Automated Model Creation from TLS Data

Jana Haličková – Alojz Kopáčik

Marrakech, FIG WW, May 2011

Topics

- Software
- Mathematical model
- Numerical solution
- Application
- Analysis - model quality
- Conclusion

Marrakech, FIG WW, May 2011
Automated Model Creation from TLS Data

Different methods

• TIN

• Non-Uniform Rational B-spline Surfaces (NURBS)

• Geometrical entities (elements) – sphere, cylinder, cube,...

Marrakech, FIG WW, May 2011

Automated Model Creation from TLS Data

2 Model creation using the level set method

• Level set equation is solve – include potential function

• Boundary search in direction of the gradient vectors of the potential function

• advantage of LSM - simply way to change the boundary topology

• Broad application in the field of natural sciences (maths, physic, biology,...) and computer graphics

Marrakech, FIG WW, May 2011
2.1 Mathematical model

Consist from 2 partial differential equations

The first partial differential equation is the Eikonal equation, which solve the distance function

\[ \frac{d}{dt} + |\nabla d| = 1 \]

\[ d(x,t) = 0 \quad x \in \Omega_0 \subset \Omega. \]

where 
- \( d \) distance function
- \( \Omega_0 \) set of measured points
- \( \Omega \) measuring (working) space
- \( x \) point of the surface

The second differential equation is the level set equation

\[ u_t + \nabla g \cdot \nabla u = 0, \]

where 
- \( u \) is the calculated level set function
- \( g \) is equall to the distance function \( d \).
2.2 Numerical solution

The numerical solution of LSM consists of 3 steps:

- **To solve the 1. PDE** – search for a fast algorithm for calculation of the distance function (for all points in data set and all grid points)
- **To find the initial function**
- **To solve the 2. PDE** – generate the final model (best fit surface) from the measured data

Marrakech, FIG WW, May 2011
calculation - using the Fixing method

Rouy – Tourin Scheme completed by fixation generate in each step n the distance function $d_{i,j,k}^n$ for all grid points

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

where

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

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

The scheme is stable for $\tau_D \leq h_D/2$.

Marrakech, FIG WW, May 2011
Definition of the initial function

two possibilities:
• Function (shape) inside the measured data set (space)
• Function (shape) outside the measured data set (space)

Build the file with all grid points in the initial space.

Set the value $\beta$ for definition of the local boundary.

Calculate the distance function $d$ of all neighbour grid points. Grid points, which $d > \beta$ will be included to the file. The procedure is stopped, when this calculation is made for all grid points of the initial space.
Determination of $\beta$

**Correct**

**Non-correct**

Automated Model Creation from TLS Data

**Solution of the second PDE**

Using the upwind principle, could be used the approximation

$$u^*_{i,j,k} = u_{i,j,k} - \frac{\tau_{i,j,k}}{h_{i,j,k}} \left[ \max \left( D_{i,j,k} G_1, 0 \right) u^*_{i,j,k} - u^*_{i,j,k+1} \right] + \min \left( D_{i,j,k} G_1, 0 \right) u^*_{i,j,k} - u^*_{i,j,k+1} + \min \left( D_{i,j,k} G_2, 0 \right) u^*_{i,j,k} - u^*_{i,j,k+1}$$

where $u$ is the initial function.

This scheme is stable for $\tau_{i,j,k} \leq h_{i,j,k}/2$.
The differences $D_{ij,k}^x$, $D_{ij,k}^y$, and $D_{ij,k}^z$ build the vector space, where the vectors generated in grid points are oriented to the calculated surface. The calculated surface build the boundary between the vectors of different orientation. The initial function which is changed by iteration in the direction of the vectors and is stopped at the boundary.

2.3 Results of experiments

Base the developed procedure was written the routine (software) in C++:

- Was used for model creation of three different objects
- All calculation were made with notebook of standard quality (power)
- Graphical presentation of results was made in Golden Software Voxler.
Automated Model Creation from TLS Data

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

---

Half cylinder
Sculpture
Vertebra

Marrakech, FIG WW, May 2011

---

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

---

Half cylinder
Geomagic Studio
LSM model

- No points: 356
- $h_D = h_S = 0.1 \text{ mm}$, $\tau_D = \tau_S = h_D/2$
- No elements in $\Omega$: $n_x = 120, n_y = 80, n_z = 60$

Marrakech, FIG WW, May 2011
Automated Model Creation from TLS Data

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

Initial function - outside

Initial function - inside

Marrakech, FIG WW, May 2011

LSM model after 300 iterations

LSM model after 300 iterations

100 iterations
300 iterations
400 iterations

Marrakech, FIG WW, May 2011

19

20
Automated Model Creation from TLS Data

Model of vertebra

Photogrammetric

Geomagic Studio

Marrakech, FIG WW, May 2011

1 Software for model creation
2 Model creation using the level set method
2.1 Mathematical model
2.2 Numerical solution
2.3 Results of experiments
2.4 Model quality
2.5 New mathematical model
3 Conclusion

1 Software for model creation
2 Model creation using the level set method
2.1 Mathematical model
2.2 Numerical solution
2.3 Results of experiments
2.4 Model quality
2.5 New mathematical model
3 Conclusion

LSM model

- No points: 746
- \( h_D = h_S = 1 \text{ mm}, \quad \tau_S = \tau_D = h_D/2, \)
- No elements in \( \Omega \) : \( n_X = 100, \ n_Y = 70, \ n_Z = 95. \)
- the initial function determined outside for \( \beta = 0.9 \)
- model after 20 and 300 iterations

Marrakech, FIG WW, May 2011
 Automated Model Creation from TLS Data

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

- initial function outside for $\beta = 6.5$
- model after 10 and 20 iterations

Marrakech, FIG WW, May 2011

Anomalia of the vector space

Marrakech, FIG WW, May 2011
Automated Model Creation from TLS Data

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

Skener Comet Steinbechler, hustota bodov redukovaná na 3 mm a 2 mm,

Pre hustotu bodov 3 mm veľkosť mriežky 0.5 mm

Modely vytvorené v Geomagic Studio a model vytvorený naším programom

Marrakech, FIG WW, May 2011
Sculpture
Geomagic Studio model

Measured data
Initial function - block
Initial function – copy of meas. data

h_D = h_S = 0.5 mm, \( \tau_S = \tau_D = h_D/2 \),
No elements in \( \Omega \) : \( n_x = 70, n_y = 55, n_z = 150 \).

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

Marrakech, FIG WW, May 2011
1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

Automated Model Creation from TLS Data

LSM model after 400 iteration – block initial function (outside)

Automated Model Creation from TLS Data

LSM model after 400 iterations – initial function – copy of data
Automated Model Creation from TLS Data

2.4 Model quality

The model accuracy and quality is influenced by two factors:

- The accuracy of the distance function
- The grid density $h_0$
The accuracy of the distance function

\[ \sigma = \sqrt{\frac{\sum E^2}{n}} \]

<table>
<thead>
<tr>
<th>Measured point density [mm]</th>
<th>( h_0 ) [mm]</th>
<th>( \sigma ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>0.3</td>
<td>0.124</td>
</tr>
<tr>
<td>3 mm</td>
<td>0.1</td>
<td>0.060</td>
</tr>
<tr>
<td>1 mm</td>
<td>0.1</td>
<td>0.043</td>
</tr>
<tr>
<td>1 mm</td>
<td>0.3</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Correlation between the measured point density, grid size \( h_0 \) and the accuracy of the distance function is given.
2.5 New mathematical model

According the analysis made, was the second PDE completed by the curvature of the calculated surface in the actually point. This will resulting in more smoothed surface.

\[ u_t + \nabla g \cdot \nabla u + g \nabla u \cdot \left( \frac{\nabla u}{|\nabla u|} \right) = 0 \]

The completed sheme is no more so stable so is important to define \( \tau_c \) with respect. In our case was used \( \tau_c = h_c^2/4 \), which genereate the need of higher number of iterations.
The new completed formula for the calculation of surface points:

\[ u_{i,j,k}^{\text{new}} = u_{i,j,k}^* - \frac{\delta}{h_x} \left[ \max \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k}^{\text{old}} \right) + \min \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k}^{\text{old}} \right) + \max \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k+1}^{\text{old}} \right) + \min \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k+1}^{\text{old}} \right) + \max \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k-1}^ {\text{old}} \right) + \min \left( D_{i,j,k} g,0 \right) \left( u_{i,j,k}^* - u_{i,j,k-1}^ {\text{old}} \right) \right] \]

\[ + \delta \cdot \tau \left[ \left( \varepsilon + u_{i,j,k}^* \right)^2 + \left( u_{i,j,k}^* \right)^2 \right] u_{i,j,k}^{\text{old}} + \left( \varepsilon + u_{i,j,k}^* \right)^2 + \left( u_{i,j,k}^* \right)^2 \right] u_{i,j,k}^{\text{old}} + \]

\[ + \left( \varepsilon + u_{i,j,k}^* + u_{i,j,k}^* \right)^2 - 2u_{i,j,k}^* u_{i,j,k}^* u_{i,j,k}^* - 2u_{i,j,k}^* u_{i,j,k}^* u_{i,j,k}^* - \]

\[ - u_{i,j,k}^* u_{i,j,k}^* u_{i,j,k}^* \right] \left[ \varepsilon + u_{i,j,k}^* \right]^2 + \left( u_{i,j,k}^* \right)^2 \right] \]

\( \delta \) will be from 0 to 1 and define the surface smoothing.
In case of surfaces (models) which edges, could be set boundary values for $\delta$ when this will be set eq. 0. The procedure is applied in two steps, first without calculation of $\delta$ and in second step with application of parameter $\delta$. 

Cylinder

LSM model for $\delta$ 0.00, 0.02 a 0.10 after 3000 iterations

Marrakech, FIG WW, May 2011
1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

Automated Model Creation from TLS Data

400 iterations without $\delta$ and 100 iterations with $\delta$ - boundary value $\delta=0.15$ (next slide).

Application on TLS data sets

- Point density 5 cm
- Point density 3 cm

Marrakech, FIG WW, May 2011
Automated Model Creation from TLS Data

1. Software for model creation
2. Model creation using the level set method
   2.1 Mathematical model
   2.2 Numerical solution
   2.3 Results of experiments
   2.4 Model quality
   2.5 New mathematical model
3. Conclusion

3. Conclusion
   - Automated model creation
   - High variability
   - Possibility to use for different data sets
   - Universal for all type of objects (surfaces)
   - Graphical interpretation possible in different software
CONFERENCE TOPICS

New methods and tools to support the effective data collection were developed in the last ten years worldwide. Many of the producers are coming with new technology at market, which determined the revolutionary evolution of methodology. The questions of effective application and usage of new technology, their reliability and operability must be discussed actually. The quality of these instruments and data processing software is the second but very important question too. The aim of the conference is to bring together professionals in the field of engineering surveying and facility management to discuss the new technologies, their applicability and operability. The conference discussion will be focused on presenting-day questions of laser scanning, usage of laser scanners in industry surrounding, for measurement of dynamic deformations, data acquisition and processing.

The topics of the conference are the following:

- actual tasks of engineering surveying,
- trends in methodology and technology development,
- engineering surveying procedures for industry (power plants, nuclear facilities, etc.),
- industrial metrology in production, assembling and finishing processes in-its calibration of used technology,
- lasers and laser measurement systems, with special emphasis on terrestrial laser scanning,
- new technology for deformation measurement,
- data integration in facility management,
- local information systems for cities and industrial applications,
- permanent GSSS networks, application in industry projects.
Automated Model Creation from TLS Data

Thank you for your attention!

Marrakech, FIG WW, May 2011