



Aušra Kumetaitienė

**MULTIPARAMETER EVALUATION
OF DIGITAL TERRAIN MODELING
TAKING INTO CONSIDERATION SURFACE
GEOMORPHIC CHARACTERISTICS**

Summary of Doctoral Dissertation
Technological Sciences, Measurements Engineering (10T)

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Vilnius „Technika“ 2005

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Aušra Kumetaitienė

**SKAITMENINIO RELJEFO MODELIAVIMO
DAUGIAPARAMETRINIS VERTINIMAS,
ATSIŽVELGIANT Į PAVIRŠIAUS
GEOMORFOLOGINES SAVYBES**

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INTRODUCTION

Topicality of the research. In compiling digital terrain models (DTM) as well as in evaluating them there are widely applied mathematical statistical measuring data processing and analysis methods. However in compiling digital models of relief and evaluating them there are certain peculiarities in mathematical statistical data application. These peculiarities are caused by the fact that relief modeling as well as analysis is considered to belong to the group of geostatic problems. The latter are peculiar for the initial results of measuring which are medium between purely random and purely determined sizes. In solving geo-statistical problems, one has to make use of regionalized data, the stochastic characteristics are the functions of geographic positions of the territory. In modeling the relief the surface geomorphologic peculiarities determine the characteristics of the functions of geographical position. Theoretical grounding of the methods used in modeling the relief surface (e.g., kriging, spline, invert distance weight (IDW), polynomial) is based on the statistical analysis of the random values. Due to the fact that the characteristics of geo-statistical measuring data are preconditioned by the geographic position, not in all territories there are equally suitable certain methods of modeling and parameters of modeling algorithms. The mentioned above reasons determine the fact that there do not exist unified digital terrain modeling methods and types, to be equally well applied for all the territories. Caused by the great variety of characteristics of the land surface relief it is possible to compile a qualitative model of the relief only if separate modeling methods have to be applied as well as parameters of modeling, after having evaluated regional geo-statistic data peculiarities. It is necessary to compile a unified technique for relief classification by selecting the best applicable relief modeling method and using it as the base to carry out detailed investigation.

Objective of the research. To investigate the accuracy dependence of digital terrain models on the methods of initial data preparation, methods of modeling, parameters of modeling, relief geomorphic characteristics as well as to determine the priorities of availability of modeling methods for different forms of the relief.

The following **goals** have been set to develop an effective model:

- To investigate accuracy dependence of the digital terrain model on the methods of initial data preparation.

- To work out a system of evaluation and classification of land relief geomorphic characteristics and carry out the zoning of the territory.
- Examine the influence of parametric functions of modeling methods to the accuracy of the model.
- Explore the influence of modeling parameters to different relief types.
- To investigate the influence of modeling methods to the accuracy of the relief model.
- Compile regressive models based on the experimental results, summarizing the correlations between the accuracy of the relief models, modeling parameters and geomorphic characteristics of the relief.
- Evaluate the quality and priority of digital terrain models by means of multi criteria analysis.

Research object. The digital terrain models of the territory of Lithuania and the measured initial data by means of different techniques in order to compile them.

Methods of research. Experimental quality investigations of digital terrain models by means of technologies of geographic systems, the mathematical statistical and multi criteria analysis of the results of investigations.

Scientific novelty of the research work:

- It has been determined dependence of the accuracy of digital terrain models from the methods of parameters of modeling, and geomorphic characteristics of the relief.
- There have been compiled regressive models describing the dependence of the accuracy of the relief models received by using different models on the parameters of modeling and geomorphic indexes of the relief.
- There has been applied for the first time the multi criteria analysis in evaluating the quality and priorities of digital terrain models.

Practical value of the research work: Based on the received results of the research and splitting into zones the geomorphic relief it has become possible to select the most suitable methods of modeling and parameters of modeling with different characteristics for the territory and compile better quality of relief model for the whole territory.

The statements to be defended:

- Classification of the relief according to the geomorphic characteristics.
- Regularities of the influence of modeling methods and their parametric functions as well as parameters of modeling to the quality of digital relief models, subjected to the characteristics of geomorphic relief.
- Possibilities of application of multi criteria analysis in evaluating the quality of digital terrain models and priorities of modeling methods.

Approval of the research work. The results of the carried out research have been published in 5 publications in the periodical scientific journals of Lithuania and in publications of the material of 4 conferences. The presentations have been made in 2 international and 4 scientific conferences in the country.

THE CONTENT OF THE DISSERTATION

Chapter 1. Review of technologies in digital relief modeling. The chapter presents the review of the scientific publications on the technologies used for digital relief modeling. After having analyzed scientific publications it has been determined that the accuracy of digital models of the relief depends not only on the accuracy of the initial data and methods of modeling as well as on the geomorphic characteristics of the relief. However the dependence has been investigated fully and completely that is why further investigation is needed.

There haven't been analyzed the integrated evaluation and selection issues of the quality of the digital relief modeling by means of multi criteria analysis methods. Taking into consideration the methodological principals of multi criteria analysis as well as in compiling the digital models of the relief the author has got very often to evaluate the indexes contradicting in between, it is possible to apply multi criteria methods for determining alternative priorities.

Chapter 2. The peculiarities of relief modeling. This chapter deals with the analyzed peculiarities of modeling of the relief. Taking into consideration the usage of parametric functions of modeling, the methods of modeling have been divided into two groups: semivariograms and weigh interpolation. The technological scheme of experimental research on the relief models quality has been worked out (1 table).

Table 1. Technological scheme on the research of the quality of relief models

Stages of modeling	Short description of the research
Analysis of initial data, used for relief modeling	Evaluation of advantages and disadvantages of the possessed data on the heights of the territory being modeled.
Stereophotogrammetric measurements of heights of the surface control points	To obtain accurate digital model of the relief stereophotogrammetric measurements are carried.
Compiling of digital relief model	Different relief models are compiled by means of kriging, cokriging, spline, weigh interpolation and multisegmental methods for the whole theory.
Analysis of geomorphologic peculiarities of the territory	Selection of geomorphologic criteria for evaluation of relief model and evaluation of the surface.
Zoning of the territory	Evaluation of the relief and territory is split into regions according to the relief type..
Research of the digital terrain model accuracy	Accuracy in territories of different relief type is investigated using heights of repeatedly stereo digitized points.
Research of the accuracy of relief models	Investigation is carried on the influence of modeling methods, parametric functions, parameters on the accuracy of relief model in territories with different geomorphologic qualities.
Analysis of the results	Statistic, regressive, multi criteria analysis, determining the most suitable priorities of modeling methods.
Compiling of digital surface model by means of the selected method	Selection of surface modeling parameters, DTM is obtained referring to the provided requirements.

Chapter 3. Research of accuracy of relief models compiled using different initial data. The chapter deals with the investigated dependence of the accuracy of digital terrain models on the types of initial data selection.

There have been analyzed such models the initial data of which have been obtained: 1) by means of vectorized horizontals 2) by means of distant method from the space (InSAR), 3) by means of orthophotogrammetric

method, 4) by stereophotogrammetric method. The results of model accuracy are submitted in table 2.

Table 2. Accuracy of digital relief models

Indexes	Method of initial data receiving			
	In conformity with vectorized horizontals	By distant method from space views (InSAR)	By ortophoto–grammetric	By stereophoto–grammetric
Number of control points, units	3115	3115	7100	3115
Medium difference of altitudes $\bar{h}$, m	-0, 71	2, 26	-2, 94	0, 74
Standard deviation σ , m	3, 92	4, 57	6, 23	1, 89
Maximum difference of altitudes $\bar{h}_{\max}$, m	18, 15	25, 17	26, 56	14, 46
Confidence interval of standard deviation, m ($P=0, 95$)	3, 78 ÷ 4, 06	4, 41 ÷ 4, 73	6, 09 ÷ 6, 37	1, 82 ÷ 1, 96

Chapter 4. Multi parametric evaluation of methods in digital terrain modeling and parameter influence on model accuracy. To carry out the experiment it has been chosen Vilnius city territory in Šeškinės Ozas, signifying itself for a great variety of the relief, that could be divided into several types of relief. The territory served for obtaining detailed and high accuracy initial data by means of stereophotogrammetric method (the standard deviation of altitude points is 0, 14 m, average distance between the points is about 6 m). The scheme has been compiled by the help of the technique that has been worked out (1 sample), the zoning has been carried out as well.

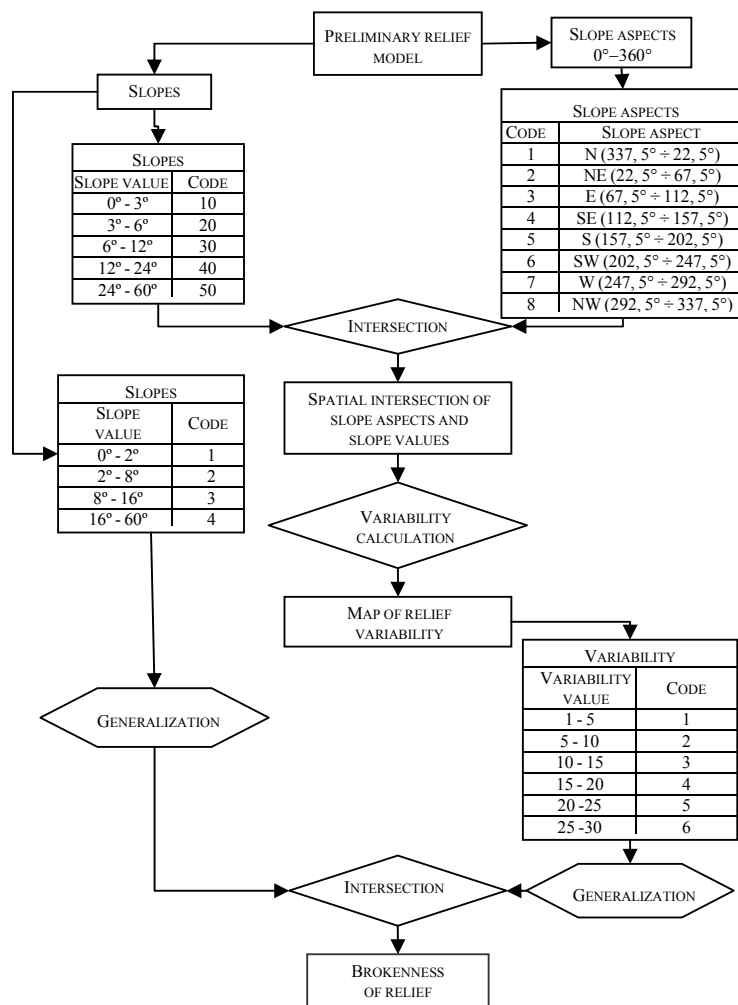


Fig 1. Scheme of relief zoning in accordance to the surface brokenness

Relief modeling methods applying parametric functions are divided into two groups: methods, using variograms for calculations and weight methods.

When carrying out the research, for compiling DTM has been used ArcGIS packet of programs with the supplements 3D Analyst, Spatial Analyst and Geostatistical Analyst. For relief modeling there have been used geostatistic surface modeling measures, choosing parameters of modeling manually.

There has been analyzed the influence of the number of points, type of semivariograms and used for interpolation to the accuracy of the models for DTM modeling, when the model is compiled by the method of kriging. The results the investigation is given in figure 2.

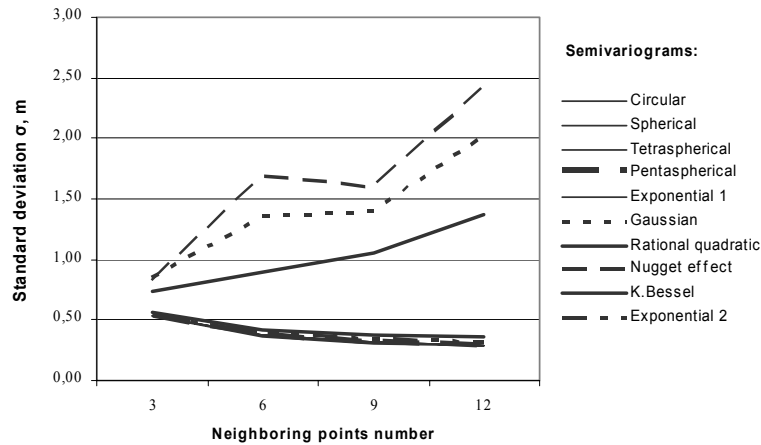


Fig 2. Dependence of errors of relief model on the type of semivariogram and on the number of neighboring points used

The results obtained exhibited that semivariograms could be divided into two groups according to the dependence of the compiled relief model on the points on the number of points: semivariograms in which the accuracy of the available relief model increase, taking more neighboring points (circular, spherical, tetraspherical, pentaspherical, exponential 1 and 2), and varioagrams from which the accuracy of the available relief model, by taking

more adjacent points, significantly is reduced (Gaussian, rational quadratic and nugget effect).

There has been investigated the influence of modelling parameters on the different types of relief (figure 3). The most accurate data have been received from 11, 12, 13, 21, 22 relief zones. The results have indicated that in the territories of great relief changes Gaussian and rational quadratic semivariograms are not to be applied.

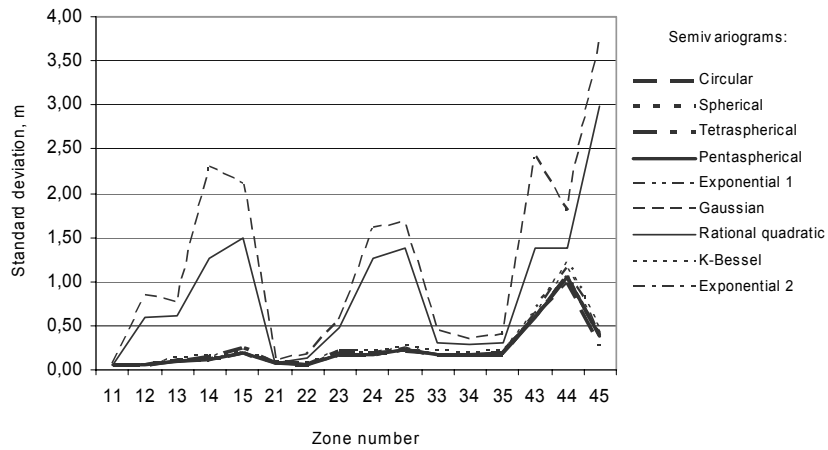


Fig 3. DTM accuracy setting indifferent relief zones

There has been investigated model accuracy dependence on both type of modeling and relief (figure 4).

There has been analyzed the dependence of relief model accuracy on the cell dimensions used in measurements and average distance between the points of initial data. The scheme is presented in figure 5.

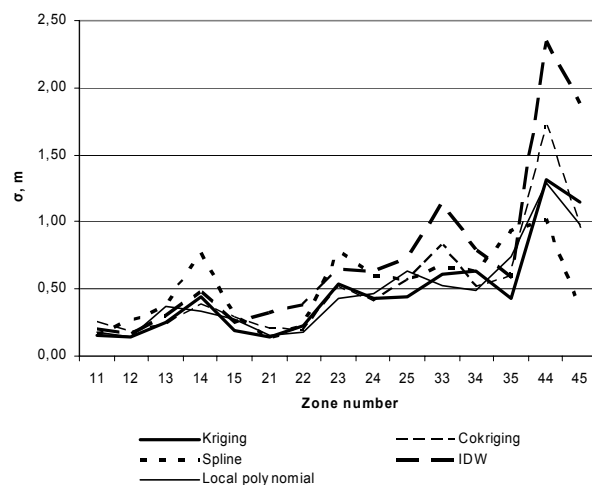


Fig 4. Graphic diagram of DTM standard deviations in separate zones

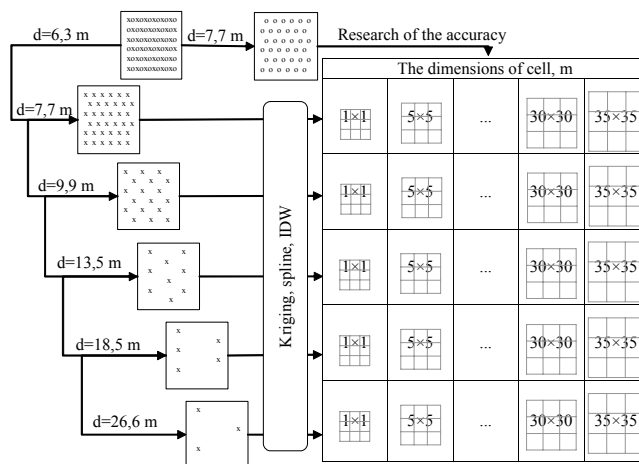


Fig 5. The research scheme on DTM accuracy dependence on the dimensions of cell and distance between points

The achieved results are submitted in figure 6. In changing the dimensions of cell from (1×1) m to (35×35) m and distance between the points from 7, 7 m to 26, 6 m, the accuracy of the models decreases up to 2 times.

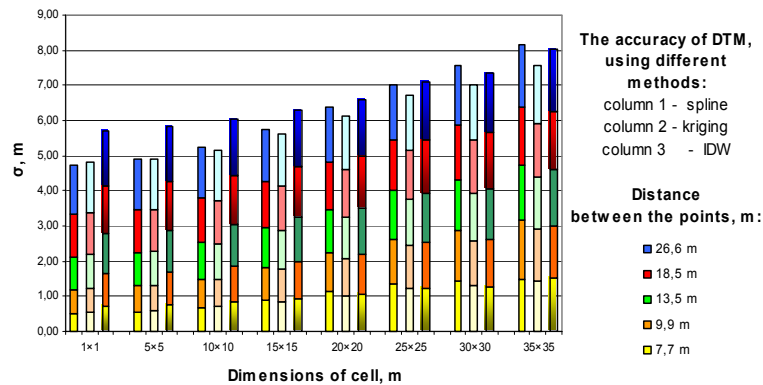


Fig 4. Influence of modeling parameters on the accuracy of DTM, using different methods

In order to statistically ground the dependence of standard deviation on the size of the cell, the distance between neighboring points, geomorphologic relief peculiarities, there has been carried out the regressive analysis of the experimental results and regressive models have been compiled. The relativity of the experimental results of regressive models adequacy is $P \geq 0,95\%$.

After having evaluated the results of DTM mathematical statistical analysis obtained by means of kriging, spline and weigh interpolation method there is being stated that kriging method is the most accurate and the most applicable in compiling of various DTM types.

The method of weigh interpolation is the least applicable for relief modeling. The vivid DTM accuracy dependence on the relief type exhibits that in compiling digital terrain models one has to evaluate the characteristics of the relief and the parameters of modeling have to be chosen taking into consideration the complexity of the surface.

The quality of the methods of DTM have been evaluated and the priorities in applying multi criteria analysis. For comparison of the modeling methods there has been used the so called TOPSIS method.(Technique for Order Preference by Similarity to Ideal Solution). The method used for quality complex evaluation of digital terrain model ling by means of multi criteria technique has been applied by nobody up till now.

CONCLUSIONS

1. The research has been carried out on determining digital terrain model accuracy dependence on the types the indicial data have been executed. The terrain model received from the stereo digitalized altitude points has been evaluated as the best one from the point of view of accuracy and particularity of details. While using experimental target standard deviation in DTM is equal to 0,14 m. The greatest discrepancies of altitudes amount to 0,40 m.
2. The dissertation presents the evaluation of the geomorphic characteristics of terrain surface as well as the classification of the territory of the terrain into zones – territory with different geomorphologic characteristics. The results of splitting into zones have been marked by double–digits: the first figure indicates the inclination of the slope ($1 \div 4$), the second – variability of the terrain ($1 \div 6$).
3. The research has been executed to determine on the methods of modeling (semivariograms and weights) on the accuracy of terrain model. It has been stated that a very significant influence on the accuracy of the model has got the type of the semivariogram. In modeling the terrain by kriging method the most precise results have been received by the help of circular semivariogram ($\sigma = 0,29 \div 0,54$ m), the least accuracy has been exhibited by applying Gaussian ($\sigma = 0,85 \div 2,03$ m) and nugget effect ($\sigma = 0,82 \div 2,42$ m) semivariograms.
4. The research has presented the modeling parameter influence on the different types of the terrain. It has been determined that the accuracy of the terrain models depends on the terrain inclination and indexes of variability. To the indexes of terrain variability there has been registered the most sensitive reaction in such cases when for the parametric functions of modeling there have been used Gaussian and rational quadrartic semivariograms. Together with the increase of terrain variability the errors of terrain model tend to increase proportionally. The terrain variability indexes have made a slight influence in cases when parametric functions have been chosen circular, spherical, tetraspherical

and pentaspherical semivariograms. In applying these semivariograms and in using the highest terrain variability indexes there have been registered standard deviations of the model 5 times less than in cases when using Gaussian and rational quadrartic semivariograms. In cases of minor terrain variability indexes the accuracy of terrain modeling does not depend on the type of semivariogram.

5. The research has investigated dependence of terrain model accuracy on the size of modeling parameter cell and the distance between the initial data points. When applying methods of mathematical statistical and multi criteria analysis it has been determined that the accuracy of the model increases by reducing the size of the cell and the distance between the points. The influence of distance between the points on the accuracy is about 10-15% higher than the size of the cell.
6. The size of the cell and the distance between the points has demonstrated a more narrow influence in case of minor terrain variability and it has demonstrated greater influence when terrain variability has been great.
7. The research has been made to analyze the influence of modeling methods on the accuracy of the terrain model. Digital terrain model has been compiled by means of kriging, spline and invert distance weighted interpolation from the points chosen when the average distance in between has been from 7,7 m to 26,6 m, cell dimensions have been taken from 1×1 m to 35×35 m. The obtained results have indicated that the most accurate results have been received in modeling the terrain by means of kriging method. The average accuracy compiled by kriging method would comprise the average accuracy of the terrain models in the zone of high terrain variability ($35 \div 46$) about 1,5 times higher than in modeling by means of spline and about 2 times higher than in modeling by means of invert distance weighted interpolation. The accuracies of minor terrain variability differ insignificantly.
8. There have been compiled regressive models describing the dependence of accuracy of the terrain models obtained by different methods on the modeling parameters and terrain geomorphologic indexes. The coefficients of the empirical regressive model determination are limited within thee boundaries $0,67 \div 0,89$ m. The equation parameters of the regressive models and general model reliability level is $q = 0,05$. That is why it is possible to state that the regressive models compiled with reliability $P \geq 0,95$ would prove the accuracy dependence on the terrain model and terrain peculiarities. This conclusion has been proved by the results of the terrain model disperse analysis.

9. For the first time in evaluating the quality of the digital terrain models and priorities there has been applied the practice of multi criteria analysis. It is possible to state on the bases of the carried out experiments that multi criteria analysis shall have to be considered an effective method in evaluating the priorities of terrain modeling methods as well as their peculiarities of application under various conditions and limits.
10. After having divided the terrain into zones according to the geomorphologic indexes there has appeared a possibility to evaluate the quality of digital terrain models and select the most suitable methods of modeling as well as parameters for the territories with particular characteristics of the terrain.

THE LIST OF SCIENTIFIC PUBLICATIONS

MOKSLINIŲ PUBLIKACIJŲ DISERTACIJOS TEMA SĄRAŠAS

In the reviewed Lithuanian Research Journals:

1. Kumetaitienė, A. Application of elevation geomorphologic classification for checking the accuracy of digital elevation model. *Geodesy and Cartography (Geodezija ir kartografija)*, Vol XXXI, No 2, 2005, p. 69–75 (in English).
2. Kumetaitienė, A.; Kumetaitis, A. Perfection of Technology in Compiling the Optimal Digital Terrain Model (Optimalaus skaitmeninio reljefo modelio sudarymo technologijos tobulinimas). *Geodesy and Cartography (Geodezija ir kartografija)*, Vol XXXI, No 2, 2005, p. 57–61 (in Lithuanian).
3. Kumetaitienė, A.; Kumetaitis, A. Analysis of the Accuracy of the Orthophoto Map at a Scale of 1:10 000 on Urban Territory (Urbanizuotos teritorijos 1:10000 mastelio skaitmeninio ortofotografinio žemėlapių tikslumo analizė). *Geodesy and Cartography (Geodezija ir kartografija)*, Vol XXVIII, No 2, 2002, p. 54–57 (in Lithuanian).
4. Žalnierukas, A.; Kumetaitienė, A. Accuracy of Point Elevations of Topographical Database Created by Stereophotogrammetric Approach (Topografinių duomenų bazių, sukurtų stereofotogrametriniu būdu, taškų altitudžių tikslumas). *Geodesy and Cartography (Geodezija ir kartografija)*, Vol XXV, No 3, 1999, p. 113–117 (in Lithuanian).
5. Žalnierukas, A.; Kumetaitienė, A.; Stankevičius, Ž. The Accuracy of the Digital Map Compiled by Stereophotogrammetric Method (Skaitmeninio

žemėlapiu, sudaryto stereofotogrametriniu metodu, tikslumas). *Geodesy and Cartography (Geodezija ir kartografija)*, Vol XXV, No 2, 1999, p. 60–68 (in Lithuanian).

In Proceedings and Theses of International and Lithuanian Conferences:

1. Kumetaitienė A., Kumetaitis A. Evaluation of the Influence of Surface Modeling Parameters on the Accuracy of Digital Elevation Models. In: The 6th International Conference „Environmental engineering“, May 26–27, 2005. Vilnius: Technika, 2005, p. 919–924 (in English).
2. Kumetaitienė, A.; Kumetaitis, A. Area Calculation of Physical Terrain Surface Using Digital Surface Models. In: Proceedings of the International Scientific Methodical Conference „Land Use and Land Management“ (Fizinio paviršiaus ploto skaičiavimas, naudojant skaitmeninius paviršiaus modelius. Tarptautinės mokslinės metodinės konferencijos „Žemės naudojimas ir žemėtvarka“ pranešimai). Kaunas: Akademija, 2004, p. 54 (in Lithuanian).
3. Kumetaitienė, A.; Zakarevičius, A. Use of Multicriteria Analysis Methods for the Decision of Problems with the Geographical Data. In: Reports from Seven's Conference of Lithuania Junior „Lithuania without Science – Lithuania without Future“ Scientists, March 25, 2004 (Daugiakriterinės analizės metodų pritaikymas sprendžiant uždavinius su geografiniais duomenimis. 7 – osios Lietuvos jaunųjų mokslininkų konferencijos „Lietuva be mokslo – Lietuva be ateities“, įvykusios Vilniuje 2004 m. kovo 25 d., pranešimai). Vilnius: Technika, p. 141–146 (in Lithuanian).
4. Žalnierukas, A.; Sužiedelytė-Visockienė, J.; Kumetaitienė, A. Lietuvos miestų kartografavimas fotogrametriniu metodu. In: Set of thesis XI World Lithuanian Science and Creativity Symposium (XI Pasaulio lietuvių mokslo ir kūrybos simpoziumas, tezių rinkinys). Vilnius: BĮ „Baltijos kopija“, 2000, p. 119 (in Lithuanian).

SKAITMENINIO RELJEFO MODELIAVIMO DAUGIAPARAMETRINIS VERTINIMAS ATSIŽVELGIANT Į PAVIRŠIAUS GEOMORFOLOGINES SAVYBES

Santrauka

Darbo aktualumas. Sudarant skaitmeninius reljefo modelius bei juos vertinant plačiai taikomi matematiniai statistiniai matavimo duomenų apdorojimo ir analizės metodai. Tačiau kuriant skaitmeninius reljefo modelius ir juos vertinant, matematinių statistinių metodų taikymas turi tam tikrų ypatumų. Šie ypatumai atsiranda dėl to, kad reljefo modeliavimas ir analizė priskiriami geostatistinių uždavinių grupei. Geostatistiniai uždaviniai ypatingi tuo, kad pradiniai matavimo rezultatai yra tarpiniai tarp grynai atsitiktinių ir grynai determinuotų dydžių. Sprendžiant geostatistinius uždavinius, tenka naudotis regionalizuotais duomenimis, kurių stochastinės savybės yra teritorijos geografinės padėties funkcijos. Modeliuojant reljefą, geografinės padėties funkcijų savybės lemia paviršiaus geomorfologiniai ypatumai. Reljefo paviršiui modeliuoti naudojamų metodų (pvz., krigingo, splain, svorinio, daugianario) teorinis pagrindimas paremtas atsitiktinių dydžių statistine analize. Kadangi geostatistinių matavimų duomenų savybės sąlygoja teritorijos geografinę padėtį, ne visur vienodai gerai tinka vieni ar kiti modeliavimo metodai bei modeliavimo algoritmų parametrai. Šios priežastys lemia, kad nėra vieningų skaitmeninio reljefo modeliavimo metodų ir būdų, vienodai gerai tinkančių visoms teritorijoms. Dėl didelės žemės paviršiaus reljefo savybių įvairovės kokybišką reljefo modelį galima sudaryti tik diferencijuotai taikant atskirus modeliavimo metodus bei tų metodų parametrus, įvertinus regioninius geostatistinių duomenų ypatumus. Parenkant geriausiai tinkamus reljefo modeliavimo metodus, būtina sukurti vieningą reljefo klasifikavimo metodiką ir jos pagrindu atlikti detalius tyrimus.

Darbo tikslas. Ištirti skaitmeninių reljefo modelių tikslumo priklausomybę nuo pradinių duomenų parengimo būdų, modeliavimo metodų, modeliavimo parametru, reljefo geomorfologinių savybių bei nustatyti modeliavimo metodų tinkamumo įvairioms reljefo formoms prioritetus.

Siekiant sudaryti efektyvų modelį, keliama šie **uždaviniai**:

- Ištirti skaitmeninio reljefo modelio tikslumo priklausomybę nuo pradinių duomenų parengimo būdų.
- Parengti žemės reljefo geomorfologinių savybių vertinimo ir klasifikavimo sistemą bei atlikti teritorijos zonavimą.
- Ištirti modeliavimo metodų parametrinių funkcijų įtaką reljefo modelio tikslumui.
- Ištirti modeliavimo parametrų įtaką skirtingiems reljefo tipams.
- Ištirti modeliavimo metodų įtaką reljefo modelio tikslumui.
- Sudaryti eksperimentinių rezultatų regresinius modelius, apibūdinančius sąsajas tarp reljefo modelių tikslumo, modeliavimo parametrų ir reljefo geomorfologinių savybių.
- Įvertinti skaitmeninių reljefo modelių kokybę ir prioritetus, taikant daugiakriterinę analizę.

Tyrimų objektas. Lietuvos teritorijos skaitmeniniai reljefo modeliai ir jiems sudaryti skirtingais būdais išmatuoti pradiniai duomenys.

Tyrimų metodika. Eksperimentiniai skaitmeninių reljefo modelių kokybės tyrimai, taikant geografinių geoinformacinių sistemų technologijas, tyrimų rezultatų matematinę statistinę ir daugiakriterinę analizę.

Mokslinis darbo naujumas:

- Nustatyta skaitmeninių reljefo modelių tikslumo priklausomybė nuo modeliavimo metodų, modeliavimo parametrų ir reljefo geomorfologinių savybių.
- Sudaryti regresiniai modeliai, apibūdinantys skirtingais metodais gautų reljefo modelių tikslumo priklausomybę nuo modeliavimo parametrų ir reljefo geomorfologinių rodiklių.
- Pirmą kartą, vertinant skaitmeninių reljefo modelių kokybę ir modeliavimo metodų prioritetus, taikyta daugiakriterinė analizė.

Praktinė darbo reikšmė: Remiantis gautais tyrimų rezultatais ir geomorfologiniu reljefo suskirstymu į zonas galima parinkti geriausiai tinkančius modeliavimo metodus ir modeliavimo parametrus su skirtingomis teritorijų savybėmis bei sudaryti geresnės kokybės reljefo modelį visai teritorijai.

Ginamieji teiginiai:

- Reljefo klasifikavimas pagal geomorfologines savybes.
- Modeliavimo metodų ir jų parametrinių funkcijų bei modeliavimo parametrų įtakos skaitmeninių reljefo modelių kokybei dėsningumai, priklausantys nuo geomorfologinių reljefo savybių.
- Daugiakriterinės analizės taikymo galimybės, vertinant skaitmeninių reljefo modelių kokybę ir modeliavimo metodų prioritetus.

Darbo aprobavimas. Atliktų tyrimų rezultatai paskelbti 5 publikacijose Lietuvos recenzuojamuose periodiniuose mokslo žurnaluose ir 4 konferencijų medžiagoje. Skaityti pranešimai 2 tarptautinėse ir 4 respublikinėse mokslinėse konferencijose.

Apimtis ir struktūra. Disertaciją sudaro įvadas, keturi skyriai, bendrosios išvados, 201 pavadinimo literatūros sąrašas, 9 pavadinimų disertacijos autorės darbų sąrašas. Bendra apimtis – 125 psl.

Pirmajame skyriuje pateikta mokslo publikacijų skaitmeninio reljefo modeliavimo klausimais technologijų apžvalga. Išnagrinėjus mokslines publikacijas nustatyta, kad reljefo skaitmeninių modelių tikslumas priklauso ne tik nuo pradinių duomenų tikslumo ir modeliavimo metodų, bet ir nuo reljefo geomorfologinių savybių. Tačiau šios priklausomybės nepakankamai ištirtos.

Antrajame skyriuje išnagrinėti reljefo modeliavimo metodų ypatumai. Atsižvelgiant į modeliavimo parametrinių funkcijų naudojimą, modeliavimo metodai suskirstyti į dvi grupes: naudojančias variogramas ir svorinius. Parengta reljefo modelių kokybės eksperimentinių tyrimų technologinė schema.

Trečiajame skyriuje ištirta skaitmeninių reljefo modelių tikslumo priklausomybė nuo pradinių duomenų gavimo būdų.

Ketvirtajame skyriuje parengta reljefo geomorfologinių rodiklių ir teritorijos zonavimo pagal reljefo savybes metodika. Atliktas eksperimentinės teritorijos skaidymas į zonas. Ištirta modeliavimo metodų tikslumo parametrinių funkcijų bei modeliavimo parametrų įtaka skirtingų reljefo tipų skaitmeninių modelių tikslumui. Sudaryti regresiniai modeliai, apibūdinantys sąsajas tarp reljefo modelių tikslumo, modeliavimo parametrų ir reljefo geomorfologinių savybių. Skaitmeninių reljefo modelių kokybė ir prioritetai įvertinti taikant daugiakriterinę analizę.

Išvados

1. Ištirta skaitmeninio reljefo modelio tikslumo priklausomybė nuo pradinių duomenų gavimo būdų. Paviršiaus modelis, gautas iš stereodigitalizuotų taškų aukščių, detalumo ir tikslumo požiūriu įvertintas kaip geriausias. Eksperimentiniame objekte skaitmeninio reljefo modelio standartinio nuokrypio įvertis yra 0,14 m. Didžiausi aukščių nesutapimai siekia iki 0,40 m.
2. Įvertintos žemės paviršiaus geomorfologinės savybės ir reljefo teritorija suklasifikuota į zonas – teritorijas su skirtingomis geomorfologinėmis charakteristikomis. Skaidymo į zonas rezultatai pažymėti dviženkliais skaičiais: pirmasis skaitmuo parodo šlaitų nuolydį ($1 \div 4$), antrasis – reljefo kintamumą ($1 \div 6$).
3. Ištirta modeliavimo metodų parametrinių funkcijų (variogramų ir svorių) įtaka reljefo modelio tikslumui. Nustatyta, kad didelę įtaką modelio tikslumui turi variogramos tipas. Tiksliausi rezultatai modeliuojant reljefą kriginio metodu gauti, taikant apskritiminę variogramą ($\sigma = 0,29 \div 0,54$ m), mažiausias tikslumas gautas, taikant Gauso ($\sigma = 0,85 \div 2,03$ m) ir slenksčio efekto ($\sigma = 0,82 \div 2,42$ m) variogramas.
4. Ištirta modeliavimo parametrų įtaka skirtingiems reljefo tipams. Nustatyta, kad reljefo modelių tikslumas priklauso nuo reljefo nuolydžio ir kintamumo rodiklių. Į reljefo kintamumo rodiklius jautriausiai reaguoja, kai modeliavimo parametrinėmis funkcijomis naudojamos Gaussian ir kvadratinės variogramos. Didėjant reljefo kintamumo rodikliams, proporcingai didėja reljefo modelio paklaidos. Reljefo kintamumo rodikliai turi nežymią įtaką, kai parametrinės funkcijos yra apskritiminės, sferinės, tetrasferinės ir pentasferinės variogramos. Taikant šias variogramas, esant didžiausiems reljefo kintamumo rodikliams modelio standartiniai nuokrypiai yra apie 5 kartus mažesni, negu taikant Gaussian ir kvadratinės variogramas. Esant mažiems reljefo kintamumo rodikliams, reljefo modeliavimo tikslumas nepriklauso nuo variogramos tipo.
5. Ištirta reljefo modelio tikslumo priklausomybė nuo modeliavimo parametrų ląstelės didumo ir atstumo tarp pradinių duomenų taškų. Taikant matematinės statistinės ir daugiakriterinės analizės metodus nustatyta, kad modelio tikslumas didėja, mažinant ląstelės didumą ir atstumą tarp taškų. Atstumų tarp taškų įtaka tikslumui apie 10–15% didesnė negu ląstelės didumas.

6. Ląstelės didumas ir atstumas tarp taškų mažesnę įtaką turi, esant mažam reljefo kintamumui ir didesnę, kai reljefo kintamumas didelis.
7. Ištirta modeliavimo metodų įtaka reljefo modelio tikslumui. Skaitmeninis reljefo modelis buvo sudarytas krigingo, splain ir svoriniu metodu iš taškų, tarp kurių vidutinis atstumas nuo 7,7 m iki 26,6 m, ląstelės matmenys imti nuo 1×1 m iki 35×35 m. Gauti rezultatai parodė, kad tiksliausi rezultatai gaunami modeliuojant reljefą krigingo metodu. Krigingo metodu sudarytų reljefo modelių vidutinis tikslumas didelio reljefo kintamumo zonose ($35 \div 46$) apie 1,5 karto didesnis, negu modeliuojant splain ir apie 2 kartus didesnis, negu modeliuojant svoriniu metodu. Mažo reljefo kintamumo zonų tikslumai skiriasi nežymiai.
8. Sudaryti regresiniai modeliai, apibūdinantys skirtingais metodais gautų reljefo modelių tikslumo priklausomybę nuo modeliavimo parametrų ir reljefo geomorfologinių rodiklių. Empyrinių regresinių modelių determinacijos koeficientai yra $0,67 \div 0,89$ m ribose. Regresinių modelių lygčių parametrų ir bendrasis modelio patikimumo lygmuo $q = 0,05$. Todėl galima teigti, kad sudaryti regresiniai modeliai su tikimybe $P \geq 0,95$ patvirtina reljefo modelio tikslumo priklausomybę nuo modeliavimo parametrų ir reljefo savybių. Šią išvadą patvirtina ir regresinio modelio dispersinės analizės rezultatai.
9. Pirmą kartą vertinant skaitmeninių reljefo modelių kokybę ir prioritetus, pritaikyta daugiakriterinė analizė. Atliktų eksperimentų pagrindu galima teigti, kad daugiakriterinė analizė yra efektyvus būdas vertinti reljefo modeliavimo metodų ir jų taikymo ypatumų prioritetus, esant įvairioms sąlygoms ir apribojimams.
10. Suskirsčius reljefą į zonas pagal geomorfologinius rodiklius, susidarė galimybė įvertinti skaitmeninių reljefo modelių kokybę ir parinkti tinkamiausius modeliavimo metodus bei parametrus teritorijoms su konkrečiomis reljefo savybėmis.

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Multiparameter Evaluation of Digital Terrain Modeling taking into Consideration Surface Geomorphic Characteristics

Summary of Doctoral Dissertation

Technological Sciences, Measurements Engineering (10T)

Aušra Kumetaitienė

Skaitmeninio reljefo modeliavimo daugiaparametrinis vertinimas, atsižvelgiant į paviršiaus geomorfologines savybes

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