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Automated Model Creation from TLS Data

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Marrakech, FIG WW, May 2011

1

Automated Model Creation from TLS Data

Topics

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

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2

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**

Different methods

- TIN
- Non-Uniform Rational B-spline Surfaces (NURBS)
- Geometrical entities (elements) – sphere, cylinder, cube, ...

Marrakech, FIG WW, May 2011 3

Automated Model Creation from TLS Data

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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 4

2.1 Mathematical model

Consist from 2 partial differential equations

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

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

where d distance function
Ω_0 set of measured points
Ω measuring (working) space
x point of the surface

Automated Model Creation from TLS Data

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2 Model creation using the level set method
2.1 Mathematical model
2.2 Numerical solution
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The second diferential 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 consist from 3 steps:

- **To solve the 1. PDE** – search for 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

Automated Model Creation from TLS Data

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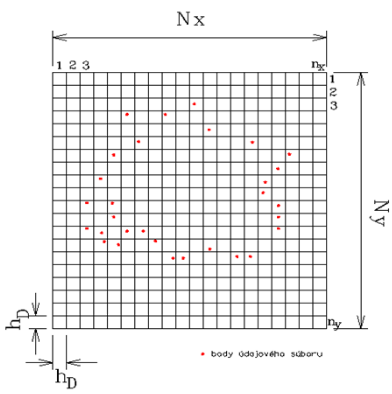
Solution of the first PDE

Space discretization - definition of the grid density h_D

Initialization – determines the distances between the measured points and the grid points (not changed during the model creation)



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

$$d^{n+1}_{i,j,k} = d^{n}_{i,j,k} + \tau_D - \frac{\tau_D}{h_D}\sqrt{\max(M^{-1,0,0}_{i,j,k}, M^{1,0,0}_{i,j,k}) + \max(M^{0,-1,0}_{i,j,k}, M^{0,1,0}_{i,j,k}) + \max(M^{0,0,-1}_{i,j,k}, M^{0,0,1}_{i,j,k})}$$

where $$M^{p,q,r}_{i,j,k} = (\min(d^{n}_{i+p,j+q,k+r} - d^{n}_{i,j,k}, 0))^2,$$

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

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

For all grid points $x_{i,j}$, which position is not fixed by the initial function or during the calculation is calculated the new solution $d_{i,j}{}^{n+1}$ using Rouy – Tourin Scheme.

When the difference between the new and old solution is smaler as the required value, the point will be fixed and not included to the next solution (step).

The calculation is finished when all points achaive the fixed stay.

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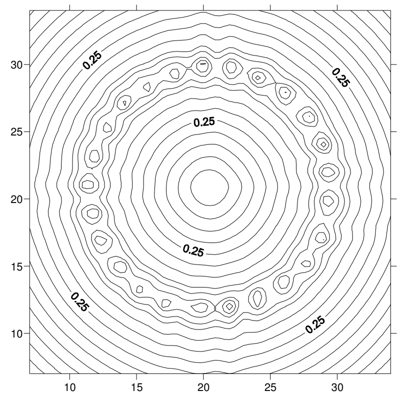
Initial data set

Distance function of the initial data set



Automated Model Creation from TLS Data

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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 β 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.

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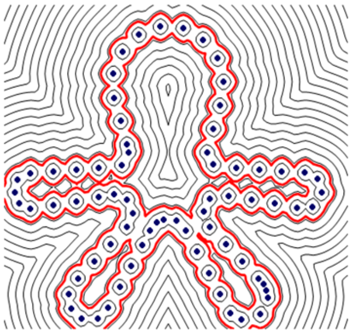
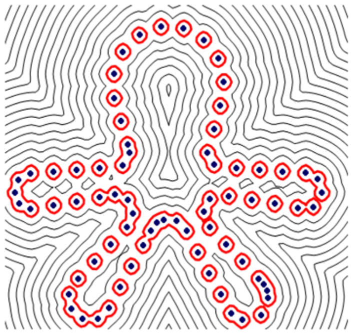
Determination of β

correct



non- correct



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Solution of the second PDE

Using the upwind principle, could be use the aproximation

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

where *u* is the initial function.

This scheme is stable for $\tau_S \leq h_S/2$.

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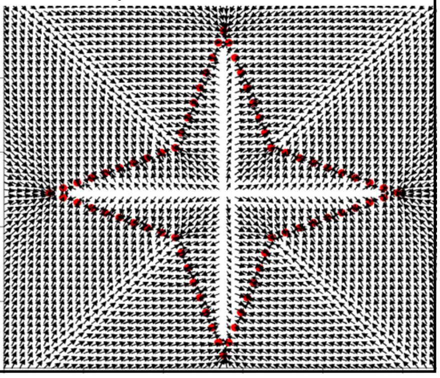
The differences $D^{x}_{i,j,k}g$, $D^{y}_{i,j,k}g$ a $D^{z}_{i,j,k}g$ build the vector space, where the vectors generated in grid points are oriented to the calculated surface. The calculated surface build the boundary between the vectors of different orientation. The initial function which is changed by iteration in the direction of the vectors and is stopped at the boundary.



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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.

Marrakech, FIG WW, May 2011 16

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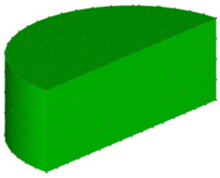
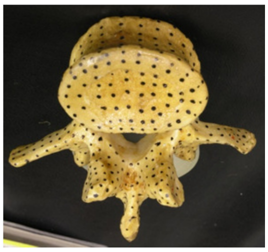
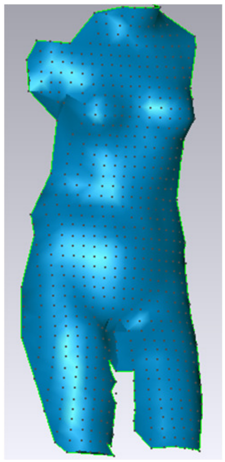
Half cylinder



Vertebra



Sculpture



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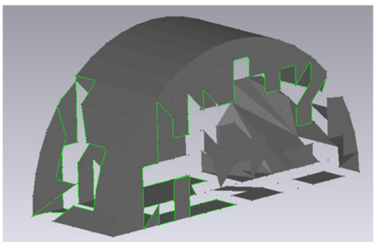
Half cylinder

Geomagic Studio



LSM model

- *No points : 356*
- $h_D = h_S = 0.1$ *mm*, $\tau_S = \tau_D = h_D/2$
- *No elements in* Ω : $n_X = 120$, $n_Y = 80$, $n_Z = 60$.

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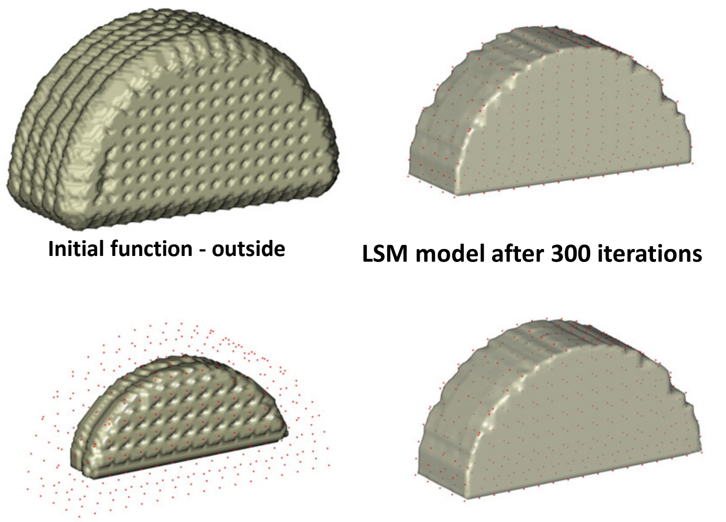

Initial function - outside | **LSM model after 300 iterations**

Initial function - inside | **LSM model after 300 iterations**

Marrakech, FIG WW, May 2011 19

Automated Model Creation from TLS Data

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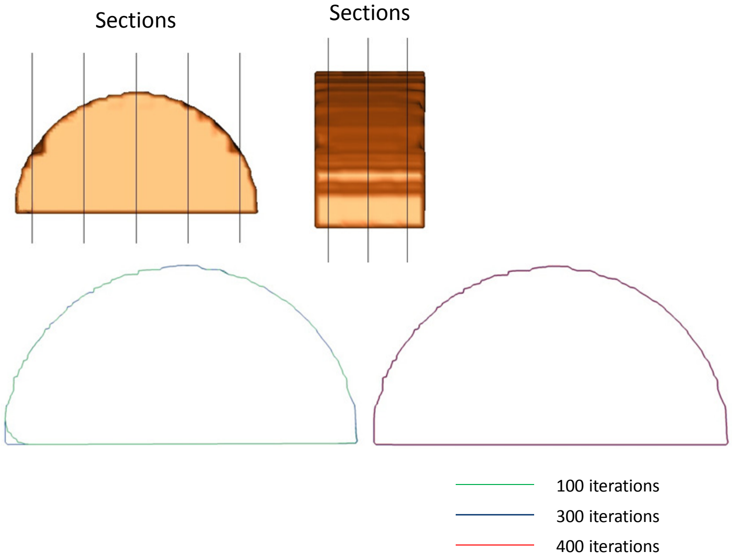
2 **Model creation using the level set method**
2.1 Mathematical model
2.2 Numerical solution
2.3 Results of experiments
2.4 Model quality
2.5 New mathematical model
3 **Conclusion**



Marrakech, FIG WW, May 2011 20

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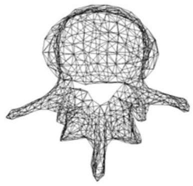
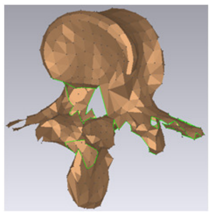
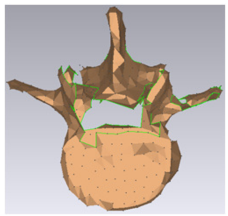
Model of vertebra

Photogrammetric





Geomagic Studio

Automated Model Creation from TLS Data

1 **Software for model creation**
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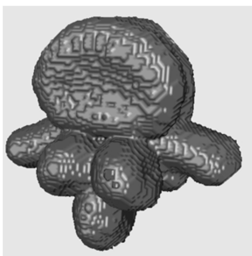
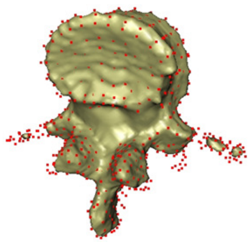
LSM model

- *No points:* *746*
- $h_D = h_S = 1$ *mm*, $\tau_S = \tau_D = h_D/2$,
- *No elements in* Ω *:* $n_X = 100$, $n_Y = 70$, $n_Z = 95$.

- the initial function determined outside for β=0.9
- model after 20 and 300 iterations





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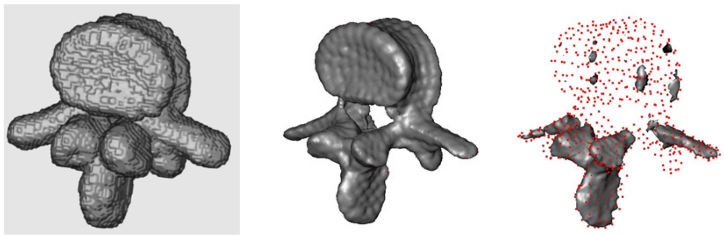
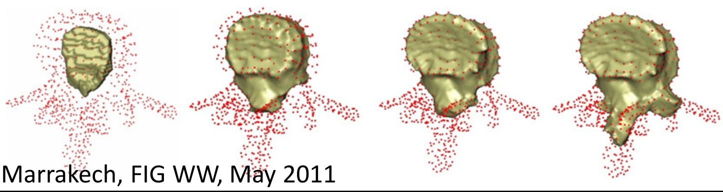
- initial function outside for β = 6.5
- model after 10 and 20 iterations



- initial function inside
- model after 40, 100, and 800 iterations



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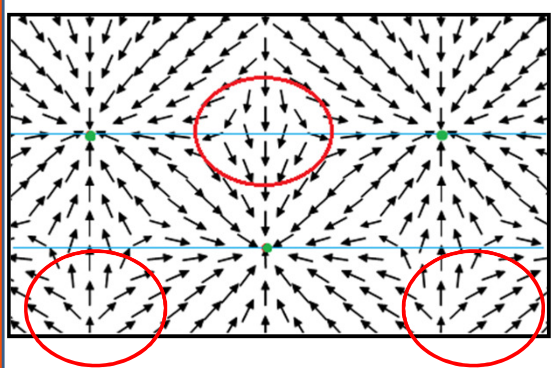
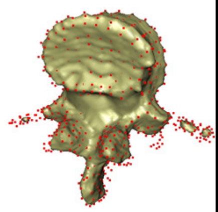
Anomalia of the vector space





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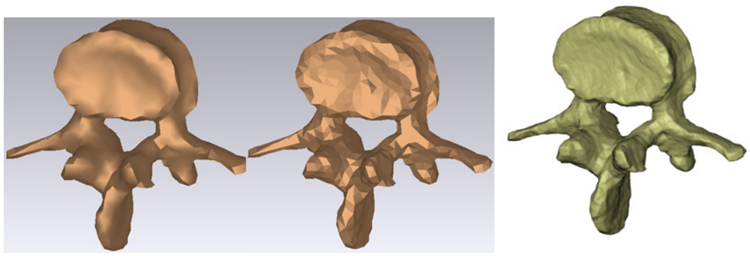
Skener Comet Steinbechler,
hustota bodov redukovaná na 3 mm a 2 mm,

Pre hustotu bodov 3 mm veľkosť mriežky 0.5 mm
Modely vytvorené v Geomagic Studio a model vytvorený naším programom



Automated Model Creation from TLS Data

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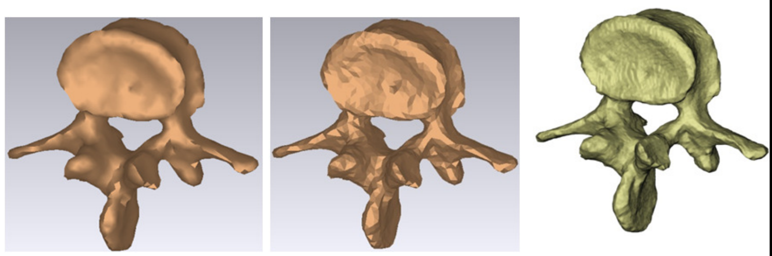
2.1 Mathematical model
2.2 Numerical solution
2.3 Results of experiments
2.4 Model quality
2.5 New mathematical model
3 **Conclusion**

Pre hustotu bodov 2 mm veľkosť mriežky 0.4 mm
Modely vytvorené v Geomagic Studio a model vytvorený naším programom



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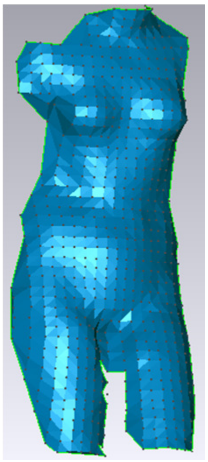
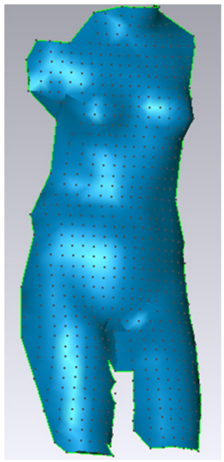
Sculpture

Geomagic Studio model





Automated Model Creation from TLS Data

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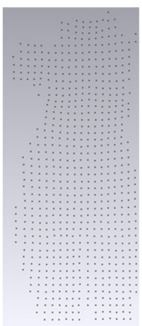
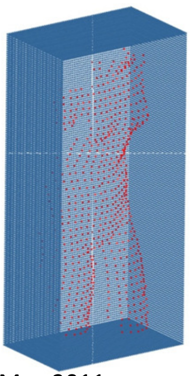
LSM model

- *$h_D = h_S = 0.5$ mm, $\tau_S = \tau_D = h_D/2$,*
- *No elements in Ω : $n_X = 70$, $n_Y = 55$, $n_Z = 150$.*

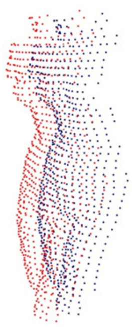
Measured data



Initial function - block



Initial function – copy of meas. data



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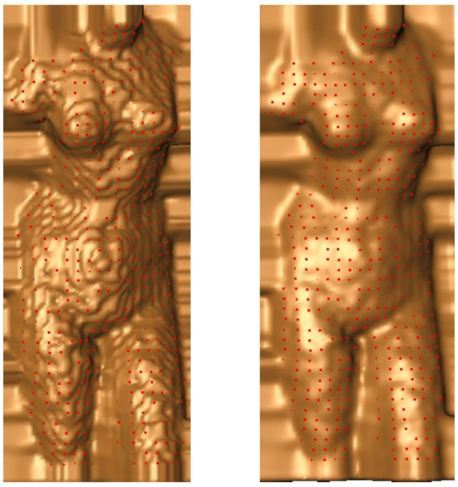
LSM model after 400 iteration – block initial function (outside)



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
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LSM model after 400 iterations – initial function – copy of data

Automated Model Creation from TLS Data

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2.1 Mathematical model
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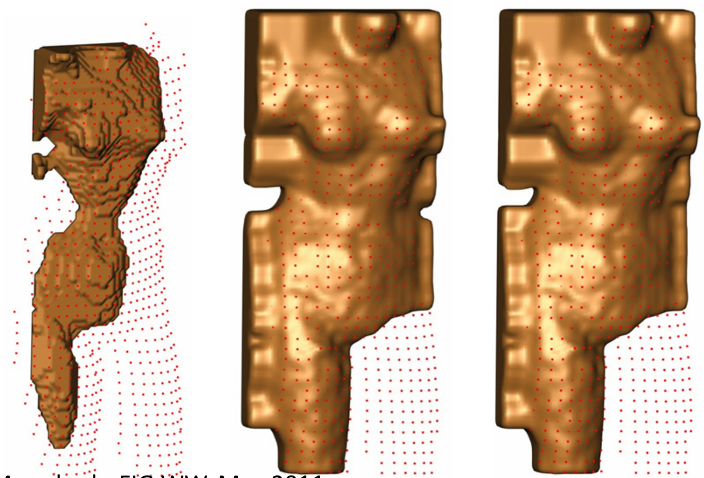
Odhad vo vnútri objektu a model sochy po 100 a 900 iteráciách



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31

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

2.4 Model quality

The model accuracy and quality is influenced by two factors:

- The accuracy of the distance function
- The grid density h_D

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32

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The accuracy of the distance function

$$\sigma = \sqrt{\frac{\sum \varepsilon\varepsilon}{n}}$$

Measured point density [mm]	h_D [mm]	σ [mm]
3 mm	0.3	0.124
3 mm	0.1	0.060
1 mm	0.1	0.043
1 mm	0.3	0.071

Correlation between the measured point density, grid size h_D and the accuracy of the distance function is given.

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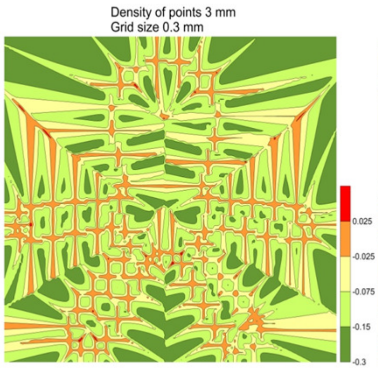
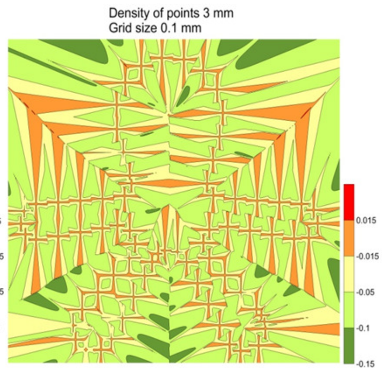
Distance function for different grid size





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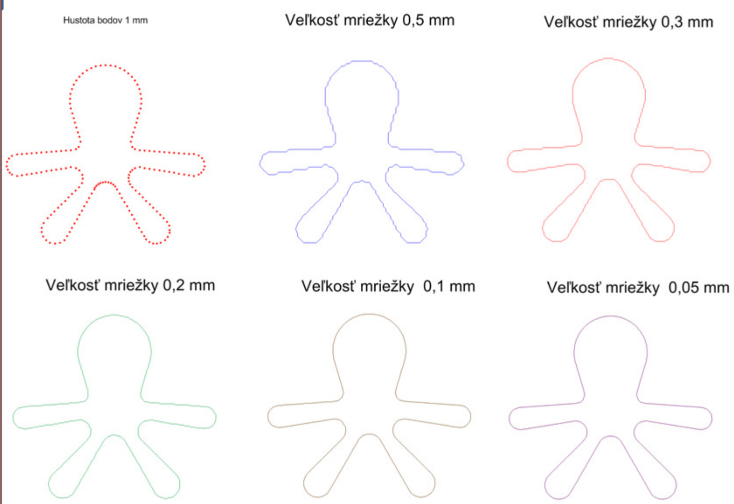
Voľba parametra h_D



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
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2.5 Nový matematický 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.

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

The completed sheme is no more so stable so is important to define τ_S with respect. In our case was used $\tau_S = h_S^2/4$, which generete the need of higher number of iterations.

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The new completed formula for the calculation of surface points:

$$
\begin{aligned}
u_{i,j,k}^{n+1} = u_{i,j,k}^{n} - \frac{\tau_S}{h_S} [& \max\left(D_{i,j,k}^{x} g, 0\right)\left(u_{i,j,k}^{n} - u_{i-1,j,k}^{n}\right) + \min\left(D_{i,j,k}^{x} g, 0\right)\left(u_{i+1,j,k}^{n} - u_{i,j,k}^{n}\right) + \\
& + \max\left(D_{i,j,k}^{y} g, 0\right)\left(u_{i,j,k}^{n} - u_{i,j-1,k}^{n}\right) + \min\left(D_{i,j,k}^{y} g, 0\right)\left(u_{i,j+1,k}^{n} - u_{i,j,k}^{n}\right) + \\
& + \max\left(D_{i,j,k}^{z} g, 0\right)\left(u_{i,j,k}^{n} - u_{i,k,k-1}^{n}\right) + \min\left(D_{i,j,k}^{z} g, 0\right)\left(u_{i,j,k+1}^{n} - u_{i,j,k}^{n}\right)] + \\
& + \delta \cdot \tau_S [\left(\varepsilon + \left(u_{i,j,k}^{y}{}^{n}\right)^2 + \left(u_{i,j,k}^{z}{}^{n}\right)^2 \right) u_{i,j,k}^{xx}{}^{n} + \left(\varepsilon + \left(u_{i,j,k}^{x}{}^{n}\right)^2 + \left(u_{i,j,k}^{z}{}^{n}\right)^2 \right) u_{i,j,k}^{yy}{}^{n} + \\
& + \left(\varepsilon + u_{i,j,k}^{x}{}^{n} + u_{i,j,k}^{y}{}^{n}\right) u_{i,j,k}^{zz}{}^{n} - 2 u_{i,j,k}^{x}{}^{n} u_{i,j,k}^{y}{}^{n} u_{i,j,k}^{xy}{}^{n} - 2 u_{i,j,k}^{x}{}^{n} u_{i,j,k}^{z}{}^{n} u_{i,j,k}^{xz}{}^{n} - \\
& - u_{i,j,k}^{y} u_{i,j,k}^{z} u_{i,j,k}^{yz} \ ] / \varepsilon + \left(u_{i,j,k}^{x}\right)^2 + \left(u_{i,j,k}^{y}\right)^2 + \left(u_{i,j,k}^{z}\right)^2
\end{aligned}
$$

δ will be from 0 to 1 and define the surface smoothing.

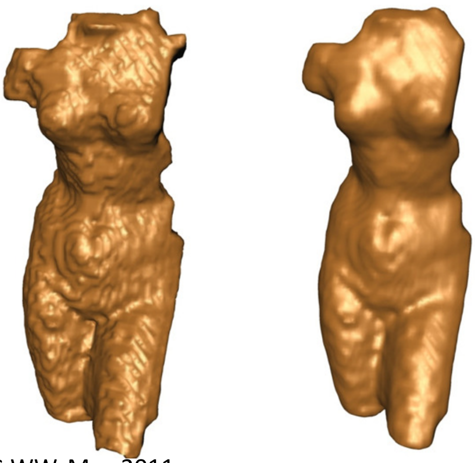
Marrakech, FIG WW, May 2011 37

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

Sculpture

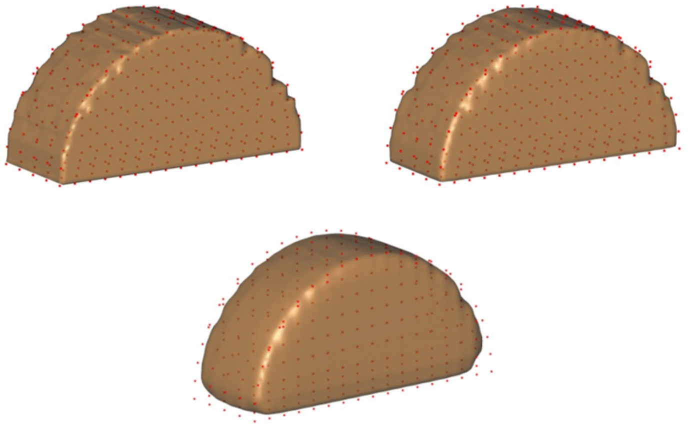
LSM model for δ=0.00 and δ=0.25 after 300 iteration



Marrakech, FIG WW, May 2011 38

Cylinder

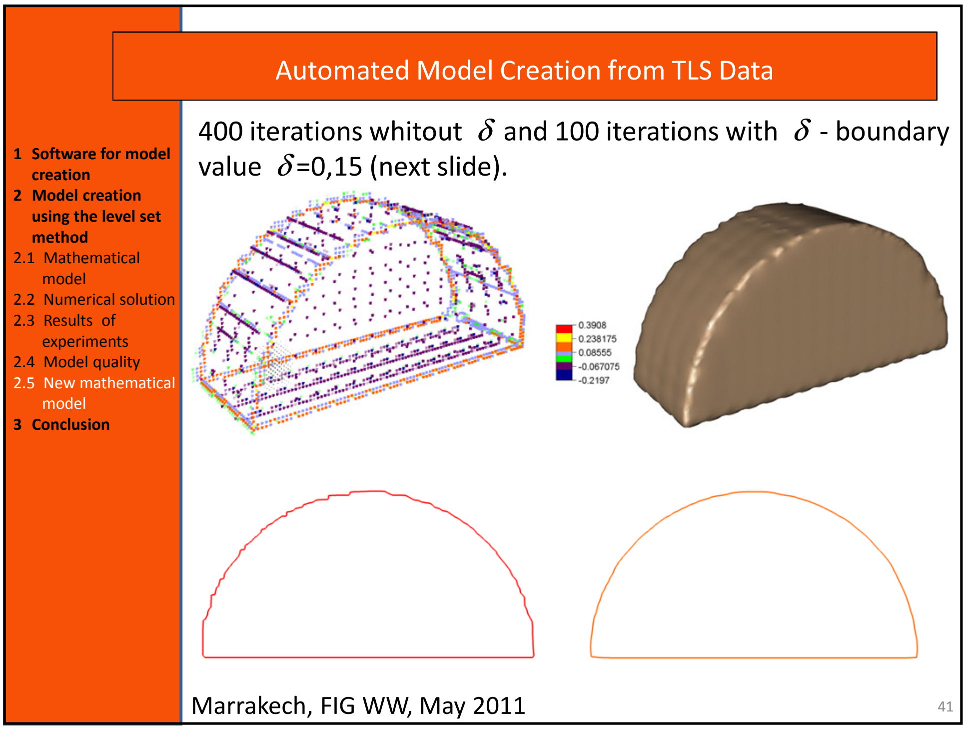
LSM model for δ 0.00, 0.02 a 0.10 after 3000 iterations



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**

In case of surfaces (models) which edges, could be set boundary values for δ when this will be set eq. 0. The procedure is applicated in two steps, first whitout calculation of δ and in second step with application of parameter δ.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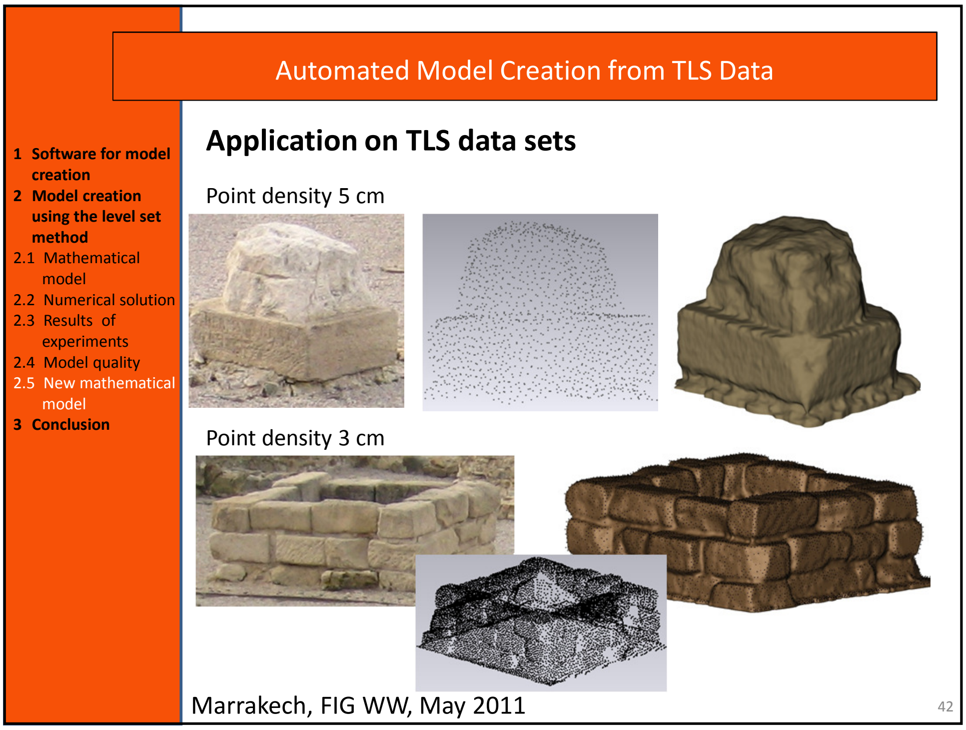
400 iterations whitout δ and 100 iterations with δ - boundary value δ=0,15 (next slide).
0.3908
0.238175
0.08555
-0.067075
-0.2197
Marrakech, FIG WW, May 2011
41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Application on TLS data sets
Point density 5 cm
Point density 3 cm
Marrakech, FIG WW, May 2011
42

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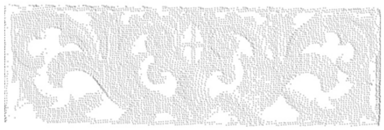

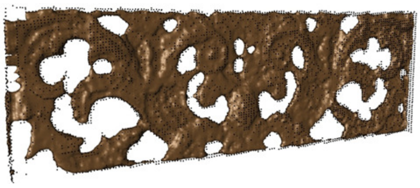

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3 Conclusion

- 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


INGEO 2011
5th International Conference on Engineering Surveying
September 22-24, 2011, Brijuni, Croatia
Home | History | Conference Topics | Programme | Scientific Committee | Registration | Accommodation
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Faculty of Civil Engineering
Department of Surveying
and
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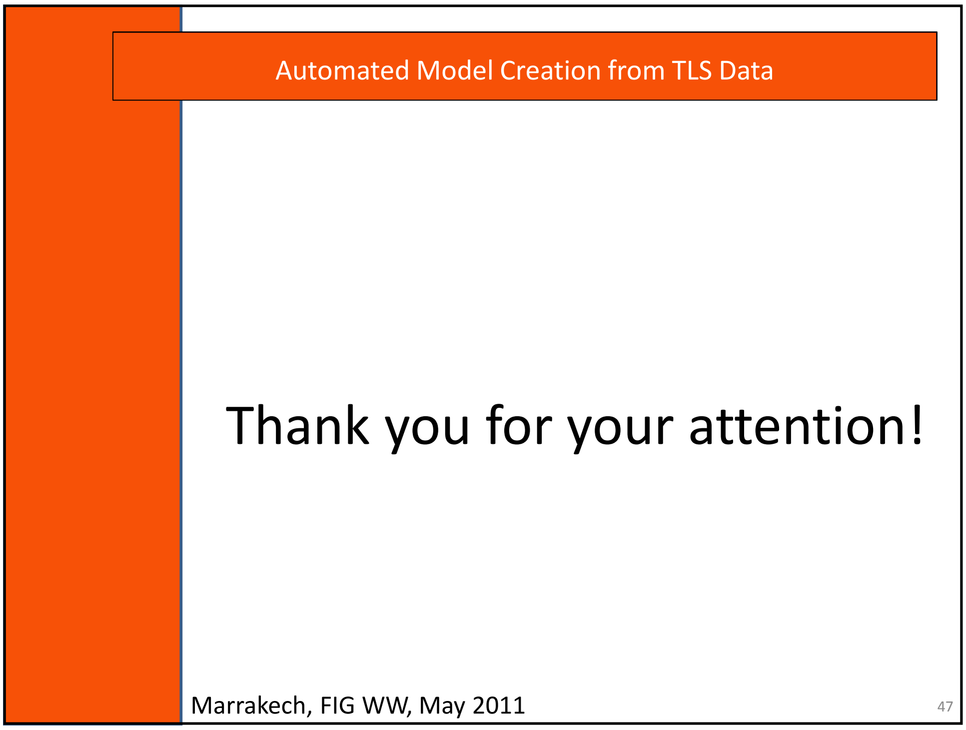
Conference Topics
New methods and tools to support the effective data collection were developed in the last ten years worldwide. Many of producers are coming with new technology at market, which determined the revolutionary evolution of methodology. The questions of effective application and usage of 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 present-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-situ 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 GNSS networks, application in industry projects.
Internet


Automated Model Creation from TLS Data
Thank you for your attention!
Marrakech, FIG WW, May 2011
47