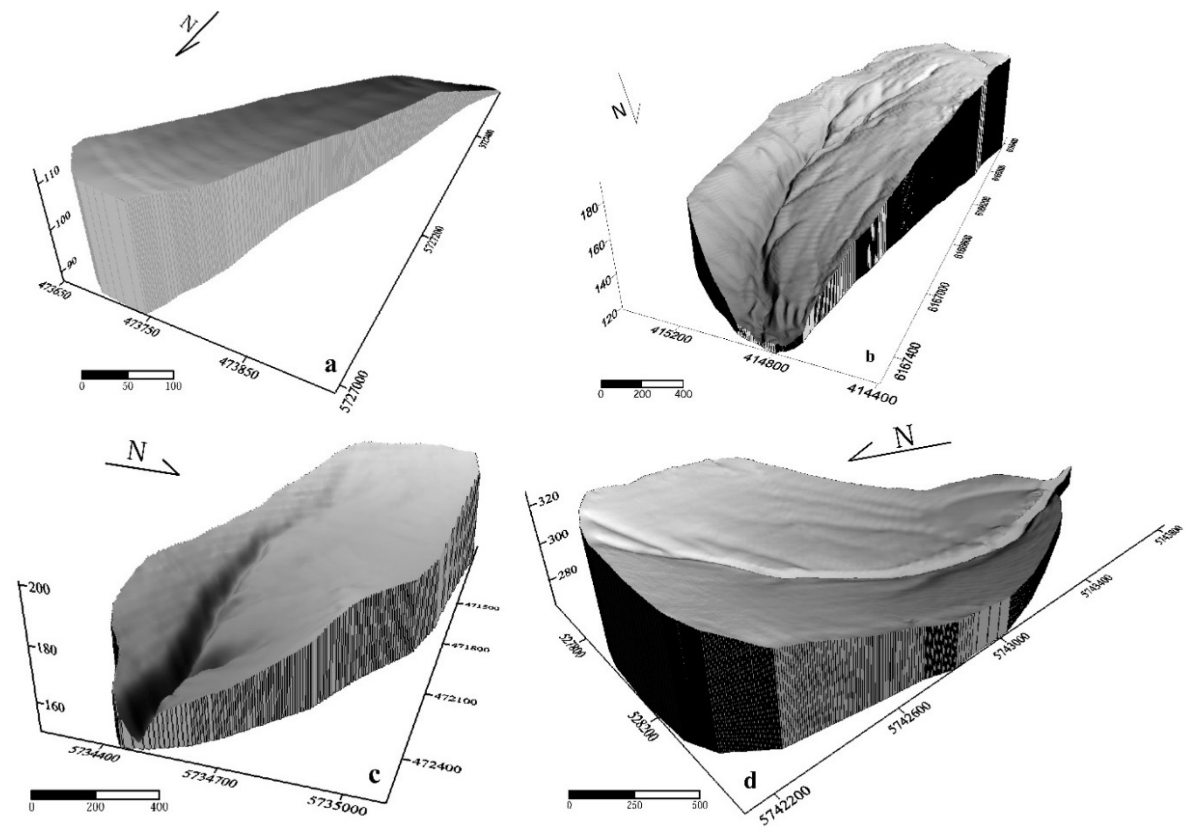

Figure 1. DEM for gully catchment in the Veduga river basin (a) and dry valleys in the basins of the river Temev Ruchey (b), Veduga (c), the river Medveditsa (d)

The evaluation of the accuracy of DEMs obtained using UAVs allows us to state that the models can be successfully used to calculate erosion losses in different parts of the temporary network. The comparison of the DEM and the UAV of gullies proved the applicability of the method for quantitative and qualitative assessment of gully erosion. DEM on small watersheds allows calculation of erosion losses in the rill and microrill using erosion models as well as direct subtraction of different-time DEMs from each other.

5. Conclusions

The construction of DEM for small catchments (figure 1) using a UAV demonstrates the potential of technology as a source of high resolution data obtained in a short time period. For the first time, data were obtained on the accuracy of the models obtained throughout the entire study area and not at individual points. In addition to the source of relief data, which can later be used to evaluate its changes after erosion processes, DEM data obtained with UAVs can be used to directly quantify the amount of material being moved after repeated surveys. However, in this case, as experience has shown in the use of TLS, the accuracy of model referencing comes to the fore, as well as the need to take into account the humidity and density of soil and ground, since when they swell / dry, surface changes reach the first centimeters. Despite the perspective of GNSS technology, obtaining high-precision data in the field is a very laborious task and it is recommended to make a geodetic control using tacheometric survey to obtain correct data about changes in the relief.

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