Digital Terrain Model from Various Data Sources of Different Quality

Tomaž Podobnikar

Ph.D. Thesis

UDC 528:91:[659.2:004](043.3)

Keywords: digital terrain model, surface, heights, geographical information system, quality control, statistic analyses.

Abstract

The form of the Earth's surface can be described with a model, recorded as continuous and usually smoothed surfaces. Surfaces are defined with a finite set of heights, measured with regard to mean sea level. Such models were in analogue form until forty years ago, but today are known as digital terrain models (DTMs). Basic principles for the management, acquisition, recording, updating, spatial analyses, visualisation, and integration of such models with other systems are well known. Despite this, new developments provide the opportunity for the improvement of DTM modelling.

One of technological challenges of the DTM production is the ever larger amount of digital data now available, which generally contains much semantic information about surface geomorphology. Despite this large amount of information, generally the mass of data does not seem useful for DTM production. Problems with such data mostly lies in its quality which is non-homogeneous, different methods and standards used for quality estimation and topological structure, making it unsuitable for terrain surface modelling. Different data quality is mainly an outcome of the method of acquisition, which can be directly or more frequently, indirectly acquired from generalised analogue data sources. Different estimation methods can cause unpredictable gross and systematic errors. Possible solutions for these problems, confirmed through applied experimentation, enable cost-effective and high quality production. The hypothesis of the thesis is that these data sources could be used as a basis for high quality digital terrain model production without the requirement of additional data.

In the first part of this thesis, the review of terrain modelling ideas from analogue to digital techniques is provided. Slovene digital terrain models from 'DMR 100' to 'InSAR DMV 25' including local models are presented more detail. A review of possible DTM applications and previous applications in Slovenia is also presented chronologically. General revision has been the basis for the evaluation of potential DTM production for the Slovene case study. For that reason DTM usage and two public polls were studied. The results of previous analyses of Slovene DTMs were examined, and approaches from elsewhere in the world considered. More detailed primary goals, scientific and applied, were defined from this research.

The scientific basis of the thesis relies on the study of specific elements of DTM modelling. Elements were described on the basis of detailed DTM definition, which include data objects, structural information, continuous functions, quality of information, and methods for implicit information analysis. Data objects describe point height data and other elements that support the model. Data acquisition, including resolution and scale is also discussed. Structural information including vector, raster, TIN, and hybrid structures for DTMs were evaluated. Every structure has particular advantages with regard to usage and data availability. Segments of continuous functions describe the terrain surface according to data source assisted by interpolation methods. Pre-processing and the processing interpolation methods for DTMs were evaluated, particularly for the variable data sources case study. With reference to particular continuous functions, some techniques of surface improvement were described, and

the transformation of terrain surfaces from specific to Slovene coordinate systems was outlined. For quality information, DTM abstraction was formed, regarding universe of discourse values. Concepts of precision, accuracy, error, and uncertainty were established. A large set of statistical and visual techniques for source and DTM quality evaluation were evaluated. Automatic hillshading and contouring were chosen for description from existing methods for deriving implicit information.

The main part of the thesis is devoted to two DTM production methods. The first method is that of simultaneous sources interpolation. The second is the weighted sum of sources. Both methods rely on substantial knowledge of used sources and the theory of DTM modelling. Further stages of DTM production were divided into pre-processing, processing, and management of DTM data. Pre-processing is based on detailed visual and statistical quality control of sources, supported by automatic regionalisation. Data was also statistically and geomorphologically corrected and improved. Processing with the first method, based on linear prediction interpolation of all sources together, considered the weights of particular data sets and data density. The second method needed less pre-processing then the first. It is based on preparation of each source with adequate interpolation to grid format with a uniform density. Selection of the most homogeneous sources in Slovenia was carried out and used for mosaicing a base DTM. All secondary sources were overlaid successively, one by one, with respect to weights, geomorphology, and threshold of reference points.

The techniques employed for DTM production were tested for each individual step of processing, and quality parameters were monitored. Data, used on the test regions were as far as possible objective and describe every part of Slovenia. The thesis concludes with a discussion about the possibilities for efficient maintaining of the terrain data - data sources, DTM and other products. For this purpose a specific DTM database structure was designed.

The base hypothesis of the thesis was confirmed with statistical and visual quality analyses for both proposed methods of DTM production. The results indicate statistically, geomorphologically and visually - a high quality and efficient DTM production in Slovenia, better than those currently used and present an expected average vertical precision of 3.5 m or better for the whole of Slovenia. An important additional product of this approach to DTMs are automatically produced contour lines, terrain skeletons and hillshading. Secondary products include acquisition of quality parameters and reduction of gross and systematic errors in geodetic databases. An extensive English summary is presented in chapter 7.

Digitalni model reliefa iz geodetskih podatkov različne kakovosti

Tomaž Podobnikar

Doktorska disertacija

UDK 528:91:[659.2:004](043.3)

Ključni pojmi: digitalni model reliefa, višine, geografski informacijski sistem, kontrola kakovosti, statistične analize.

Povzetek

Oblikovanost zemeljskega površja je lahko opisana z modelom, zapisanim z zveznimi in pogosto gladkimi ploskvami. Ploskve so določene s končno množico višin, izmerjenih glede na srednji nivo morja. Še pred štiridesetimi leti so bili taki modeli analogni, danes pa jih poznamo kot digitalne modele reliefa (DMR). Temeljna načela zajemanja, shranjevanja,

vzdrževanja, upravljanja, prostorskih analiz, vizualizacij in vključevanja DMR v druge sisteme so znana. Kljub vsemu se odpirajo nove tehnološke možnosti, ki omogočajo izboljšave DMR.

Med tehnološkimi izzivi za izdelavo DMR so vedno večje količine raznovrstnih digitalnih podatkov, ki lahko vsebujejo veliko semantičnih informacij o oblikovanosti površja. Kljub veliki količini informacij se tak konglomerat podatkov na splošno ne zdi primeren za izdelavo DMR. Problemi so predvsem v nehomogeni kakovosti, uporabi različnih metod in standardov pri ocenah kakovosti ter v topoloških strukturah, neprimernih za modeliranje ploskev površja. Različna kakovost podatkov je predvsem posledica načina zajema, ki je lahko neposreden, še pogosteje pa posreden iz generaliziranih analognih virov. Zaradi različnih metod ocene kakovosti lahko naletimo na nepričakovane grobe in sistematske napake. Gospodarno izdelavo in visoko kakovost DMR omogočajo z aplikativnimi poskusi podprte rešitve omenjenih težav, kakršne so obravnavane v disertaciji. Hipoteza disertacije je, da je možno podatke različnih virov brez dodatnega zajema uporabiti kot osnovo pri izdelavi DMR visoke kakovosti.

V prvem delu disertacije so opisane ideje modeliranj reliefa, od analognih do digitalnih tehnik. Podrobneje so analizirani DMR Slovenije, od začetkov pri DMR 100 do najnovejšega InSAR DMV 25, skupaj z lokalnimi modeli reliefa. Navedene so možne aplikacije DMR ter kronološko opisana dejanska uporaba DMR v Sloveniji. Pregled posameznih DMR je osnova za ovrednotenje možnosti izdelave DMR na primeru Slovenije. V ta namen je bila analizirana uporaba DMR in obstoječi anketi. Preučeni so bili rezultati predhodnih slovenskih analiz DMR ter analizirane vizije in usmeritve v svetu. S pomočjo raziskave v prvem delu so bili definirani natančnejši osnovni teoretični in aplikativni cilji.

Teoretične osnove disertacije se naslanjajo na elemente modeliranja DMR. Elementi so obrazloženi glede na podrobno definicijo DMR, ki se nanaša na objekte podatkov, informacije o strukturi, zvezne funkcije, informacije o kakovosti in na metode za analizo implicitnih informacij. Zapis podatkov vsebuje višine točk in drugih elementov, ki podpirajo model. Sledi razprava o zajemu podatkov ter ločljivosti in merilu. Med informacijami o strukturi DMR so opisane vektorska, rastrska, TIN in hibridna struktura. V odvisnosti od namena uporabe in razpoložljivosti virov ima vsaka izmed struktur določene prednosti. Množica zveznih funkcij opisuje ploskev reliefa glede na vire podatkov pri uporabi interpolacijskih metod. S poudarkom na različnih virih so ovrednotene interpolacijske metode za predobdelavo in obdelavo DMR. V odvisnosti od tipa zveznih funkcij so opisane nekatere tehnike za izboljšanje ploskve površja ter transformacija podatkov iz drugih koordinatnih sistemov v slovenskega državnega. Informacije o kakovosti temeljijo na abstrakciji DMR glede na področje obravnave. Opisan je koncept natančnosti, točnosti, napak in nedoločljivosti. Za pridobivanje informacij o kakovosti virov in DMR je sistematično opisano tudi veliko število statističnih in vizualnih tehnik. Med mnogimi metodami za analizo implicitnih informacij sta podrobneje opisani samodejno senčenje in izdelava plastnic reliefa.

Najpomembnejši del disertacije temelji na dveh metodah izdelave DMR. Prva je metoda hkratne interpolacije virov, druga pa metoda utežnega seštevanja virov. Obe se naslanjata na pripravo za modeliranje ter na dobro poznavanje virov in teorije modeliranja DMR kot prvih korakov pri izdelavi DMR. Sledi predobdelava, obdelava in upravljanje z DMR. Predobdelava virov temelji na podrobni vizualni in statistični kontroli kakovosti virov, podprti s samodejnimi regionalizacijami. Pri tem dobimo statistično in geomorfološko popravljene in izboljšane podatke. Obdelava s prvo metodo, temelječo na hkratni interpolaciji vseh virov, upošteva uteži in gostoto posameznih virov podatkov. Druga metoda narekuje manj obdelave kot prva in temelji na pripravi vsakega vira s točno metodo interpolacije v celično mrežo enotne ločljivosti. Osnovni DMR je izdelan z mozaičenjem najbolj homogenih virov. Ob

upoštevanju uteži, oblikovanosti površja in vertikalnega odstopanja od referenčnih točk so nato z zaporednim prekrivanjem, drug prek drugega, upoštevani vsi sekundarni viri.

Uporabljene tehnike izdelave DMR so bile preverjene po posameznih korakih obdelave s spremljanjem parametrov kakovosti. Podatki, uporabljeni po testnih območjih, so karseda objektivno opisovali vsak del Slovenije. Zadnji del disertacije obravnava možnosti učinkovitega upravljanja s podatki o reliefu - z viri, DMR in drugimi izdelki. V ta namen je predstavljena zbirka digitalnih podatkov reliefa (ZDPR).

Hipotezo disertacije potrjujejo statistične in vizualne analize kakovosti, temelječe na izdelkih obeh predlaganih metod izdelave DMR. Rezultati omenjenih analiz napovedujejo statistično in geomorfološko-vizualno kakovostnejšo ter na učinkovitejšo izdelavo DMR Slovenije od do sedaj najboljših. Za vso Slovenijo je realno pričakovati povprečno vertikalno natančnost okoli 3,5 m ali manj. Pomembni dodatni proizvodi koncepta izdelave DMR so samodejno izdelane plastnice ter skelet in sence reliefa. Med stranske izdelke pa spada pridobitev parametrov kakovosti ter odprava nekaterih grobih in sistematskih napak uporabljenih geodetskih zbirk.