

## **AUTOMATIC DIGITAL ELEVATION MODEL GENERATION, PROBLEMS AND RESTRICTIONS IN URBAN AREAS**

**Naci YASTIKLI<sup>\*</sup>, Karsten JACOBSEN<sup>\*\*</sup>**

<sup>\*</sup> *Yıldız Technical University, Civil Engineering Faculty, Department of Geodesy and Photogrammetry, Beşiktaş, 80750, Istanbul, Turkey, ynaci@yildiz.edu.tr*

<sup>\*\*</sup> *Institute for Photogrammetry and GeoInformation, University of Hannover, Neinburger Str. 1, D-30167, Germany, jacobsen@ipi.uni-hannover.de*

### **ABSTRACT**

Digital elevation models (DEM's) have been used wide range of application in civil engineering, planning, natural resource management, earth science and military studies. DEMs also became an indispensable source for Geographic Information Systems, which is playing a vital role for example in decision-making, urban and town planning. The generation and updating of DEM's in urban areas has to be fast, accurate and economic, because of the rapid development in such areas. Terrestrial measurement are too time consuming and expensive. Together with recent progress of image matching techniques and intelligent filtering, the automatic generation of DEM's became possible. The purpose of this paper is to provide an overview of the automatic creation of DEM's under the difficult condition of a build up area. The operational steps, general aspects, problems and restrictions of automatic generation of DEM's are investigated by using aerial images of Hannover, Germany as a test data set.

### **KENTSEL ALANLARDA OTOMATİK SAYISAL YÜKSEKLİK MODELİ ÜRETİMİ, SORUNLAR VE SINIRLAMALAR**

#### **ÖZET**

Sayısal yükseklik modelleri inşaat mühendisliği, planlama, doğal kaynakların yönetimi, yer bilimleri ve askeri çalışmalar olmak üzere bir çok alanda kullanılmaktadır. Sayısal yükseklik modelleri (SYM) aynı zamanda kentsel planlama ve karar vermede kilit rol oynayan Coğrafi Bilgi Sistemlerinin vazgeçilmez bir veri kaynağı olmuştur. Kentsel alanların hızlı gelişimi nedeni ile SYM' nin üretimi ve güncelleştirilmesi hızlı, doğru ve ekonomik olmalıdır. Klasik ölçme yöntemleri çok zaman alıcı ve pahalıdır. Görüntü eşleme ve filtreleme tekniklerindeki son gelişmelerle birlikte otomatik SYM üretimi mümkün hale gelmiştir. Bu makalenin amacı , zorlukların bulunduğu kentsel alan örneğinde otomatik SYM üretimine genel bir bakış sağlamaktır. Otomatik SYM üretiminin işlem adımları, genel özellikleri sorun ve sınırlamaları Almanya'nın Hannover şehrine ait hava fotoğrafları test verisi olarak kullanılarak incelenmiştir.

## 1. INTRODUCTION

DEM is defined by the U.S. Geological Survey (USGS), the digital cartographic representation of the terrain at regularly spaced intervals in x and y directions using z values referenced to a common vertical datum. In some countries Digital Terrain Model (DTM) is used similar meaning with DEM, representing the bare earth surface uniformly spaced z-values. DTMs can also include the elevation of important topographic features on land, irregularly spaced mass points and breaklines to better characterize the bare earth terrain. DTMs are normally more expensive and time consuming to produce than DEMs, because breaklines are ill suited problem for automatic collection. A Digital Surface Model (DSM) is similar to a DEM or DTM. A DSM depicts the elevation of the top surfaces of buildings, trees, towers and other features elevated above bare ground, which is the difference of DSM from DEM or DTM.

DTM's were used at first for road design. In the field of mapping, the first applications of DTM's were limited to the derivation of contour lines. Today the DEM is considered as an independent new product and used for the representation of topography. Many applications in GIS do use derived products of DEMs and DTMs, like contour lines, profiles, slope models, 3D-scenes and perspective views. Because of the wide use of orthophotos in GIS application, the accurate, fast and economic generation of DEM's became an important research topic. Conventional DEM generation has been used successfully for many years based on manual measurements with analytical plotters. The recent development of digital photogrammetry has led to the automatic generation of DEM's by image matching including also the automatic reduction of the derived data of the visual surface to points just representing the bare soil.

## 2. DATA ACQUISITION

The generation of digital elevation models includes the following main steps:

- 1) image matching
- 2) filtering and interpolation.

We also can add editing and checking (quality control and quality assessment) as a third step. For data acquisition different techniques have been used like digitising of contour maps, ground survey (tachymetry), real time GPS, traditional photogrammetry, laser scanning and airborne or space borne interferometric synthetic aperture radar (InSAR). As mentioned before, the traditional source of these data is the aerial photogrammetry. The manual data acquisition by human operators with analytical plotters is accepted as a common way of data acquisition. In digital photogrammetry the manual measurement is replaced by automatic image matching. By using image matching techniques, we can obtain the height values automatically. Similar to the traditional method, the automatic generation of DEM's based on aerial or space images includes following steps:

- 1) determination of corresponding points (image matching)
- 2) filtering and interpolation (surface fitting)
- 3) checking and editing of the DEM's (quality control and quality assessment).

Image matching or in other words, identification of conjugate points, is a major topic in computer vision and digital photogrammetry. An introduction to image matching will be given in the next chapter. The object points determined by automatic image matching do represent the visible situation including vegetation and buildings – the digital situation model (DSM) and not the height of the surface (DEM). The objects located above the surface and also the few mismatchings have to be filtered out for getting a DEM. This has to be followed by an interpolation to fill the gaps and / or to generate a DEM with an equal spacing. Last step of the automatic generation of DEM is the checking and editing (quality control) of the DEM. The first two-steps can be handled mainly automatically.

### **3. IMAGE MATCHING**

Digital image matching can be defined as “automatically establishing the correspondence between primitives extracted from two or more digital images depicting at least partly the same scene” [1]. Using different image matching methods, many tasks in digital photogrammetry have been carried out automatically, such as; interior orientation, relative orientation, point transfer in aerial triangulation, absolute orientation and DEM generation [2, 3, 4, 5].

We can classify the matching methods as following:

- a) Area based matching
- b) Feature based matching
- c) Symbolic matching

Area based matching is the most popular matching method in digital photogrammetry. Grey values are accepted as matching entities. The main idea is to compare the grey value variation between two images and determine the similarity by correlation or least squares techniques.

Cross correlation, is a well known procedure for a fast computation. The theory of this algorithm is based on normal case images and a horizontal plane in the matching window – this includes some limitations for inclined areas. The least squares matching is fitting the grey values of a sub-window in one image to a sub-window in the other in using affine parameters for the geometric relation and also a linear change of the grey values. The least squares matching algorithm provides a very high accuracy level, 0.1 pixel can be reached. A disadvantage of this matching method is the small convergence radius, so very good approximations (2-4 pixels) are required. By this reason, it has to be combined with another method of automatic image matching.

The feature based matching is using derived features of the original image. Points, edges and areas are used as features [6]. In feature based matching, features are extracted from the original images and the matching is performed between these extracted features, which are used as conjugate entities. The definition of the similarity measures for feature matching is a complex task. Feature based matching method also yield to sub pixel accuracy. Feature based methods are quite robust and do not require very good approximations. The obtainable accuracy for feature based matching is in the range of 0.3-0.4 pixel [7].

The symbolic matching method is using the symbolic description of images as matching entities. This method is also called relational matching. Grey values or other derived feature similarities are measured by cost functions. This method is not very accurate but robust. The method is rarely used in digital photogrammetry for automatic DEM generation [8, 9, 10].

The image matching can be made in the object or in the image space. Image matching in the object space requires the exterior and interior orientation and can generate directly the ground coordinates. It can also use the relation between neighbored images, mainly that corresponding points are located on epipolar lines. On the other hand the matching in the image space, which is mostly used together with region growing methods, do have the advantage to be independent upon the image geometry. So also images with a special geometry like space or microscope images can be handled with the same program. Only for the generation of ground coordinates, the special image geometry has to be respected.

#### **4. PROBLEMS AND RESTRICTIONS OF AUTOMATIC DEM GENERATION**

Automatic DEM generation has no problems if the terrain is open, has a sufficient texture and not a too strong inclination. Unfortunately, the terrain is mostly covered by buildings, houses, gardens, trees, bushes in urban areas, which prevent visibility and direct capture of the point located on terrain surface. In such cases most of matched points do not represent the terrain surface and cannot be used for DEM generation. Automatic DEM generation also fails in densely built up city areas, where constructions and tall building shadow prevent the visibility of terrain surface. In such cases interactive control and editing may not be really successful [11].

A human operator will set the floating mark on the ground if it is not totally covered by vegetation. The automatic DEM generation cannot separate between the bare soil, vegetation and buildings, but it generates a very dense cloud of points, which can be used for an automatic elimination of the points not belonging to the ground. In classical approach, this problem is solved interactive control and editing. Elimination of the matched points, which is not belonging to terrain surface, can be done by filtering techniques. This is not possible with simple filtering techniques which will generate points located between the visible surface and the ground, but with more qualified programs analysing the DSM for points not belonging to the DEM [12,13].

#### **5. INTERPOLATION**

After image matching and filtering, the gaps of the DEM have to be filled, the DEM has to be densified or a regular grid has to be computed based on randomly distributed points. The interpolation can be based on different methods like Triangulated Irregular Network (TIN), polynomial functions, splines, moving average or tilted planes, which can be grouped as first class. The second class of interpolation method is finite elements. The third class of interpolation methods is based on least squares interpolation or predictions, which are statistical methods. If the data acquisition is optimal, that means density and distribution of the 3D points is appropriate in relation to the terrain, the differences in accuracy of the different methods are limited [14].

## 6. CHECKING AND EDITING OF DEM

The first steps of DEM generation are automatic tasks, which require a human operator only for the specification of the control values. For checking and editing of the DEM, also called quality control, a human operator is essential. This step is required because a totally automatic generation of a DEM has some limitations. Mostly the accuracy of a DEM is specified by the vertical quality of DEM points, but the influence of the interpolation together with the spacing is also important. The accuracy of DEM is related to the type of terrain (smooth or rough) and the spacing. There is no general accuracy specification regarding DEM's but some approach can be found in [7]. Using different visualization methods such as wire frame and shading, gross errors can be detected just by visual inspection. Digital photogrammetric systems are quite appropriate for checking and editing. DEM points are easily superimposed on stereo-pairs in 3D and can be manually corrected, but the manual improvement is very time consuming, so an accurate generation and qualified filtering of the DEM is important.

## 7. INVESTIGATIONS AND RESULTS

For checking the automatic DEM generation, a test with a stereo model has been performed. The area of case study, covering the area of the EXPO fair in Hannover, was selected because this area has an urban structure including bushes, trees and buildings. Aerial photos with an image scale 1: 12 000 were flown in 1999 with a normal angle aerial camera. The image orientations have been obtained from the survey administration "Landesvermessung und Geobasisdaten Niedersachsen" (LGN).



Figure 1: (a) Test area



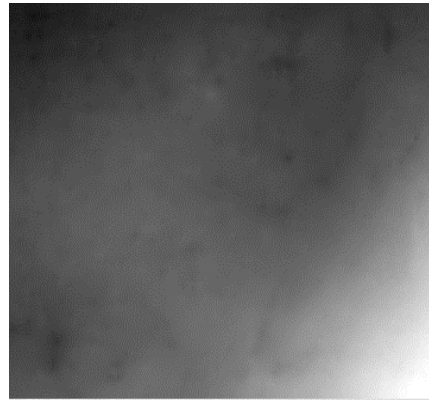
(b) Points determined by automatic image matching

The images have been scanned with a pixel size of 28  $\mu\text{m}$ . For the data handling, the program package SIDIP, developed by the Institute for Photogrammetry and Geoinformation, of the University of Hannover (IPI), has been used. The automatic image matching was made by program DPCOR of this package. It is using a least squares matching based on the region growing method, starting from few seed points [15] measured with DPLX. Window size, maximal number of iterations, row step, column step (distance of neighboured points to be matched in pixels) and the lower limit for the

correlation coefficient used for the generation of approximate values are the control parameters of DPCOR. Figure 1a, 1b shows the test area and the points determined by automatic image matching (black points showing matched points).



Figure 2. (a). Grey value coded DSM of test area without filtering



(b) Grey value coded DEM of test area after filtering

It is obvious that the matching algorithm failed in areas covered by buildings, and trees (see Figures 1a and 1b). In addition some mismatched points are included. The 3D-object coordinates of conjugate points using known image orientations and camera information are computed by intersection with program BLINT. The ground points were interpolated for regular distributed points (grid method) without filtering using program LISA (see Figures 2a). Perspective views of the DSM also together with draped images do give a better understanding of the problems and limitations of automatic DEM generation in urban areas (Figure 3a and Figure 3b).

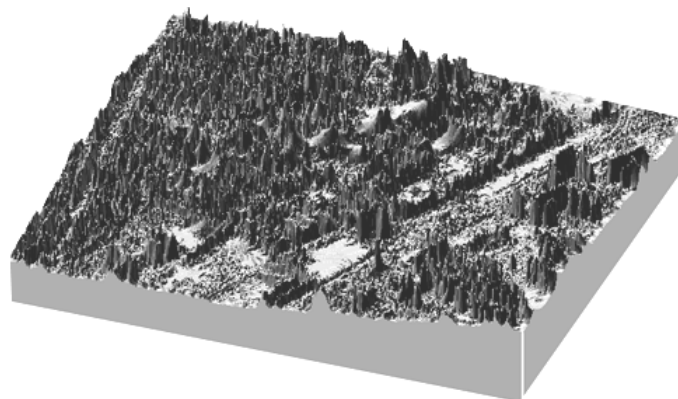


Figure 3. (a) Perspective view of DSM

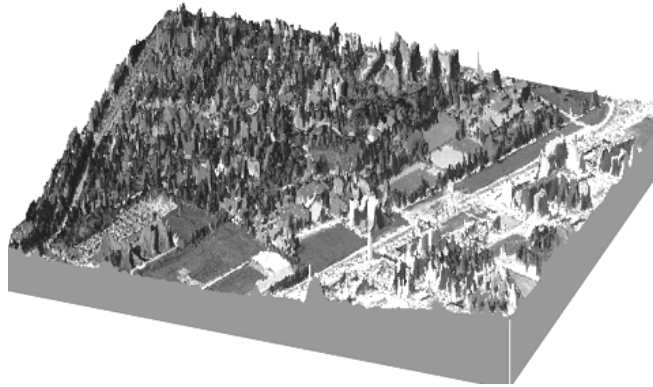


Figure 3. (b) Perspective view of DSM with draped image

Another problem in urban areas is the filtering of the DSM to a DEM. As it can be seen above that several points are not located on the ground. A manual improvement to the ground points is very time consuming and also not required. Thus, program RASCOR was used to filter the DSM to a DEM automatically. Program RASCOR has been developed by the Institute for Photogrammetry and Geoinformation (IPI), for the analysis and filtering of DEM's. It combines seven different methods of terrain analysis and filtering. The required parameters for the filtering are identified by the program itself (see Figure 2b). Using program RASCOR, points located not on the surface but on vegetation and buildings were identified and eliminated without manual intervention [12]. Figure 4a and Figure 4b do show a perspective view of the DEM and a perspective view of the DEM with the draped image after filtering.

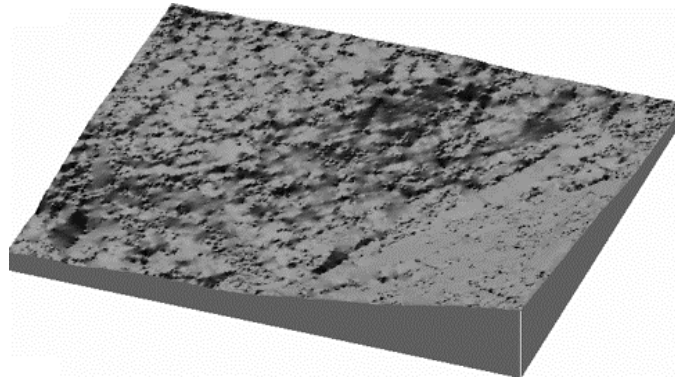


Figure 4. (a) Perspective view of DEM after filtering

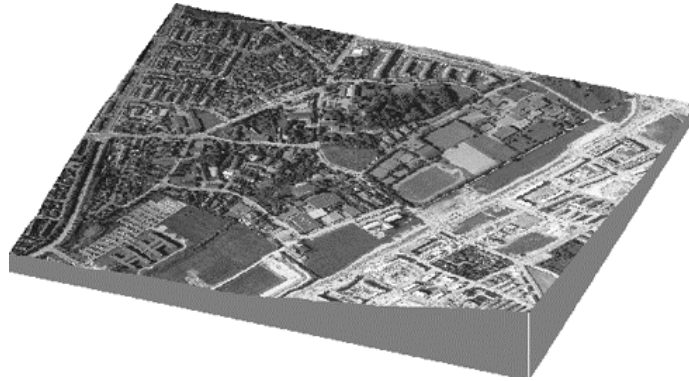


Figure 4. (b) Perspective view of DEM with the draped image after filtering

The last also important step of the automatic DEM generation is the checking and editing. The root mean square vertical error of the generated DEM points has been analysed in relation of the DEM of the survey administration (LGN) having 12.5 m spacing. The accuracy specification of the LGN-DEM is about 1m as mean information for the whole federal state, but it may be more precise in areas where it has been created by more modern techniques. The height differences were obtained by interpolating of the checkpoints to the automatic generated DEM without any editing. The achieved root mean square of 7802 differences is 0.52 m with a maximal difference of -2.42 m, which means, the LGN-DEM is quite better than the general specification. The vertical accuracy of measured points in stereo model can be defined as follow:

$$\sigma_h = m_r * \frac{h}{b} * \sigma_{px} \quad (7.1)$$

where,

$m_r$  : image scale,

$h$  : flying height,

$b$  : photo base,

$\sigma_{px}$  : standard deviation of x parallax.

The expected vertical accuracy of the ground points is  $\sigma_h \leq hg / 10000$  ( $hg$  = flying height above ground). The rule of thumb for the vertical accuracy is based on a  $\sigma_{px} = 9\mu\text{m}$ . In this case the flying height above ground corresponds to 3700m corresponding to  $\sigma_h = 0.37\text{m}$ . So the achieved mean square differences can be explained by the same accuracy of the reference data like for the determined data ( $0.52 \text{ m} = 0.37 * \sqrt{2}$ ). That means by the automatic process the same accuracy like for usual manual photogrammetric measurement has been reached.



## **8. CONCLUSION**

The automatic DEM generation based on image matching is giving us an economic, accurate and fast solution compared to conventional analytical DEM measurement also under the difficult conditions of the used test. The accuracy of the automatic DEM generation depends on several factors like: scale of aerial image, used focal length, type of terrain (smooth or rough), image texture and coverage by vegetation and buildings. In general urban areas are causing problems for automatic image matching. The digital surface model achieved by image matching has to be changed to a digital elevation model containing only points on the ground. This can be made by a qualified program for filtering the DSM. If the building and trees are not located very densely, the filtering can be done without interactive editing. In the described test, the obtained accuracy corresponds to the quality of a manual photogrammetric measurement.

The problems and restrictions of in urban areas covered by dens vegetation and building may not be overcome by image matching techniques and interactive control and editing. A multi-sensor approach is considered only feasible solution to the problem. Combined use of automatic DEM generation and LIDAR (Light Detection And Ranging) technology can be best solution for the problems and restrictions of urban areas covered by dens vegetation and building. LIDAR technology is capable of penetrating through vegetation cover and its smaller field of view solve the visibility problem of terrain surface caused by constructions and tall building.

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