Development of a new algorithm for automated point extraction from hyperbolic reflections in GPR data and comparison with SPOT-GPR results

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An example of cooperation between scientists from France, Germany, Italy and Serbia who started working together thanks to the COST Action TU1208

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Reasons & Related work

- Solutions for fast and accurate (automated) data extraction from GPR data are a highly interesting topic for GPR scientific community
- Approaches: Signal processing or image processing
- Image processing – time demanding, noise sensitivitty
  - Full, dense radargrams or tresholded, sparse radargrams
    - Simplification – extraction of data from hyperbolic reflections (e.g. binarization)
    - Segregation of small two-dimensional sections from a dense radargram (segments of interest - SOI) and data extraction from the hyperbolic reflections
  - Unsupervised (e.g. Hough transform) or supervised procedures (e.g., Artificial Neural Networks – ANN)

General steps of the automated algorithm

1. Detection of segments of interest (SOI)

2. Finding apexes

3. Finding points on the prongs

4. Detection and removal of interfered hyperbolas

5. Data extraction

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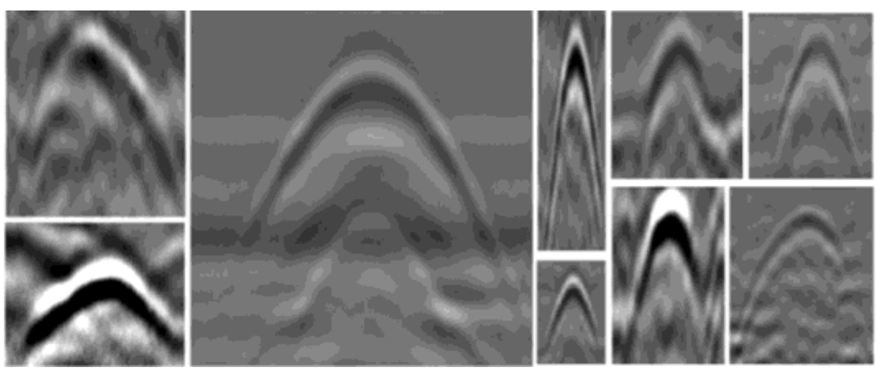
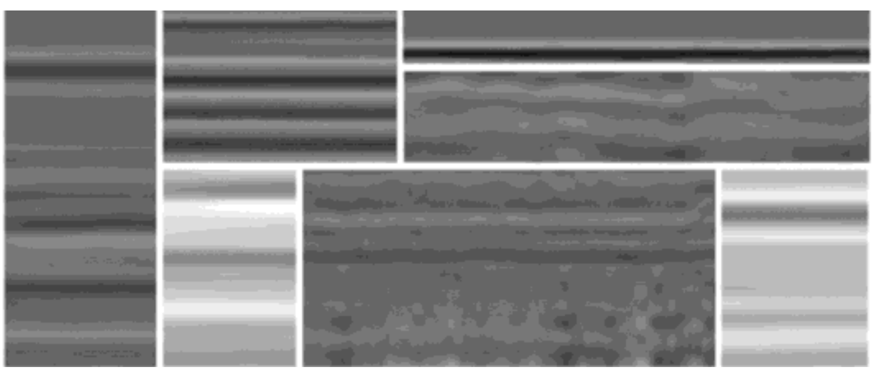
1. Detection of segments of interest (SOI)

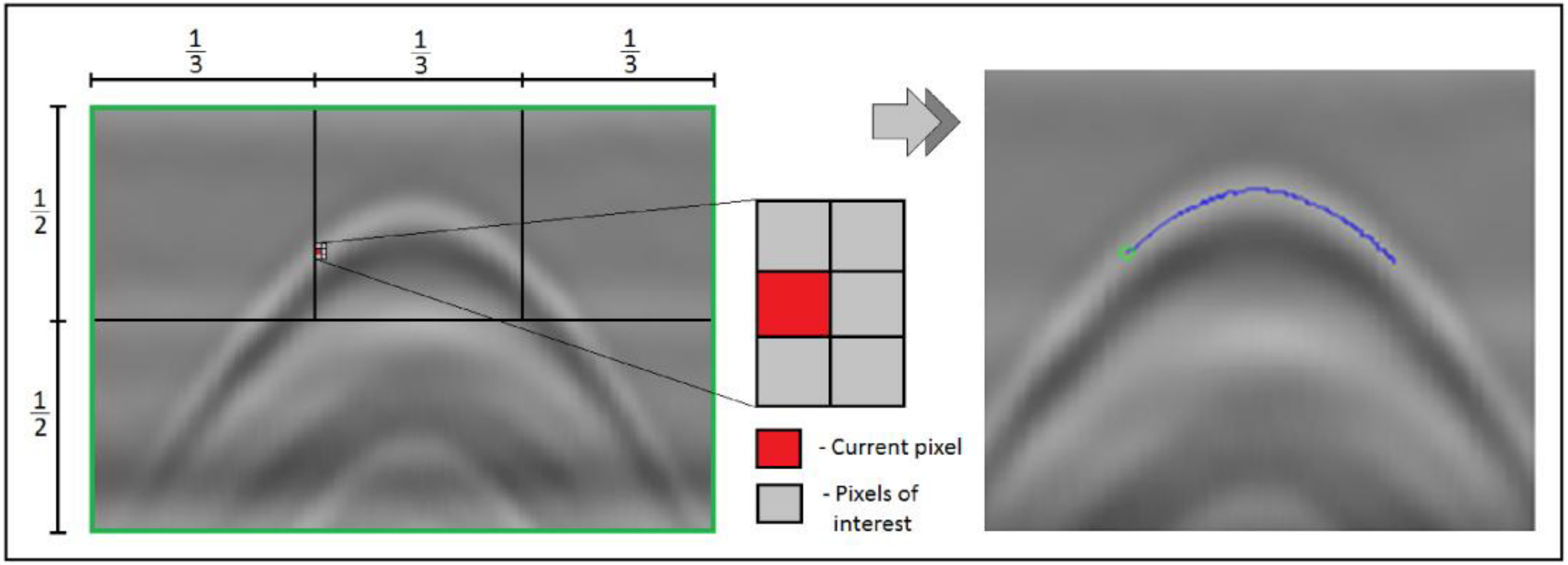
- STEP 1: Conversion to raster format using *rad2bmp*.
- STEP 2: Locating of SOI using MatLAB GUI *trainCascadeObjectDetector* (*COD)*
  - Training set: positive and negative training samples
  - Using real and/or synthetic data





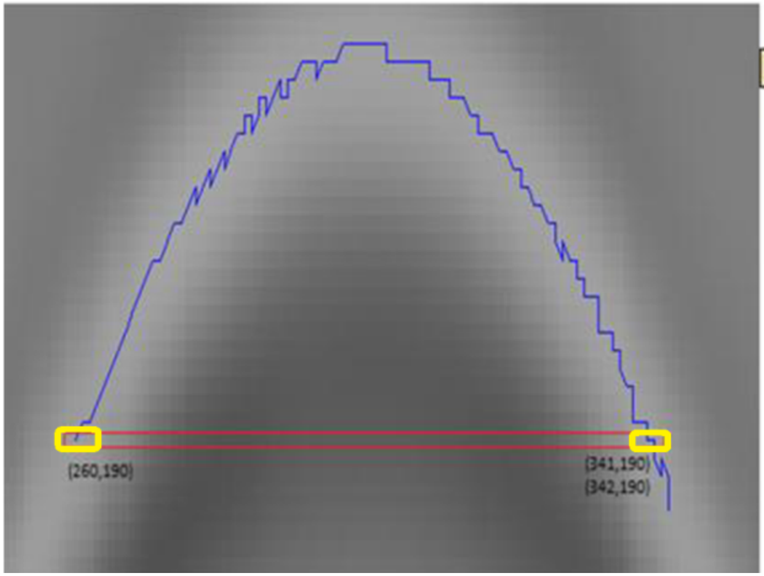
2. Finding apexes (slide 1/2)

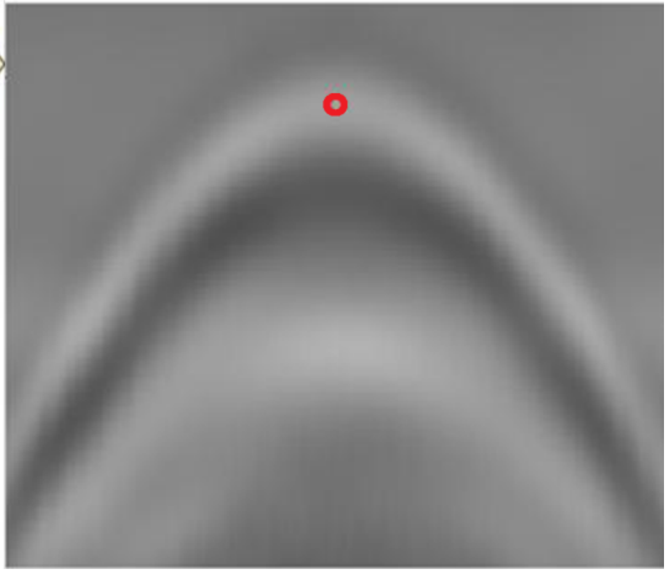
- STEP 1: Finding the initial pixel for search in SOI
- STEP 2: Forming a sub-matrix with dimensions 3x2 around of initial pixel with current pixel in the second row and the first column
- STEP 3: Finding local maximums in sub-matrix 3x2 (iteratively)



2. Finding apexes (slide 2/2)

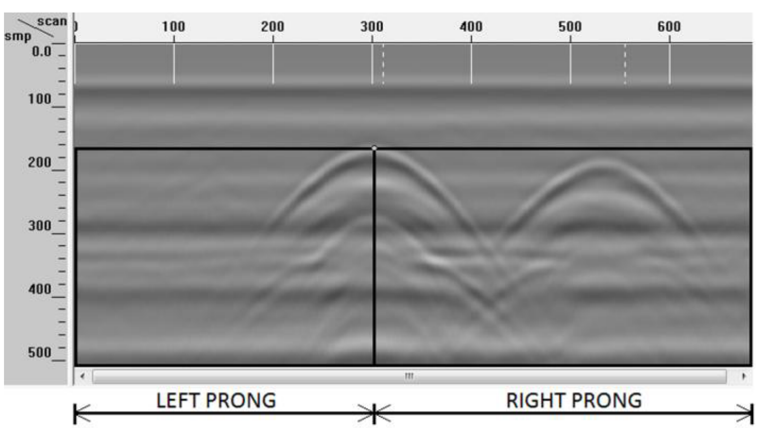
- Pixels with minimum row index indicate the row where apex is located
- Points are divided into two groups: the ones that belong to the left prong and the ones that belong to the right prong
- Sr1 and Sr2 are calculated as mean values of pixels in the bordering rows of right and left prongs (yellow zone)
- The column of the apex is calculated as the mean value of Sr1 and Sr2

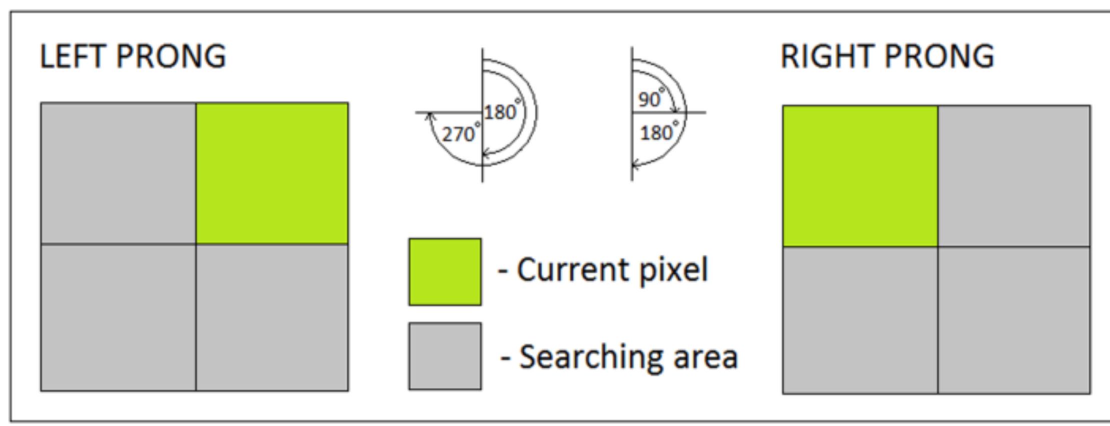




3. Detection of points on the prongs

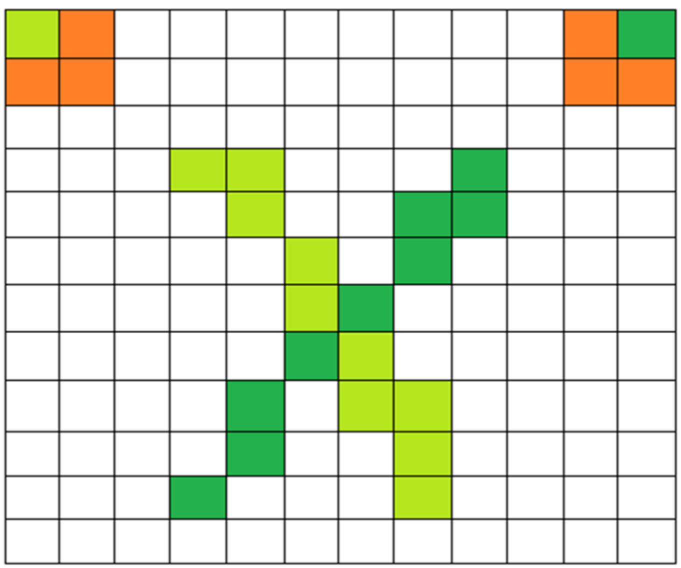
- The start of the search is
  - The upper right corner (for the left prong)
  - The upper left corner (for the right prong)
- Finding local maximum in a sub-matrix 2x2, iteratively, to the stopping criterion (pixel intensity ratio of apex point and current search window points on prong)

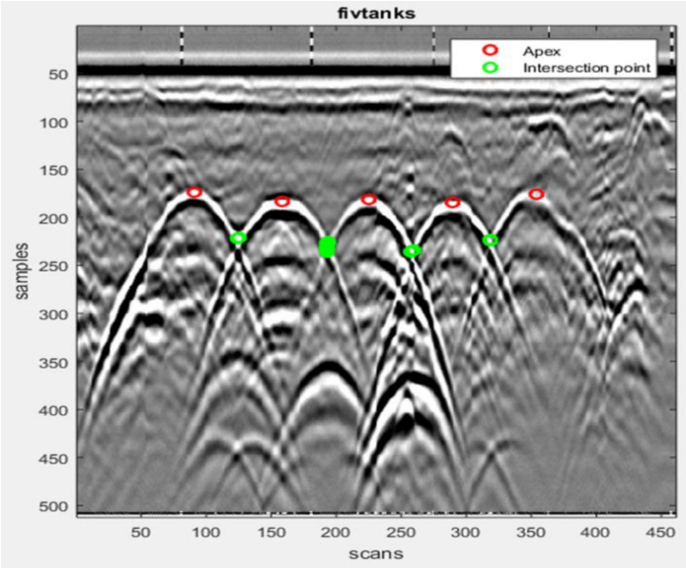




4. Detection and removal of interfered hyperbolas

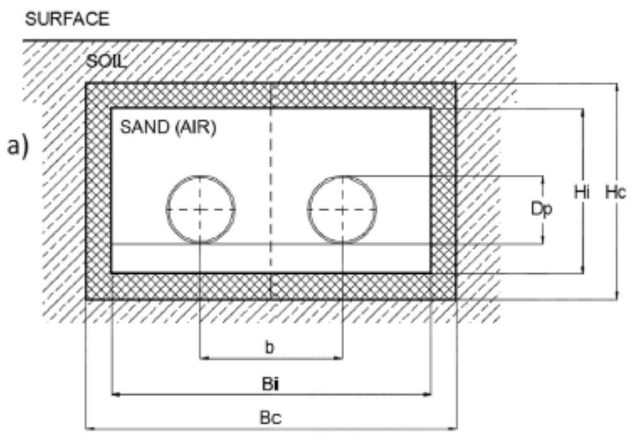
- STEP 1: Finding crossing points (maximum difference between row and column of the pixel at the position of left and right prong crossing is one)
- STEP 2: Checking whether the columns of crossing points contain apex which is located under the crossing points
- STEP 3: Eliminate interfered hyperbolas

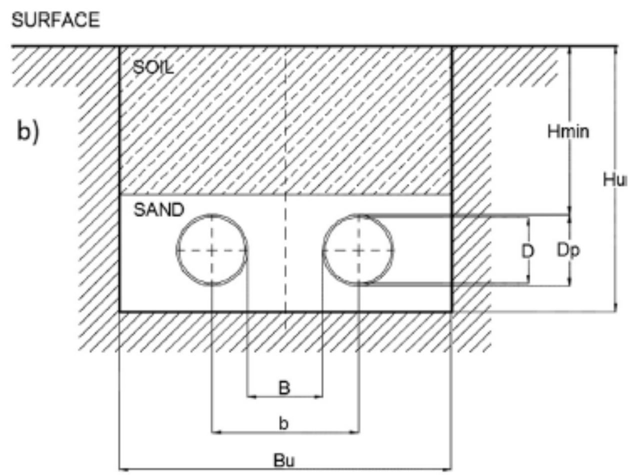


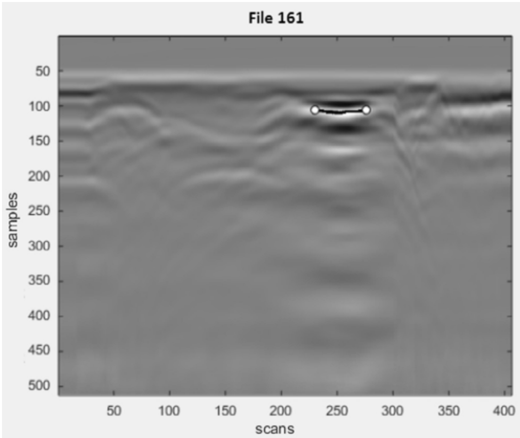


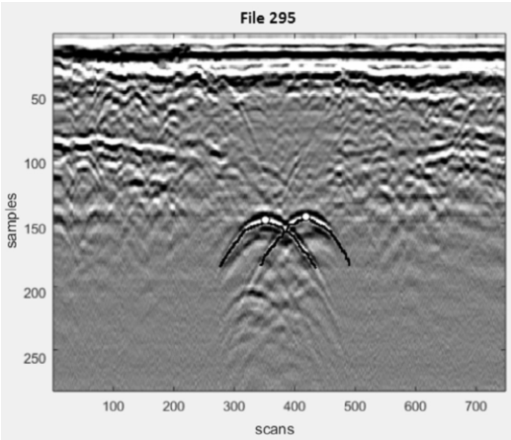
Algorithm applications on complex structures

- With minor modifications, this algorithm can also be applied to the case of district heating systems









More information

- A. Ristić, Ž. Bugarinović, M. Vrtunski, M. Govedarica, "***Point coordinate extraction from localized hyperbolic reflection in GPR data***", Journal of Applied Geophysics, Volume 144, September 2017, Pages 1-17

- A. Ristić, Ž. Bugarinović, M. Govedarica, L. Pajewski, X. Derobert, "***Verification of Algorithm for Point Extraction from Hyperbolic Reflections in GPR Data***", IWAGPR 2017, 9th International Workshop, Edinburgh, UK, June 28-30 2017, DOI: 10.1109/IWAGPR.2017.7996109

- A. Ristić, M. Vrtunski, M. Govedarica, L. Pajewski, X. Derobert, "***Automated Data Extraction from Synthetic and Real Radargrams of District Heating Pipelines***", IWAGPR 2017, 9th International Workshop, Edinburgh, UK, June 28-30 2017, DOI: 10.1109/IWAGPR.2017.7996046

- A. Ristić, Ž. Bugarinović, M. Vrtunski, M. Govedarica, D. Petrovački, "***Integration of modern remote sensing technologies for faster utility mapping and data extraction***", Construction and Building Materials, Volume 154, November 2017, Pages 1183-1198

Comparison with SPOT-GPR

The following slides show a comparative overview of the results of

1. **SPOT-GPR**: a freeware tool for target detection and localization in GPR data developed within the COST Action TU1208
2. Automated point coordinates extraction from localized hyperbolic reflections in GPR data (**APEX**)

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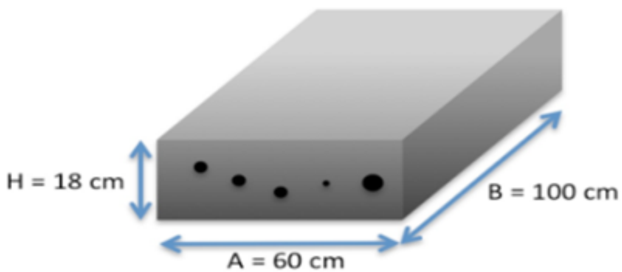
Test-case geometric model (synthetic data created using gprMax)

Concrete 1

Cells 1.1 – 1.3 can be simulated in 2D and 3D. In 2D, the concrete cell size is A x H; in 3D, the cell size is A x B x H.



Transmitter:

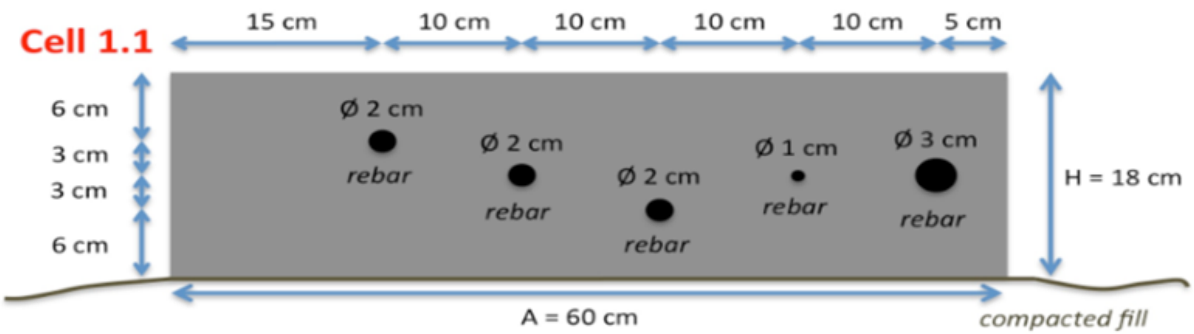
- ✓ Central frequency: f = 1.5 GHz
- ✓ Pulse time-shape: Ricker
- ✓ 2D source: line of current
- ✓ 3D source:
  - Hertzian dipole // B or // A
  - Bow tie antenna // B or // A
  - GSSI antenna

- ✓ Rx and Tx are at 2 cm from concrete-air interface
- ✓ The distance between Tx and Rx is d = 10 cm

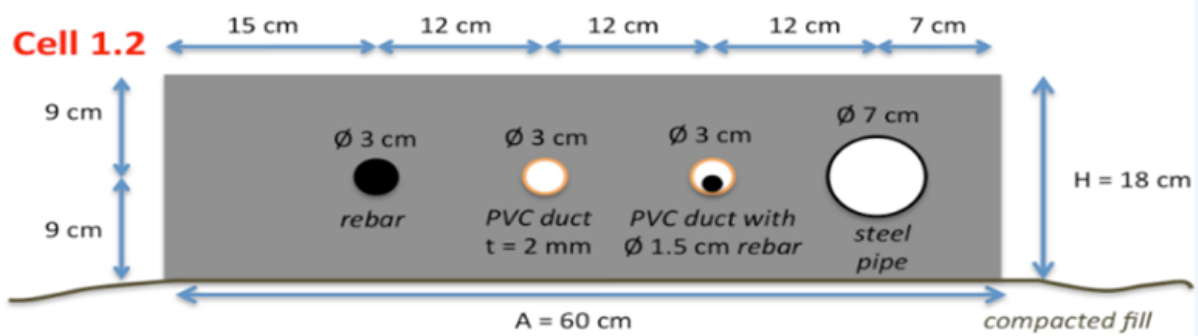
Output:

- ✓ B-Scan with step 5 mm
- ✓ A-Scan above the center of each scatterer
- ➢ Total field and back-scattered field
- ➢ Time window: 5 ns

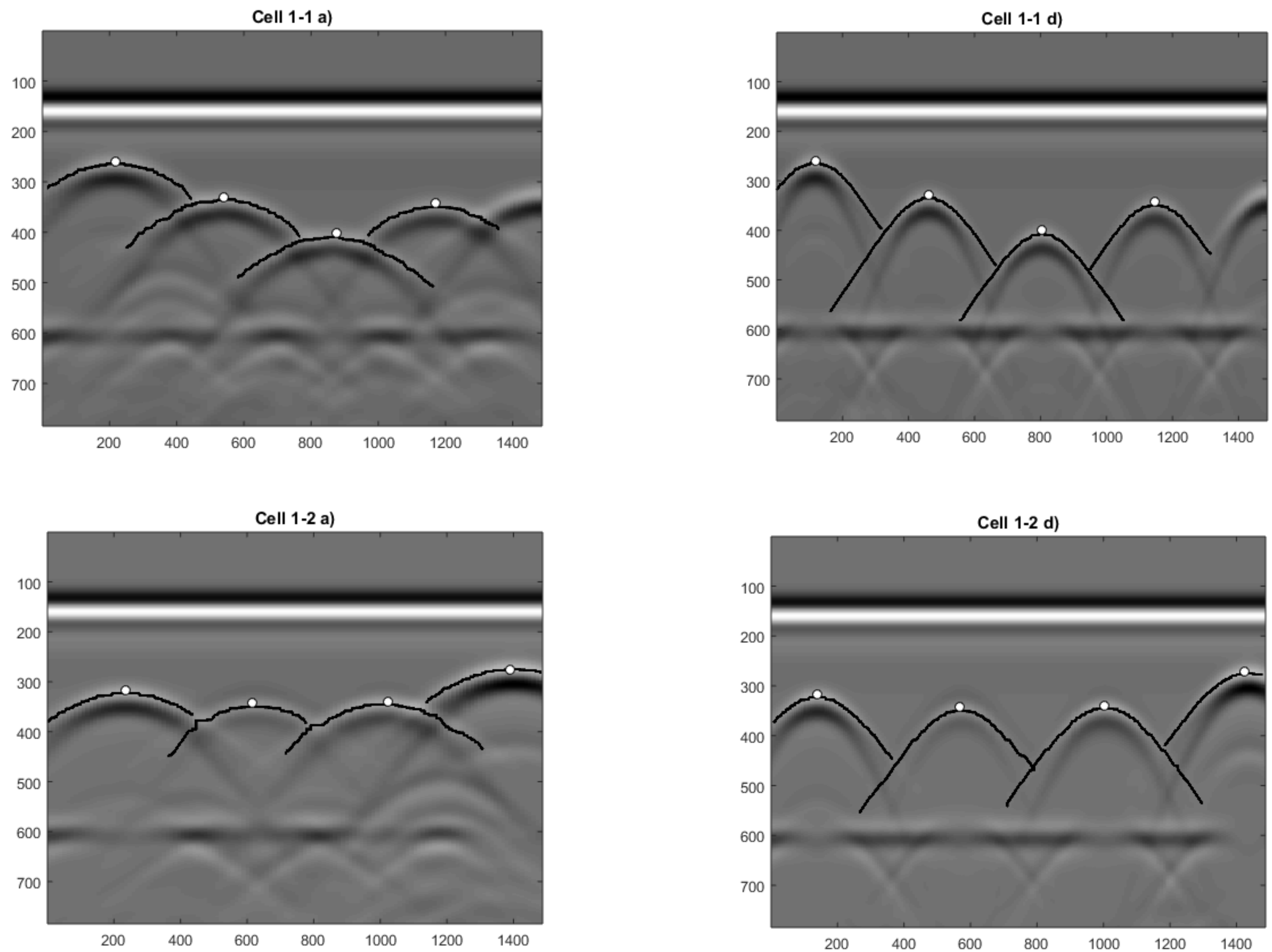
Cell 1.1



Cell 1.2



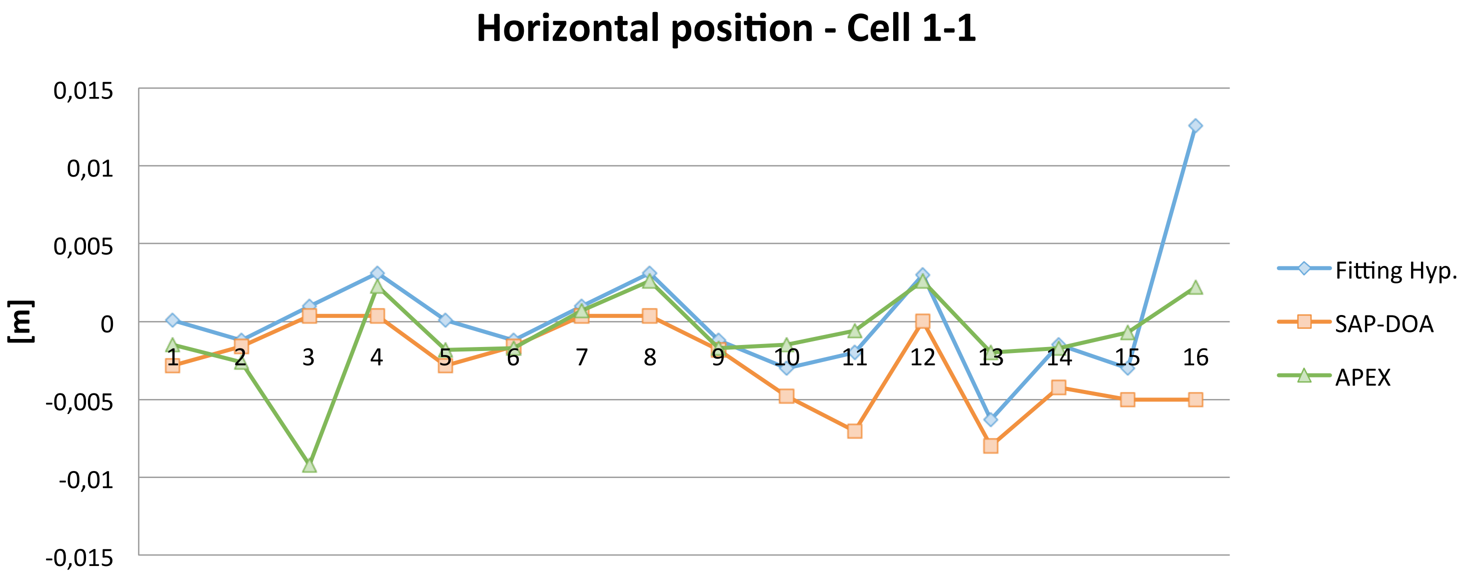
APEX – point extraction results (slide 1/5)

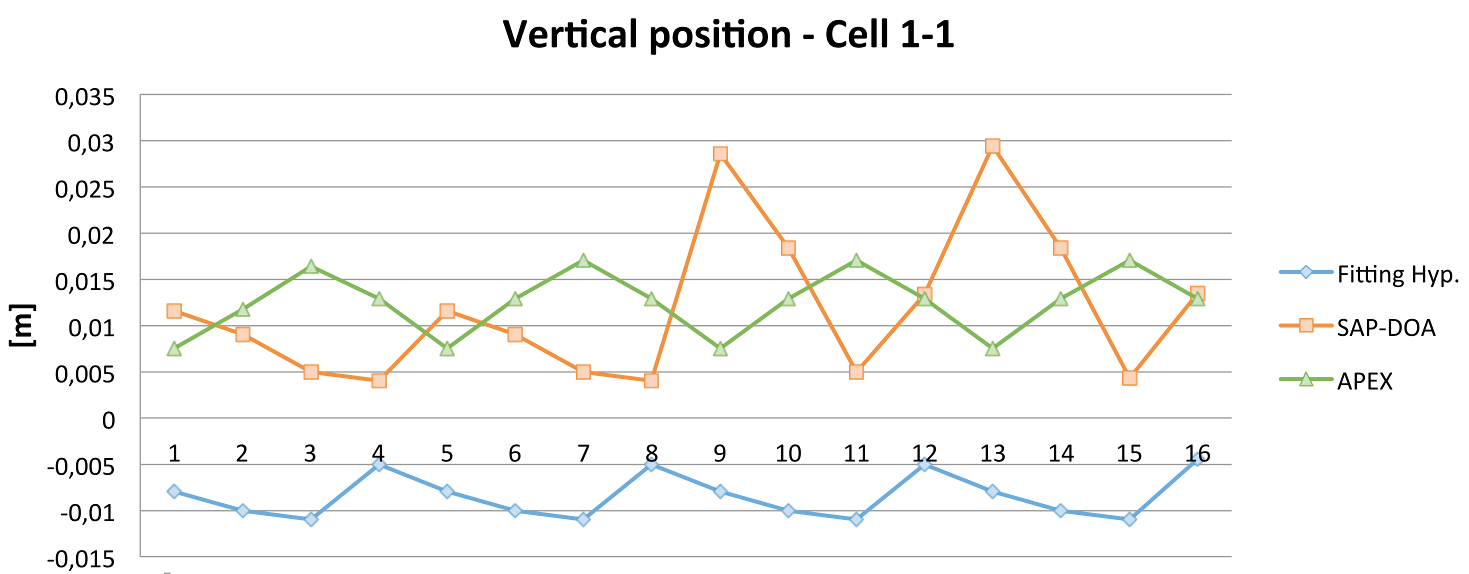


Comparative results: Cell 1-1 (slide 2/5)

Cell 1-1 a)						
Object	**Hyp. position error [m]**		**SAP-DOA position error [m]**		**APEX position error [m]**	
No. 1: Left edge	0.0001	-0.008	-0.0028	0.01155	-0.0015	0.0075
No. 2: Left	-0.0012	-0.01	-0.0016	0.009	-0.0026	0.0118
No. 3: Centre	0.001	-0.011	0.00035	0.005	-0.0092	0.0164
No. 4: Right	0.0031	-0.005	0.0004	0.004	0.0023	0.0129
No. 5: Right edge	0.007	-0.015	0.0054	0.0112	-	-
Cell 1-1 b)						
Object	**Hyp. position error [m]**		**SAP-DOA position error [m]**		**APEX position error [m]**	
No. 1: Left edge	0.0001	-0.008	-0.0028	0.01155	-0.0018	0.0075
No. 2: Left	-0.0012	-0.01	-0.0016	0.009	-0.0017	0.0129
No. 3: Centre	0.001	-0.011	0.00035	0.005	0.0007	0.0171
No. 4: Right	0.0031	-0.005	0.0004	0.004	0.0026	0.0129
No. 5: Right edge	0.007	-0.015	0.0054	0.0112	-	-
Cell 1-1 c)						
Object	**Hyp. position error [m]**		**SAP-DOA position error [m]**		**APEX position error [m]**	
No. 1: Left edge	-0.0012	-0.008	-0.0018	0.0286	-0.0017	0.0075
No. 2: Left	-0.003	-0.01	-0.0048	0.0184	-0.0015	0.0129
No. 3: Centre	-0.002	-0.011	-0.007	0.005	-0.0006	0.0171
No. 4: Right	0.003	-0.005	0.00001	0.01336	0.0026	0.0129
No. 5: Right edge	0.007	-0.015	0.001	0.0142	-	-
Cell 1-1 d)						
Object	**Hyp. position error [m]**		**SAP-DOA position error [m]**		**APEX position error [m]**	
No. 1: Left edge	-0.0063	-0.008	-0.008	0.0294	-0.002	0.0075
No. 2: Left	-0.0015	-0.01	-0.0042	0.0184	-0.0017	0.0129
No. 3: Centre	-0.003	-0.011	-0.005	0.0043	-0.0007	0.0171
No. 4: Right	0.0126	-0.0045	-0.005	0.0135	0.0022	0.0129
No. 5: Right edge	0.007	-0.0155	0.008	0.014	-	-

Cell 1-1 graphical overview (slide 3/5)





Comparative results: Cell 1-2 (slide 3/5)

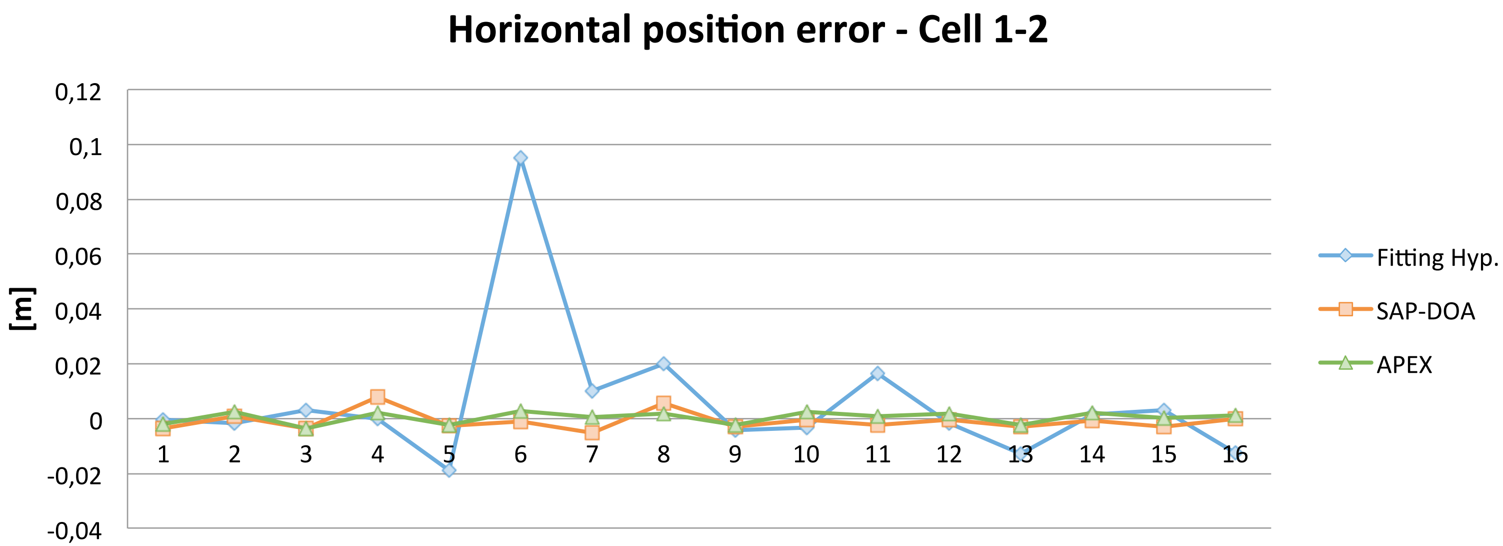
Cell 1-2 a)						
Object	Hyp. position error [m]		SAP-DOA position error [m]		APEX position error [m]	
No. 1: Left edge	-4.72E-04	0.0149	-0.0035	0.0107	-0.002	0.0121
No. 2: Left	-0.0018	0.0054	0.001	0.011	0.0026	0.0029
No. 3: Centre	0.003	0.0064	-0.0036	0.0171	-0.0036	0.0039
No. 4: Right	2.80E-05	0.0338	0.008	0.0193	0.0023	0.0068

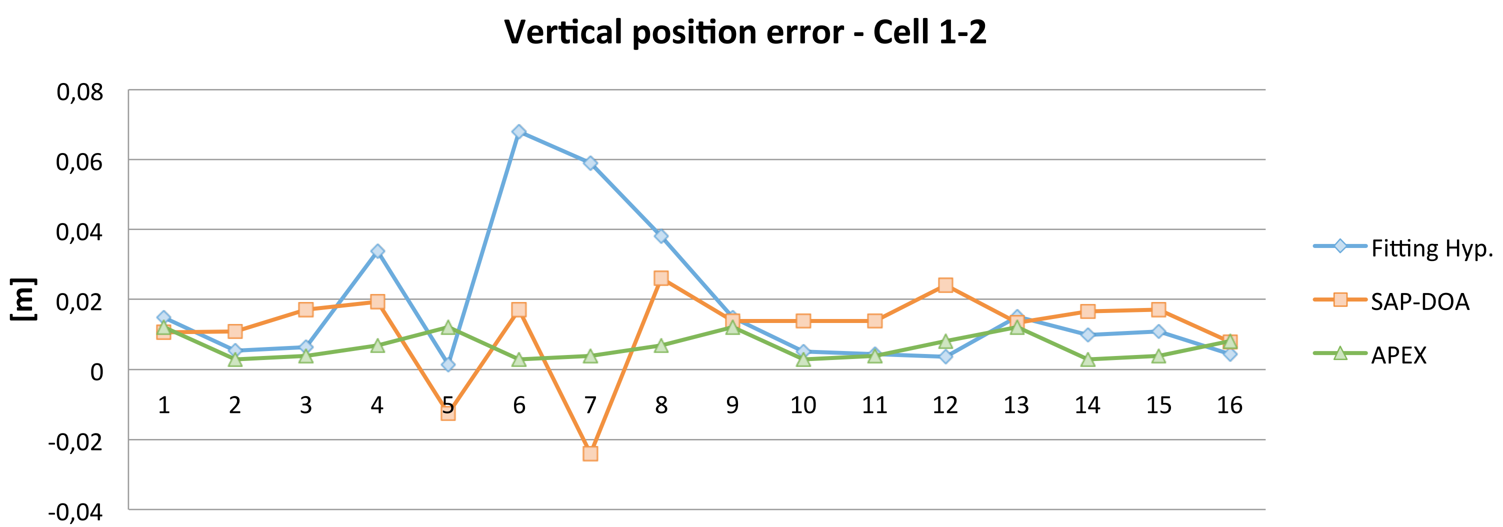
Cell 1-2 b)						
Object	Hyp. position error [m]		SAP-DOA position error [m]		APEX position error [m]	
No. 1: Left edge	-0.019	0.00147	-0.0025	-0.0126	-0.0022	0.0121
No. 2: Left	0.0951	0.068	-0.001	0.017	0.0027	0.0029
No. 3: Centre	0.01	0.059	-0.0053	-0.0241	0.0007	0.0039
No. 4: Right	0.02	0.038	0.0056	0.026	0.0019	0.0068

Cell 1-2 c)						
Object	Hyp. position error [m]		SAP-DOA position error [m]		APEX position error [m]	
No. 1: Left edge	-0.0043	0.0148	-0.003	0.0138	-0.0024	0.0121
No. 2: Left	-0.0032	0.0051	-0.0003	0.0139	0.0024	0.0029
No. 3: Centre	0.0165	0.0043	-0.0022	0.0139	0.0009	0.0039
No. 4: Right	-0.0015	0.0037	-0.0003	0.0241	0.0019	0.0082

Cell 1-2 d)						
Object	Hyp. position error [m]		SAP-DOA position error [m]		APEX position error [m]	
No. 1: Left edge	-0.0127	0.015	-0.003	0.0134	-0.0024	0.0121
No. 2: Left	0.0015	0.01	-0.0007	0.0167	0.0022	0.0029
No. 3: Centre	0.003	0.011	-0.003	0.017	0.0002	0.0039
No. 4: Right	-0.0126	0.0045	0.00001	0.008	0.0011	0.0082

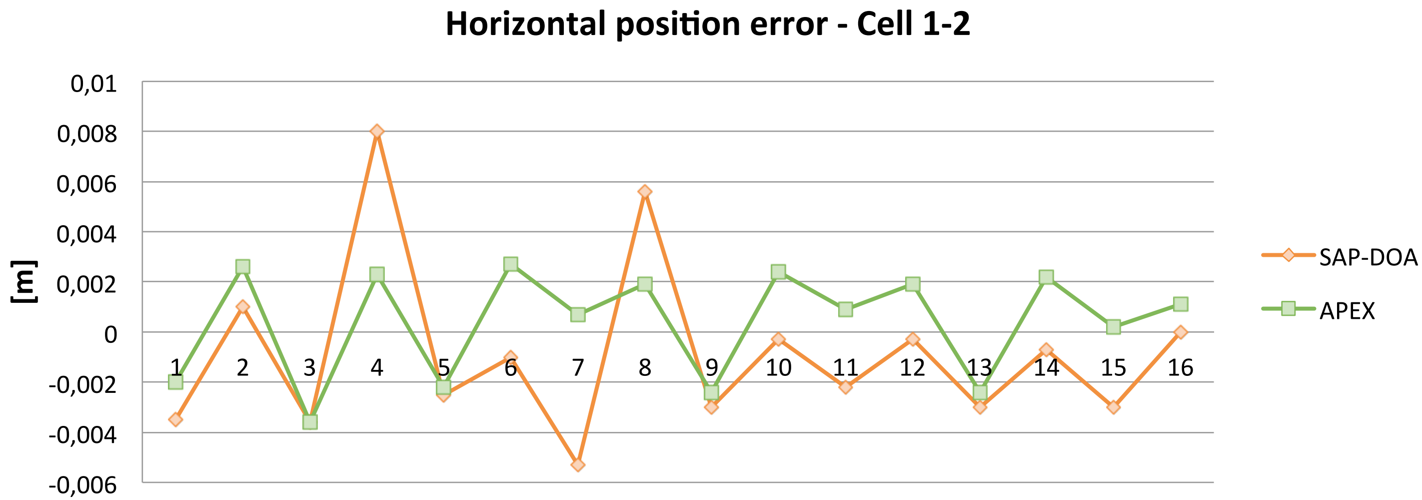
Cell 1-2 graphical overview (slide 4/5)

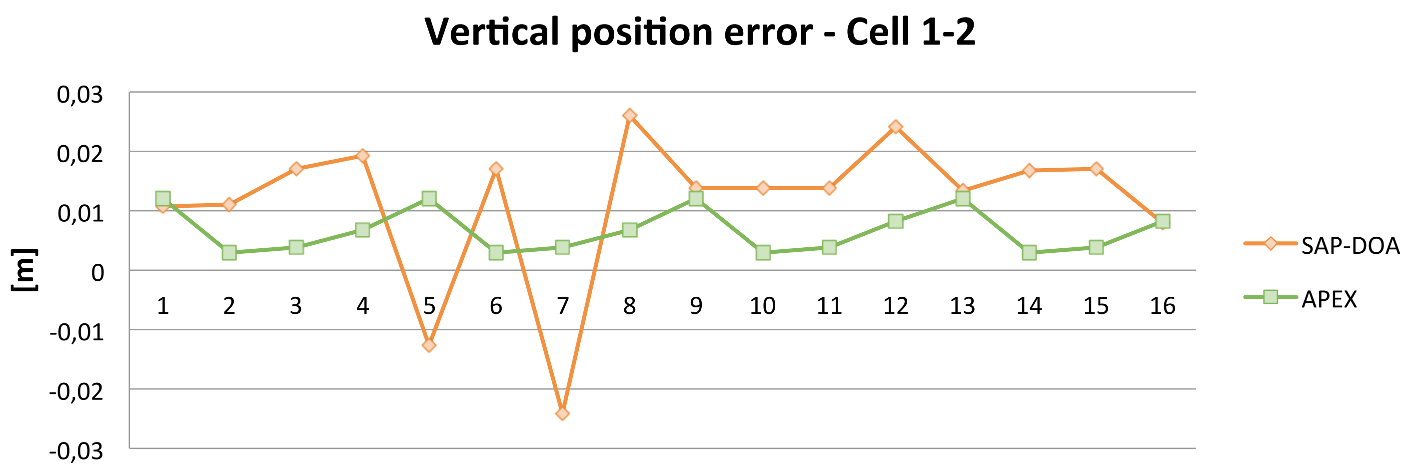




Results - summary (slide 5/5)

- SAP-DOA vs APEX





Summary (slide 1/2)

Algorithm 1 (hyperbola fitting)

- Yields less accurate results for depth coordinate (as expected)
- The main problem of algorithm 1 is apex estimation in case of crossed hyperbolic reflections, and also in situation when hyperbolic reflections are one beneath the other (the way the points for fitting are selected is problematic)
- Position coordinates are determined with sufficient accuracy

Algorithm 2 (SAP-DOA)

- Yields very good results for both coordinates of the apex (position and depth)
- Produces results when other prong of hyperbolic reflection is not visible (Cell 1-1, No. 5 – right edge)

Summary (slide 2/2)

Algorithm 3 (APEX)

- Results are similar to SAP-DOA
- Best results in determining the depth
- Apex of hyperbolic reflection (Cell 1-1, No. 5 – right edge) was not detected since entire right prong was missing, and the apex was on the very edge of the domain

Conclusions

- Both algorithms performed well on synthetic data
- A similar comparison should be done on experimental data (COST TU1208 open database of rardargrams can be useful)
- Both algorithms can be applied on objects of non-cylindrical shape, such as a concrete channel containing heating pipelines
- Extracted points from hyperbolic reflections can be used to estimate the values of some other parameters (e.g. utility diameter and average velocity) by applying appropriate model and fitting

Thank you for your attention!

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