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APPLICATION OF SELF-ORGANIZING NEURAL NETWORKS FOR THE DELINEATION OF EXCESS WATER AREAS

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Abstract

In recent times Artificial Neural Networks (ANNs) are more and more widely applied. The ANN is an information processing system consisting of numerous simple processing units (neurons) that are arranged in layers and have weighted connections to each other. In the present study the possible application of an unsupervised neural network model, the self-organizing map (SOM), for the delineation of excess water areas have been examined. By means of the self-organizing map high-dimensional data of large databases could be mapped to a low-dimensional data space. Within a data set, it is able to develop homogeneous clusters, thus it can be effectively applied for the classification of multispectral satellite images. The classification was carried out for an area of 88 km^2 to the south of Hódmezővásárhely situated in the south-eastern part of Hungary, which is frequently inundated by excess water. As input data, the intensity values of the pixels measured in six bands of a Landsat ETM image taken on 23rd April 2000 were used. To perform the classification, three different sized neural network models were created, which classified the pixels of the satellite image to 9, 12 and 16 clusters. By using the gained clusters three thematic maps were created, on which different types of excess water areas were delineated. During the validation of the results it was concluded that the applied neural network model is suitable for the delimitation of excess water areas and it could be an alternative to the traditional classification methods.

Keywords: Artificial Neural Networks (ANNs), excess water, multispectral classification

INTRODUCTION

In recent times Artificial Neural Networks (ANNs) are more and more widely applied. The ANN is an information processing system consisting of numerous simple processing units (neurons) that are arranged in layers and have weighted connections to each other. Their construction and operating principle are based on the biological neural networks, and their significant feature is adaptiveness, i.e. they solve the problems by learning from examples and not by means of programming. Since several types exist, the 'neural network' designation rather means a model range than a concrete process. Their field of application is quite varied; sample-association, classification, optimization and similarity identification. They are applied in various fields of science, also in geography. The significance of their application is based on the sharp increase in the amount of geographical data. In recent times several data collecting techniques are widely used e.g. the multi- and hyperspectral remote sensing, thus the resolution of the data rapidly increases both in geometric and attribute space. Neural networks could be a really effective alternative for the analysis of the high-dimensional data. Their application in the field of geography is discussed in more detail in the works of Agarwal P. et al. (2008) and Hewitson B. C. et al. (1994).

The aim of this study is to delineate excess water areas on the basis of satellite images by using a neural network. The study area is in the vicinity of the settlement Batida, situated on the left bank of the River Tisza, to the south of Hódmezővásárhely. The term of excess water was defined in a number of ways, and the main point was summarized by Rakonczai J. et al. (2001) as follows: 'Excess water is a kind of surplus water on the surface of a certain (drainage) area or in the pores of the arable land/near-surface formations, that inhibits the growth of vegetation and damages the man-made buildings.' Excess water is a yearly recurring problem which endangers 45% of the area of the country, 60% of the arable lands, more than 4 million hectares altogether. Therefore the exact delineation of these areas is highly important, for which the different remote sensing methods provide the most objective way (Rakonczai J. et al. 2001).

The delineation of excess water areas was carried out by the classification of medium spatial resolution multispectral satellite images. During the processing of multispectral satellite images, classification is a fundamental procedure, through which the pixels of the image are classified according to their spectral features, by mathematical methods. As a result a thematic map was created which makes it possible to visualize the information stored in satellite images in a more expressive way. The classification was performed via one type of the neural networks, the so-called self-organizing map that creates classes in the training samples by unsupervised learning. Several examples could be mentioned referring to the application of neural networks in multispectral classification. According to Awad M. (2010), the multispectral classification carried out by self-organizing maps is more precise than the Isodata classification. In the opinion of Aitkenhead M. J. et al. (2007) ANNs are a quick and accurate method for mapping land cover change. Pacifici F. et al. (2009) carried out urban land use classification on the basis of the sample analysis of high resolution satellite images, performed by neural networks. Barsi Á. (1997) could be mentioned from Hungary, who classified a Landsat TM image by one type of the neural networks. In his opinion, this method provides as accurate results as the traditional methods.

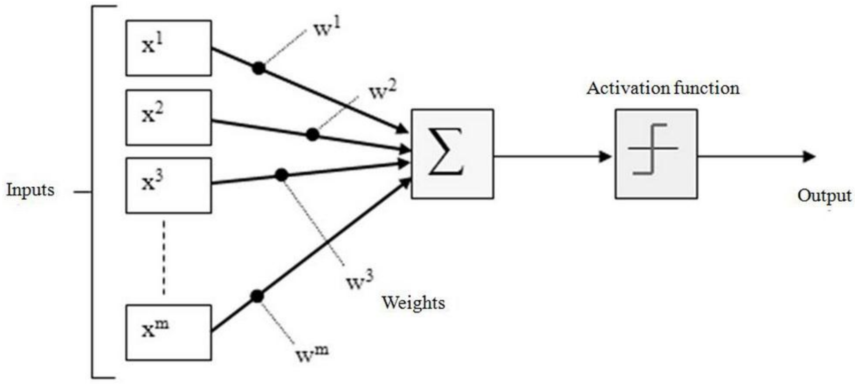

Fig. 1 Sketch of a neuron

ARTIFICIAL NEURAL NETWORKS (ANNS)

The structure of Artificial Neural Networks (ANNs) is similar to the human brain in that the storage of knowledge takes place in connected processing units (neurons). A processing unit converts the weighted sum of the incoming inputs by the help of an activation function. The most commonly used activation functions are the linear function, the sigmoid function and the step function. The result obtained is sent to other neurons through the outgoing connections of the neuron (*Fig. 1*).

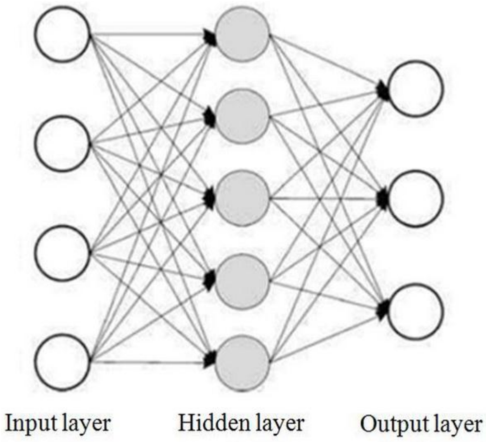

Fig. 2 Structure of an Artificial Neural Network (ANN)

The neurons are arranged into layers. Every net has an input layer for feeding input data and an output layer for visualization of the results. Between these layers a number of hidden layers could be found (*Fig. 2*). The learning of the net is realized by the modification of the weights between the neurons. Supervised and unsupervised learning methods could be distinguished. In case of supervised learning the training set includes both the input samples and the output samples. During an iteration process, the weights of the connections between the neurons undergo such changes that the appropriate result is added to the given input sample. In case of unsupervised learning only the set of input samples is known, while the output neurons compete for the input samples on the basis of certain similarity aspects. The weight vectors of winning neurons vary based on their added input value. By the help of such types of nets, regularities could be observed in the distribution of the sample data.

There are several types of ANNs, which could differ in certain elements from the general model. They have several advantages over the traditional methods, as their application does not depend on the statistical distribution of the input data, they are not sensitive to incomplete and disturbed samples and are able to process huge amount of data.

Self-organizing map

The self-organizing map (SOM, Kohonen Map) applied in this research was created by Kohonen (Kohonen T. 2001), and this is the most widespread ANN which carries out unsupervised learning. It classifies the n-dimensional input samples (n>2) by means of unsupervised learning, and adds them to the elements of a lower-dimensional output layer. The similar samples are associated with the neighbouring elements of the output layer, i.e. apart from the distribution of the samples in the input space, it also learns the topology between them. The self-organizing map performs data clustering and dimension reduction at the same time. Therefore it is suitable for the solution of different problems and it can be an alternative besides other methods e.g. the principle component analysis and the k-median clustering.

Self-organizing maps are made up of two layers, the input and output (or Kohonen) layers, that are connected with each other through all of their neurons (*Fig. 3*). Data is fed into the input layer, which has the same number of neurons as the number of input variables. Classification takes place in the Kohonen layer, the number of classes created during the learning process will be equal to the number of neurons located here. In this layer the neurons are located in a 1D, 2D or 3D topological position that enables connection between the neighbouring neurons. The 2D topology is the most widespread, in which the elements are arranged in square grid or hexagonal pattern. Each neuron has an n-element weight vector, where ‘n’ equals to the dimension of the input vector. The initial weight vectors of the neurons are usually determined by random numbers or, for the acceleration of the learning process, along the first two principle component vectors of the sample data.

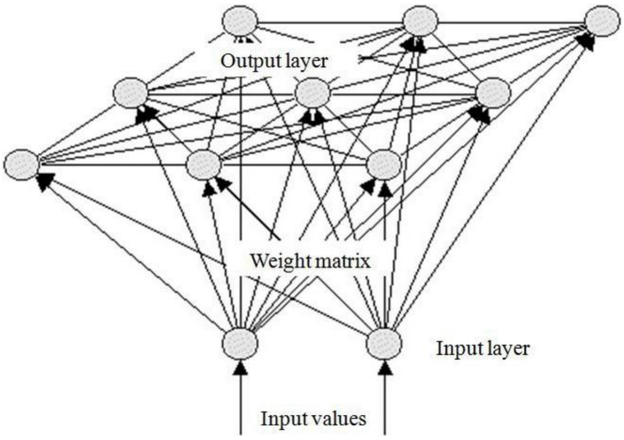

Fig. 3 Self-organizing map (Kohonen T. 2001)

The learning of the net takes place according to the Kohonen rule, on the basis of which the processing units learn competitively. The model searches for the weight vector of the most similar i.e. the winning neuron in each input sample. This is usually calculated on the basis of Euclidean distance. The model modifies and shifts the weight vector values of the winning neuron and those in its certain topological neighbourhood circle towards the value of the input sample. The degree of modification at *t* time is determined according to the Kohonen rule (Borgulya 1998):

$$\Delta W_j(t) = \eta(t)h_{cj}(t)(X(t)-W_j(t)),$$

where
- Wj is the weight vector of the j^{th} element
- η is the learning rate decreasing in time
- h_{cj} is the neighbourhood function, which decreases from the winning neuron ‘c’
- X is an input sample vector.

At the beginning of the learning process a larger learning rate and neighbourhood circle are used, which allow large-scale modifications providing the addition of the similar input samples to the neighbouring neurons. By the decreasing of the learning rate and the neighbourhood circle, the fine-tuning of the model is the next step towards the end of the learning process.

The learning algorithm of a self-organising map can be described as follows (Hewitson et al. 1994):

1. The initiation of the net by giving the geometry and the number of neurons.
2. Giving the initial weight vectors of the neurons.
3. Giving a sample case to the net.
4. Determination of the winning neuron connected to the sample.
5. Modification of the weight vectors of the winning neuron and the topologically neighbouring neurons based on the Kohonen rule.
6. Slight reduction of the learning rate and the neighbourhood circle.
7. Repetition of the last four steps until the convergence is reached.

The different types of visualization of the created model make the analysis of the results possible. If the distribution of the input sample in the data space is examined, the position of the neurons in the data space, their distance from each other or the component planes could be visualized. The component planes represent the strength of the neuron weights regarding each variable. Through the examination of the similarity of the component planes, the connections between the variables could be detected.

Self-organising maps can be used together with other visualization tools, thus in case of geographical applications they can be connected to geographical maps or integrated into geographical information systems.

STUDY AREA AND DATA USED

The 88 km^2 study area is situated in the vicinity of the settlement Batida, to the south of the town of Hódmezővásárhely, in the southern part of Tiszántúl (the region east of the River Tisza) in the Great Hungarian Plain. The area is covered by young alluvial deposits, on which vertisols and fluvisols were formed. Most of it is under agricultural cultivation. There are several abandoned river meanders and point bars in the study area. Classification was performed on the basis of medium resolution Landsat 7 ETM satellite images taken on 23rd April 2000. For the validation of the results color infrared aerial photographs of the Lower Tisza Valley region taken by the ARGOS Studio of VITUKI Plc. on 23rd March 2000 were used.

Numerous software exist for the training and visualization of self-organising maps, which were also included in some large software packages and in software made for this special demand (e.g. SOM_PAK developed by Kohonen). Their integration with geographical information systems has not really been widespread yet (Coleman A. M. 2008), but certain programmes offer such tools (e.g.

IDRISI). Matlab was chosen for our analysis, as it provides more complex analysing and visualizing methods. Matlab is a mathematical program system with a special programming language, developed for numeric calculations. It is applied in many fields and a large number of modules are available for the different applications. In our research the tools of the Neural Network Toolbox were applied, which can be used for the planning, simulation and visualization of different types of neural networks, among others the self-organising maps.

PROCESS OF ANALYSIS

Matlab offers many kinds of parameterization possibilities during the planning process of the self-organising map. The size of the net, the type of the topology and the neighbourhood function, the size of the neighbourhood circle and the number of the training iterations could be set. Three nets of different sizes were created for the classification, the output layers of which consisted of 3x3, 3x4 and 4x4 processing units arranged in a 2D hexagonal topology. The process of the analysis is going to be presented through the example of a net consisting of 4x4 neurons (*Fig. 4*).

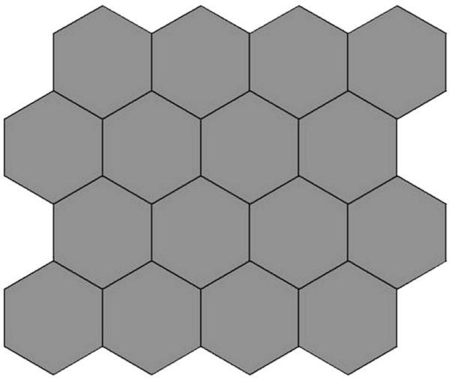

Fig. 4 Self-organising map consisting of 4x4 neurons

Intensity values measured on six bands (blue, green, red, near infrared and two medium infrared bands) of the pixels of the Landsat ETM satellite image were used as input data. The training process consisted of one thousand iterations, that is, the whole set of samples was fed one thousand times to each of the three nets. After training, the simulations of the models were run in case of each net. *Figure 5* demonstrates that how many input samples were added to the individual neurons, for instance how many pixels were sorted to each class in case of a net consisting of 4x4 neurons.

The further evaluation of the results was performed by ArcGIS software, and included the creation of thematic maps by merging the clusters according to the appropriate theme, and the creation of the required legend.

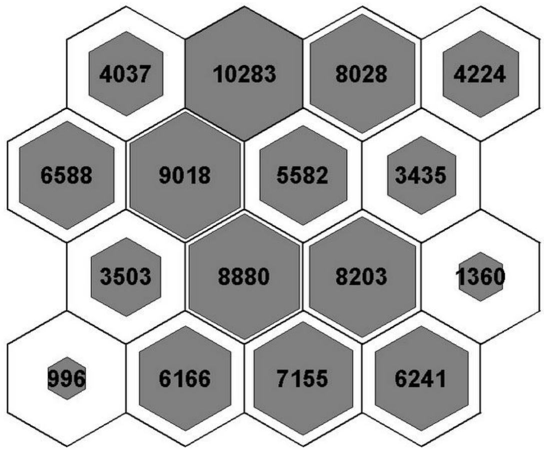

Fig. 5 Number of inputs added to the individual neurons

RESULTS

For the delineation of inland water areas it was practical to merge the clusters into a small number of classes, because the individual clusters could have been specified only by the help of an exact field work. Analysing the composite planes, it could be determined to which neurons were the pixels having different reflectance features added. On the basis of this the following 5 classes could be separated: open water surface, dry soil, water saturated soil, vegetation and vegetation in water. *Figure 6* shows that pixels with the same reflectance values were projected to the neighbouring neurons, as a characteristic of the self-organising map. The classes created were represented in a thematic map as well (*Fig. 7*).

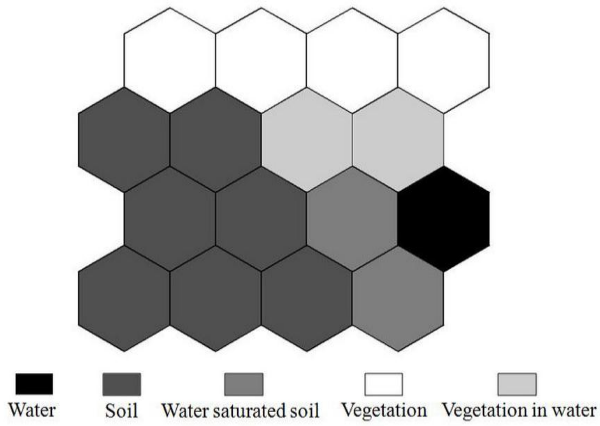

Fig. 6 Position of the classes of excess water mapping

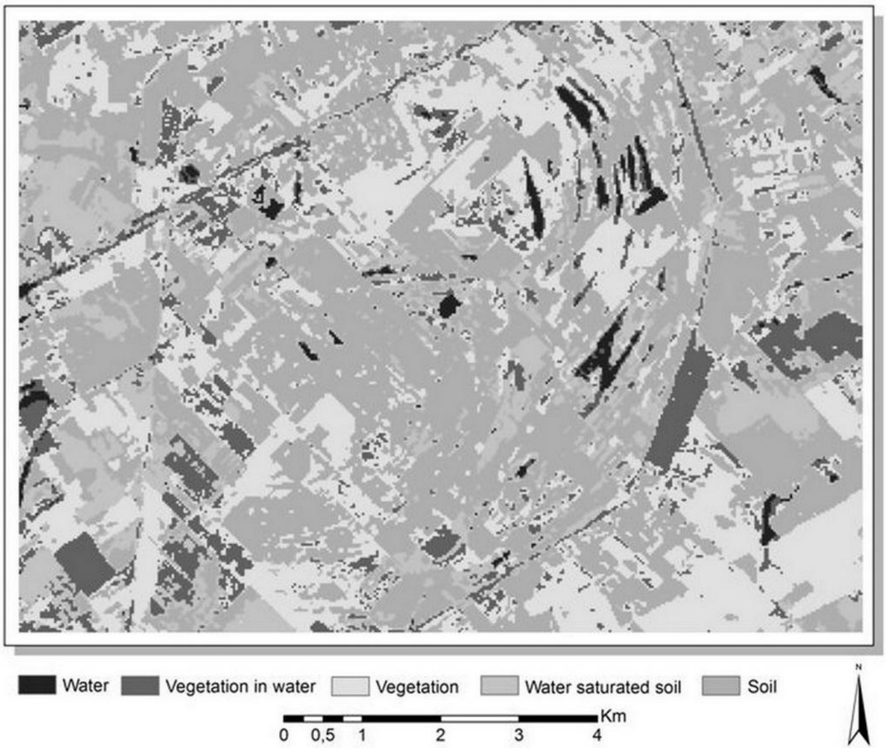

Fig. 7 Classification of the settlement Batida and its surroundings

Table 1 Differences in the extension of the classes for the three models

	3x3	**3x4**	**4x4**
Open water surfaces	2.03%	1.74%	1.45%
Water saturated soil	13%	19.65%	15.41%
Vegetation in water	12%	10.2%	9.62%
Dry soil	49.3%	41.48%	45.15%
Vegetation	23.65%	26.93%	28.35%

On the thematic map, created on the basis of the results of the three neural networks, open water surfaces and even those, which are not entirely covered with water are well separable. *Table 1* shows how large the differences were in the extensions of the different land cover types.

It was not possible to quantify the accuracy of the results owing to the lack of appropriate field survey data. However, excess water areas of great extension could be delineated in all the three cases by comparing the thematic maps with aerial photographs (*Fig. 8*). It is the delineation of transitional classes where there are more considerable differences as it is difficult to determine how high moisture content indicates another class. In our opinion, the application of more neurons makes it possible to determine this boundary more precisely.

CONCLUSIONS

As a result of this present research, it could be concluded that the type of neural network applied is suitable for the thematic classification of satellite images. By the help of this method excess water areas have been successfully delimited in the study area. For the examination of the effectiveness of this method, it will be required to compare the results with those gained from traditional classification methods. In the application of self-organising maps, the possibility of their extension is a great asset, since this way they can simultaneously manage data from different sources. Thus, besides the spectral information of the satellite images, other data could also be used for the classification, for instance elevation models and other thematic layers, e.g. soil and geomorphological

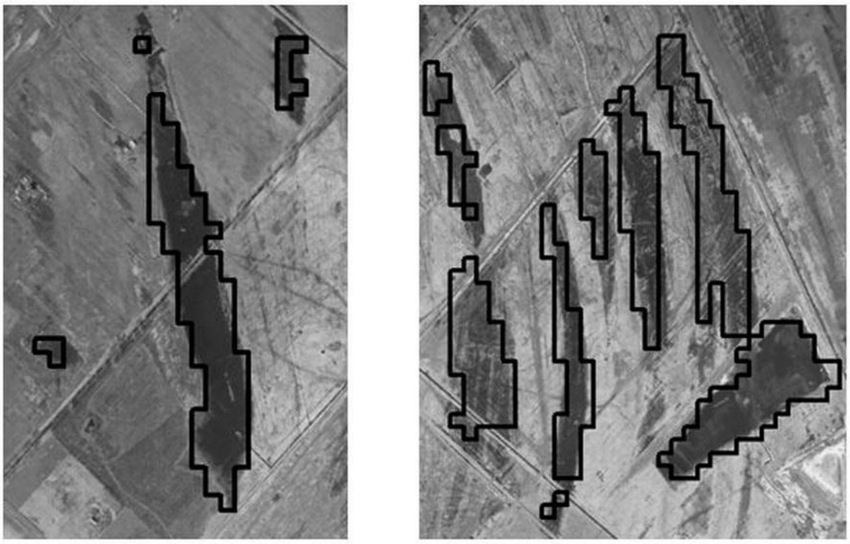

Fig. 8 Comparison of the delimited excess water areas with aerial photographs

maps. The shape recognition function of the self-organising maps could make it possible to identify frequently inundated landforms, for example abandoned river meanders and point bars.

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SMALL FORMAT AERIAL PHOTOGRAPHY – REMOTE SENSING DATA ACQUISITION FOR ENVIRONMENTAL ANALYSIS

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Abstract

Since February 2008, an advanced system has been developed to acquire digital images in the visible to near infrared wavelengths. Using this system, it is possible to acquire data for a large variety of applications. The core of the system consists of a Duncantech MS3100 CIR (Color-InfraRed) multispectral camera. The main advantages of the system are its affordability and flexibility; within an hour the system can be deployed against very competitive costs. In several steps, using ArcGIS, Python and Avenue scripts, the raw data is semi-automatically processed into geo-referenced mosaics. This paper presents the parts of the system, the image processing workflow and several potential applications of the images.

Keywords: small format aerial photography, data acquisition system, image processing, Python

INTRODUCTION

Acquiring aerial photographs and their digital analysis are traditionally long and expensive processes (Warner W. S. et al. 1996). As digital cameras, computers and GPS receivers became available at lower price ranges, the amount of time and cost needed for the acquisition process and the analysis is gradually reduced, which highly increases the operativity of the system (Licskó B. – Ditzendy A. 2003, Bakó G. 2010). Earlier the colour infrared small format digital cameras were mainly used for surface measurements (Warner W.S. et al. 1996). The near infrared spectrum is mainly used in vegetation monitoring but it also promotes the identification of the areas covered with water (Rakonczai J. et al. 2003, Tucker D. et al. 2005).

THE ADVANTAGE OF USING SMALL FORMAT AERIAL PHOTOGRAPHY

The development of a small format aerial photography system that is able to take colour infrared (CIR) aerial photographs was started at the spring of 2008 by the Department of Physical Geography and Geoinfomatics at the University of Szeged. Out of the numerous advantages of the system, its cost efficiency and its operativity can be highlighted. Beyond the price of the digital camera, that was a single investment of the department, only the costs of the flights and the wages of the human resources participating in the processing have to be paid. The fact that the system is easy to operate becomes particularly important in projects that investigate quickly changing phenomena (Bakó G. 2010).

Inland excess water, as a temporal water surface – depending on the weather conditions – can evolve rather quickly, but its extension can diminish relatively fast as well. To discover a mapping methodology for excess water and to be able to model its development, it is inevitable to know the actual extent of the area covered with water (Licskó B. – Ditzendy A. 2003). The country-wide aerial photography campaigns carried out every 5 years provide photographs with inappropriate time resolution. By using our small format aerial photography system, photographs can be taken at any time at any frequency, which provides basic data for further analyses.

Not only the time resolution, but the spatial and spectral resolution of the photographs adjusts better to the needs of the research. The size of the smallest object (pixel) on the surface that can be mapped falls within the sub-meter interval and it can be altered depending on the altitude of the flight. This harmonizes well with the size range of the examined excess water coverage. In comparison: while the satellite images provide only 4, 10 or 30-meter resolution data, the country-wide aerial photography data provides 1-meter resolution.

Our camera is able to record in 3 spectral bands of the electromagnetic spectrum: in the visible green (G), the red (R) and the near infrared (NIR) bands. Out of these, the near infrared band is of particular importance, as in this band the water surfaces nearly completely absorb the incoming radiation and thus they appear as dark, black territories, which are easy to detect both visually and also by using image-processing techniques. By using the red (R) and near infrared (NIR) spectra together, the vegetation can be differentiated. On the other hand, the traditional aerial photographs – provided by the country-wide aerial photography, for example – cover only the spectrum of visible light and thus they provide much less spectral information regarding the excess water areas.

INTRODUCING THE RECORDING SYSTEM

A Duncantech MS 100 CIR (colour infrared) digital multispectral camera forms the basis of the acquisition system. Additional components are an attached data storage computer – equipped with a framegrabber card –

Fig. 1 Hardware elements of the recording system (left)
and the Cessna 127 airplane with the CIR camera fixed into its luggage space (right)

and GPS receivers (Mobile Mapper CE and Garmin GPSMAP 296) that help the navigation and also record the flight path (*Fig. 1*).

The Duncantech MS3100 digital multispectral camera contains 3 single CCD sensors (*Fig. 2*). The sensors detect the photons of the red (R), green (G) and near infrared (NearIR) spectra separately, depending on the prism (which splits the light) in front of the sensors (*Table 1*). The 3 sensors can be programmed separately, which means that not only their gain but also the applied integrating time can be adjusted to the needs of the users. This way it is possible to strengthen the IR spectrum – which is used to take photographs of vegetation and water surfaces – taking advantage of their special NIR reflectance.

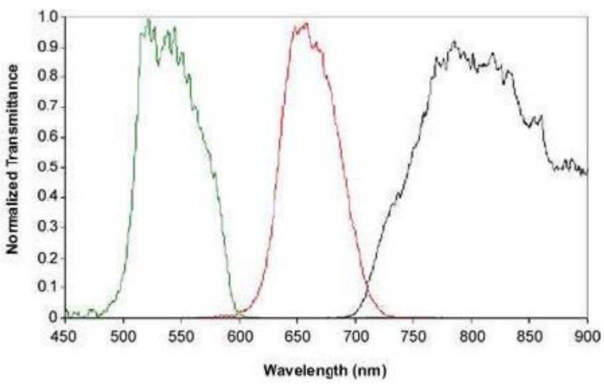

Fig. 2 Sensitivity of the green, red and near-infrared sensors

The sensors are built up of 1392x1040 pixels, the physical size of each is 4.65x4.65 micron. The radiometric resolution of the detectors is 10 bit therefore they are able to differentiate maximally between 2^{10}, i.e. 1024 intensity values. This way relatively low reflectance differences between recorded object can be identified. The ground resolution of the data always depends on the optics and flight height. Using the high-speed Tokina AT-X 17 AF Pro objective at a flight altitude of 2000 m the spatial resolution is 62 cm.

Table 1 Recording spectrum of the CIR camera

	CIR configuration (nm)		
Band	*Range*	*Center*	*Width*
Blue	-	-	-
Green	**530 – 570**	**550**	**40**
Red	**640 – 680**	**660**	**40**
NIR	**768 – 832**	**800**	**65**

A mini computer with a National Instruments IMAQ 1428 type framegrabber PCI card was used to store the photographs. The transportation of the data from the camera to the framegrabber is done through Camera Link connection, in three channels, each of which transports 10 bit data to the framegrabber. The further settings of the data recording – the frequency of exposure, the name and the place of the saved photos, the integration time and the sensitivity of the sensors – happens at the time of acquisition with the DT Control software supplied with the camera.

During the acquisition, navigation was carried out by a Garmin GPSMAP 296 aviation GPS device following the planned flight. The actual flight path was recorded with a Thales Mobil Mapper CE type GPS receiver. While the Digiterra Explorer mobile GIS software running on the Windows CE based device helps the navigation, the GPS Status application of the Thales records the GPS data in NMEA format. Subsequent processing of the GPS data provides one meter accuracy flight track.

To carry out the flight a Cesna 172 type airplane was used, which is the property of the partner company. In the four-seater airplane the person sitting next to the pilot directs the navigation and operates the camera. While the camera is in a construction fixed to the side of the plane, the data recording and energy supplier components – the batteries and the inverter – are in the luggage space of the plane.

The hardware elements of the system presented above cost nearly 13,000 Euro. The cost of operation is about 250 Euro for an hour long flight, which of course changes depending on the distance of the destination and the shape of the acquisition area. As our point of departure is the Szeged Airport, our primary destination is the southern part of the Great Hungarian Plain. Nevertheless the flexibility of our system allows its installation into any airplane that has got a door on its luggage space.

FLIGHT PLAN

While preparing the flight plan, it has to be decided in which way to cover the area to be recorded. Not only the planned flight paths have to be recorded, but also the necessary time intervals between the exposures. To do this not only the speed of the flight and the size of the area covered by a single photo – in case of a fixed objective, the latter depends only on the altitude of the flight – has to be known, but also the distance between the photos (b) and the distance between the rows of photos (d) have to be defined. To facilitate later processing, the photos have to overlap each other by a minimum of 50% in the flight direction by 20-30% on adjacent flightpaths. Taking these requirements into consideration, on a flight altitude of 2000 m, at the speed of 150 km/h the frequency of exposure is 1 photo/ 4 seconds and the distance of the neighbouring paths – in case the camera is fixed perpendicular to the flight direction – is 600 meters (*Fig. 3*).

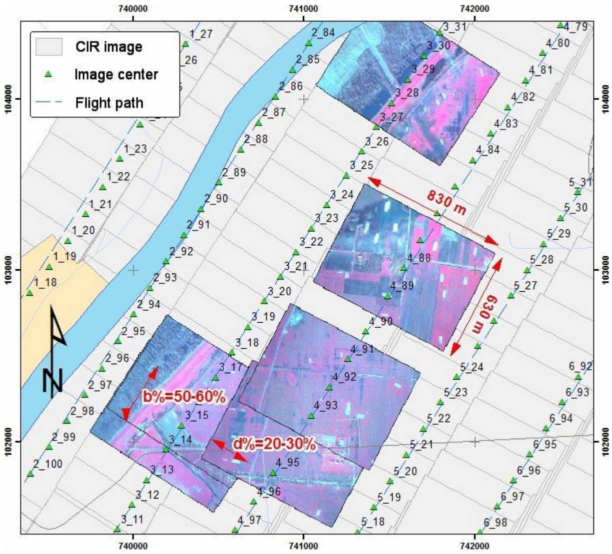

Fig. 3 A part of the recorded area with the planned and the actual flight paths, some sample images and characteristic parameters

Our inland excess water project had 3 sample areas (*Fig. 4*), the total extension of which was 69.7 km^2. Out of these sample areas area I (Tápairét) and area II (Batida) was recorded two times during the excess water period of spring 2010: on 24th March 2010 and on 9th June 2010. The recording was carried out based on the same flight path on both occasions. The 10 lines of flight, the nearly 100 CIR images captured at each line, resulted in 1804 (895+909) images by the end of the second day.

Acquisitions have already been carried out for previous projects of the department and for external partners as well. In the course of these projects approximately an area of 1000 km^2 was recorded (Tobak Z. et al. 2008, Kitka G. et al. 2010). For urban ecology research high spatial resolution – 50 cm pixel size – colour infrared (CIR) data has been acquired for the total area of Szeged (van Leeuwen B. et al. 2009).

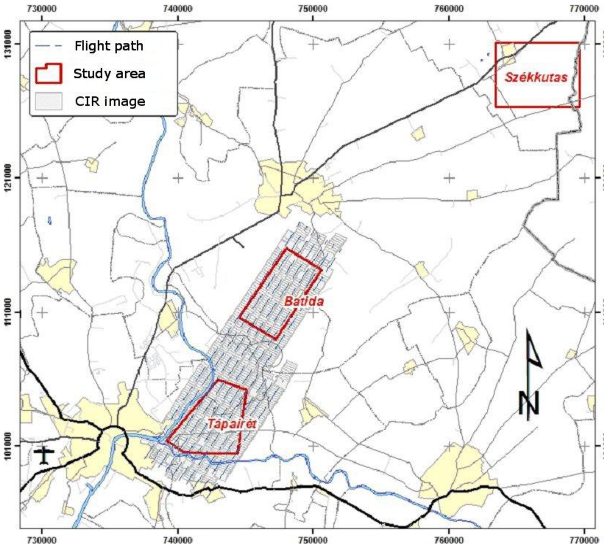

Fig. 4 Study areas covered with excess water and their surroundings with flightlines and the footprints of the images

IMAGE PROCESSING

During the preparation of the aerial photography, the flight and the processing of the raw data, different types of software had to be used. All through the work these software were customized to our needs and therefore the processing of the numerous photos could be made more automatic.

During the preparation of the flight plan, the flight altitude was determined on the basis of the size and the shape of the area under survey and the desired resolution. Having known the image sizes calculated from the altitude of the flight, the flight paths were determined. It is practical to orientate the lines in north-south or east-west directions, although it is possible to rotate the images in any directions at any angles by the processing software. The planned lines were loaded in Digiterra Explorer in shape file format based on the Hungarian national projection (EOV).

The image exposure can be controlled and its parameters can be set in real time during the flight. The data logger and the control software of the camera allow the modification of Gain and the Integration Time. This makes the adaptation to the different light conditions possible. New series of images were created for each line of flight for which separate log files, containing the parameters of the camera and the exact time of exposure, were generated by the program. The images were recorded in three-band TIFF files with 8-bit colour depth per band.

In the first step of processing the x, y and z coordinates and the time data of the flight were extracted from the NMEA file recorded every second by the GPS. Then based on these records a dBASE table was generated. The time field of the table is joined (Table Join) with the log file of the camera thus the records of the table are joined with the images. With this operation real EOV coordinates (x, y) were assigned to the central point of each image. In the next step these coordinates – and the spatial resolution – were used for the generation of the so-called world files.

World files are simple ASCII text formats, with which geographical coordinates can be assigned to JPEG and TIFF files. In this way, using the coordinates recorded by the GPS, geo-referenced images can be made from our images quickly and automatically. Only in case of image rotation angles of 0 or 180 degrees is the application of the world files an effective method, therefore the flight directions were chosen in a way to make this possible. The generation of the .tfw world files connected to the TIFFs requiring a rotation angle of 0 or 180 degrees was carried out with Avenue script in ArcView 3.2 software. In case of a different rotation angle the ArcGIS Rotate tool was also used in a Python script besides the world files. By means of the world files, a rough geometric correction was attained, the accuracy of which was better than 150-200 m, depending on the circumstances of the flight. In the next step the aim was to create an orthophoto mosaic of the whole studied area by the assembling and geo-correction of the single images. During the preparation of this process the TIFF with world file was converted to IMG format by another Python script. In the ERDAS Imagine image-processing software tie points between the images of the block (image series) were automatically generated, and after their filtering the block was transformed to EOV. A single, coherent image file was made from the individual images by mosaicing.

Fig. 5 summarizes the image processing workflow and demonstrates the data and operations used, the applied GIS and image processing technologies, and different types of software.

APPLICATION OF PROCESSED IMAGES

The geometrically corrected CIR images can be used in a wide range of studies. The common characteristic of these studies is that they require high spatial and temporal resolution and visible as well as near infrared spectral information.

All of the above-mentioned requirements are of major importance during the exact delineation of the areas covered with inland excess water. In the classification procedure based on the artificial neural network (ANN) under development in our department these images are the most important input data besides a high resolution

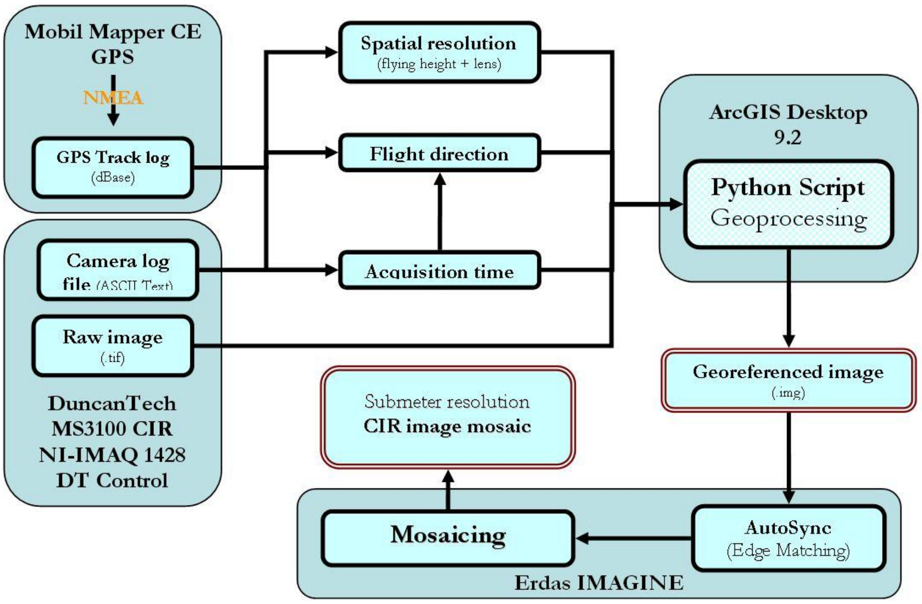

Fig. 5 Flow diagram of image processing from the raw images to the image mosaic

digital elevation model. The images supplied by the three bands are used as separate input layers both in the training and the simulation phases.

Besides the above-mentioned, ANN-based, method visual information can also be interpreted by the conventional image analyzing methods. During the mapping of sources of pollution harmful to the environment – for example, illegal landfills, water reservoirs etc. – high spatial resolution and operativity are key issues (Mucsi L. et al. 2004, Szatmári J. et al. 2008). A GIS database can be created from the different type of contaminating objects identified on the basis of the images (Warner W. S. 1994, Tobak Z. et al. 2008, Kitka G. et al. 2010).

The red and near infrared bands of the sensor are well applicable for the monitoring of vegetation. These ranges of the electromagnetic spectrum are used for most of the vegetation indices. The estimation of the amount of biomass and chlorophyll, the separation of different forest types and the assessment of vegetation health are research topics for which good quality data can be provided (Ladányi Zs. et al. 2011).

The monitoring of vegetation can be carried out in the urban environment as well. The remote sensing analysis of the complex and heterogeneous urban surfaces, with adequate spatial accuracy, can only be carried out if the geometric resolution is high. However, the spectral information content of the colour infrared images is narrow compared to the hyperspectral data. By their combination and by the development of multi-level classification methods, the advantages of both can be exploited.

FUTURE OPPORTUNITIES, CHALLENGES

Our system – in its present state – is not suitable to completely replace the traditional methods of aerial photography. It does not contain inertial or other spatial reference system therefore there is no possibility to eliminate errors arising from the irregular movements of the airplane. Positional errors depending on the weather conditions can partially be corrected by automatic switching point measurement.

Conversion of the energy values measured by the sensor (DN) to surface reflectance values would need further developments. Field reference samples should be used for this during acquisition. The differences between the histograms of the images can be corrected by histogram matching.

Both hardware and software developments are needed in the future. For greater spatial coverage and thus more cost-effective recording, the replacement of the small-format camera (1392x1040 pixels) to a medium-format one (7220x5410 pixels) is among our plans. The expansion of the GPS measurements with an inertial measurement unit (IMU) is planned for faster and more accurate geometric correction. The self-made programs carrying out automatic processing also need further development by which the time elapsed between the image exposure and the production of processed – and even analyzed – images can be reduced.

During the developments the targets set at the creation of the system are kept in mind. Although the value of the entire system increases due to financial investments, the costs of operation and processing are kept on a cost-effective level. In addition, operativity, which is the main advantage of the system, remains and is further improved.

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