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Algorithms for automatically detecting and filtering ground covered objects for exact generation of DEM

Automatic generation of DEM based on image matching technique is an important part in digital photogrammetry. DEM has been found widely in practical applications as in the fields of surveying, civil engineering, road design, agriculture, military, etc. For large DEM project, accuracy, efficiency, and economy are the three main factors to be taken into account. Accuracy is the first important factor to be considered. The effect of modeling methods on DEM accuracy have been tested. The characteristics of terrain surface are considered as a difficult and traditional topic in generating of DEM. Terrain surface may be open or covered with different objects. For generation of accurate DEM, objects on terrain surface must be detected and filtered. There are many methods for detecting and filtering objects which have been found on the terrain surface. Some of them are basing on mutual location of measured points along definite profiles (geometric analysis) or on images converted.

This article presents formulas for automatically detecting and filtering covered objects on the base of the geometric analysis of measured points mutually located along determined profiles in *X* and *Y*-direction.

INTRODUCTION

Automatic generation of DEM (Digital Elevation Model) by Image Matching technique (sometime using other term "Image Correlation") [1, 10] plays an important part in digital photogrammetry. The accuracy of automatically generated DEM is nowadays most essential. The factors which have influence on DEM accuracy are source data. They can be contour form taken topographic maps or aerial photography; size of regular net (grid); characteristics of terrain and the modeling methods. Terrain characteristics are considered traditionally difficult theme of investigations in accuracy estimation of DEM, especially for terrain with large coverage by objects and vegetation. It is especially true for automatically generated DEM with matching technique. For exact automatic generation of DEM, covered objects have to be automatically identified (detected) and eliminated (filtered) during computational process. For this aim different methods are used basing on geometry analysis of measured points of DEM located mutually along fixed profiles and on iterative transformed digital images [3, 8].

The accuracy of generated DEM can be estimated on the base of elaboration of orthophotography [6]. The accuracy estimation of flat surface approximation on the basis of interpolation in measured squares net was analyzed and published in [11].

Practical accuracy received from [5] shows, that RMS error of point height of DEM generated with fully automatic method (Image Matching Technique) is even about 3.3 × greater than RMS error of DEM generated with analytical photogrammetry for flat terrain, and about 1.7 × for hilly terrain and about 1.9 × for mountainous terrain. DEM errors generated with interactive method (semi automatic) comparing to analytical method have been achieved for three upper characteristics of terrain: 4 × ; 1.2 × ; 1.5 × worse. Such a large error of DEM generated with fully automatic method was due to not performing any edition or correction by operator and without any filtering of this ''raw'' DEM. Systematic errors have not been removed. Author of the paper [5] has not given any information concerning influence of the systematic errors.

Automatically generating DEM for town and urban terrain will be very arduous, difficult and sometimes unattainable. Ascertaining that automatic detection of buildings in urban areas by Image Matching Technique is yet not fully solved [8]. In practice, this theme is continually topical and in advance of investigations [2, 14].

One of principle advantages of fully automatic generation of DEM is economy and time consumption. The time needed for measuring a DEM manually on analytical plotter is about 4 hours per stereo model (about 5000 points), whereas in case of fully automatic process the time is only 1.8 hours for digital images with pixel resolution of 15 μm and 0.6 hours with pixel resolution of 30 μm [8].

In practice, some digital photogrammetric workstations offered by different firms have introduced algorithms for detection and filtering of objects. Explicit algorithms are not given in any of their publications [3]. From the point of view of theory it is difficult to estimate the optimum of proposed programs. Therefore the problem of automatic detecting and filtering of coverage on terrain surface is still important.

In this article, the algorithms for automatic detection (identification) and filtering (elimination) of objects existing on terrain surface, such as houses and trees are included in the computational process of generating DEM. It appears that these algorithms are also useful to detecting break-lines in open terrain.

1. *Rule of automatic generation of DEM*

Terrain surface can be represented in a general mathematical form as follows:

$$Z = F_n (X,Y) \tag{1}$$

where X, Y, Z – terrain point coordinates of DEM, F_n – the polynomial function of n degree.

In practice, DEM is formed basing on regular net. For this case, selected function F_n in (1) is the bilinear function:

$$Z = a_0 + a_1X + a_2Y + a_3XY \tag{2}$$

The surface of type (2) is illustrated on Fig.1.

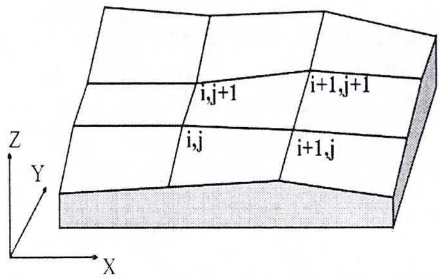

Fig. 1. Bilinear interpolation surface in regular net

After absolute orientation of the stereo model, images are transformed to normalized (epipolar) images. As result of this operation $py = 0$ and $px = f(\Delta h)$. On the base of Multi-point Matching technique [9] we obtain observation equation system (3) in image space, accepting lengths of squares sizes equal to 1:

$$v(x_a) = g_2'(1 - x)(1 - y)dp_{i,j} + g_2'x(1 - y)dp_{i+1,j} + g_2'(1 - x)ydp_{i,j+1} +$$

$$+ g_2'xy_{i+1,j+1} - \Delta g \tag{3}$$

where $v(x_a)$ – residuals of observations to the points on epipolar lines on the model, x, y – interpolated point coordinates in image space, $dp_{i,j}$; $dp_{i+1,j}$; $dp_{i,j+1}$; $dp_{i+I,j+1}$ – corrections to initial parallaxes at points (Fig.1), g_2' – derivatives in x direction on epipolar line of right image, Δg – differences of grey values of point (pixels) on left and right image.

Equation system of (3) and its solutions are written in matrix form:

$$\mathbf{V} = \mathbf{AX} - \mathbf{L} \qquad \text{with weight } \mathbf{W}$$

$$\mathbf{X} = (\mathbf{A}^T\mathbf{WA})^{-1}\mathbf{A}^T\mathbf{WL} \tag{4}$$

where: **A** – the matrix of unknown coefficients, **X** – the one column matrix of unknown dp, **L** – the column matrix of free expressions Δg, **W** – the matrix of weights.

Equation (3) determines the basic algorithm of Multi-point Matching method for generating DEM. The algorithm realizes automatic measurement of horizontal parallaxes which is well-known from classical photogrammetry.

2. *Algorithms for automatically detecting and filtering object on terrain surface*

There are different methods to automatically detecting and filtering object coverage on terrain surface. The methods for effective and practical use are presented bellow.

2.1. Method based on computing local slope of terrain along definite profiles

The results of automaticaly generating DEM are written in primitive file of point heights of squares net, in which there are points committed error from title of object coverage. On definite profile e.g. along X direction the graphical representation of measured points DEM is shown on Fig. 2a.

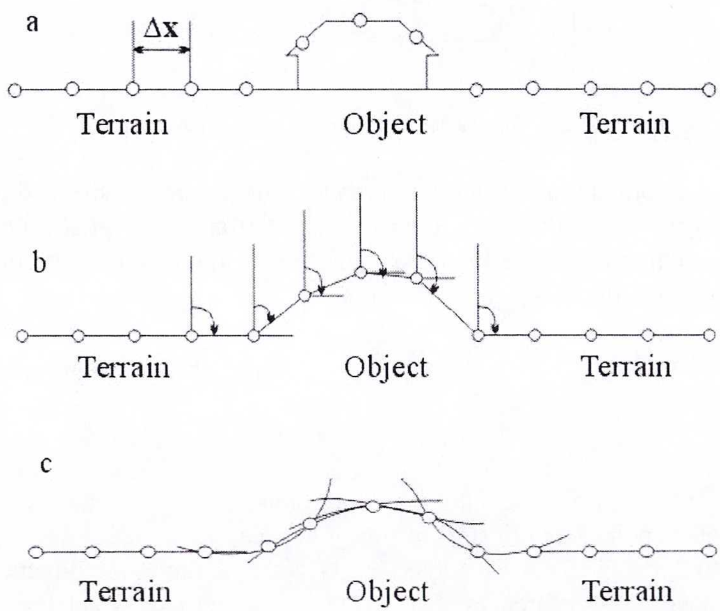

Fig. 2. Graphical representation of point heights of DEM along fixed profile: a) Measured point heights of squares along fixed profile, b) Computing local slopes of terrain along fixed profile, c) Computing local trends of terrain along fixed profile

As in Fig. 2b we can first calculate differences of height $AZ_{i,j+1}$ between nearest two points in X direction and after that following angles α_i (i = 1, 2, 3...):

$$\Delta Z_{i,\, i+1} = Z_{i+1} - Z_i$$

$$\alpha_i = \mathrm{arctg}(\Delta Z_{i,\, i+1}/\Delta X) \tag{5}$$

For given terrain, from old maps or from local measurements we can define a slope threshold α_g of terrain. The slope threshold can be also defined as average angle calculated using formula (5). With on accepting of the slope threshold we put condition for detecting objects as follows:

$$| \alpha_i | \leq | \alpha_g | \tag{6}$$

where $\alpha_i > 0$ – convex point; $\alpha_i < 0$ – concave point; $\alpha_i = 0$ – point in local planar surface.

If condition (6) is not satisfied then at the point $(i + 1)$ with height Z_{i+1} is object found. The registered height of point $(i + 1)$ has to be filtered and terrain height corrected to magnitude $\Delta Z_{i,\, i+1}$.

After [15] to equation (3) we add two conditional equations relating two local slopes of terrain along X direction (angle α) and Y direction (angle β) in the following form:

$$\begin{aligned} dp_{i,j} - dp_{i+1,j} + G_\alpha d\alpha + F_\alpha^0 + \Delta p_{xX}^0 = 0 \\ dp_{i,j} - dp_{i,j+1} + G_p d\beta + F_\beta^0 + \Delta p_{xY}^0 = 0 \end{aligned} \tag{7}$$

Then, we will obtain new equation system with unknowns α_i, and β_i. In this manner unknowns of inclination angles of terrain along X and Y direction with the vertex in point (i,j) will be simultaneously counted together with $dp_{i,j}$. At this, functions F_α and F_β are definite with the dependence:

$$\begin{aligned} F_\alpha = p_{i,j} - p_{i+1,j} + \frac{\Delta X \mathrm{tg}\alpha}{Z_{i,j}^2 + Z_{i,j}\Delta X \mathrm{tg}\alpha} = 0 \\ F_\beta = p_{i,j} - p_{i,j+1} + \frac{\Delta X \mathrm{tg}\beta}{Z_{i,j}^2 + Z_{i,j}\Delta Y \mathrm{tg}\beta} = 0 \end{aligned} \tag{8}$$

where: ΔX, ΔY – sizes of squares net (Fig. 2a), $Z_{i,j}$ – local point height of DEM, $G_\alpha = (\partial F_\alpha / \partial \alpha)$; $G_\beta = (\partial F_\beta / \partial \beta)$ – partial derivatives of function (8) in relation to α and β, Δp_{xX}°; Δp_{xY}° – the initial values of difference of horizontal parallaxes between points (i, j), $(i + 1, j)$ on profile along X direction and between points (i, j), $(i, j + 1)$ on profile along Y direction (look Fig. 1).

Solving the new system [(3) + (7)] in simultaneous process of computation by least squares we obtain $dp_{i,j}$ and immediate values of angles α_i and β_j with vertex in point (i, j) ($i = 1, 2, 3...$ – number of profile along X direction and $j = 1, 2, 3...$ – number of profile along Y direction). Using condition (6) in turn for α_i and β_j the operation system makes detecting simultaneously objects in space 2D. In this manner detecting process is more exact and faster with high reliability.

2.2. Method based on computing local trend of terrain surface

In this method instead delimitation of local angles of terrain surface, the local trends on terrain surface will be formed from groups of points DEM lying on fixed profile (Fig. 2c). To detect objects lying on surface we compute *absolute curvature K* (or *Gauss' curvature*) according to given formula (9) in higher mathematics ''differential geometry'':

$$K = \frac{1}{R_1 R_2} \tag{9}$$

where: R_1, R_2 – the main radiuses marked as solutions of square equation:

$$(rt - s^2)\, R^2 + h\, [2pqs - (1 + p^2)\, t - (1 + q^2)\, r]\, R + h^4 = 0 \tag{10}$$

where: $p = (\partial Z/\partial X)$, $q = (\partial Z/\partial Y)$, $r = (\partial^2 Z/\partial X^2)$, $s = (\partial^2 Z/\partial X \partial Y)$, $t = (\partial^2 Z/\partial Y^2)$, $h^2 = 1 + p^2 + q^2$ – the first and second partial derivatives of function (1) in relation to X, Y, Z.

For given surface of type (1) the value of Gauss' curvature will be expressed in form:

$$K = \frac{rt - s^2}{h^4} \tag{11}$$

The problem detecting objects lying on terrain surface leads to investigation of curvature property at given points along fixed profile. Terrain local trend at given points will be definite in dependence on magnitude and sign of Gauss' curvature K. We have three cases:

- $K > 0$ ie. R_1, R_2 in (9) are in the same sign — > convex point,
- $K < 0$ ie. R_1, R_2 in (9) are in the inverse sign — > concave point,
- $K = 0$ ie. One of two Gauss' curvature radiuses is infinitely great — > point on horizontal straight line.

The given surface in the bilinear function (2) has curvature K in point with well-known X, Y as follows:

$$K = \frac{-a_3}{[1 + (a + a_3 Y)^2 + (a_2 + a_3 X)^2]^2} \tag{12}$$

We examine now local trends in given points lying on definite profile along each X and Y direction.

a) Profile in X direction (Y = constans).

In equation (12) putting in $Y = Y_c$ = const and $X = X_i = i\, \Delta X$ where: $i = 1, 2, 3\ldots$ – the number of points on fixed profile j; ΔX – the size of square (Fig. 2a). We have:

$$K_{X_i} = \frac{-a_3}{[1 + (a_1 + a_3Y_c)^2 + (a_2 + a_3X_i)^2]^2} \tag{13a}$$

The X_i in (13a) should be determined from the function (2) with $Y = Y_c = \text{const}$ as follows:

$$X_i = \frac{Z_i - (a_0 + a_2Y_c)}{(a_1 + a_3Y_c)} \tag{13b}$$

It is visible that Gauss' curvature in considered point is dependent on its height and coefficients: a_0, a_1, a_2, a_3 characterizing surface generated from certain group of given points. The magnitude of Gauss' curvature may be determined simultaneously with coefficients: a_0, a_1, a_2, a_3 by creating new function in the form (13c):

$$F_X(K_{X_i}, a_0, a_1, a_2, a_3) = K_{X_i} + \frac{a_3}{[1 + (a_1 + a_3Y_c)^2 + (a_2 + a_3X_i)^2]^2} = 0 \tag{13c}$$

The function (13c) is non-linear. After approximation of equation (13c) in Taylor's series, we obtain correction equation system:

$$dK_{X_i} + \frac{\partial F_X}{\partial a_0}da_0 + \frac{\partial F_X}{\partial a_1}da_1 + \frac{\partial F_X}{\partial a_2}da_2 + \frac{\partial F_X}{\partial a_3}da_3 + F_X^0 + K_{X_i}^0 = v_{X_i} \tag{14}$$

After calculating first derivatives the equation system (14) will be written in the form similar to (4) and then solved by least squares method. For determining five unknowns K_{X_i}, a_0, a_1, a_2, a_3 it is necessary to have at least five neighboring points ($n \geq 5$) lying in a definite profile. For next points $i(i = n + 1; n \geq 5)$ lying on the same profile we repeat computation for obtaining following magnitudes K_{x_i}, which describe local trends of terrain surface along fixed profile in X direction.

To solve system (14) the initial values a_0, a_1, a_2, a_3 have to be known. These initial values can be computed using equation (2) with at least four measured points on DEM. Next, initial values $K_{x_i}^0$ will be determined from (13a).

For detecting and filtering objects lying on terrain surface along certain profile we set up the following condition:

$$| K_{X_i} | \geq | K_g | \tag{15}$$

$K_{X_i} > 0$ – convex point; $K_{X_i} < 0$ – concave point; $K_{X_i} = 0$ – point in horizontal line where – K_g is the threshold magnitude of terrain surface curvature that was determined for given terrain. In case, when condition (15) is not fulfil in considered point i then in this point the object is found.

b) Profile in Y direction (X = const.)

In similar manner we can qualify local trends of terrain surface along fixed profile in Y direction (X = const.). Putting in $Y = Y_i = i\,\Delta Y$ where: $i = 1, 2, 3...$ – the number of points on fixed profile j; ΔY – the size of square. We have

$$K_{Y_i} = \frac{-a_3}{[1 + (a_1 + a_3 Y_i)^2 + (a_2 + a_3 X_c)^2]^2} \tag{16a}$$

where:

$$Y_i = \frac{Z_i - (a_0 + a_2 X_c)}{(a_2 + a_3 X_c)} \tag{16b}$$

Analyzing of local trends in Y direction is driven similarly to (14) and (15).

2.3. Method based on orthophoto

This method relies on secondary realization of Image Matching technique of orthophoto images transformed from original one. Objects of covered terrain as houses, trees etc, from regard on one's own heights, are source of forming rest horizontal parallaxes on orthography. Thanks this, objects are perfectly visible on background of flat profile (Fig. 3) [8, 13].

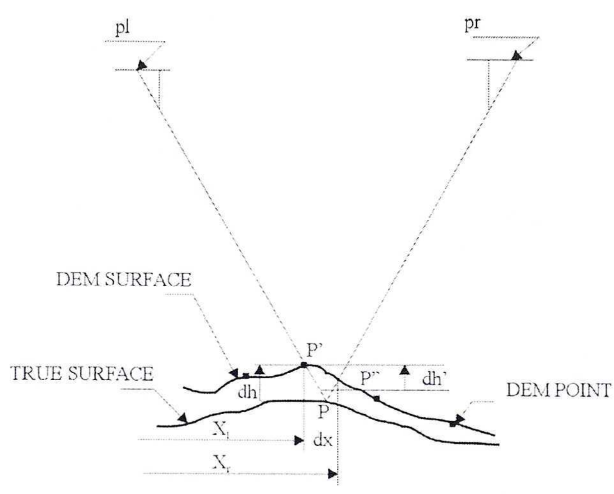

Fig. 3. Relationship between orthophoto and DEM error

Orthophoto are obtained first of all from differential rectification technique. After that we realize projection equation in the form (17):

$$x_i = aX_D + bY_D + cX_DY_D + d$$
$$y_i = eX_D + fY_D + gX_DY_D + h \tag{17}$$

where: x_i, y_i – counted point coordinates of orthophoto, X_D, Y_D, Z_D – point coordinates received from primitive DEM of original images.

For determining 8 unknown coefficients *a, b, c, d, e, f, g, h* in equation (17) we must have group of *n* points ($n \geq 4$) evenly located in two corresponding systems of orthophoto and DEM. These select points have to be on terrain surface. After determining these coefficients the transformation of remaining points from DEM system into orthophoto system is performed. Next, we generate again automatic DEM with image matching technique. Relationship between rest parallax and height dh' of object is written as follows (Fig. 3):

$$dh' \approx dh = dx \frac{H}{B} \tag{18}$$

where: B – base-length of photograph, H – flight height over ground, dh' – is practically height correction of DEM in point P'.

Relating to this group of methods is also one basing on transformed images, which are interactively obtained using digital filters and under supervision of an operator. Secondary DEM obtained from transformed images could be used for delimitation of objects coverage on ground (Edge Detection). A few of digital filters for edge detection are already used in practice.

CONCLUSIONS

In this article three methods with algorithms for automatically detecting objects covering on terrain surface are presented. Two first methods basing on geometry analysis were considered as very mathematical. Using these two methods the accuracy of automatically generating DEM will be more accurate. Efficiency and accuracy of methods for automatically detecting objects depend on the use of mathematical model with algorithms for realizing this model. The investigation of mathematical models for automatically detecting objects in generating DEM on the basis of image matching technique permits significant improvement in digital photogrammetry.

The work [3] introduces this problem with interesting results of investigations that about 80–90% of point heights of objects lying on surfaces became detected and filtered, that the DEM accuracy will raise about 35–65% in dependence on using methods for automatically detecting and filtering. Unfortunately, in this work as same as another publications there are not algorithms but only graphical descriptions relating to this problem have been presented.

Other conception to overcome a barrier of ground coverage relies on use of laser technique [1, 12]. This idea is especially effective for DEM elaboration of terrain with vegetation coverage, because laser beam could penetrate through vegetation layer. Combination of laser technique and digital images gives powerful possibilities for automation of generating DEM in difficult terrain. There are two sets of points describing the same terrain, one obtained from laser technique and one from generated DEM of digital images. Having these two DEM we can use them to carry out ''Surface Matching'' method. In this manner objects could be detected and filtered. This idea is also effective for urban terrain.

Proposed idea of laser technique is very modern. We must investigate whether this method is more economical than the methods basing on geometry analysis worked out for automatically detecting and filtering objects in acceptable accuracy.

REFERENCES

[1] Akermann F., *Techniques and strategies for DEM generation.* An Addendum to the Manual of Photogrammetry. ASPRS, 1995, pp. 135–141.

[2] Baillard C., Dissard 0., 2000: *A stereo matching algorithm for urban Digital Elevation Models.* PE&RS; Vol. 66, No 9, 2000, pp. 1119–1128.

[3] Gasior D., *Filtracja elementów pokrycia Ziemi w procesie automatycznego tworzenia numerycznego modelu terenu.* Rozprawa doktorska. Warszawa 2000.

[4] Halava U., *Object-space least-squares correlation.* PE&RS, Vol. 54, No 6, 1988, pp. 621–626.

[5] Jiaanya Gong, Zhilin Li, Haigang Sui, Yi Zhou, Effects of various factors on the accuracy of DEM: An intensive experimental investigation. PE&RS, Vol. 66, No 9, 2000, pp. 1113–1117.

[6] Kaczyński R., Ziobro J., *Digital aerotriangulation for DTM and orthophoto generation.* ISPRS. Comm. IV, Symposium, Vol. 32, T4, Stuttgard 1998.

[7] Raid Al-Tahir, Schenk T., *On the interpolation problem of automated surface reconstruction.* IAPRS, Part B3, 1992, pp. 227–232.

[8] Raye Norvelle F., *Using iterative orthophoto refinements to generate and correct digital elevation models (DEMs).* An Addendum to the Manual of Photogrammetry, ASPRS, 1995, pp. 151–155.

[9] Rosenholm D., *Multi-point matching using the least-squares technique for evaluation of three-dimensional models.* PE&RS, Vol. 53, No 6, 1987, pp. 621–626.

[10] Schenk A. F., *Automatic generation of DEMs.* An Addendum to the Manual of Photogrammetry, ASPRS, 1995, pp. 145–150.

[11] Wysocki J., *Zagadnienie oceny dokładności aproksymacji powierzchni terenu przy pomocy modelu numerycznego (cyfrowego).* Przegląd geodezyjny, 11/2000, s. 6–9.

[12] Habib A., Kelley D., Aamamaw A., *New approach to solving matching problem in photogrammetry.* IAPRS, Vol. XXXIII, part B2, 2000, pp. 257–264.

[13] Nowak K., *Rectification of digital imagery.* PE&RS, Vol. 58, No 3, 1992, pp. 339–344.

[14] Zinnmermann P., *Colour image matching for DTM generation and house extraction.* IAPRS, Vol. XXXIII, part B3, 2000, pp. 697–703.

[15] Ke L. C., *Least squares multi-point matching for DEM with consideration of correlated neighbouring pivels and terrain height differences.* Geodezja i Kartografia, Vol. L, No 1, 2001, pp. 45–56.

- IAPRS – International Archives for Photogrammetry and Remote Sensing.
- ISPRS – International Society for Photogrammetry and Remote Sensing.

- PE&RS – Photogrammetric Engineering and Remote Sensing.
- ASPRS – American Society for Photogrammetry and Remote Sensing.

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Algorytmy do automatycznej detekcji i filtracji obiektów pokrywających teren dla dokładnego generowania DEM

S t r e s z c z e n i e

Automatyczne generowanie cyfrowego modelu wysokościowego DEM (Digital Elevation Model) opierające o technikę dopasowania obrazów (image matching) jest jednym z głównych zadań w fotogrametrii cyfrowej. DEM ma szerokie zastosowania w różnych dziedzinach jak w projektach inżynierskich, rolnictwie, wojskowej operacji itd. Trzy główne czynniki, które należy oddać do oceny przy analizie jakości generowania DEM są to dokładność, efektywność i ekonomiczność. Dokładność DEM jest pierwszym czynnikiem ważnym oddanym do analizy. Na dokładność generowania DEM wpływają dokładność źródłowych danych, rozmiary siatki regularnej stosowanej do interpretacji, charakterystyki powierzchni terenu i metoda modelowania. Charakterystyki terenu są rozważane jako tradycyjnie trudnym tematem w generowaniu DEM. Dla dokładnego utworzenia DEM, obiekty pokrywające teren jak budynki, drzewa, itd. powinien być detekcyjne i filtracyjne.

W niniejszym artykule przedstawia się algorytmy do automatycznej detekcji i filtracji obiektów wystających ponad teren dla dokładnego wygenerowania DEM, basując na geometrycznej analizie pomierzonych punktów siatki wzdłuż określonego profilu w kierunku X i Y.

Лёнг Чин Ке

Алгоритмы автоматизированного распознавания и фильтрации объектовна поверхности местности для точного образования цифровой модели местности (DEM)

Р е з ю м е

Автоматизированное образование цифровой высотной модели DEM (Digital Elevation Model), основанное на технике приспособления изображений (image matching), является одной из главных задач цифровой фотограмметрии. Цифровая модель местности имеет широкое применение в разных областях, таких как инженерские проекты, сельское хозяйство, военные операции и других. Три основные факторы, которые должны оцениваться в анализе качества созданной цифровой модели местности, это точность, эффективность и экономичность. Точность цифровой модели

местности является первым анализированным фактором. Точность образования цифровой модели местности определяют точность источниковых данных, размеры регулярной сетки применяемой в интерпретации, характеристики поверхности местности и метода моделирования. Характеристики местности причисляются традиционного к сложным темам образования цифровой модели местности. Для точного образования этой модели необходимым является присутствие возможности распознавания и фильтрации объектов на поверхности местности, таких как здания, дерева и др.

В статье представлены алгоритмы автоматизированного распознавания и фильтрации объектов высовывающихся выше поверхности местности для точного создания цифровой модели местности, основываясь на геометрическом анализе измеренных пунктов сетки вдоль определённого профиля в направлениях *X* и *У*.