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IMPACT OF NEW MAPPING TECHNOLOGIES ON COMMUNICATION OF GEOSPATIAL INFORMATION

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Abstract: GPS, new sensors and increased computational power have dramatically changed mapping of Earth systems. Highly automated data acquisition from space, air and ground enables collection of massive amounts of data at short time intervals creating spatio-temporal, digital representations of landscape features at unprecedented level of detail and accuracy. Advances in computer graphics and data distribution via Internet are changing the communication of geospatial information by increased use of electronic media with high level of interaction, dynamics and 3D visualization. To illustrate some of these trends examples of terrain mapping using LIDAR and Real Time Kinematic GPS are presented.

Keywords: Digital Elevation Model, LIDAR, visualization

Introduction

Over the past decade, geoinformation field has evolved from a highly specialized niche to a discipline with an extensive range of applications. Digital georeferenced data are now used by general public for basic tasks such as driving directions, but at the same time, geospatial technologies play a major role in complex situations requiring high level of expertise, such as real time response to natural disasters. According to the Open GIS Consortium “Approximately 80% of business and government information has some reference to location, but until recently the power of geographic or spatial information and location has been underutilized as a vital resource for improving economic productivity, decision-making, and delivery of services". This situation is changing rapidly due to several important trends:

- new mapping and monitoring technologies produce massive volumes of spatio-temporal georeferenced data (for example, laser altimetry - LIDAR [2], Interferometric Radar - IFSARE, multispectral aerial and satellite imagery, real time kinematic surveys); These highly automated and efficient mapping technologies enable repeated mapping of large areas over short time intervals extending a 2D static representation of landscape by a 3D spatio-temporal representation, stored in a digital form;

- on-line distribution of data shortens the time between the data acquisition and data distribution. It makes the geospatial data accessible to a broad group of users, from general public to professionals. The access to data is often seamless, defined by the user, rather than predefined, e.g. by a digital version of topographic sheets. Multi-scale storage automatically changes the scale of provided data as well as map contents, depending on the zoom-in level. Both government and commercial sites offer the most recent data currently available for a given area with practically continuous updates. General access to near real-time data, often represented by dynamic maps, is becoming standard for some rapidly changing phenomena, such as weather, as well as water and air quality;

- growth in the Internet based GIS Services is reflected by greatly improved WebGIS sites that are extending their capabilities from data viewing and navigation to more complex tasks such as spatial query and on-fly coordinate transformations. While geospatial analysis is still rather limited, developments in distributed computing (GRID) and improvements of network speed and bandwidth will make it increasingly common. Location based services, wireless spatial information brokerage and mobile GIS further extend the access to digital geospatial data.

- new mapping technologies and GIS tools have stimulated the development of a new generation of process-based, spatially distributed models that are being increasingly used for management and decision making. New approaches to human-computer interaction are being explored to improve the communication of complex results of these simulations and to enable more natural interactivity in their applications.

All of these developments have profound impact on methods for communication of georeferenced information. The geospatial data delivery is rapidly changing from computer generated but static paper maps to interactive digital media, while the methods of graphical representation expand to include 3-dimensional and dynamic graphics. Due to the fact that the measurements are performed directly from the stored georeferenced data, there is less focus on high positional accuracy of the graphical representation, however, effective communication of spatial features and their relationships along with fast access to underlying quantitative and qualitative data is becoming increasingly important. This does not mean that paper map is disappearing. The new technology makes its production cheaper and a paper map is often preferred in education, planning, field work and navigation thanks to its large format a seemingly trivial possibility to fold it, a convenience that has yet not been effectivelly replicated in a digital form.

To illustrate the use of the new mapping technologies and the methods for processing and communication of the resulting data we describe applications of LIDAR and Real Time Kinematic GPS surveys for analysis of terrain morphology and its change.

New 3D mapping technologies and modeling of elevation surface

Probably the most important recent innovation in terrain mapping has been LIDAR (LIght Detection And Ranging). Laser, mounted in an airplane, samples terrain using overlapping, several hundred meter wide swaths measuring elevation every 1-3 meters with reported vertical accuracy 15 cm in bare areas. Rather than the typical points or profiles, carefully selected by the surveyor or operator to best represent the major topographic features, the result of LIDAR measurements are massive point clouds of x,y,z data (Figure 1a,b) capturing every detail or feature greater than 1-3m. This poses specific challenges for creating graphic representations of such detailed topography and complex, semi-automated procedures are needed to process the data. Creating satisfactory contour-based terrain model is time consuming and requires significant manual intervention. DEMs or TINs based on minimally processed input data lead to noisy contours that are difficult to interpret (Figure 2a). While the data can be smoothed to obtain acceptable contours, valuable detail is often lost. On the other hand, 3D interactive visualization of LIDAR data is simpler and enables preservation of high level of detail. After removal of outliers using filtering techniques or wavelets the original x,y,z data can be rasterized using bining (assignment of points to grid cells) for lower resolution models. Spatial interpolation, for example by regularized spline with tension ([8], Chapter 7), can be used for high resolution (1-2m) model (Figure 3c). Graphical representation of topography is then obtained in the form of 2D shaded elevation surface or as an interactive 3D model with lighting and shading enhancing the 3D perception (see full images at [7] and OpenOSX [12]). Wide range of interactive software tools with capabilities similar to the ones described in our previous article [5] are now available for PC platform and 3D visualization of elevation surfaces is becoming the main tool for communicating the results of LIDAR surveys. It is interesting to note that although the tools for interactive 3D visualization have been available for over a decade, it is the new 3D mapping technology and availability of high resolution terrain data that is stimulating the wider use of visualization for communication of terrain data.

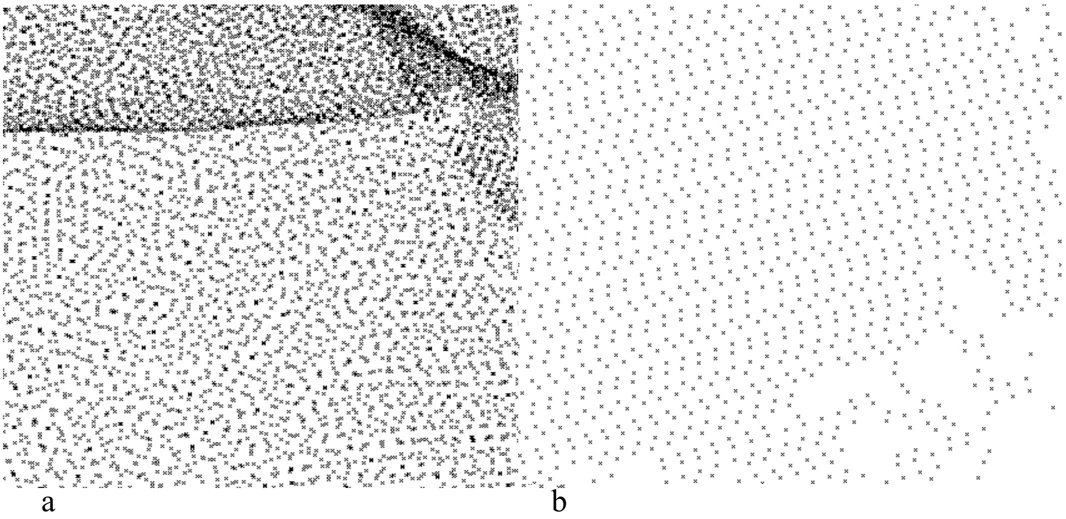

Figure 1. Spatial pattern of point clouds for different LIDAR systems a) NASA'a ATM with elliptical scanning pattern, flight altitude 700m, the denser sampling indicates swath overlay; b) Leica Geosystems aeroscan with linear scanning pattern and multiple returns, flight altitude 2300m. The points are for the last return representing bare ground, the "empty" spaces are in the areas where LIDAR did not reach the ground.

To illustrate terrain modeling based on the LIDAR data we present a study of sand dune migration on the North Carolina, USA coast. The studied dune field called Jockeys Ridge is located within a state park and it is surrounded by developed areas. Due to almost continuous wind, the dune is moving slowly in SW direction, leaving the park area and overtaking neighboring roads and homes [3]. The dune migration has become a serious management issue as it requires costly removal of sand from overtaken areas. To assess the spatial distribution and rates of sand erosion and deposition the dune was surveyed several times over the past decade, with the two most recent (1999, 2001) measurements performed by LIDAR. The 1999 LIDAR survey was performed by USGS, NASA and NOAA using ATM-II LIDAR as a part of post-hurricane survey. The data were downloaded from the Internet using LIDAR Data Retrieval Tool (LDART [4]) that allows users to download the data from an interactively selected area [11]. The tool provides on-fly coordinate transformation and gridding using several different types of methods (but not interpolation). The technical details for the LIDAR and the surveys are described on the web site and in the metdata file provided with each data set. The ATM LIDAR has elliptical scan pattern with single return (Figure 1a), that means that it does not penetrate the vegetation. The dune itself is therefore surveyed very accurately while the vegetated areas are represented by the first return elevation rather than commonly used bare ground. When the given points are binned at 1m resolution the resulting surface has large number of gaps (Figure 3a), however, at 3m resolution simple bining results in a DEM that is suitable for many applications and 1 order of magnitude more detailed than the standard 30m USGS DEM (Figure 3b). By using high quality spatial interpolation a continuous, 1m resolution surface can be created capturing such details as fences burried in the sand, street light poles, and cars, as well as terrain breaklines such as dune crests. Visualizing such high resolution DEM in 3D space with interactively adjustable lighting, z-exaggeration, spatial query and fly-through animation provides detailed graphical representation highlighting the geomorphologic properties of this dune field. See different representations using the same data set at OpenOSX [12] and [7].

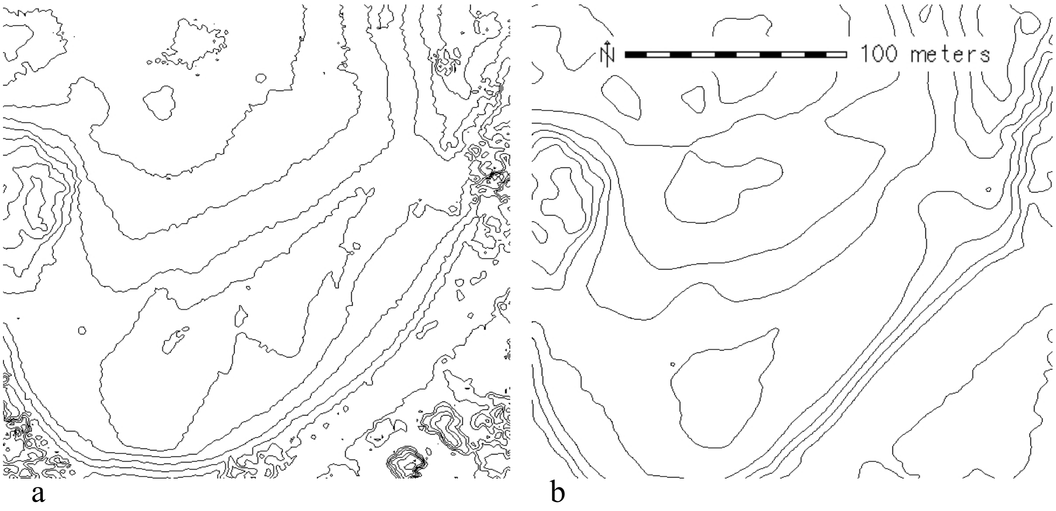

Figure 2. Detail of contourlines derived from LIDAR based DEMs a) 1999 ATM, interpolated without smoothing at 1m resolution, includes buildings and vegetation, b) 2001 Leica, interpolated from pre-processed data with vegetation and buildings removed. Note, that most differences are due to the actual topographic change rather than by differences in technology.

The 2001 LIDAR survey was performed under NC state Flood mapping program by a private company using a newer LIDAR technology capable of penetrating vegetation [10]. After extensive processing, the data have both the vegetation and the buildings removed. The sampling pattern is slightly different and the density of points is higher in open areas (dune) than in vegetated areas where only portion of the signal reached the bare ground (Figure 1b, lower-right corner).

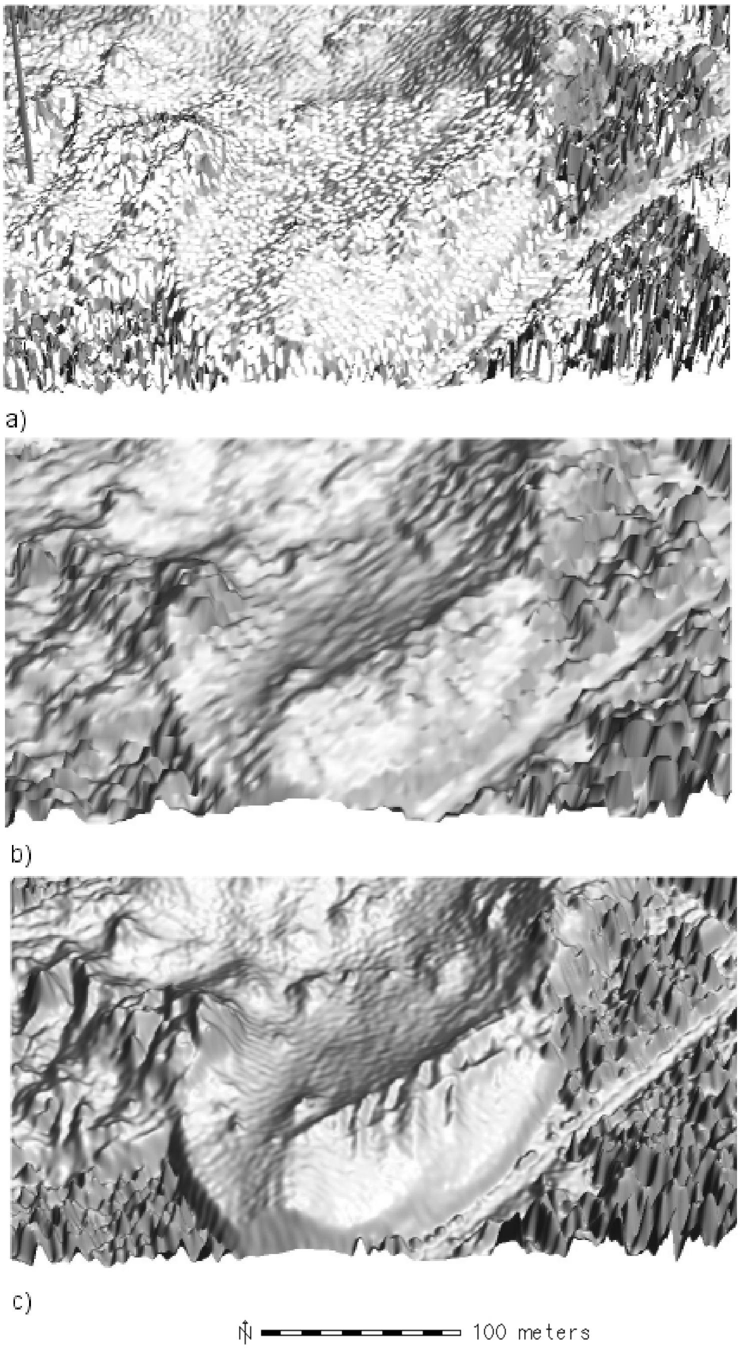

Figure 3. 3D views of LIDAR based elevation surfaces a) binned at 1m resolution, b) binned at 3m resolution, c) interpolated at 1m resolution by RST. See http://skagit.meas.ncsu.edu/~helena/measwork/jockeys/lidar.html for the 3D views of the entire dune field.

In spite of these differences the data obtained from both LIDAR systems are consistent within the 25cm RMSE in the stable, open areas (roads, parking lots). DEMs from both surveys as well as DEMs derived from contours for the 1995 and 1974 surveys can be viewed and compared in the web document [6].

To assess the pattern and rate of dune movement both surfaces were overlayed and areas of erosion and deposition were identified (Figure 4). Quantitative analysis of the pattern shows that the dune is moving horizontally in the SW direction at an average rate 20 m/year and towards the East at 1 m/year. Horizontal movement is accompanied by dune flattening, the main ridge has lowered its elevation from 43m in 1950 to the current 24m. The sand is moving over very short distances and deposits in front of dune slip faces, rather than being blown out of the park, so only those areas where the dune slip faces directly reach the roads and homes are affected. Besides representation of horizontal dune migration, the 3D visualization using multiple surfaces enables us to overlay both surfaces, and interactively slice through the model using cutting planes, creating a continuous series of profiles. Such interactive, continuous profiles provide excellent insight into the spatial patterns of topographic change. Topographic analysis based on secondary parameters using slopes and curvatures, especially for identification of dune crests and slip faces is described by [6] and some results can be viewed in the web document [7].

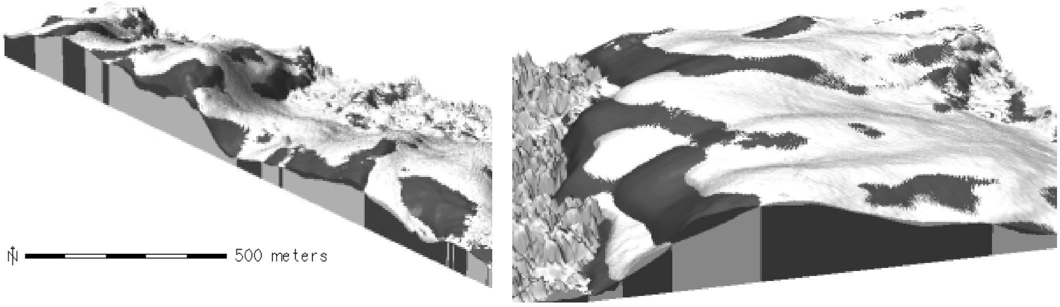

Figure 4. Overlayed 1999 (white) and 2001 (dark grey) elevation surfaces with snapshots of dynamic continuous crossections that can be interactively rotated or panned through the surfaces. The dark areas on the surface (2001 is on top) indicate sand deposition, white areas (1999 on top) have lost sand.

In addition to LIDAR, fast, but 1-2 magnitudes less dense, topographic surveys can be performed by real time kinematic GPS (RTK-GPS) [1]. Using the method, the elevation data are obtained by automatically sampling of the surface along a surveying vehicle path with a selected step (usually around 1m) and 10-15cm vertical accuracy. Data coverage can be very dense along the paths, however, for practical reasons, distance between the paths is usually much larger (10-100m). As opposed to LIDAR, attributes can be assigned during the mapping, which is important for proper representation of breaklines, man-made objects and other features. RTK-GPS is commonly used for precision farming, road surveying, beach monitoring etc. Comparison with the elevation surfaces generated from LIDAR data (Figure 5a,b) shows th reduced detail in RTK-GPS-based topography, however, the missing detail represents features that are usually close or only slightly higher that the RMSE of both methods (~20cm). As an example we provide the topography of Cape Fear in year 2000 based on LIDAR and in year 2002 based on RTK-GPS after the cape has grown significantly due to the nourishment of neighboring beach.

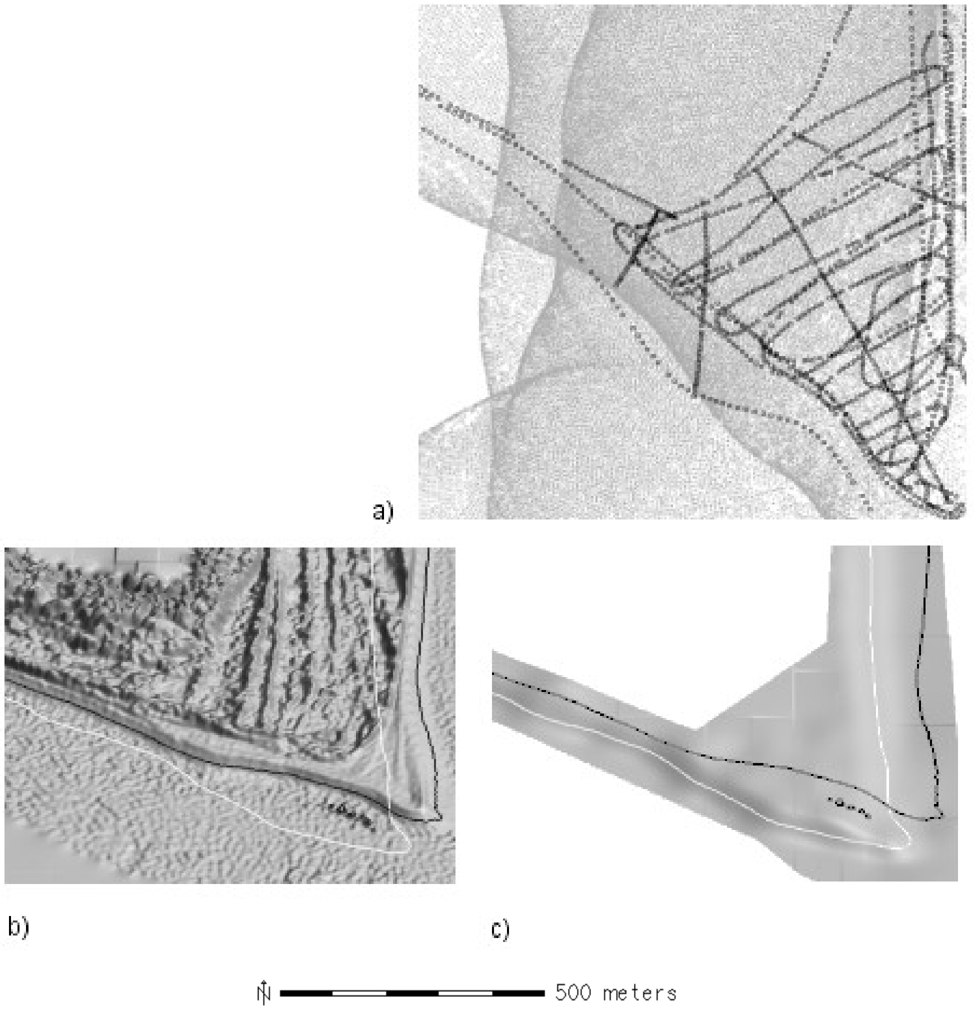

Figure 5. Sampling pattern and resulting surfaces for Cape Fear, NC: a) point could from LIDAR is shown in grey while the RTK-GPS are the black square symbols, b) LIDAR-based topography from 1997 includes a series of dunes and vegetation, c) RTK-GPS based surface from 2002 includes only the lower part of the beach (most dunes were eroded during the hurricanes in 1998, 1999). The cape is a highly dynamic feature as shown by the migration of 0m contourline (black is 1997, white is 2002).

Conclusions and future of communicating geospatial data

New types of geospatial data, such as point clouds and high resolution mutlispectral imagery along with new generation of users better trained to interact with 3D models of the world than work with its 2D static representation accelerate the adaptation of new communication approaches. 3D visualization is now becoming common and the most exciting developments are happening at the cross-section of digital technology and traditional models. An excellent example is the Illuminated Clay project [9] based on the idea of Tangible User Interface. This project combines a flexible model from clay with laboratory laser scanner and projector to create an interactive environment where the users can interact with the model by changing manually its shape and observe in real time the change in topographic parameters (e.g. slope) projected over the model. The system is aimed for design purposes but the concept can have significant impact on the future of communication of geospatial information.

Acknowledgment

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Resumé

Vplyv nových technológií mapovania na komunikáciu geopriestorových informácií

Za posledné desaťročie došlo k veľkému rozvoju geoinformatiky a vzniku množstva jej aplikácií. Digitálne, polohovo lokalizované údaje nachádzajú bežné využitie medzi širokou verejnosťou, napríklad pri plánovaní trás, no zároveň tieto údaje a technológie s nimi spojené zohrávajú významnú úlohu pri riešení zložitých situácií (napr. pri prírodných katastrofách). Tento nárast významu geografických informácií je dôsledkom viacerých trendov. Patria k nim:

- vznik nových mapovacích a monitorovacích technológií, ktoré umožňujú mapovanie veľkých území v relatívne krátkych časových intervaloch (LIDAR, IFSARE, satelitné snímače, kinematické GPS),
- elektronická distribúcia údajov, ktorá skracuje čas medzi meraním a využitím geografických informácií,
- rozvoj GIS služieb v prostredí internetu (WebGIS),

- rozvoj novej generácie priestorových modelov, ktoré slúžia na riadenie a rozhodovanie.

Tento vývoj ovplyvňuje aj spôsob komunikácie polohovo lokalizovanej informácie. Prezentácia sa presúva od papierových máp (vytvorených v počítači) k interaktívnym digitálnym médiám, využívaniu 3-D grafiky a animácií. Zvyšuje sa význam vizualizácie, ktorá efektívne komunikuje priestorové prvky a ich vzťahy s rýchlym prepojením na súvisiace kvantitatívne a kvalitatívne údaje.

Na príklade použitia technológií LIDAR-u (LIght Detection And Ranging) a RTK GPS (Real Time Kinematic GPS) pri analýze morfologických vlastností terénu a jeho zmien ilustrujeme možnosti týchto technológií a spôsob komunikácie výsledkov. Pri LIDAR-e sa laserom, umiestnenom na palube lietadla, sníma povrch terénu, výsledkom čoho je veľké množstvo (zhluky) bodov, ktorých vertikálna presnosť je 15 cm na plochách bez vegetácie. Vytvorenie vrstevnicového modelu reliéfu z takýchto údajov je náročná úloha a vyžaduje ďalšie spracovanie údajov (napr. filtrovaním, interpoláciou, zhladzovaním) (Obr. 2). Jednoduchší prístup predstavuje vytvorenie digitálneho modelu reliéfu a jeho zobrazenie pomocou 3D interaktívnej plochy. Na Obr. 1 je znázornené rozmiestenie meraných bodov rôznymi systémami LIDAR-u pri meraní migrácie pieskovej duny na pobreží Severnej Karolíny v U.S.A. Pomocou kvalitnej interpolácie sa z pôvodných údajov podarilo vytvoriť taký model duny, ktorý presne zachytáva ploty v piesku a terénne hrany. Analýza morfologických vlastností pieskovej duny vyžaduje 3-D vizualizáciu s nastaviteľnými parametrami osvetlenia, prevýšenia, priestorovými dopytmi a animácie preletov nad terénom (Obr. 3). Pri skúmaní zmien tvaru duny je vhodné použiť operáciu naloženia povrchov reprezentujúcich tvar duny v rôznych časových intervaloch na seba, alebo rezy v rôznych smeroch tvoriacich spojitú sériu profilov charakterizujúcich zmeny povrchu (Obr. 4).

Okrem LIDAR-u je možné využiť topografické merania pomocou RTK GPS. Ich princípom je meranie súradníc bodov pri pohybe vozidla s krokom okolo 1 m a vertikálnou presnosťou 10-15 cm. Počet takto získaných bodov je o 1-2 rády nižší ako pri LIDAR-e. K údajom je možné už počas merania priradiť atribúty. Príkladom je meranie zmien mysu Cape Fear a porovnanie s meraniami pomocou LIDAR-u (Obr. 5).

Uvedené príklady dokumentujú potrebu interaktívnej 3-D vizualizácie priestorových údajov získaných pomocou nových technológií mapovania. Vývoj v tejto oblasti určite prinesie ďalšie nové, inovatívne spôsoby interakcie s modelmi a komunikácie s geopriestorovými údajmi.

Text k obrázkom:

Obr 1. Priestorové rozmiestnenie bodových zhlukov z rôznych systémov LIDAR-u a) NASA ATM s eliptickým vzorom skenovania, hustejšie miesta naznačujú prekryty snímania; b) Leica Geosystems aeroscan s lineárnym vzorom skenovania a viacnásobnými odrazmi. Body su z posledného odrazu reprezentujúceho pevný povrch (podklad), „prázdny" priestor je v oblastiach, kde LIDAR nedosiahol až na podklad.

Obr. 2 Detail vrstevníc odvodený z digitálneho modelu reliéfu pripraveného z údajov LIDAR-u a) 1999 ATM, interpolovaný bez zhladzovania a s rozlíšením 1m, obsahuje budovy a vegetáciu, b) 2001 Leica, interpolovaný z predpripravených údajov bez vegetácie a budov. Väčšina rozdielov je spôsobená topografickými zmenami a nie rozdielmi v technológii.

Obr. 3 3D pohľady na povrchy reprezentujúce nadmorskú výšku a) rasterizované v rozlíšení 1 m, b) rasterizované v rozlíšení 3 m, c) interpolované metódou RST v rozlíšení 1 m. 3D pohľady na celú oblasť duny su k dispozícii na adrese http://skagit.meas.ncsu.edu/~helena/measwork/jockeys/lidar.html.

Obr. 4 Prekryv povrchov duny z roku 1999 (biely) a 2001(tmavošedý) s ukážkami profilov, ktoré je možné interaktívne rotovať, posúvať a naklánať pri štúdiu zmien. Tmavošedé plochy na povrchu terénu reprezentujú ukladanie piesku, na svetlých plochách je erózia.

Obr. 5 Merania na myse Cape Fear, NC a) zhluk bodov z LIDARu (1997) je šedý, RTK-GPS body sú označené čiernymi štvorcami; b) terén modelovaný z LIDARu zachytáva duny aj vegetáciu, c) RTK-GPS povrch reprezentuje len spodnú časť pláže. Cíp mysu je veľmi dynamický, čo dokazuje migrácia nulovej vrstevnice (1997-čierna, 2002 – biela).

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