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ANALYSIS OF URBAN SURFACES USING HIGH SPATIAL AND SPECTRAL RESOLUTION AERIAL IMAGERY

Theses of PhD Dissertation

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INTRODUCTION AND OBJECTIVES

Since the industrial revolution, the continuous process of urban migration at global level can be observed. Due to the urbanization processes, on the relatively small area of cities, a large population is found. This results in intensively used, dynamically changing environments. The structure of the built-up area and the determination of the current situation of the land use and the land cover provide principal information for urban planning and urban management, but also raise many data collection and data processing questions.

For the analysis of the mass and energy balance in the urban environment it is essential to understand the spectral and geometrical characteristics of the materials composing the surface. The developments in remote sensing data collection during the last decennia have resulted in large, but often requiring complex processing, data sets becoming available to researchers of urban ecology.

Recent research is concentrated – through the analysis of reflectance spectra of materials and high resolution based stereo-photogrammatrical and segmentation methods - on the identification of land cover types using a combination of datasets with spectral and spatial information.

My research objectives can be summarized by the following points:

1. Small Format Aerial Photography (SFAP) offers a cost-effective and operational data collection opportunity - with appropriate spatial, spectral and temporal resolution - compared to the traditional methods of aerial photography. This research was part of the **in-house development of an aerial data collection system** that was taking place at the Department of Physical Geography and Geoinformatics. Apart from the **presentation of the advantages and disadvantages of the system, the development and documentation of its image processing methods are my research aims**.

2. Simultaneously with the appearance of imaging spectrometry, researchers started to create spectral libraries. Until now, in Hungary, a detailed library of specific materials of urban land cover has not been created. **The objective of this research is to create an -** as complete as possible **- spectral library of man-made (urban) surfaces** (found in Hungary) **based on AISA Dual aerial imagery**.

3. In this research color infrared (CIR), true color (RGB), thermal infrared (TIR) and hyperspectral (AISA Dual) remote sensing imagery of varying spatial and spectral resolutions was used. **The research aim is to study such (data fusion based) processing and interpretation methods, which – by integrating various types of data, based on their favorable characteristics - can improve the accuracy of the classification of urban surfaces.** For the evaluation of the results various field and image reference data is available. **To map field reference data, a mobile GIS method will be developed**.

4. **For several selected study areas in the city of Szeged high resolution land cover maps with many categories will be created** using spectral and spatial (shape and height) information based classification methods. These will be **cross-checked** with the existing Urban Atlas and Corine Land Cover **databases**.

5. **The research objective is to perform spatial statistical analyses on the various built-up and utilized study areas in the city**. These are recognized based on other sources. The comparison will be performed using the most accurate classification results.

6. In the summer of 2008, thermal data was collected from the complete city. **The aim is to analyze the relationship between urban land cover and surface temperature** at selected areas in Szeged, and **to draw general conclusions** from the results.

7. The research objective is the **exploration of** already realized or **potential urban applications** of the, for this study, collected or used aerial imagery.

8. The **limitations and sources of problems** of the use of airborne remote sensing data with high spatial and spectral resolution in urban environments are reviewed and **suggestions for solutions** are provided.

RESULTS

The study areas of this research were selected based on their built-up characteristics. They also had to represent the particular land cover types occurring in Szeged, as well as the different types of built-up areas and surfaces that can be found in large cities in Hungary in general. In the area of Alsóváros mostly family houses with gardens and relatively narrow streets can be found. In the inner city, apart from high density built-up and tall buildings, wide streets are common. In the Tarján area, high rise apartment ("panel") buildings with large green areas surrounding them are characteristic.

1. In this study, aerial remote sensing data with various spectral and spatial resolutions were used. The imagery was partly collected by an **in-house developed data collection system** which development and operation was described in detail. **Three different types of cameras were successfully built into a 4-seat airplane. Flight planning, power problems, navigation, data storage and preprocessing challenges have been dealt with as well.** The coarse geometric correction of the color infrared (CIR) and thermal (TIR) imagery has been solved by post processing of the navigational data using custom ArcView and ArcGIS scripts. Mosaics of 50 cm CIR and 2.5 meter TIR images have been created from the complete area within the levees surrounding the inner city of Szeged. Using a Trimble data acquisition system with a spatial resolution of 10 cm, true color data was collected from the city (*Table 1.*).

Table 1. Main parameters of the data acquisitions
(A – worldTIFF, B – CSV, C – TIFF, D – IMG)

SENSOR	Acquisition date	Spatial resolution [cm]	Image size [px]	Image size [m]	Image size [MB]	Number of images [db]	Size of mosaic [MB]
DuncanTech MS3100 (CIR)	20.4.2008 25.6.2008	50	1392x1040	696x520	4,1[A]	335	~600[D]
Flir ThermaCam P65 (TIR)	12.8.2008 14.8.2008	250	320×240	800x600	0,36[B]	285	~18[D]
Trimble Aerial Camera (RGB)	30.3.2011	10	7216x5412	721x541	117[C]	317	~11600[D]

Due to its superior operability and flexibility compared to traditional aerial photography campaigns, small format data collection using small airplanes is become increasingly popular. Nevertheless, problems with the current processing methods, in particularly with accurate georeferencing and radiometric correction of the CIR images, should not be underestimated.

In case of the earlier preprocessed AISA Dual hyperspectral data – besides a theoretical description of the radiometric, geometric and atmospheric calibration the opportunities for optimization of the data set, like spatial and spectral dimension reduction were analyzed. On one hand, data reduction was performed by the selection of study areas, while on the other hand, 119 noisy bands were filtered out manually, as well as by applying PCA and MNF transformations.

2. Before the creation of the land cover maps, a **spectral library consisting of 22 elements was created based on the image information of the hyperspectral data set**. Different colored roof tiles (red, purple and gray), special roofs (schist, plastic, glass or metal) as well as roofs of high rise apartment buildings, irregular aged or colored

asphalt roads, concrete surfaces and decorative paving, and tree and grass vegetation were analyzed. By measuring the spectral angle differences, the **homogeneity** of the different elements (training data sets) **was analyzed**. By examination accurately (E.g. grass and trees) and inaccurately (E.g. roofs with gray tiles) determined classes were identified. The **separability between** the different land cover **categories was analysed** based on their spectral angle difference and the Jeffries-Matusita distance measured in the spectral space. This identified several problematic classes, like for example roof tiles of different colors (red, purple, gray) and asphalt, concrete and basalt paved areas (*Table 2.*). The creation of the spectral library was described in detail. After creating the library - every spectra that was used later in the classifications as reference - was compared to other sources and analyzed. In general, the particular characteristics of a material are clearly recognizable by its reflectance spectrum.

Table 2. Spectral separabilities between some elements of the spectral library calculated with spectral angle mapper (SAM) and Jeffries-Matusita Distance algorithm

2010	old red	purple	gray	new red	high ap. buildings	trees, shurbs	grass	asphalt	basalt paving	SAM
old red	1	0,708	0,701	0,935	0,677	0,142	0,17	0,64	0,519	old red
purple	1,454	1	0,564	0,715	0,53	0	0	0,397	0,258	purple
gray	1,971	1,764	1	0,681	0,89	0,013	0,046	0,756	0,623	gray
new red	1,677	1,592	1,985	1	0,655	0,122	0,149	0,624	0,5	new red
high ap. buildings	1,964	1,963	1,973	1,999	1	0,018	0,052	0,786	0,653	high ap. buildings
trees, shurbs	1,99	1,999	1,999	1,999	2	1	0,925	0,181	0,264	trees, shurbs
grass	1,999	1,999	2	2	2	1,99	1	0,22	0,304	grass
asphalt	1,99	1,946	1,712	1,997	1,8	1,999	2	1	0,845	asphalt
basalt paving	1,99	1,99	1,925	1,999	1,822	1,999	1,999	1,282	1	basalt paving
Jeff-Mat.	old red	purple	gray	new red	high ap. buildings	trees, shurbs	grass	asphalt	basalt paving	VIS-SWIR

3. One of the aims of the research is **the - separated and also integrated- evaluation of the spatial and spectral information content of data sets to use them in classifications**. Land cover mapping based on spectral information can just be successfully applied based on CIR and hyperspectral data. Automatic (ISODATA) and supervised classification (Minimum Distance, Maximum Likelihood and Spectral Angle Mapper) techniques were tested. Maximum 21 categories were identified using the latter ones. Based on the color infrared data, an overall accuracy of 70-80% was reached, depending on the study areas and classification method (*Table 3.*). In case of the hyperspectral data set, the maximum likelihood classification gave an overall accuracy of more than 85%. The automatic classification methods were mostly successful in the identification of vegetation. Most problematic are the spectrally similar road cover and roof cover classes which resulted in misclassifications. Using thresholds based on the height information, the classification could be improved significantly.

Table 3. Accuracy assessment of the supervised classification of CIR data in different study areas and for different land cover classes

CIR		*Tarján*		*Belváros*		*Alsóváros*
Maximum Likelihood	Prod.Acc.	Users Acc.	Prod.Acc.	Users Acc.	Prod.Acc.	Users Acc.
grass	90,98%	79,79%	95,97%	77,78%	93,12%	92,27%
tree	73,52%	87,36%	86,67%	97,79%	90,71%	91,71%
vegetation in shadow	94,58%	86,74%	100,00%	100,00%	99,44%	100,00%
bright vegetation	100,00%	100,00%	---	---	---	---
bright road	98,41%	97,38%	98,97%	77,27%	91,53%	38,30%
road	64,62%	39,75%	47,51%	53,57%	58,99%	69,54%
road in shadow	99,14%	92,74%	88,59%	87,27%	88,81%	92,25%
dark 'panel'	74,85%	84,56%	65,22%	64,52%	83,54%	65,02%
bright 'panel'	96,44%	84,72%	---	---	---	---
roof 1 (red)	91,26%	95,92%	96,34%	98,75%	96,03%	94,53%
roof 1b (bright red)	---	---	58,14%	100,00%	---	---
roof 1c (red in shadow)	---	---	87,25%	91,55%	100,00%	95,73%
roof 2 (gray)	---	---	54,65%	32,87%	53,95%	65,08%
roof 3 (metal sheet)	---	---	73,66%	90,42%	---	---
soil (sand)	---	---	---	---	---	---
Overall Accuracy		**81,02**		**80,36**		**77,76**
Kappa Coefficient		**0,7829**		**0,7840**		**0,7545**

* panel : high rise apartment building

The reliability of the classifications can be improved by incorporating the spatial information content of images. The segments and height information derived from stereo and high resolution imagery - using only three spectral bands and a proper criteria system - are suitable for the large scale urban land cover mapping. By increasing the dimensions of the feature space, the classification accuracy can be improved further (*Table 4.*). In this case, it is important to realize that the segmentation parameters and thresholds are derived empirically, and therefore need to be adapted appropriately when the method is applied in a different area.

Table 4. Accuracy assessment of the segment based classifications with different scale parameters and input data

Overall Accuracy *Kappa Coefficient*	*scale 50*	*scale 100*	*scale 200*	*scale 300*
RGB (1-3)	**0,61** **0,58**	**0,65** **0,62**	**0,69** **0,67**	**0,61** **0,58**
CIR (1-3)	**0,23** **0,18**	**0,18** **0,13**	**0,14** **0,08**	**0,12** **0,06**
MNF (1-8)	**0,67** **0,65**	**0,68** **0,66**	**0,69** **0,66**	**0,66** **0,63**
RGB (1-3) + DSM	**0,74** **0,72**	**0,72** **0,70**	**0,73** **0,71**	**0,76** **0,74**
RGB (1-3) + DSM + CIR (1-3)	**0,56** **0,53**	**0,56** **0,53**	**0,56** **0,53**	**0,59** **0,56**
RGB (1-3) + DSM + MNF (1-8)	**0,79** **0,78**	**0,79** **0,77**	**0,72** **0,70**	**0,73** **0,71**

Analysis of the main land cover classes show that the grass and tree classes are most accurately classified by the Maximum likelihood classification of the MNF transformed hyperspectral data set. High rise apartment building roofs and other special roof types (schist, metal, plastic) are better classified by the Maximum likelihood method based on PCA transformed data. The tiles with the different colors were most effectively identified using segmentation. To label the image objects, not only the 3 bands of the RGB images were required but the height information from the surface model and the MNF transformed AISA Dual data as well (*Table 5.*).

Table 5. Accuracy assessment of different classifications according to the main land cover categories and algorithms

Input data (method) [%]		RGB + hyper (MNF) + DSM (segment)		hyper (PCA / ML)		hyper (MNF / ML)		CIR (MD)		CIR (ML)	
		User's	*Producer's*	*User's*	*Producer's*	*User's*	*Producer's*	*User's*	*Producer's*	*User's*	*Producer's*
Vegetation		86,96	86,95	95,39	96,12	**98,91**	**97,69**	79,84	80,15	91,71	92,80
Roof	red tile	**96,06**	**92,51**	75,64	86,24	84,27	90,19	89,94	78,67	85,37	79,06
	colored*	*89,52*	*59,21*	68,41	60,27	*69,28*	*73,44*	32,54	26,23	48,98	54,30
	special**	100,00	76,06	**100,00**	**96,97**	93,33	85,71	94,20	63,41	90,42	73,66
	high app.build	65,52	100,00	**90,55**	**86,67**	76,41	83,42	64,41	55,00	60,59	64,21
Road	asphalt	70,08	62,07	**94,20**	**89,08**	90,10	87,86	64,27	71,39	72,01	81,84
	concrete	**75,89**	**100,00**	63,64	77,78	54,55	60,00				

* purple and gray tiles ** schist, metal, plastic roofs

For the evaluation of the classifications, **field reference maps and a data collection method**, based on Digiterra Explorer, **were developed**. Apart from the preprocessing phase in the office, the method controls the field work, while giving special attention to characteristic mapping errors (e.g. building displacement, cover).

4. The land cover of the various study areas was thoroughly analyzed during the testing of the different classification methods based on the resulting output maps. Any misclassifications were explained in detail. The proportion of the different land cover classes in the various study areas and their associated mapping problems can be exemplary for areas with similar structure. The classifications resulted in **detailed, large scale land cover maps with many classes of the selected areas**. These can serve as a basis for urban land use and built-up maps. The possibilities to extend the maps to the complete spatial extent of the city were limited due to the lack of data, the radiometric heterogeneity of the CIR images and limited computer processing power.

5. **The spatial distribution of the land cover and land use in the study areas was analyzed based on the CLC50 and the Urban Atlas data**. Due to its 1:50000 scale, the CLC50 only provides overall generalized information. The Urban Atlas has a more detailed resolution and shows more categories. The results of the Maximum Likelihood classification of the MNF transformed hyperspectral data was compared to the Urban Atlas database. It can be concluded that **the land cover maps created in this study**, with their better spatial resolution, differences in applied methodology, and partly different thematics, coincide well with the results of the large international mapping campaigns. For example, when the soil sealing ratio decreases, the building and road paving proportion also decreases and the vegetation ratio increases. Therefore, my land cover maps **are better applicable in local, small scale decision making processes**.

6. **Data from the thermal camera** was used to identify 4 different categories (soil-vegetation-building-pavement). **Only the spatial pattern of the street network**, which is much warmer than its surroundings, **could be properly delineated**. The buildings and vegetated surfaces could not be clearly separated. Apart from the general analysis of the thermal maps from two different dates, more specific analysis of the surface temperature and its influencing factors – mostly the land cover - were executed at 5 characteristic built-up areas.

7. Several **existing and future applications of the used data sources and their derived maps** were discussed. Besides a narrow view on the urban environment, also the larger urban surrounding and supporting rural region were taken into consideration. Current experience shows that the CIR images can be successfully applied in water management (E.g. Inland excess water mapping), while the airborne thermal data is suitable for e.g. urban climate research. The orthophoto maps with high spatial resolution improve the tools available to urban management and utilities. Hyperspectral imagery is mostly applied for the monitoring of green surfaces in the urban environment and not for the creation of detailed land cover maps as presented in this research.

8. During the creation and processing of the small format imagery and hyperspectral data, **many problems** and **challenges** have been encountered. These were in the first place related to the planning and execution of the SFAF data acquisitions, as well as to the geometric correction of the individual images. The problems have been **partly solved in this study**. The newly gained experiences can be used in the planning of new data acquisition campaigns to reduce problems. Clear weather conditions and high sun position should have a high priority when executing data collection flights to reduce the negative shadow effect. The disturbing effect of tree canopy covering the surface can be reduced with data acquisition outside vegetation periods. The topographic distortion and covering of lower objects by high buildings can be remediated by the data collection from multiple angles, although this requires more complex processing methods. Ground data collection at the same time or very close to the time of the remote sensing data acquisition is not only useful for atmospheric correction but can also

serve as ground truth during the accuracy assessment of classification results. An inertial navigation system (INS), although costly, would considerably improve the accuracy and speed of the georeferencing of the small format imagery. During the definition of the analyzed land cover categories, special attention should be given that the spectral separabilities between the classes are sufficiently large. Further analysis of the object based procedures may result in improved determination of the segmentation parameters, and may allow for the inclusion of more complex shapes and spatial connections into the classification, next to the spectral and height characteristics that have been used until now.

OWN PUBLICATIONS RELEVANT FOR THE THESES

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Geoinformatikai Tanszék, pp. 524-529. ISBN:978-963-306-175-6

FIRST AUTHOR STATEMENTS

The undersigned, ***Dr. László Henits*** as first (responsible) author of „Henits L., Tobak Z., Mucsi L., van Leeuwen B., Szatmári J. (2011): Nagy felbontású távérzékelt adatok alkalmazása a városi felszínborítás vizsgálatában - lehetőségek és problémák. In: Lóki J. (szerk.): *Az elmélet és a gyakorlat találkozása a térinformatikában II.*, Debrecen: Debreceni Egyetemi Kiadó, pp. 43-51." declares that the candidate's role in the part of the article describing data acquisition and data processing is of key importance, and that this part supports result 1 and 3 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. László Henits 2.10.2013

The undersigned, ***Dr. János Rakonczai*** as first (responsible) author of „Rakonczai J., Unger J., Mucsi L., Szatmári J., Tobak Z., van Boudewijn L., Gál T., Fiala K. (2009): A napfény városa naplemente után - Légi távérzékeléssel támogatott hősziget-térképezés Szegeden. *Földrajzi Közlemények* **133**:(4) pp. 367-383. 431-436." declares that the candidate's role in the part of the article describing TIR data acquisition, data processing and analysis of the relationship between land cover and land surface temperatures is of key importance, and that this part supports result 1 and 6 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. János Rakonczai 2.10.2013

The undersigned, ***Dr. József Szatmári*** as first (responsible) author of „Szatmári J., Szijj N., Mucsi L., Tobak Z., van Leeuwen B., Lévai C., Dolleschall J. (2011): A belvízelöntések térképezését és a belvízképződés modellezését megalapozó térbeli adatgyűjtés. In: Lóki J. (szerk.): *Az elmélet és a gyakorlat találkozása a térinformatikában II.*, Debrecen: Debreceni Egyetemi Kiadó, pp. 27-34 declares that the candidate's role in the part of the article describing data collection is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

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The undersigned, ***Dr. József Szatmári*** as first (responsible) author of „Szatmári J., Tobak Z., van Leeuwen B., Dolleschall J. (2011): A belvízelöntések térképezését megalapozó adatgyűjtés és a belvízképződés modellezése neurális hálózattal. *Földrajzi Közlemények* **135**:(4) pp. 351-364." declares that the candidate's role in the part of the article describing data acquisition and CIR data processing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. József Szatmári 2.10.2013

The undersigned, ***Dr. József Szatmári*** as first (responsible) author of „Szatmári J., van Leeuwen B., Tobak Z., Rakonczai J., Mucsi L., Unger J., Gál T., Fiala K., Németh Cs. (2010): Légi távérzékeléses módszerrel támogatott hőtérképezés Szegeden. In: Lóki J., Demeter G. (szerk.): *Az elmélet és a gyakorlat találkozása a térinformatikában*, Debrecen: Debreceni Egyetemi Kiadó, pp. 321-328." declares that the candidate's role in the part of the article describing data acquisition and TIR data processing is of key importance, and that this part supports result 1, 6 and 7 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. József Szatmári 2.10.2013

The undersigned, ***Dr. János Unger*** as first (responsible) author of „Unger J., Gál T., Rakonczai J., Mucsi L., Szatmári J., Tobak Z., van Leeuwen B., Fiala K. (2009): Air temperature versus surface temperature in urban environment. In: *The 7th International Conference on Urban Climate*, Yokohama, Japán, 2009.06.29-2009.07.03., Paper 375624-1-090514014110-003." declares that the candidate's role in the part of the article describing TIR data acquisition is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. János Unger 2.10.2013

The undersigned, ***Dr. János Unger*** as first (responsible) author of „Unger J., Gál T., Rakonczai J., Mucsi L., Szatmári J., Tobak Z., van Leeuwen B., Fiala K. (2010): Városi hősziget mező modellezése légi felszínhőmérsékleti mérések alapján. In: Putsay M. (szerk.): *Műholdmeteorológia*, **35**. Meteorológiai Tudományos napok, Budapest, 2009.11.19-2009.11.20., pp. 57-60." declares that the candidate's role in the part of the article describing TIR data acquisition and data preprocessing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. János Unger 2.10.2013

The undersigned, ***Dr. János Unger*** as first (responsible) author of „Unger J., Gál T., Rakonczai J., Mucsi L., Szatmári J., Tobak Z., van Leeuwen B., Fiala K. (2010): Modeling of the urban heat island pattern based on the relationship between surface and air temperatures. *Időjárás / Quarterly Journal of the Hungarian Meteorological Service* **114**, pp. 287-302. IF: 0.548" declares that the candidate's role in the part of the article describing TIR data acquisition and data preprocessing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. János Unger 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Mezősi G., Tobak Z., Szatmári J., Barta K. (2012): Identification of inland excess water floodings using an artificial neural network. *Carpathian Journal Of Earth And Environmental Sciences* **7**:(4) pp. 173-180. IF: 1.495 declares that the candidate's role in the part of the article describing CIR data collection is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Szatmári J., Tobak Z., Németh Cs., Hauberger G. (2009): Opportunities for the generation of high resolution digital elevation models based on small format aerial photography. In: *HunDEM 2009 - GeoInfo 2009*, Miskolc, pp. 100-108." declares that the candidate's role in the part of the article describing data acquisition and data processing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Tobak Z., Szatmári J. (2008): Development of an integrated ANN-GIS framework for inland excess water monitoring. *Journal of Environmental Geography* **I:**(3-4), *pp. 1-6* declares that the candidate's role in the part of the article describing CIR data collection is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Tobak Z., Szatmári J., Mucsi L., Fiala K., Mezősi G. (2009): Small format aerial photography: a cost effective approach for visible, near infrared and thermal digital imaging. In: Car A, Griesebner G, Strobl J (szerk.): *Geospatial crossroads*, Heidelberg: Herbert Wichmann Verlag, pp. 200-209." declares that the candidate's role in the part of the article describing data acquisition and data processing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Tobak Z., Szatmári J., Barta K. (2010): Új módszerek alkalmazása a belvizek keletkezésének vizsgálatában és monitorozásában. In: Lóki J., Demeter G. (szerk.): *Az elmélet és a gyakorlat találkozása a térinformatikában*, Debrecen: Debreceni Egyetemi Kiadó, pp. 121-130 declares that the candidate's role in the part of the article describing data acquisition and data processing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013

The undersigned, ***Dr. Boudewijn van Leeuwen*** as first (responsible) author of „van Leeuwen B., Tobak Z., Szatmári J. (2012): Belvíz osztályozás hagyományos módszerrel és mesterséges neurális hálóval. In: Nyári D. (szerk.): *Kockázat - Konfliktus - Kihívás: A VI. Magyar Földrajzi Konferencia, a MERIEXWA nyitókonferencia és a Geográfus Doktoranduszok Országos Konferenciájának Tanulmánykötete*, Szeged: SZTE TTK Természeti Földrajzi és Geoinformatikai Tanszék, pp. 524-529 declares that the candidate's role in the part of the article describing data acquisition and data processing is of key importance, and that this part supports result 1 of the thesis. Furthermore, I declare that I will make this statement about this part of the article only once.

…………………….. Dr. Boudewijn van Leeuwen 2.10.2013