Automated Model Creation From TLS Data

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Key words: TLS data processing, automatisation, software development, model creation, data analysis

SUMMARY

The creation of the 3D model from the data set obtained by TLS or photogrammetry is often very complicated and time-consuming process. There are many approaches in processing these data. Commercial software use mainly three approaches in creation of 3D models: triangulation, non-uniform B-spline surface (NURBS) or the replacement of data points by the mathematical defined objects. The different software packets available on the market fit more or less to the different tasks of the model creation. Due to the very high price level of these software packets is difficult to use the best one for the each task.

The paper presents the new method for model creation based on the level set method (LSM). The developed procedure is effective especially by model creation from small density data sets and achieves very good results from the data obtained by close range photogrammetry method, also. The application of the LSM takes view minutes by the data sets with high density. The paper brings examples and first results of the procedure application.

SUMMARY

3D Modelbildung von TLS und photogrammetrischen Datenreihen ist oft relativ komplizierte und anspruchsvolle Aufgabe. Es gibt viele verschiedene Methoden für Verarbeitung von Daten. Die professionale Software basiert an Triangulation, Non-uniform B-spline (NURBS) oder Regression. Es gibt verschiedene Softwarepacket die passt mehr oder wenig zu der Aufgabe der Modelbildung. Wegen der hohen Preiss ist sehr kompliziert die beste Lösung für jede Aufgabe zu finden.

Im Bericht ist die neue Methode für Modellbildung, welche ist auf Grund der bekannte level set method (LSM) entwickelt, vorgestellt. Die neu entwickelte Software ist effektiv besonders bei Modelbildung von Datenreihe kleiner Konsistenz und erreicht sehr gute Ergebnisse auch bei Verarbeitung der photogrammetrischen Datenreihen. Applikation der LSM braucht nur einige Minute auch bei Datenreihe mit höherer Konsistenz. Im Bericht sind auch die erste Ergebnisse und die mögliche Applikationen vorgestellt.

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1. INTRODUCTION

The creation of the 3D model from the data set obtained by scanning or photogrammetry is often very complicated and time-consuming process. The principal aim of processing the data is the creation of the model S´ which approximates the real shape S as much as possible. The main difficulties of surface reconstruction from point clouds include unknown connection or ordering information among the data points, unknown topology of the original surface, and the noise and non- uniformity in the data.

There are many approaches in processing these data. Commercial software use mainly three approaches in creation of 3D models: triangulation, non-uniform B-spline surface (NURBS) or the replacement of data points by the mathematical defined objects. The first two methods are used for the creation of models of objects with complicated topology. The third one is used for the creation of models if it is possible replace the part of object with mathematically defined entities as sphere, cube, block, cylinder or spire. The different software packets available on the market fit more or less to the different tasks of model creation. Due to the very high price level of these software packets is difficult to use the best one for the each task.

The possible way to solve this problem is the development of software based on new mathematical approach. The presented method solves the fundamental problem of surface reconstruction on the continuous level by constructing models using differential geometry and partial differential equations. This method consists of the solution of two advective partial differential equations. Solution of the first partial differential equation gives us the distance function. Solution of the second partial differential equation gives us the function which represents the final 3D model. The whole solution is realized on the simple rectangular grid in the domain Ω. The data set Ω_0 – set of points obtained by scanning or photogrammetric methods, build the subset of Ω.

The developed software uses the level set method and enables automated model creation according the chosen parameters, which describes the density of the points in the data set and the grid. The paper brings the mathematical model of the used method and proposes their numerical solution. The next parts present results of numerical experiments and examples.

2. THE MATHEMATICAL MODEL

The method for the creation of 3D models using LSM is based on the solution of the distance function. Distance function for the surface S in the domain Ω can be define as

$$d(x) = dist(x, S), \qquad (1)$$

where S is the surface represented by points, curves or surface patches,
x is the arbitrary point on the surface S or out of surface S and $x \in \Omega$.

If point x is situated on the surface S than the distance function satisfies the condition

$$d(x) = 0 \qquad (2)$$

The distance function $d(x)$ to an arbitrary data set Ω_0 solves the Eikonal equation with a Dirichlet type condition

$$d_t + |\nabla d| = 1 \qquad d(x,t) = 0 \qquad x \in \Omega_0 \subset \Omega. \qquad (3)$$

in the domain $\Omega \times [0,TD]$ where Ω_0 is the subset of Ω.

The second partial differential equation is

$$u_t + \nabla g \cdot \nabla u = 0, \qquad (4)$$

where $(x, t) \in \Omega \times [0,TS]$ and $g(x) = d(x)$, ∇g is advective velocity.

This equation is often called level set equation and methods which utilize this equation as level set methods (LSM). A basic idea in the LSM is that the moving curve or surface corresponds to the evolution of a particular level (curve or surface) of the so-called level set function u that solves some form of the following level set equation (4), where ∇g describe the velocity of this motion (Bourgine, P. et al, 2009).

3. NUMERICAL REALIZATION

The numerical solution consists of three steps:

- to solve the first partial differential equation– finding a fast algorithm to compute the distance function to an initial data set on rectangular grids,
- to find a good initial surface,
- to solve the second partial differential equation for the level set function (Zhao, H. K. et al, 2001).

3.1 Solving the first partial differential equation

The calculation of the exact distance function to big data set could be takes a long time. From this reason is better to solve this problem by the method of approximation, e.g. by the Eikonal equation. It exist many different methods for solving this equation. Next is described the usage of so-called Fixing method which is based on Rouy-Tourin scheme expended the fixation.

The first step is the discretization of the equation by conditions given in (3). It was used the explicit time discretization with time step τ_D. Resulting the 3D discretization based on the Rouy-Tourin scheme we obtain the uniform 3D grid with square elements, where h_D is the size of the grid. The choice of the parameter h_D depend on the density of points in the data set. After the discretization of Ω were assigning exact values at grid points around the points of the data set (initialization). These values are fixed in the next calculations. We assign very small positive values first, at all other grid points. These values will be updated in the next calculations.

When $d_{i,j,k}^n$ represent the approximate value of the exact distance function d for each grid point in the time step n, the Rouy-Tourin scheme for equation (3) will be (Bourgine, P. et al, 2009)

$$d_{i,j,k}^{n+1} = d_{i,j,k}^{n} + \tau_D - \frac{\tau_D}{h_D}\sqrt{\max(M_{i,j,k}^{-1,0,0}, M_{i,j,k}^{1,0,0}) + \max(M_{i,j,k}^{0,-1,0}, M_{i,j,k}^{0,1,0}) + \max(M_{i,j,k}^{0,0,-1}, M_{i,j,k}^{0,0,1})} \quad (5)$$

where $M_{i,j,k}^{p,q,r} = (\min(d_{i+p,j+q,k+r}^{n} - d_{i,j,k}^{n}, 0))^2,$ (6)

$p, q, r \in \{-1,0,1\}, |p| + |q| + |r| = 1,$

this scheme is stable for $t_D \leq h_D/2$.

The Rouy-Tourin scheme applied to the time relaxed Eikonal equation produces in every point monotonically increasing values approaching the value of the distance function. This means that at some moment, the value will reach some steady state and it will not change anymore. This fact allows us to implement to the calculation so-called fixation that makes the computation faster. We consider the index set F that contains the indices $\{i, j, k\}$ of the grid points which differences between value of distance function $d^{n-1}{}_{i,j,k}$ and $d^{n}{}_{i,j,k}$ is less than the defined deviation. These points will be fixed and can be excluded from the calculations. The calculation will be finished when all grid points are fixed – they reach steady state.

3.2 Finding a good initial surface

In this method is continuously deformed an initial surface to the final surface by the second partial differential equation (4). This equation is solved for level set function to capture the deformation. The procedure starts with simple surface such as rectangular box. If this starts with an initial surface that is too far from the real shape, the creation of final surface takes long time. The good initial surface helps to speed up the convergence to the equilibrium (final) surface. In many situations the good initial surface is also needed to avoid spurious local minimum.

Also is important to find the good initial surface (guess) for the calculation. This guess can be, e. g. the outer level contour of the distance function $d(x) = \varepsilon$ that encloses the data set. We can use very simply procedure to find this exterior contour surface, which start from any initial exterior region that is a subset of the true good guess. All grid points that are not in the initial exterior region are set as interior points. If the grid point with position (i, j, k) is exterior point, all its interior neighbors which satisfies $d_{i\pm 1,j\pm 1,k\pm 1} \geq \varepsilon$ are set as exterior points. The whole procedure is applied to every exterior point only once and will be finished when will check all exterior points (Zhao, H. K. et all, 2000).

The choosing of the value ε is very important. We would like to choose ε as small as possible. However in the discrete case if we choose ε too small the contour $d(x) = \varepsilon$ consist of separated small spheres around data points. To get a good initial surface the choice of the parameter ε depends on the density of points in the data set. The figure 1 brings example of the correct choosing on the left and wrong choosing of ε on the right. On the left figure the contour $d(x) = \varepsilon$ (represented in red) is the continuous line and on the right figure the contour creates more discontinuous objects.

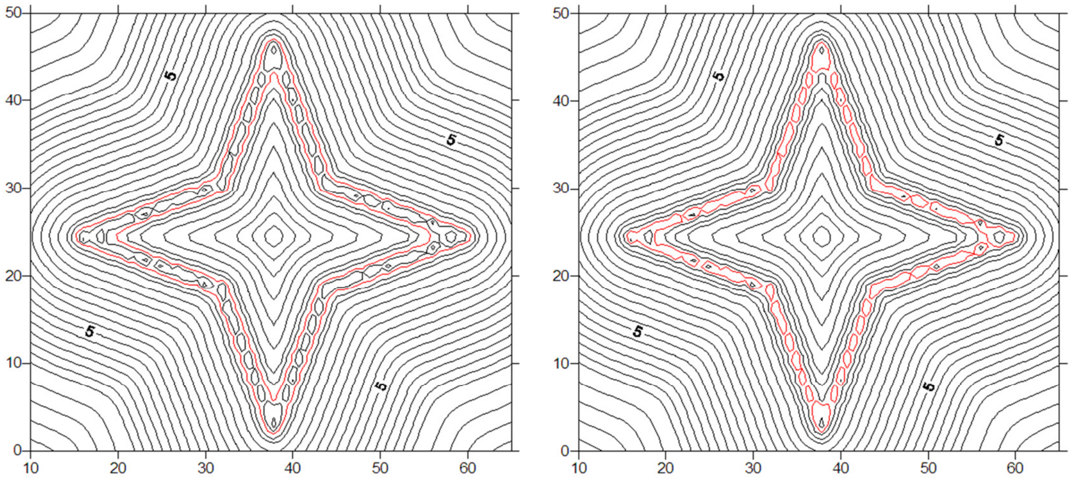

Fig.1 The choosing of value ε – correct (left) and wrong (right)

3.3 Solving the second partial differential equation

In order to solve the second partial differential equation numerically, is use explicit time discretization with time step τ_S. The 3D discretization with the grid size $h_S = h_D$ is based on the upwind principle. If will be define the central differences $D^x_{i,j,k}g$, $D^y_{i,j,k}g$ a $D^z_{i,j,k}g$ *as*

$$
\begin{aligned}
D^x_{i,j,k}\, g &= -\left(g_{i+1,j,k} - g_{i-1,j,k}\right)/(2h_S),\\
D^y_{i,j,k}\, g &= -\left(g_{i,j+1,k} - g_{i,j-1,k}\right)/(2h_S),\\
D^z_{i,j,k}\, g &= -\left(g_{i,j,k+1} - g_{i,j,k-1}\right)/(2h_S),
\end{aligned}
\qquad (7)
$$

we get the following approximation of (4)

$$
\begin{aligned}
u^{n+1}_{i,j,k} = u^{n}_{i,j,k} - \frac{\tau_S}{h_S}\big[\ &\max\left(D^x_{i,j,k}\, g, 0\right)\left(u^n_{i,j,k} - u^n_{i-1,j,k}\right) + \min\left(D^x_{i,j,k}\, g, 0\right)\left(u^n_{i+1,j,k} - u^n_{i,j,k}\right) +\\
&+ \max\left(D^y_{i,j,k}\, g, 0\right)\left(u^n_{i,j,k} - u^n_{i,j-1,k}\right) + \min\left(D^y_{i,j,k}\, g, 0\right)\left(u^n_{i,j+1,k} - u^n_{i,j,k}\right) +\\
&+ \max\left(D^z_{i,j,k}\, g, 0\right)\left(u^n_{i,j,k} - u^n_{i,k,k-1}\right) + \min\left(D^z_{i,j,k}\, g, 0\right)\left(u^n_{i,j,k+1} - u^n_{i,j,k}\right)\ \big]
\end{aligned}
\ . \ (8)
$$

This scheme is stable for $t_S \leq h_D/2$.

The velocity ∇g from the 2D data set (in red) is represented on the figure 2, were the advective velocity ∇g drives all level lines of the initial function to model of object (Bourgine, P. et al., 2009).

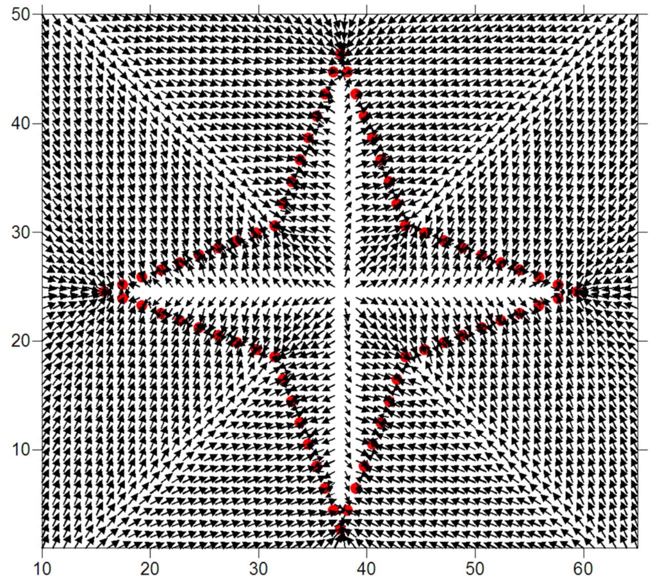

Fig. 2 Representation of ∇g

According the described numerical solution was made the software procedure as consol aplication in language C. For graphical presentation of the results were used Surfer (for 2D) and Voxler (for 3D) from Golden Software. The visual comparison of the same data sets were processed with commercial software Geomagic.

4. EXAMPLES

The Department of Surveying the STU was involved to the research detection of the humane vertebra depreciation. In the framework of this research there was requested to create its 3D model. The data set was obtained by method of close range photogrammetry and the model was created manually by connecting of measured surface points (Fig. 5).

To compare the results was applied the new procedure based on LSM for creation of vertebra model, whit the grid size 0.1 mm. The computation took 2 minutes. The creation of the vertebra model was exactly automatic. It was also used the software Geomagic, which produce the model uncompleted and needed high density of data points (Fig. 6).

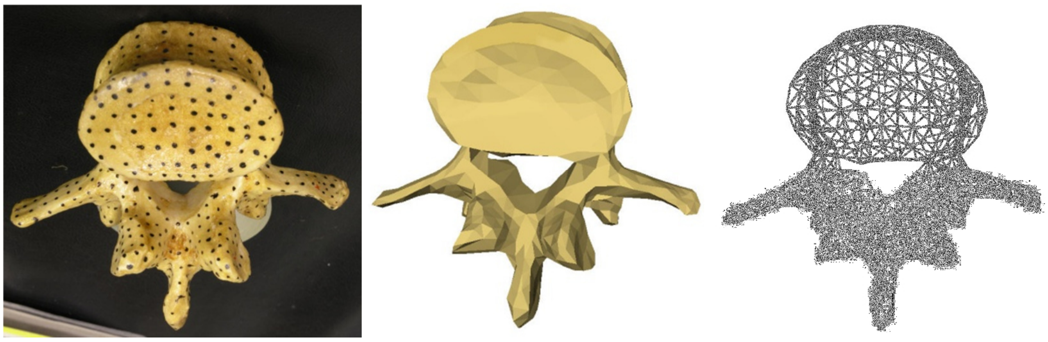

Fig. 5 Picture of vertebra and manually created model (Bartos, P. et al., 2006)

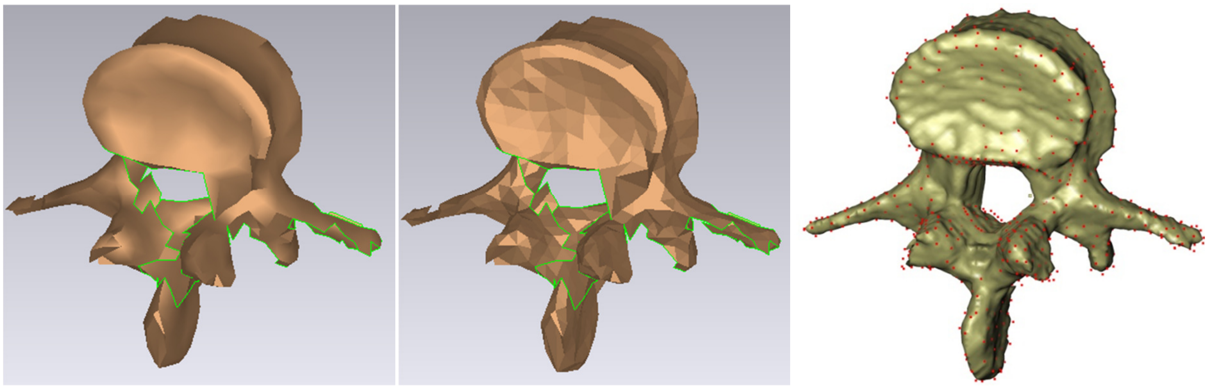

Fig. 6 Model of vertebra from the data set obtained by close range by Geomagic – smooth shading (left) and flat shading (in the middle) and by LSM (right)

Besides close range photogrammetry data were obtain of other data set by TLS. The density of points in data set was chosen 3 mm and 2 mm. First was created the model from data set with density 3 mm, by the grid size 0.5 mm. The computation took about 2 minutes. The model creation by Geomagic took only few seconds, but the model is little detailed with more holes. The model created using LSM correspondents with the real shape more (Fig. 7 and 8).

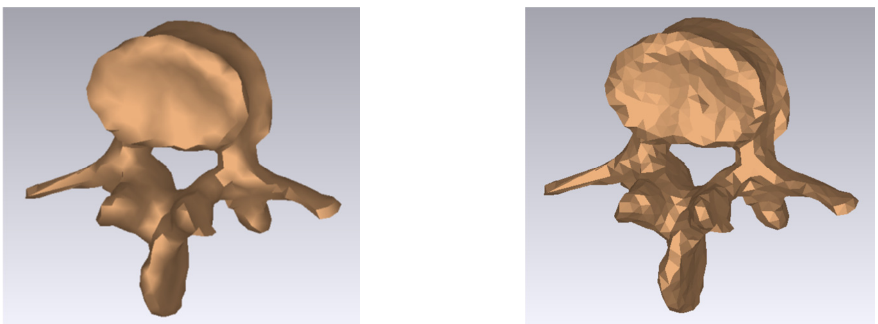

Fig. 7 Model of vertebra from the data set with density 3 mm created by Geomagic – smooth shading (left) and flat shading (right)

Fig. 8 Model of vertebra from the data set with density 3 mm created by LSM

The model created by Geomagic from data set with density 2 mm is on figure 9. The model creation by LSM took 3 minutes, the grid size was 0.4 mm (Fig. 10).

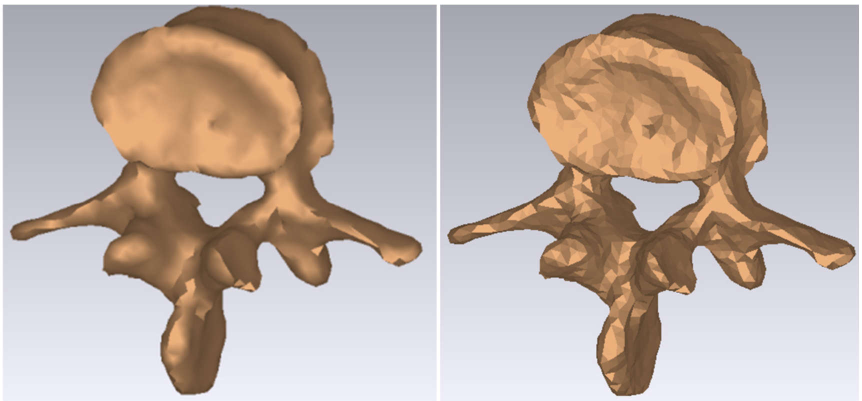

Fig. 9 Model of vertebra from the data set with density 2 mm created by Geomagic – smooth shading (left) and flat shading (right)

Fig. 10 Model of vertebra from the data set with density 2 mm created by LSM

Because the developed mathematical model can be used only for model creation of closed objects, were proposed two solutions in the case of unbounded object. Software can fill up other missing walls or it can make a copy of all points of data set in selected distance *b*. The choosing of the solution depends mainly on the shape of object.

It was applied both proceedings for the model creation of the part of the statue. In the first case the data set build the front wall and another five walls were created automatically by software. In the second case the software made a copy of data set in the selected distance *b* (Fig. 11).

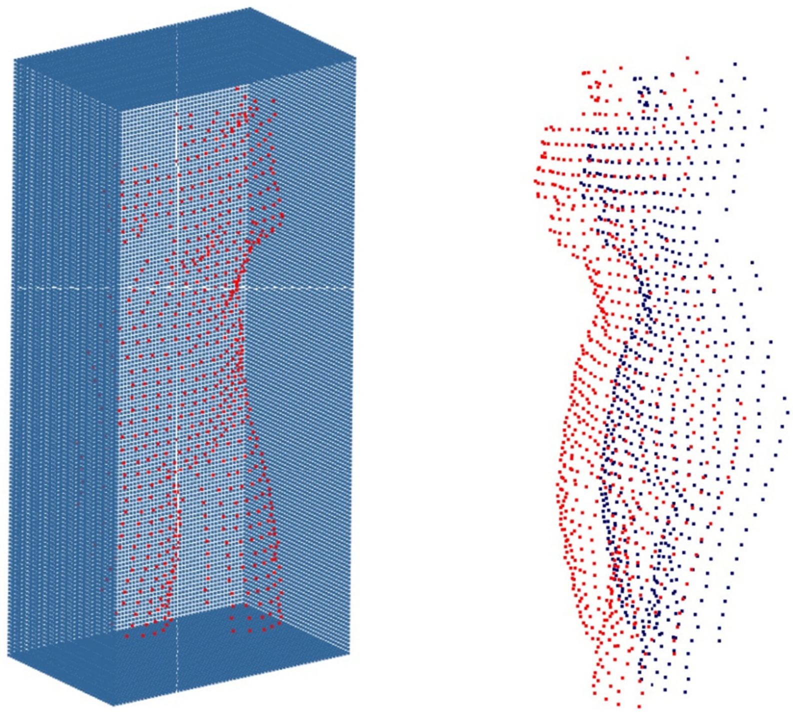

Fig 11. Representation of modified data – the original data are red and the supplemented data are blue color.

The application of both methods took only a few minutes, the created models are on figure 12.

It was made simulation of the program behavior by the creation of narrow object models, to detect the convenient choosing of the distance *b*. Four data sets with the different density and configuration of points were chosen. In the first three cases the software created the correct model of the rectangle. In the fourth case it didn´t manage to create the model of object (Fig. 13). In some parts of the rectangle the vector of velocity directs to the points of opposite side of object. From this reason it is not possible to create model because the vector causes the deformation parts of the front side and these parts are pulled to the points of back side. This phenomenon is caused by the fact that the point situated on back side is more closely than points situated on the front side. The points of the data set are green, the probable line of the object model is blue and the problematic part is in the red circle (Fig. 14).

Fig. 12 Models of the part of statue created by two solutions

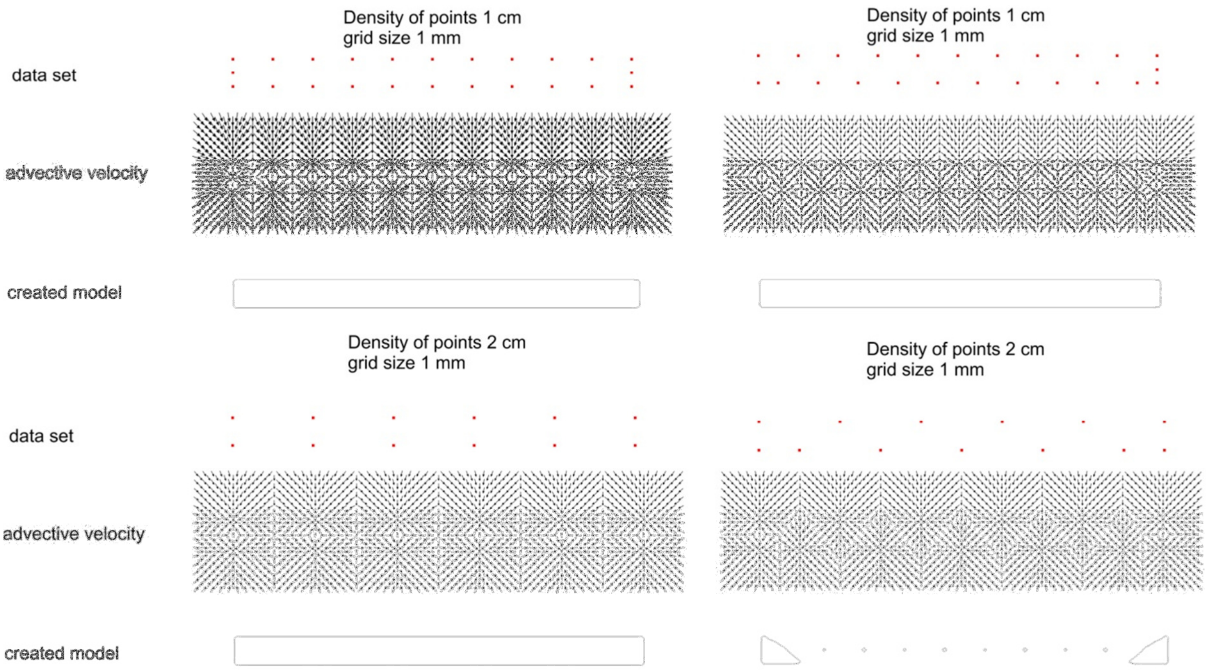

Fig. 13 Creation of narrow object models

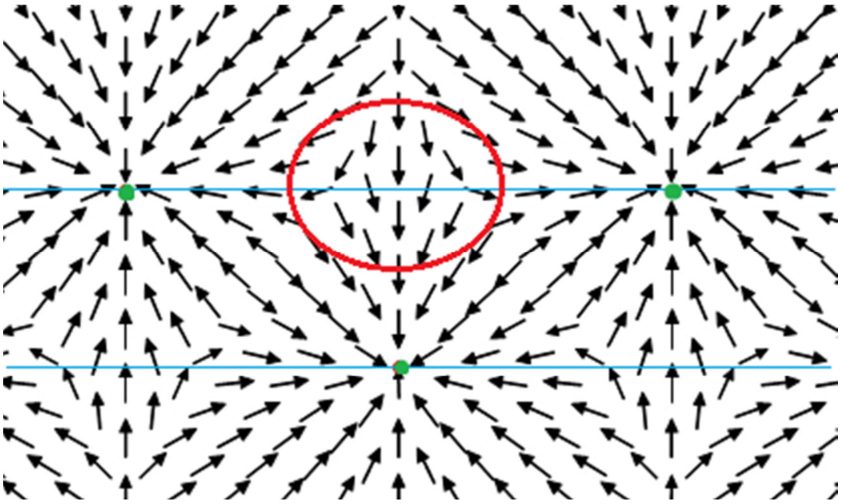

Fig. 14 Detail of the velocity vector anomalia

The choice of the distance *b* mainly depends on the configuration of the data points. Resulting from this experiment the distance *b* must be bigger than the biggest distance between neighboring points of the original data set.

5. CONCLUSION

The paper presents the new method for model creation based on the LSM. The developed procedure depends on the computation of the distance function to the data set. The LSM is used as a numerical tool to deform and construct surfaces on fixed rectangular grid. For computing the distance function the fixing algorithm is used.

The developed procedure is effective especially by model creation from small density data sets. Commercial software often fails by the model creation from this type of data. The application of the LSM takes view minutes by the data sets with high density. The developed procedure reached very good results from the data obtained by close range photogrammetry method, also.

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BIOGRAPHICAL NOTES

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