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EXTRACTION OF DIGITAL SURFACE MODELS FROM CORONA SATELLITE STEREO IMAGES

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Abstract

Satellite images can be utilised for observing surficial changes, especially efficient in the monitoring of larger areas. The comparative analysis of high resolution images from earlier periods with recent data can provide insight in the scale of changes in topography, and with meteorological, hydrological and other historic records, can lead to better understanding and more reliable modelling of the predominant processes causing mass movement.
More accurate morphometric and visual analysis of the topographic changes is possible using digital surface model (DSM), which can be obtained from satellite stereo images. In this paper, the authors evaluated methods of creation digital surface models obtained from satellite images from the CORONA program in monitoring surficial mass movement processes in the Fruška Gora mountain area, in the southern part of the Vojvodina province in Serbia. This area is of particular interest because of its favourable geographic location, rich geo- and cultural heritage and increasing demand for exploitation, which results in greater impact of natural hazards.
The CORONA images were chosen because of good availability of high resolution coverage for the whole area from the period of past four decades.

Keywords: remote sensing, Fruška gora, CORONA satellite images, automated digital surface model extraction

INTRODUCTION

By 2002 the Department of Geography, University of Novi Sad managed to establish bilateral relations with the Department of Physical Geography and Geoinformatics at the University of Szeged, Hungary, which opened up the possibility of mutual geomorphological studies via the application of geoinformatical tools. One major aim of this research project was the creation of a digital elevation model of the study area using reliable, yet the oldest available data sources. This model will be compared to a model recording the modern conditions of the area in order to evaluate any past changes. This new modern model is based on data recorded during field surveys and gained via the analysis of recent high-resolution satellite images.

For the accuracy of the investigations aerial photographs and satellite images used in the study must have a spatial resolution of at least 3 m. Such photos and images are lacking from Serbian official sources. However, we have come across a database of former CORONA spy satellites, where stereo image pairs could have been readily purchased of the study area. The present study gives an overview of the analysis of these images and the extraction of the DSM using the elucidated information.

STUDY AREA

The study area located along the river Danube north of the Fruška Gora is very similar in morphology to the loess areas of Paks and Dunaföldvár, in Central Hungary. These loess-covered Pleistocene surfaces located along the rivers are frequently subjected to landslides and mudslides. Although a detailed geographic survey of the mentioned study area was implemented as early as the end of the 19th century, these studies are no match to the complex geomorphological studies implemented on Hungarian loessy areas. Thus there are no historical records available for the observable landslides of the area. The only option for understanding the dynamics of these mass movement processes is to find information sources, enabling the preparation of digital elevation models for the past 40-50 years and compare them with those prepared on the basis of modern field data.

Satellite image analysis can yield limited results in the investigation of certain surficial processes, thanks to their periodic nature characterized by a relatively longer stasis. The only exception might be the relatively recent landslides, where high resolution images of the affected area prior and after the events are readily available. Areas along the Danube frequently subjected to landslides (e.g. the vicinity of Dunaföldvár) have enjoyed much attention by geomorphologists during the second half of the 20th century in Hungary, primarily related to the works of Pécsi (Pécsi M. 1991). These landforms are frequently observable in the Lower Danube area, especially in the vicinity of the city of Novi Sad and the northern foothills of the Fruška Gora (Tarcal or Köles Hills). Unfortunately, no matter how close this region was to the area of present day Hungary, the known political and other tensions; for example, war prevented Hungarian experts from joining the geomorphological investigations of the area.

Table 1 The main features of the cameras and film used during the KH-4B mission (Dashora A. et al. 2007)

System	*Corona KH-4B*
Time of recording	08.02.1969
Mission no.	1106
Orbit height	150 km
Camera type	Panoramic
Angle of twin cameras	30°
Focal length	609.6 mm
Film type	Panchromatic
Film resolution	160 line/mm
Actually usable film size	55.37 x 756.9 mm (mm x mm)
Area covered	14x188 km
Scale	1:247500
Field resolution	1.83 m

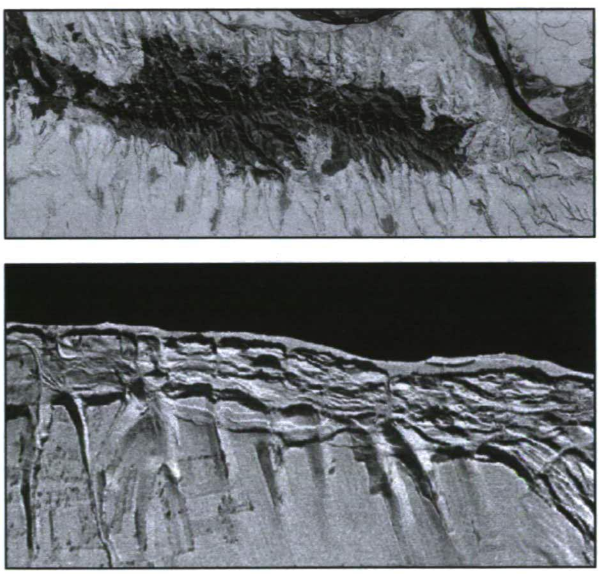


Fig. 1a-b The Fruška Gora hills and a landslide affected area on the right banks of the river Danube (SE of Novi Sad as seen on the CORONA image of 08.02.1969 (40x17 km)

APPLIED MATERIAL

In February 1995 US president Bill Clinton (1995) exempted from secrecy in a special resolution the satellite images taken by the spy satellites CORONA (KH 1-4), ARGON (KH-5), and LANYARD (KH-6). The resolution disclosed more than 860,000 images taken between 1960 and 1972. These images are open to the public and can be ordered from the USGS using the homesite of USGS EarthExplorer.

A stereo image analysis is somewhat hampered by the fact that parameters necessary for interior orientation is only partially known and exterior parameters are not available for the CORONA images. Thus it was necessary to review processing methods available for the CORONA images in the literature.

As part of the IMPETUS project (Altmaier A. – Kany C. 2002) DSM was prepared for an area of ca. 100 km^2 using stereo images of the CORONA KH-4B satellite over Morocco. To derive the ground control points a differential GPS technique was applied with an accuracy of 10 cm in *x*, *y* and *z* directions. Schenk T. et al. (2003) set up a camera model for the KH-4A/B systems using collinearity equations. The derived algorithm was tested using calibration points gained from a KH-4A stereo image pair and regular topographic maps of the study area. Field accuracy was tested via affine and polynomial transformation of the studied images.

Bayram B. et al. (2004) were tracing shoreline changes near Istambul using a CORONA image taken in 1963 and panchromatic SPOT-4 and IRS-1D images taken at the end of the 1990s. For the rectification of the KH-4A image pairs affine, projective and rubber sheet transformation methods were applied and evaluated in terms of field accuracy. All three studies arrived at the conclusion that CORONA images, in the form of stereo pairs are suitable for tracing surficial changes for the past 30-40 years, yielding sufficient accuracy and thrift, comparable to modern high resolution satellite images.

METHODS

Processing of satellite stereo images

Several time periods were found in the archive of the USGS (08.02.1969, 26.05.1972), when stereo images were taken for the mentioned study area (*Table 1*). From these the ones taken in 1969 had no cloud cover. The ordered negatives were scanned by colleagues of the Ministry of Defence Mapping Company at a resolution of 12 μm (*Figs. 1a-b*). In 2003 a single negative roll costed 18 USD.

For processing the ERDAS OrthoBase Pro digital photogrammetric software pack was utilized, and an approximative aerial triangulation result was found using such parameters as focal length, orbit height, film pixel size and ground control points. Perfectly accurate orientation requiring extreme computation power was practically unachievable (Schenk T. et al 2003). This was not our ultimate goal however, as we mainly aimed our work at deriving usable morphological data suitable for the preparation of digital surface models for geomorphological studies from these images, in an efficient and eco-

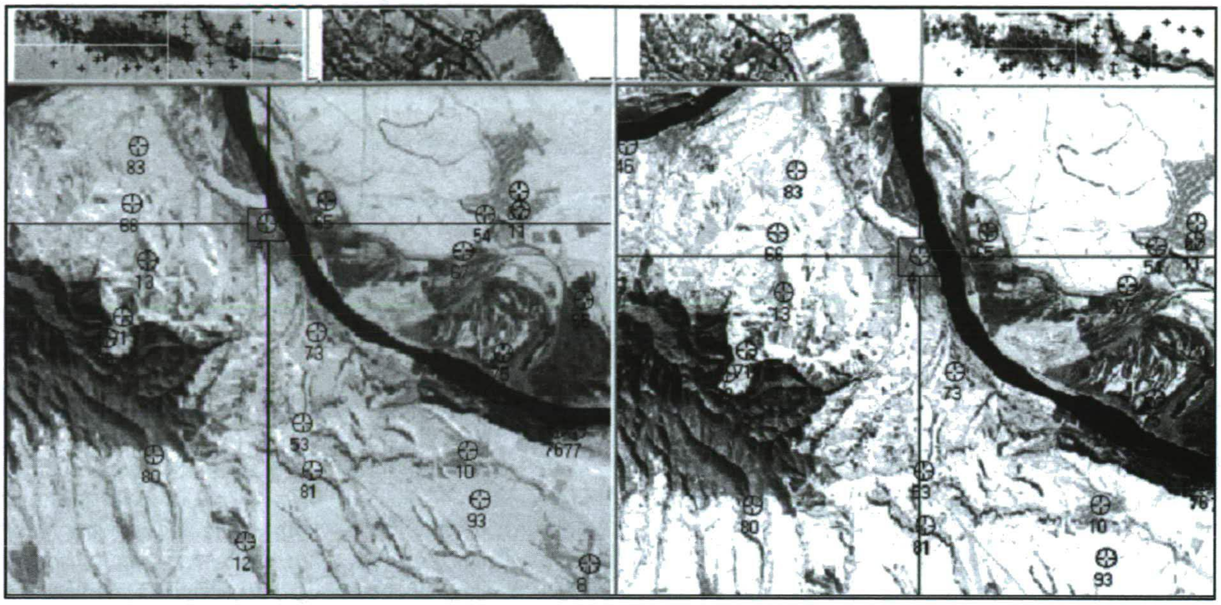


Fig. 2 The absolute orientation of the CORONA images using ground control points

nomic way to meet the expected accuracy requirements as well.

The next step was the relative orientation of the stereo image pair with using ca. 40 tie points. The automatic tie point generation method yielded no sufficient amount and quality of homologue points as the winter images were taken among conditions of partial suficial snow cover. The automatic matching algorithm thus could not identify homologue points on larger homogenous snow covered areas. In these areas tie points were measured manually.

For the exterior orientation, ground control points were recorded in the mountain and its foothills using relative rapid static GPS measurements (*Fig. 2*), the basis point was set up on the roof of the building hosting our department at Szeged.

The length of the baseline was ca. 145 km, ensuring a good accuracy for the image analysis. On the satellite images taken 36 years ago ca. 30 interest points were identified at crossings of paved roads, on the trajectory of creeks charging into the river Danube, and rails of bridges crossing the creeks and canals charging into the Danube. A good ground control point was found near the Iriski–Venac Monument located in the central, highest part of the Fruška Gora, which monument managed to survive the 1999 NATO bombings, unlike the TV tower, which stands as a stunning and saddening memento of futile clashes from the closure of the 20th century (*Fig. 3*).

The transformation of the GPS coordinates to the local reference system was not without any difficulties. An approximating solution was found to this problem (Timár G. et al. 2002, 2004). The development of a reliable coordinate transformation method for studying dynamic surface changes is a task to be solved in the future.

After the assignment of suitable control and tie points, an aerial triangulation was implemented using a

Fig. 3 The Novi Sad TV tower in 2004

self-calibrating direct linear transformation offered by the program (Altmaier A. – Kany C. 2002). This method does not require the knowledge of either the interior orientation data of the camera or the predicted exterior parameters. After multiple runs and the evaluation of the residuals for tie and control points as well as the RMS error values, the best outcome was chosen via elimination of points yielding the largest error from the numerous iterates.

Extraction of DSM

After this, a digital surface model (DSM) was generated. The algorithm was basically congruent with that used during the automatic tie point detection. Correlation is a frequently applied approach in photogrammetry for finding the common tie points of two images. Automatic DSM generation is achieved by a combined application of correlation calculations and tie point identification in digital photogrammetric software packages.

Using the query operator a series of feature points was determined on the images under study. Feature points are the center points of a window with acceptable greyscale and contrast values. Feature points on the other hand are also object points marking a single object, e.g. road crossing, bridge rail, monument etc. After the determination of interest points on a single image, the corresponding points are also identified in adjacent images, including the corresponding objects (Lee H. Y. et al. 2003). The next step is the calculation of cross-correlation between the sample window and the search window. The sample window is on the reference image, while the search window is on the adjacent image. As an interest point on the initial image might have several corresponding tie-points on the adjacent image, the program calculates a correlation coefficient for each suitable set of corresponding points. This coefficient expresses the rate of similarity between the corresponding interest points of the adjacent images. The higher the value the greater the similarity is (0.8-1).

Strategic parameters influence the success and accuracy of transformations. The most important parameters are those of the sample and search window sizes and the chosen correlation coefficient.

RESULTS

Accuracy assessment

A raster DSM image of 5 m grid size was created for the entire area (*Fig. 4*), an ESRI 3D shape file of ca. 450000 points. Furthermore, to set the most optimal program values a raster DSM of 2 m grid size was also generated for the south-east foothill area, and used for preliminary studies of the slopes with mass movements directed towards the Danube (*Figs. 5a-c*). In order to determine the exterior accuracy of the aerial triangulation and surface modelling methods, a new series of DGPS measurements is needed. Interior accuracy statistics might be helpful in the evaluation process. In the final solution every single tie points (GCP) had to be used due to the large spatial extent of the study area. In the iterative runs, a single GCP was left out and identified as verification point. The residuals received for these verification points always fell within the range of acceptable error in all three X, Y and Z directions as depicted on *Table 2*.

The calculated error values were compared to the exterior accuracy values of the known published studies. The verification results of two studies are depicted in *Table 3*. Altmaier A. and Kany C. (2002) used DGPS measurements to check the accuracy of 120 points, while Schenk T. et al. (2003) used 1:24000 topographic maps and 20 points to verify their results of image analysis. When we look at the findings of their and our studies we

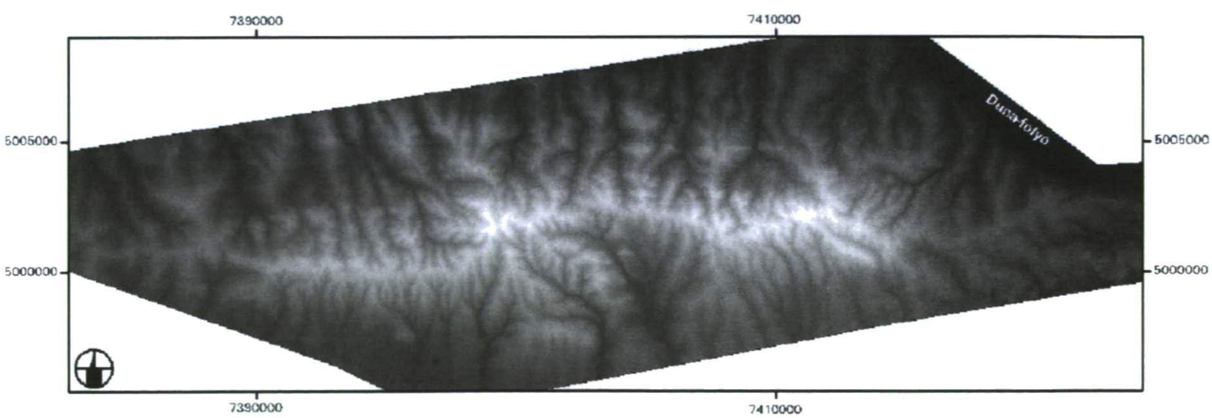


Fig. 4 A DSM of 5m grid size of the Fruška Gora (coordinate system: Gauss-Krüger, Yugoslavia)

can conclude that the digital photogrammetric analysis of CORONA KH-4A/B satellite images generally yield a vertical accuracy of 10-25 and a horizontal accuracy below 10 m. Considering the relatively low cost of images and the relatively large area covered by an image pair subjected to study, these findings are rather satisfying.

Table 2 Residuals received for aerial triangulation, DSM verification for the surficial interest points expressed in meters

	Aerial triangulation			*DSM img*	*DSM 3D shape*
	X	*Y*	*Z*	*DSM Z – GCP Z*	
minimum	0.6	4.4	3.4	2	5.3
maximum	15.5	12.9	24.9	25.1	27.1
average	6.7	8.0	8.6	10.7	13.7

Table 3 Collective results of accuracy studies in referred works (Altmaier A. – Kany C. 2002, Schenk T. et al. 2003)

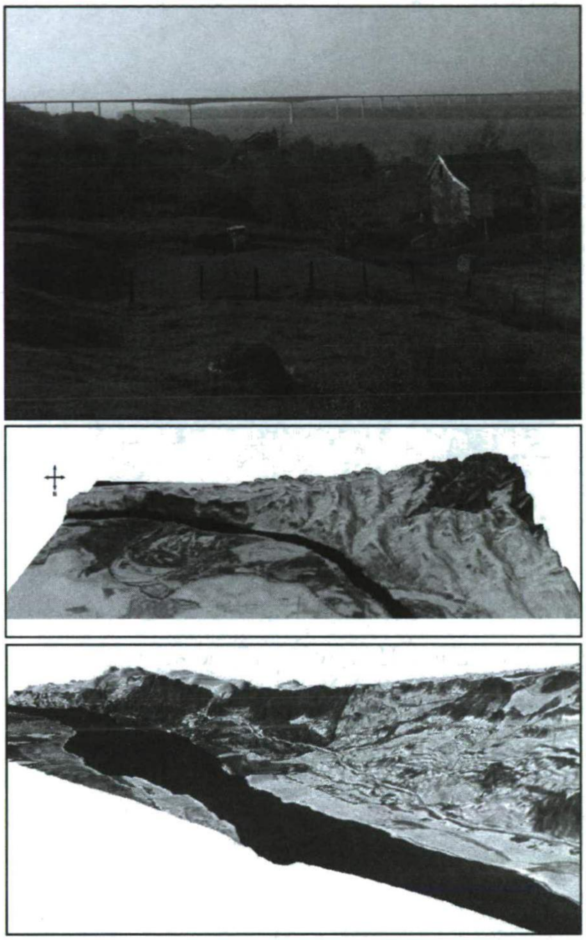
	Average			
	X	*Y*	*Z*	*DSM Z – DGPS Z*
Aerial triangulation for two models (A. Altmaier)	2.5-4.8	2.7-5.7	12.5-21.6	-
Aerial triangulation (T. Schenk)	6.2	5.6	12.34	-
DSM (A. Altmaier)	-	-	-	9.7-13.3

Possibilities for spatial visualization and other uses

Using the oriented model and the gained DSM, an orthophoto of the study area was generated with a resolution of 2x2 m using the OrthoBase program. The raster DSM was used as an input into the ERDAS VirtualGIS module, orthophotos and other vector layers like contour-lines were placed on the surface model. The DSM 3D shape points were evaluated using ERDAS Stereo Analyst module, using an anaglyph and real spatial visualization approach, and StereoEyes liquid crystal glasses.

The available vector overlays were applied on the DSM to check the real spatial orientation of the individual data points. 2D vectorial overlays can be easily transformed into 3D overlays in most 3D image processing systems. The attribute tables can be individually displayed and edited during the evaluation process.

The DSM of 2 m resolution is also applicable for geomorphological investigations. One cross-section was drawn according to DSM (*Fig. 6a-b*), which is comparable with other section drawn by Pécsi M. (1979) at Dunaföldvár (*Fig. 6c*) Hungary. Comparing this old section with new, field measurements it can be used for the calculation of speed of landslide processes.



Figs. 5a-c A virtual image of the study area derived via the combination of an orthophoto and the DSM of 2 m grid size (photo: Mészáros M.)

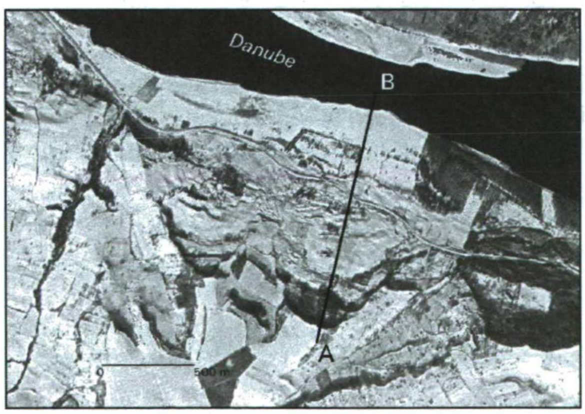


Fig.6a Landslides on the Corona image on the riverbank of Danube east to Fruška gora

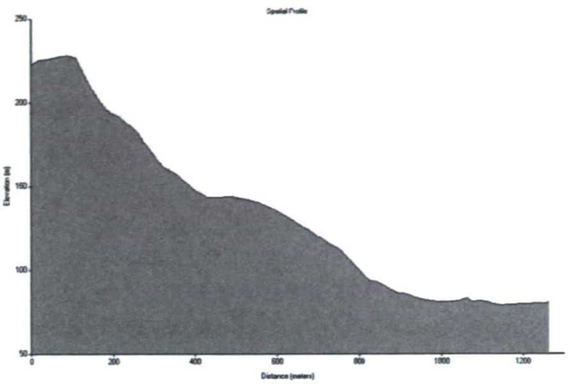


Fig. 6b Cross section of landslide marked on *Fig. 6a*

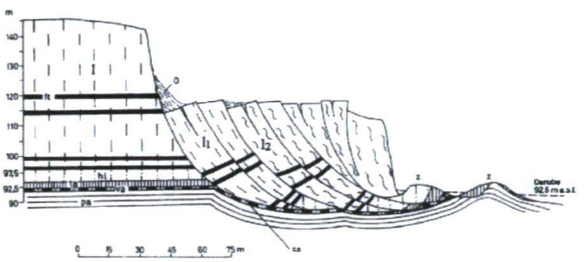


Fig. 6c The Dunaföldvár river-bank landslide to the S of the Danube's 1560 km mark (Pécsi M. et al. 1979)

l=loess sequence in primary position (autochtonous); l1=loess recently displaced by sliding; l2=waste of earlier slides; h1 pale pink sandy loess; o=talus; z=earth heap and Pannonian clay arising from the Danube's bed; fl=fossil soils; ta=dark grey clayey loam soil; pa=Pannonian clay; va=red clay, cs=sliding plane

SUMMARY

A DSM of the Fruška Gora was prepared using photogrammetric approaches and field GPS records. Corona stereo satellite images were not applied in Hungary before to create DSM. A raster type DSM image of 5 m grid size was created for the entire area, with an ESRI 3D shape file of ca. 450,000 points. Furthermore, to set the most optimal program values a raster type DSM of 2 m grid size was also generated for the north-east foothill area. The geometric resolution was adequate enough to visualize such geomorphological phenomena as land slides, erosion valley, etc.

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