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PHD THESIS ABSTRACT

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Researches Regarding Digital Image Processing for Structural Information Extraction and 3D Models Generation

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1 Introduction

The thesis focuses to identify the steps necessary to extract digital elevation models from physical scanned maps and it aims to offer at least one solution for each of the steps.

A digital elevation model (shortly, DEM) is a bidimensional array of values that shows the spatial distribution of altitude samples corresponding to terrain area. A DEM is useful to create digital 3D representations. Without a graphical display a DEM is a format less intuitive for a human user, but very clear for a computer. A DEM is a digital format for the shape of a terrain area and it represents a starting point for automatizing many types of analysis regarding Earth's (but not only) surface, e.g. urban (rural) planning, GIS systems, management of water supplies, GPS, etc.

The most accurate way to obtain a digital elevation model is based on synthetic aperture radar and interferometry, but this is complex and expensive solution. Interpolating the altitude values obtained from a scanned map is an alternative approach to acquire a DEM in situations such as follows: the DEM is not publicly available or the DEM is too expensive for a specific application and it is enough to have only an approximation of the relief for a given area.

2 Survey of the domain

This section presents a survey of approaches related to information (not only altitude data) extraction from scanned maps.

A recent work in the field is the PhD thesis published in 2004 at University of Joensuu by Pavel Kopylov [16]. It focuses on the processing of the scanned maps aiming to reduce the size at storage. Kopylov developed a method of compression that is based on decomposing the images in levels of information using the color and the semantic separation. The proposed approach produces a storage format for the mobile devices that decomposes the maps in hierarchic levels.

J. Childs (2003) [4] concentrates on interpolating the altitude contours extracted from a printed map. He proposes a method of approximation based on Franklin's algorithm [10] - which is a solver for overdetermined Laplace systems.

Gousie et al. (1998) [11] follows the problem of converting contours, from a state that represents incomplete altitude information to a state that shows complete altitude information.

Stephen Wise (between 1995-1999) [29] [30] develops and implements (initially in FORTRAN) an algorithm to remove unwanted information from a scanned map containing data about types of soil. The method is efficient only for well defined color blocks, obtained with a specific scanning method (i.e. Spot Color Scanning).

Kaiyan Feng (2001) [9] continues the work of S. Wise, both of them graduated the same university (University of Sheffield). He introduces two new methods to remove unwanted information from a scanned map image. He develops and implements a sliding window algorithm that considers the texture from the analysing window and assumes that unwanted information has a specific texture.

Pierre Soille (between 1992-2003) [25] [24] focuses on applications of mathematical morphology in the field of physical geography. The study considers digital elevation models and it presents methods of producing spatial distributions from contours, but also approaches to automatically extract drainage networks.

Patrice Arrighi [1] continues the work of P. Soille and he presents in 1999 a paper that shows a method to extract the topographical contours from a scanned map using the color information and different filtering techniques. The solution uses morphological filtering and geodesic interpolation. This paper is often cited in the field that current thesis is also aiming to produce results.

H. Lahdesmaki [17] in his master thesis published in 2001 at Tampere University of Technology develops methods for post processing the data extracted from a scanned topographical map with the purpose of increase the readability of inscriptions.

It is important to consider also the aliasing and the false colors that result after scanning process. For compensate them, Khotanzad et al. [14] proposes an approach of extracting the topographical contours using a set of key colors. The paper suggests to consider five sample images for each two colors combination and the method is based on histograms and Eigen values.

Hedley et al. (1992) [12] combines the spatial information with color information to eliminate the scanning effects. The proposed approach is based on gradient.

Spinello et al. (2003) [26] develops an algorithm of quantization in HSV color space for scanned maps. Delaunay technique of triangulation is adopted to approximate the surface described by the topographical contours.

3 Hidden Markov models applied on scanned maps

The thesis focus is to find steps necessary for extracting a digital elevation model from a color-coded relief map and to offer a solution for each of the steps.

As an initial approach, more steps are identified as follows: preprocessing for halftoning removal, linework removal, color clustering process, gap filling, elevation contours extraction, color-coded contours conversion into a sparse elevation dataset and interpolation of the sparse DEM. A digital elevation model (DEM) is a bidimensional array of values representing the spatial distribution of the altitude data corresponding to a terrain area that allows the generation of 3D renderings for different earth surface areas. Halftoning is a technique used in color printing to simulate colors based on few basic colors. The term linework denotes the unwanted information within the scanned map that consists in thin and sharp edges.

A WHMM (Wavelet Domain Hidden Markov Model) is a probabilistic model for the wavelet coefficients of a signal. For this work, the signal is an image. The WHMM consists in 4 parameters: mu – mean matrix, si – variances matrix, ps – probability mass functions matrix, es – state transition probability quadrants matrix. Two state variables were considered: S (small variance), and L (large variance). In this thesis it was assumed that the wavelet coefficients have similar statistical features within the same scale. The training step yields the model and the likelihood computation step generates the pdfs (probability density functions) matrix. The main drawback of a WHMM based approach is the computation time.

The main purpose of the preprocessing is the removal of halftoning effect, widely used in printing for color-coded relief maps. The proposed method is based on WHMM noise removal algorithm. The model, the pdfs matrix and the wavelet coefficients (within the finest scale) are used for a 2D Wiener type filtering. Color distortions may appear due to the fact that RGB components are processed separately. If the color clustering algorithm (that comes into a later step) is insensitive to these distortions the final result is not affected.

The linework removal step eliminates the unwanted GIS layers from the color-coded relief map leaving only the altitude data. Two approaches were proposed for the linework removal. The first one is based on the WHMM and is applied on an intensity plane of the image obtained by taking a simple average of the RGB components. It works at 2×2 pixels blocks level, and not at pixel level. This can be o drawback for identifying very fine edges. The second approach considered for linework removal is based on vector gradient edge detector. The method combines two edge detectors: the Euclidean distance, a metric efficient in the intensity domain and the vector angle, a metric efficient in the hue domain. Undetected isolated linework pixels may appear after this step. In order to improve the results a morphological majority type operation is applied after edge detection.

The color clustering process generates distinct solid colored blocks for each distinct elevation area that appears in the map. Before clustering, the image is vector median filtered and manual edited (e.g. larger lakes cannot be fully eliminated by the linework removal algorithm) in order to reduce distortion. The clustering method chosen is the minimum variance quantization algorithm. It needs as an input argument the number of different elevation region within the image plus one (the white linework pixels). Due to incompletely removal of the dithered effect, some isolated wrong classified pixels may appear (need manual editing).

The gaps left after linework removal are filled using a multi-pass majority filter, applied on the color-clustered image to reclassify the white pixels on the basis of their surrounding pixels. The linework pixel located in the center of the analyzing window is replaced by the most abundant, non-linework, colored pixel value from the surrounding 3×3 window. Large areas of white pixels need multiple passes of the algorithm. For a good enough result a manual editing is needed, too.

The elevation contours are extracted through a sliding-neighborhood operation. Considering a 3×3 processing window, if at least one horizontal or vertical neighbor is different than central pixel, the color for the central element is preserved, otherwise the new color is white (not a border pixel).

The color-coded contours are converted into elevation (a sparse DEM). First, the colors are indexed in elevation ascending order as in the map's legend. Then, a 3×3 sliding window is applied. If the central element is white it yields a zero in the output matrix. Otherwise, if the color index has neighbors with less index value, it produces the lowest elevation value denoted by the color; else it gives the highest elevation value denoted by the color.

The purpose of the interpolation step is to convert the sparse data set into a full DEM. The proposed approach solves the system of equations $A \cdot z = b$ by using an iterative algorithm, the LSQR algorithm. The system of equations is formulated as follows:

- Considering that the sparse elevation data set is a $N \times N$ matrix, pretend that all the $N^2 = M$ points have unknown elevations $z_{i,j}$.
- Create an equation for each $z_{i,j}$ setting it to the average of its neighbors as in the equation:

$$z_{i,j-1} + z_{i,j+1} + z_{i+1,j} + z_{i-1,j} - 4 \cdot z_{i,j} = 0$$

- For each of the k points whose elevation e_i are known create an additional equation $z_i = e_i$.

Some steps of the method (e.g. WHMM based algorithms) are computational expensive. The process is not fully automated. But the approach can be a good help for the map digitizing domain when used with manual editing. Improvements are needed in order to reduce (or completely eliminate) the manual editing and increase the efficiency of some steps of the approach. All the above methods are implemented using Matlab. Speed improvements are made by implementing some computational expensive steps in C under Matlab.

4 Kriging interpolation and CIE L*u*v* color space

As mentioned in the previous section, the objective of the thesis is the development and analysis of methods for producing digital elevation models from physical scanned maps having as little as possible human interaction. The course of the work revealed new ideas, so other new approaches are proposed as follows: automatic identification of the altitude layers based on the map's legend in the CIE L*u*v* color space, preprocessing using the mean shift filtering, color clustering based on the randomised local search method and gap filling using geostatistics (i.e. *kriging*).

The map's legend may contain adjacent colors that have small dissimilarities and CIE L*u*v* is a perceptual uniform color space efficient in the measurement of small color differences using the Euclidean metric.

The preprocessing's main purpose is to reduce (to remove) the halftoning effect (see previous section for a definition). Anti-aliasing effect (a method used in graphics for smoothing the jagged edges), which may appear around the edges within the map image, should also be reduced by the preprocessing step. The role of the mean shift filtering is to reduce the number of colors within the scanned map by a discontinuity preserving smoothing. The mean shift algorithm used in this work employs a 5-dimensional feature space (the $L * u * v*$ coordinates + the position of the pixel within the image). 2 resolution parameters (h_r, and h_s - the radius of the analyzing window in the color space, respectively, in the spatial space) controls the quality of the filtering. The mean shift filtering method searches for the local maxima of density by moving iteratively the 5D analyzing window until the magnitude of the shifts becomes less than a threshold. In the experiments it was considered $h_s = 7$. The legend image was filtered with $h_r = 6.5$ in order to eliminate as many as possible from the artifacts, while the map image was filtered using $h_r = 2$, for avoiding the distortions over small area elevation regions.

Randomised Local Search (RLS) color clustering was designed to be insensitive to the initialisation. The RLS method has as input the color image (X), the number of clusters (M) and the number of iterations (T). The initial values for the centroids (C) are generated by taking randomly values from the image. An optimal partitioning is generated by finding the nearest centroid for each element in X. A three-step procedure (that includes a random swap, a local repartition and a k-means clustering) is used to generate global changes to the clustering structure and to perform local fine tuning. An objective function is used to iterate the process. In this thesis the RLS color clustering was used for extracting the colors from the map's legend. In this thesis it was considered $T = 100$ and $M = [elevColors + 1]$ = the number of elevation layers denoted by the map's legend plus one.

The proposed approach for identifying the elevation layers from a color-coded relief scanned map includes the following steps: color extraction from the map's legend, preprocessing of the map image, computation of Euclidean distance (within CIE L*u*v* space) between each color from the legend and each pixel within the map image, threshold process on the result produced by the legend's color that offered the minimum Euclidean distance, median filtering to remove isolated wrong values, overlaps identification between the extracted elevation layers.

The gaps left by the removal of non-elevation layers and the removal of artifacts caused by the printing process and scanning process are filled using a kriging based method. Kriging was developed by D.G.Krige (1962) and is a geostatistical method for estimation of the unknown values within a sparse data set. Kriging is based on semivariograms. Semivariograms shows how the average difference between values at pairs of points changes with the distance between points. Experimental semivariograms are obtained by fitting with theoretical models (in the current work, a general version of the exponential-Bessel was used as a theoretical model). The colors within the sparse map image are indexed in the elevation ascending order based on the map's legend. The resulting values after kriging are rounded to the nearest integers. The results are evaluated (i.e. how well the experimental semivariogram was fitted to the theoretical one) using cross validations (i.e. $Q1$, $Q2$).

Other two objectives appeared in the course of work: preprocessing using Kuwahara filter and evaluation of the results using maps created based on SRTM-3 data, free available at NASA/JPL. SRTM-3 data yields image maps of size 1201 by 1201 pixels and covers Earth areas situated between 56 degrees south and 60 degrees north latitude.

Kuwahara filter is a statistical approach that measures the variance of pixels in many subregions of a neighborhood around each pixel. Whichever region has the lowest variance is taken to represent the region to which the central pixel should belong, and it is assigned the mean value from that subregion When applied to halftoned images that have been digitized with a scanner, this filter can eliminate the halftone patterns and leaves the edges unaffected. The Kuwahara filter offered the best results in removal of halftoning effect while the computational time was the lowest.

The computational time is significantly reduced by implementing in C under Matlab (i.e. MEX files) some critical steps of the method.

5 Personal contribution

The main personal contributions given by this dissertation are mentioned as follows. Two processes were proposed as a solution for the problem above mentioned: one centered around hidden Markov models in the wavelet domain and one based on kriging. New image processing applications have been developed for the hidden Markov models: halftoning effect removal and linework detection within a scanned map. The vector gradient edge detector has been used to develop a method for linework removal. This thesis, also, proposes a algorithm for extracting altitude contours from a physical scanned map using a sliding window operation. It has been shown that the mean shift filtering can be an efficient way to remove the halftoning effect. It has been developed a method to extract altitude layers from scanned physical map using the randomised local search clustering, the map's legend and the comparison of Euclidean distances in the CIE L*u*v* color space. It has been proposed a new approach to fill in the gaps after linework removal based on kriging interpolation.

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