MTA SZTAKI

Hungarian Academy of Sciences
Institute for Computer Science and Control

Laser scanning for cultural heritage applications

Csaba Benedek

Distributed Events Analysis Research Laboratory (DEVA)

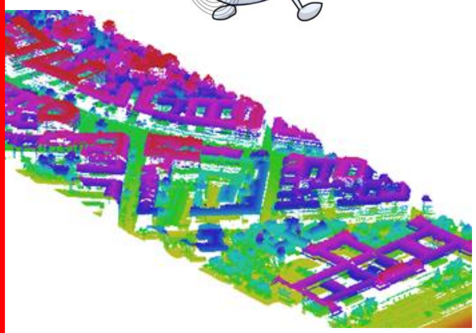
http://web.eee.sztaki.hu/i4d/

COSCH Training School on Heterogeneous visual data fusion techniques - acquisition and algorithms

07-09 December 2015

Outline

Aerial Lidar



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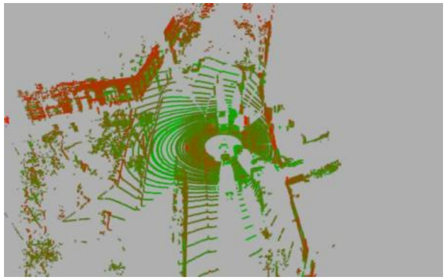
Velodyne HDL 64-E
Car-mounted laser scanner



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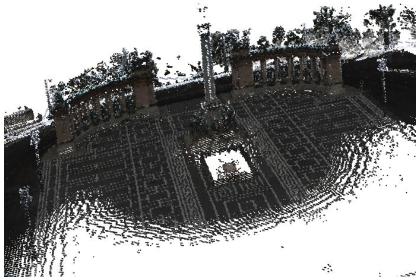
Lidar based terrestrial mapping

BUDAPEST KÖZÚT

Multi-sensorial mobile mapping system



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developement is our common passion

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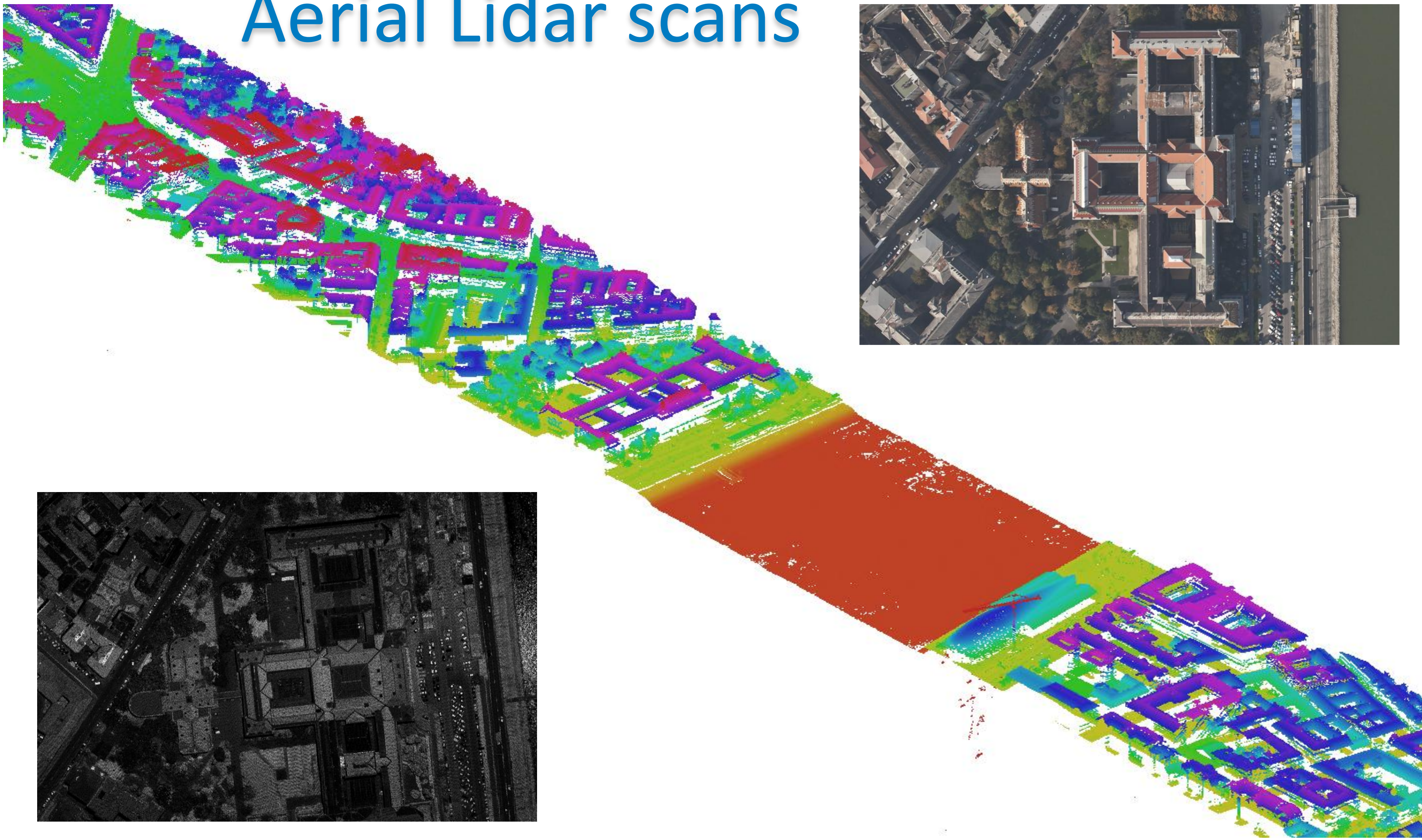
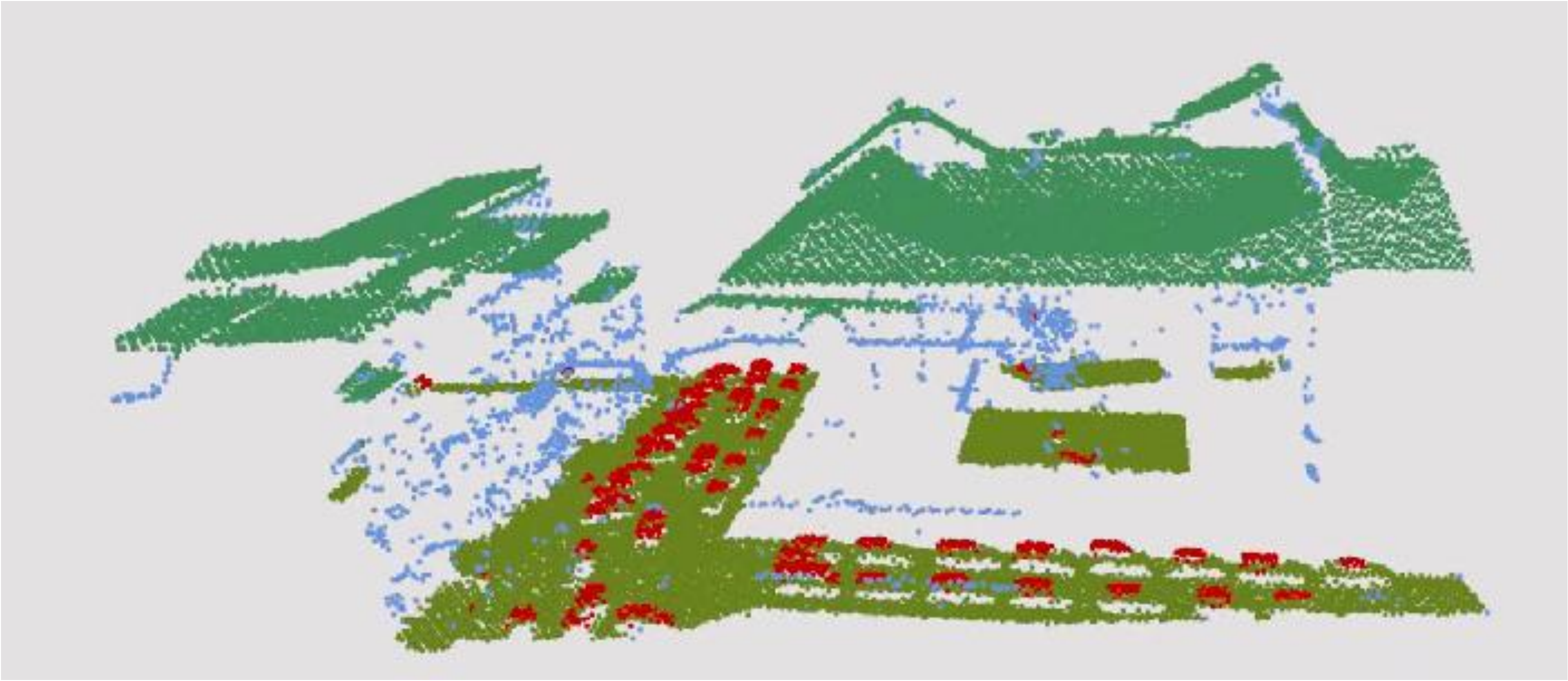
Aerial Lidar scans

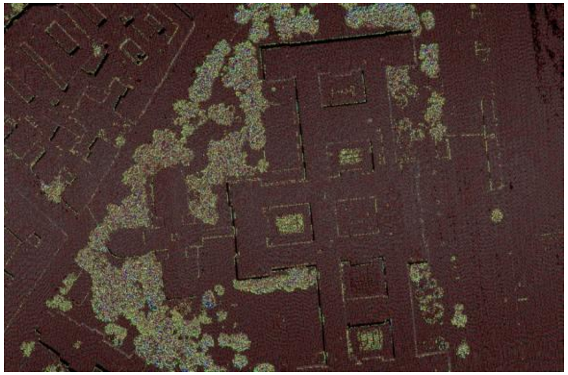


Point cloud segmentation

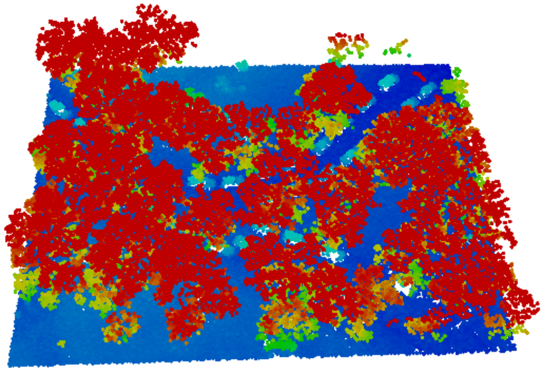


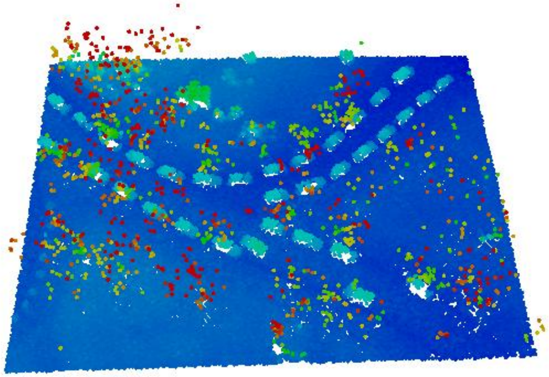
Vegetation filtering by echo number information

Optical aerial image

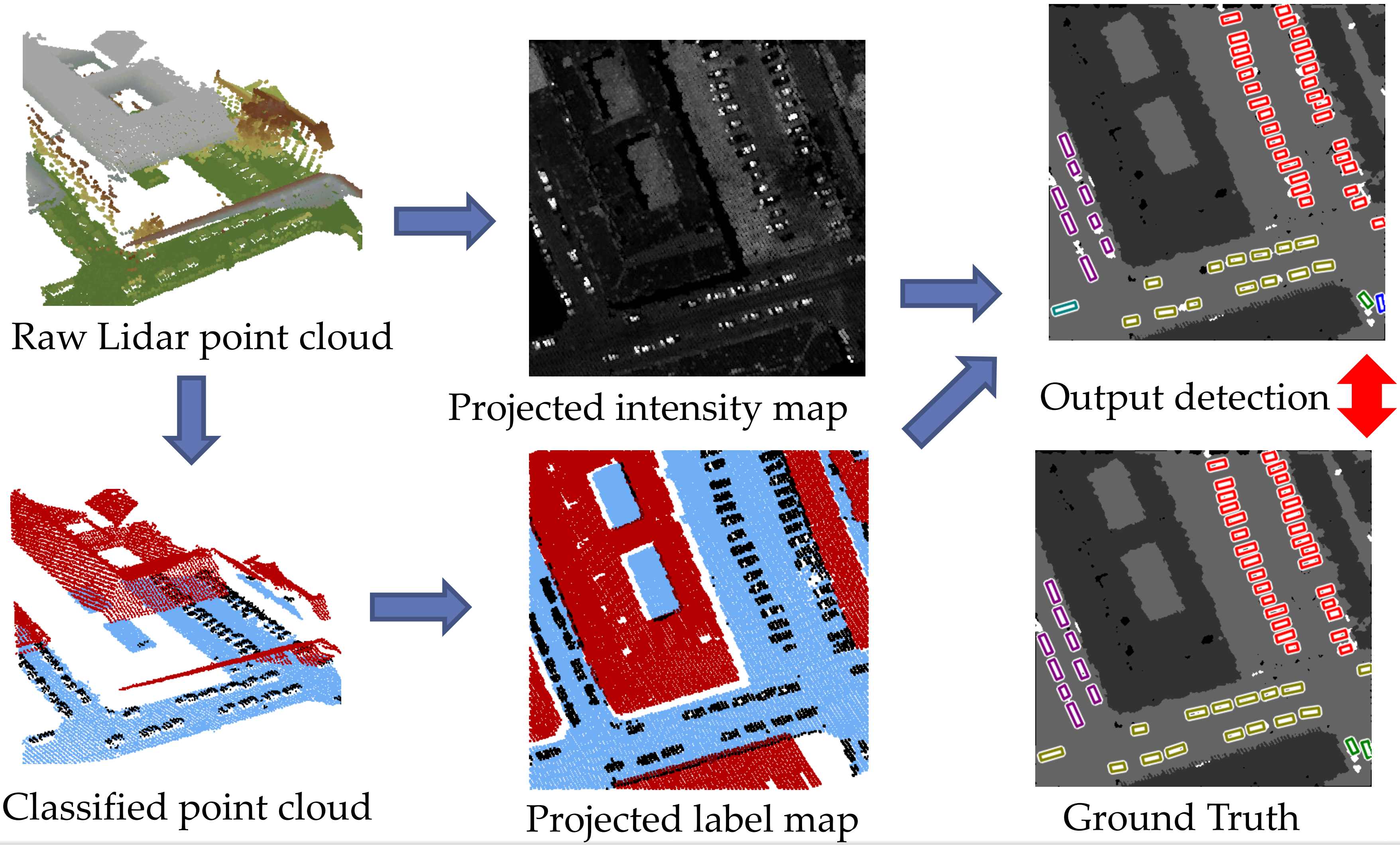


LIDAR echo map

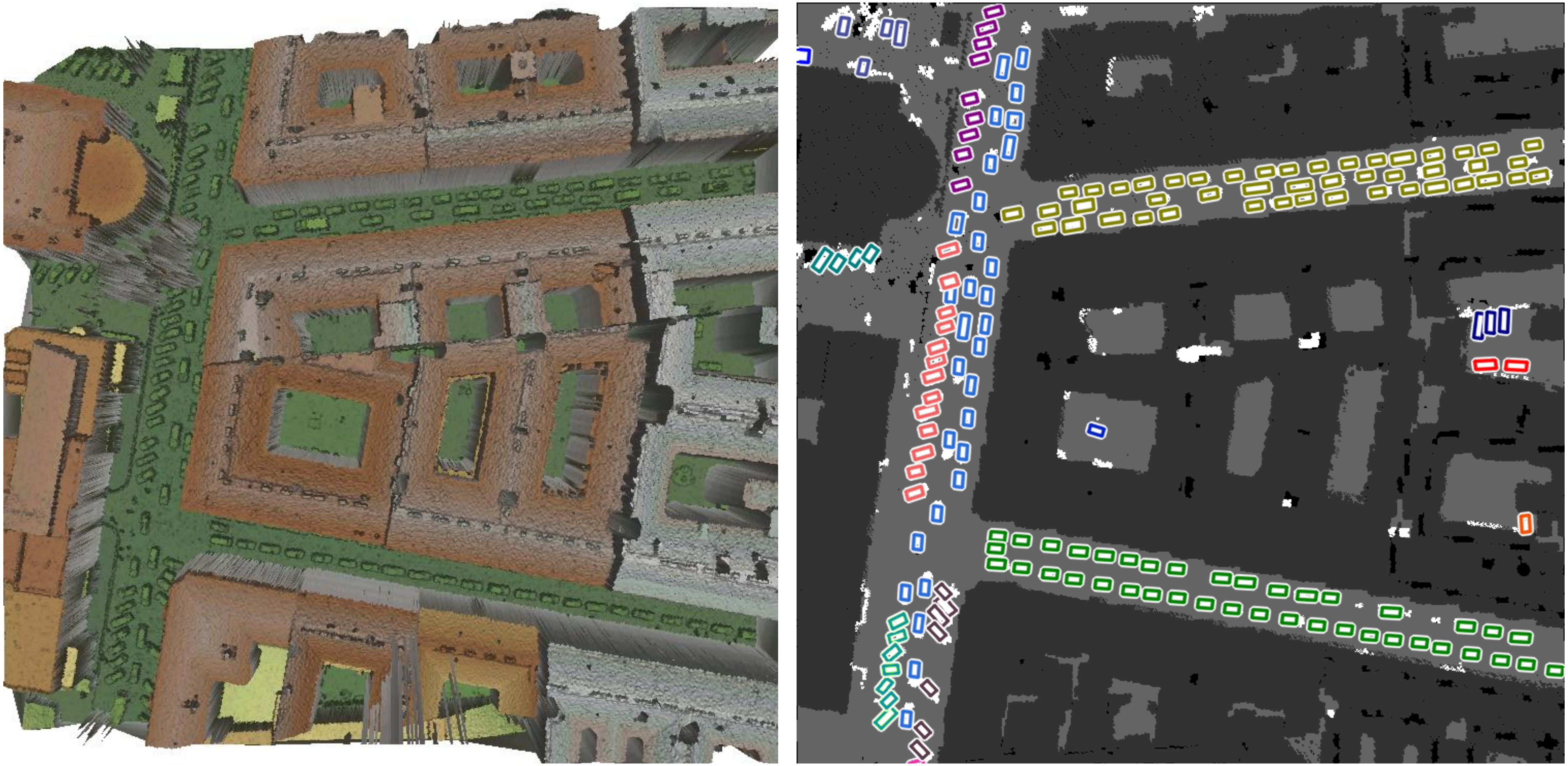




City models: vehicles should be detected and removed

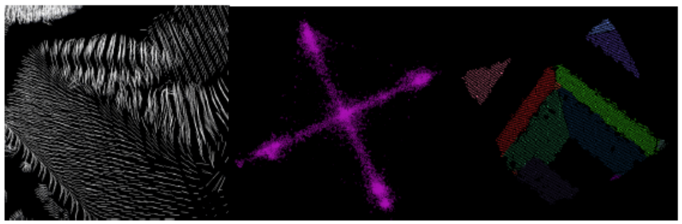


Vehicle detection and traffic segmentation

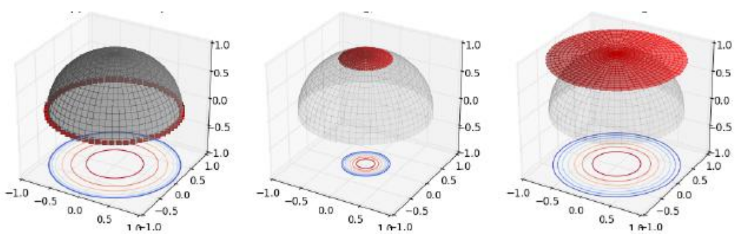


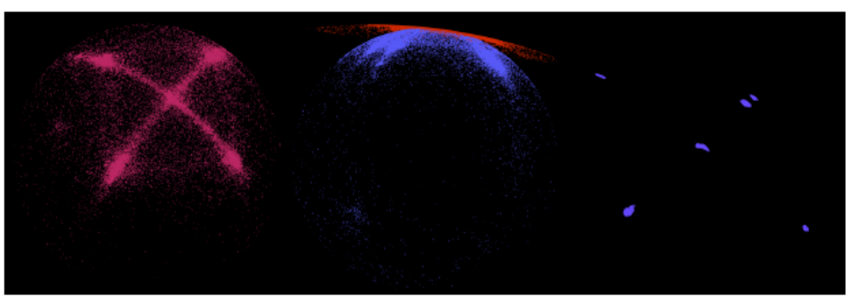
- Traffic interpretation: e.g. parking vehicles may be included in the reconstructed cities

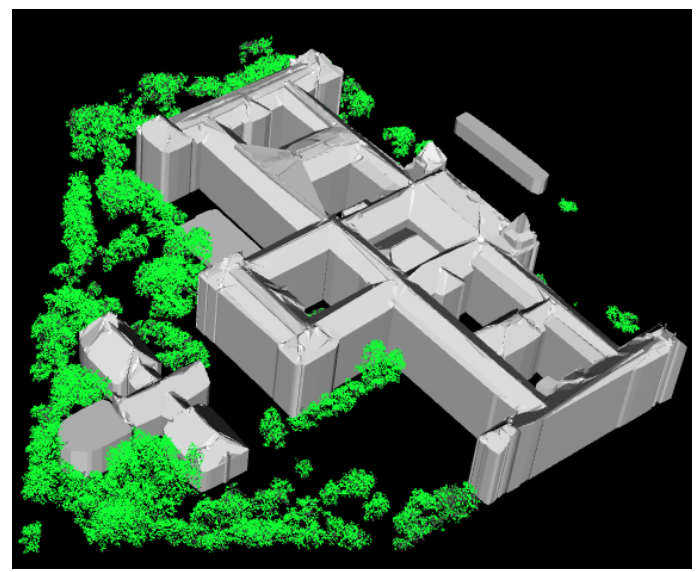
City reconstruction from Lidar



(a) (b) (c)

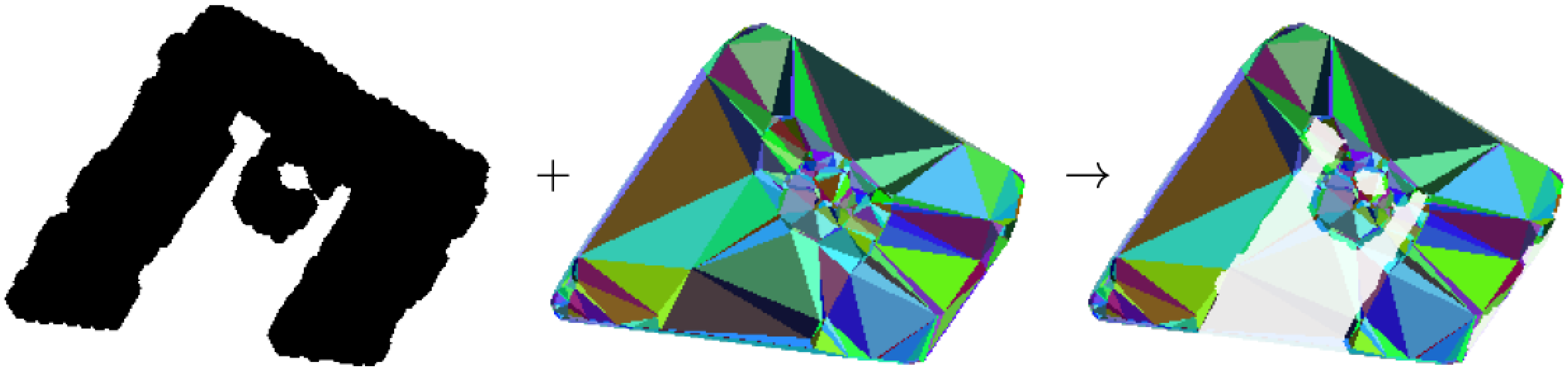






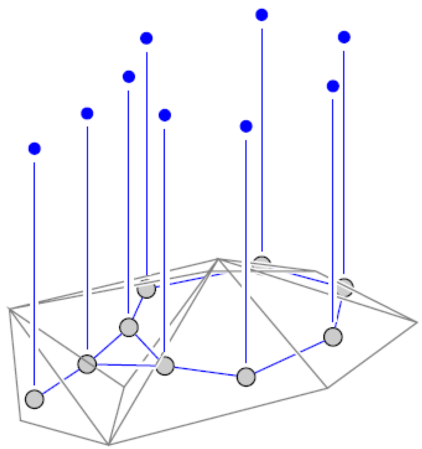
Task

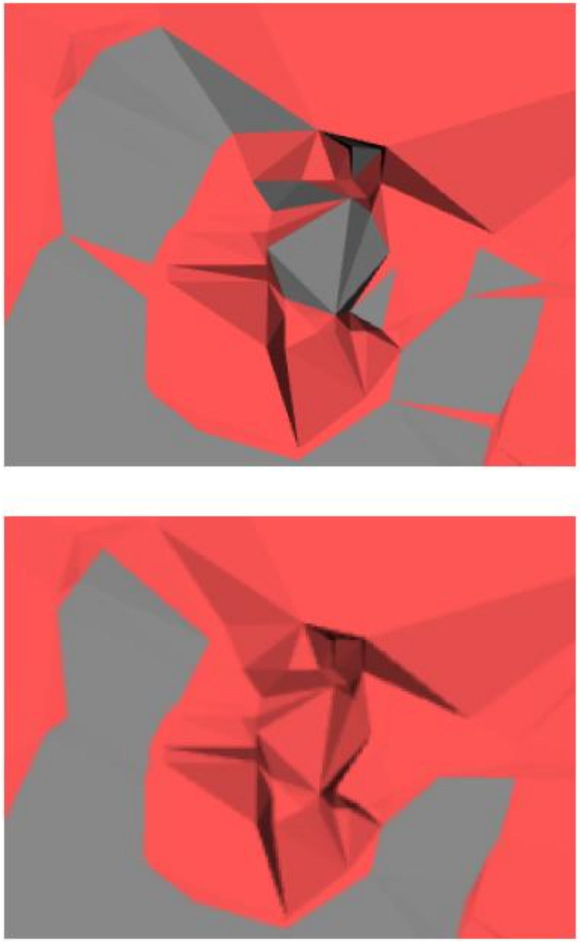
- Convex triangulation + removing false triangles



Triangle classification

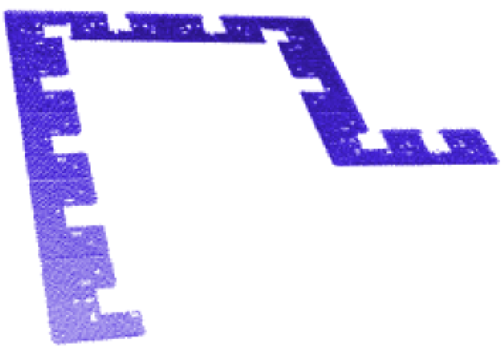
- Markov Random Field (MRF) model for removing false triangles from the mesh
  - Nodes: triangles
  - Edges: triangle neigborhoods



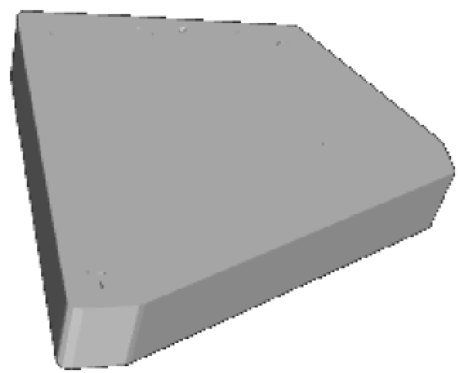


Naive way vs. MRF

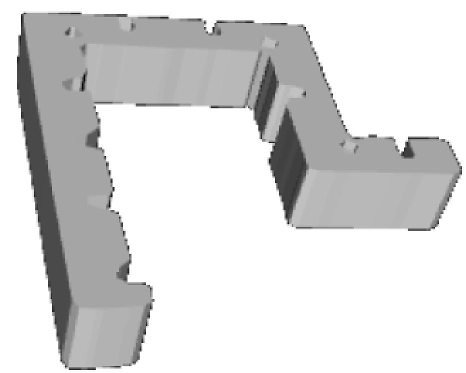
Workflow - results



Point cloud

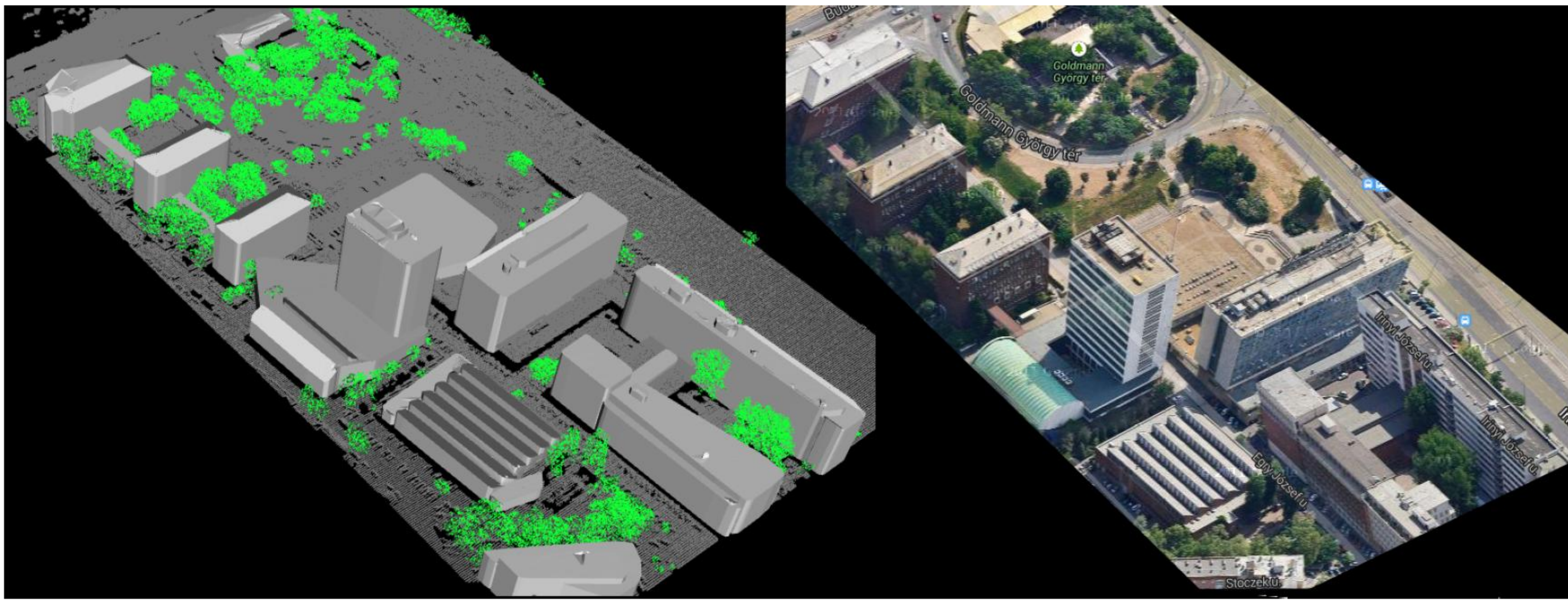


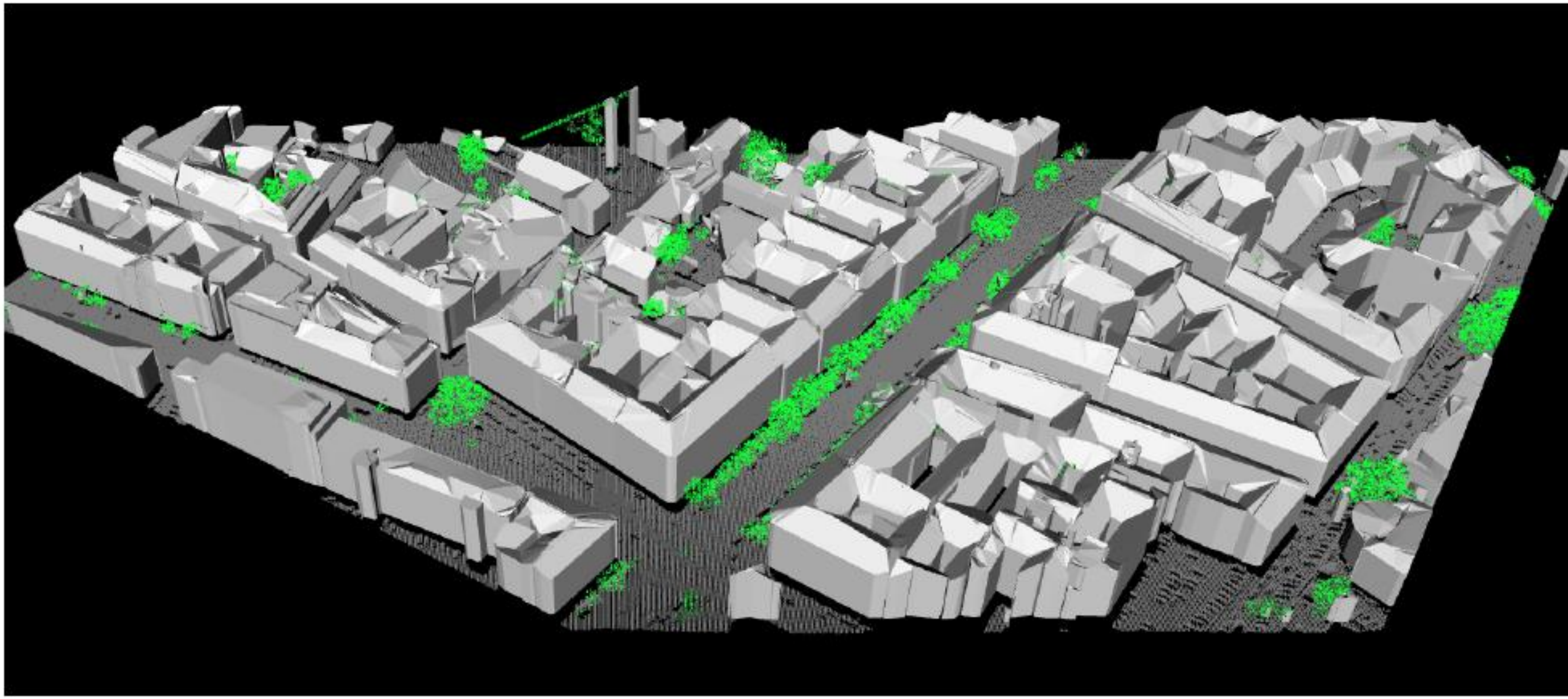
Convex triangulation

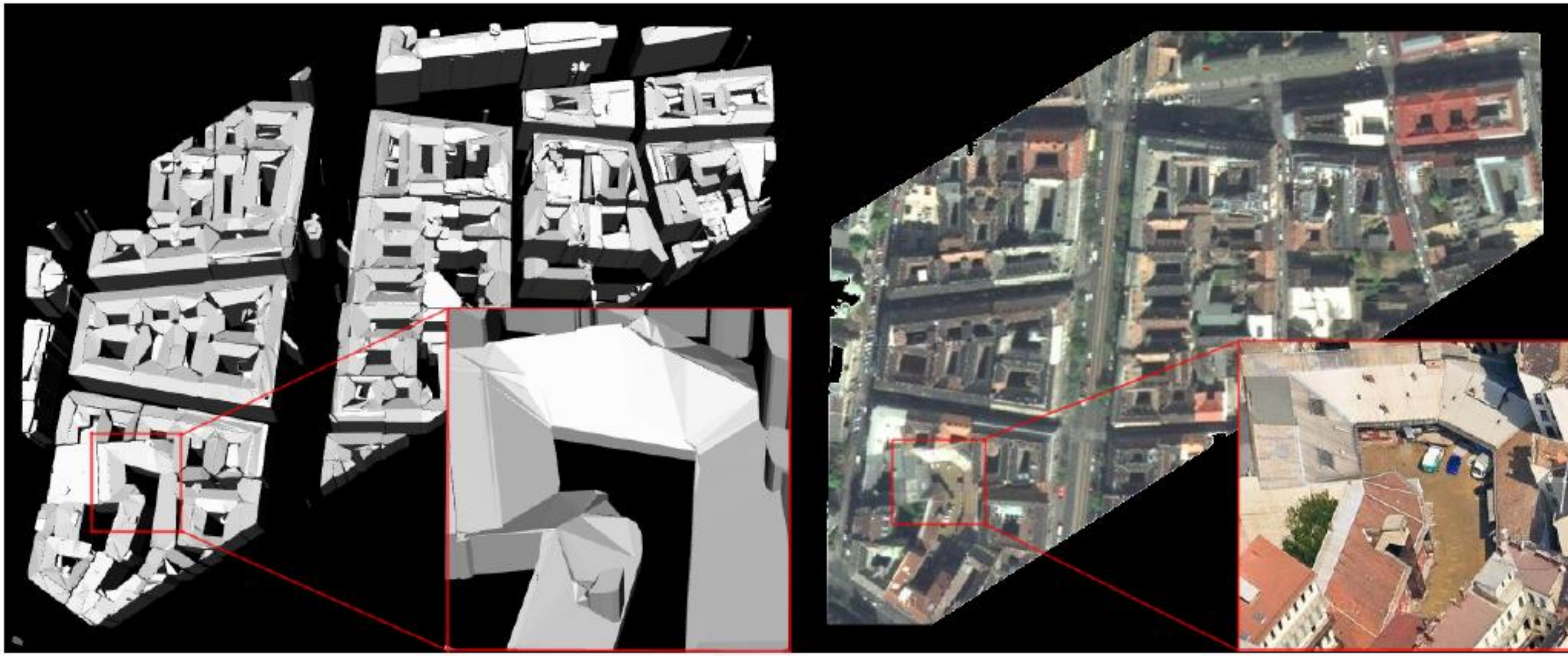


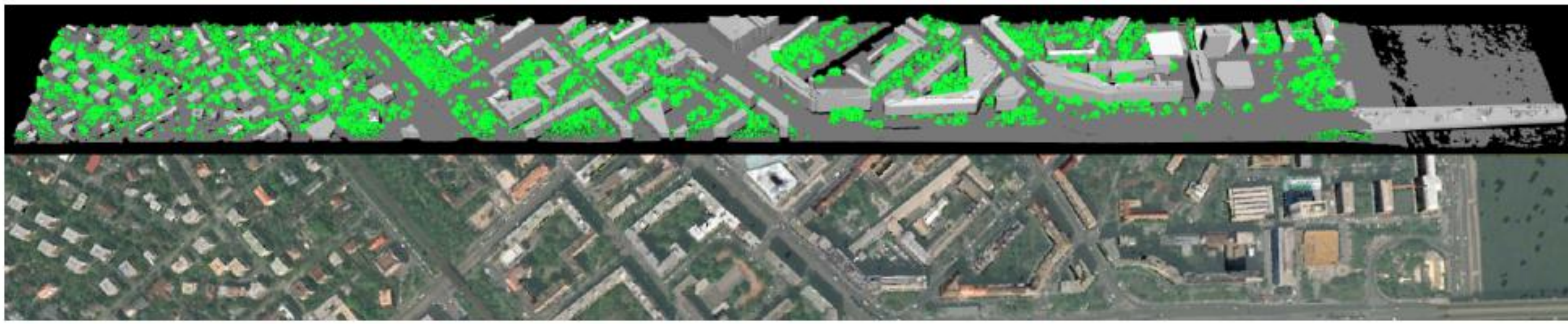
Concave triangluation

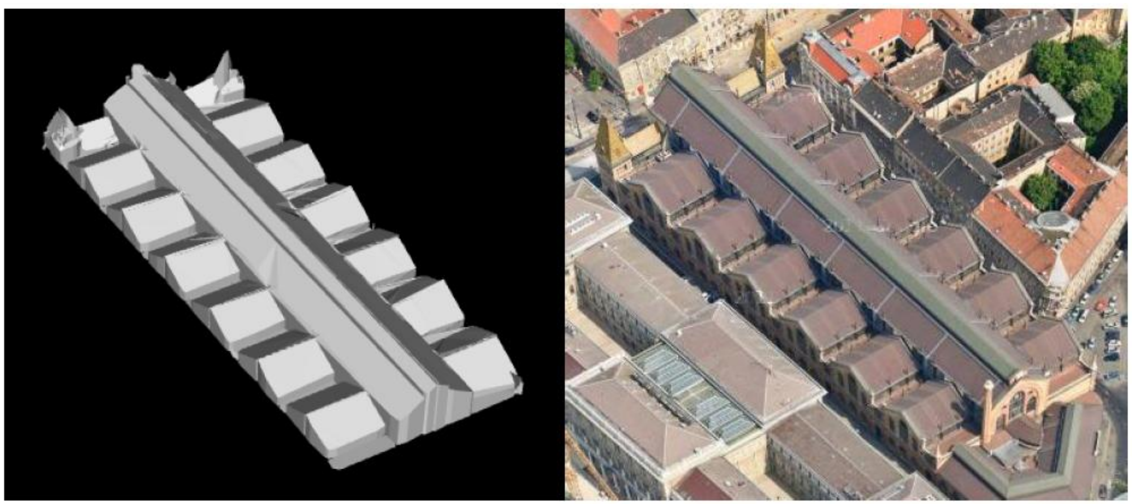
Results

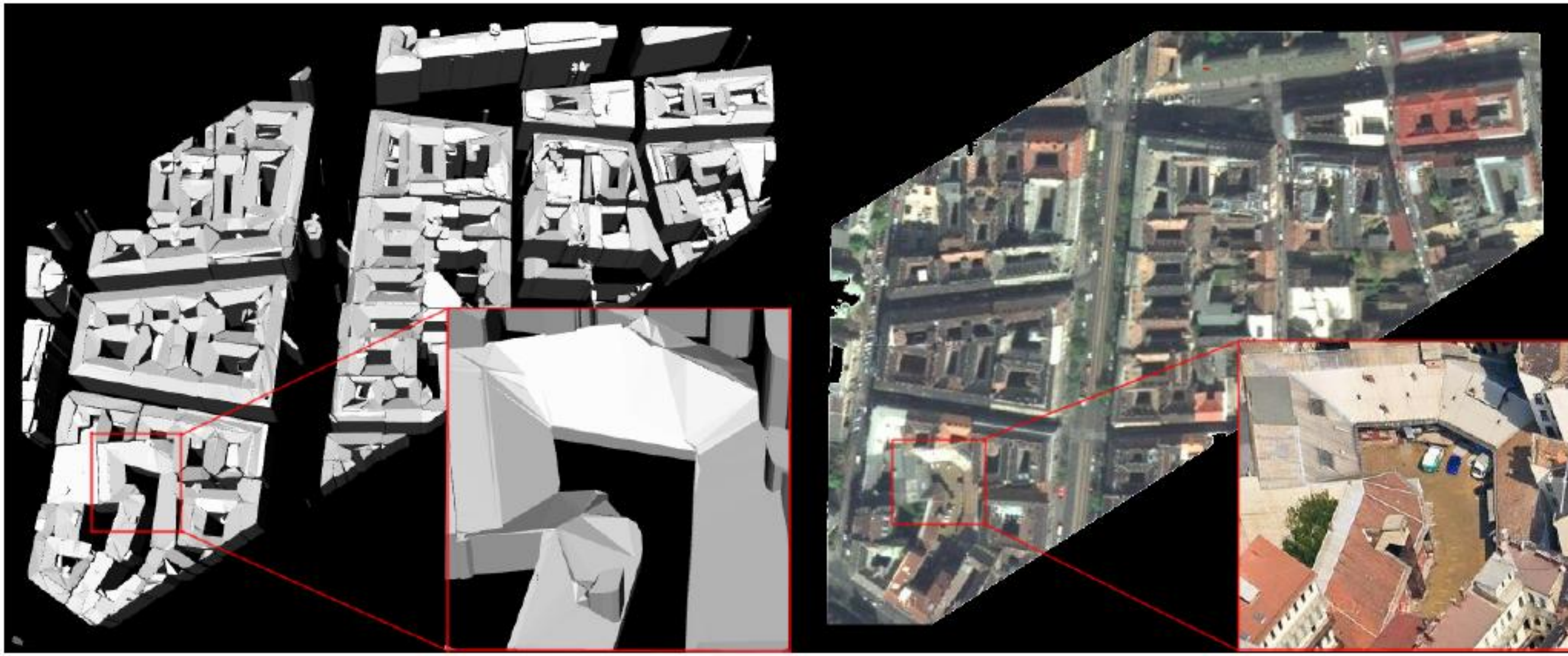




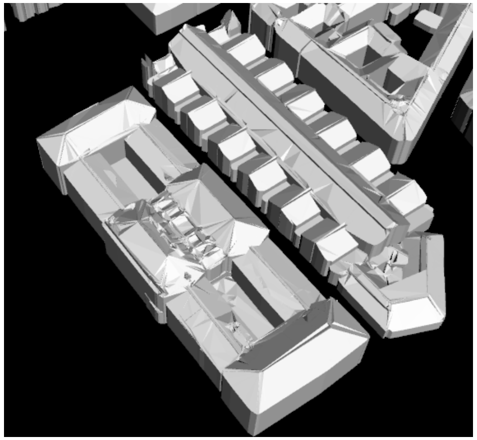








Texturing with satellite images

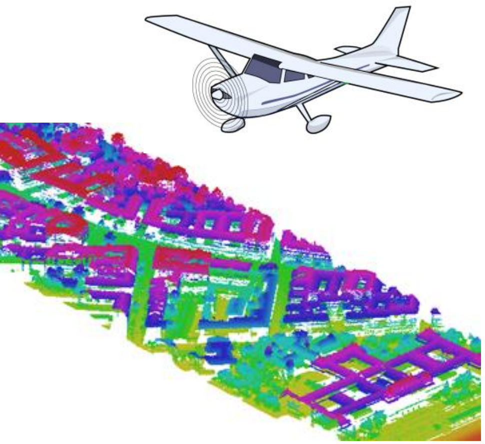


3D reconstructed city model

Lidar based geometric city model
– automatic texturing with up-to-date satellite images

Outline

Aerial Lidar



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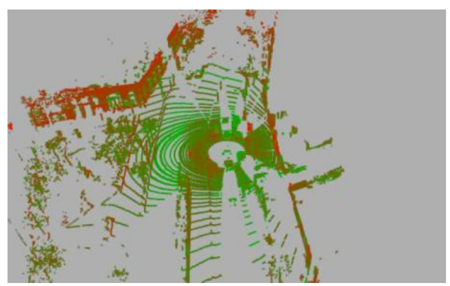
Velodyne HDL 64-E
Car-mounted laser scanner



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Lidar based terrestrial mapping

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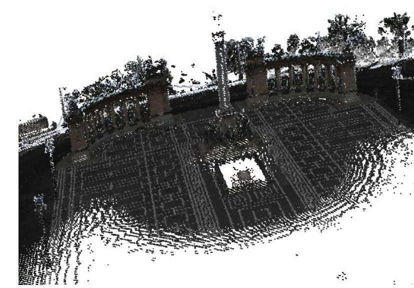
Multi-sensorial mobile mapping system



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developement is our common passion

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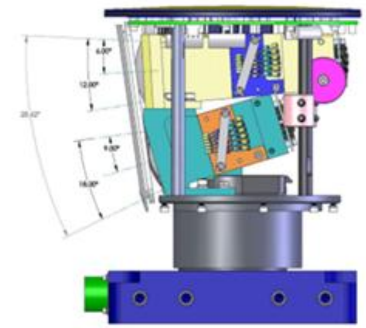
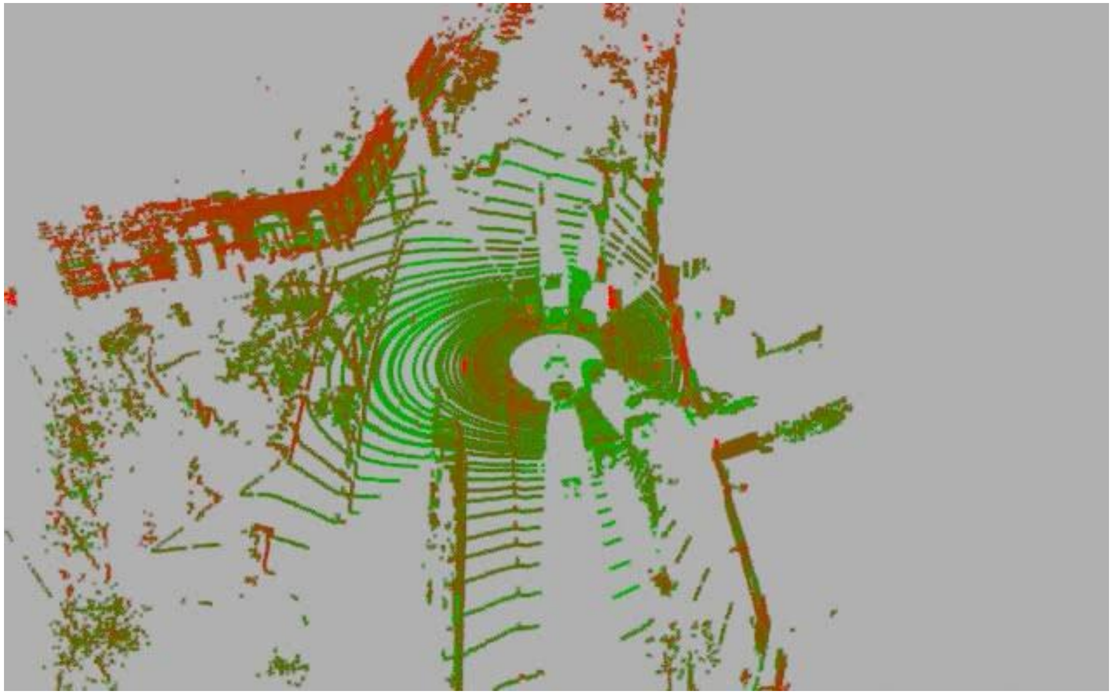
Velodyne LIDAR

Link to the video

Velodyne LIDAR



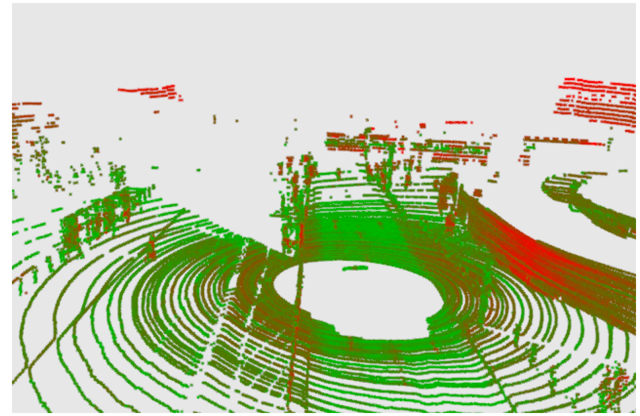
- **Hardware**: Velodyne HDL-64E LIDAR
- **Output:** 2.5D point cloud sequence from outdoor environments
- **Technical data:**
  - 64 laser and sensor
  - 120 m distance
  - <2cm accuracy
  - >1.333M points/sec



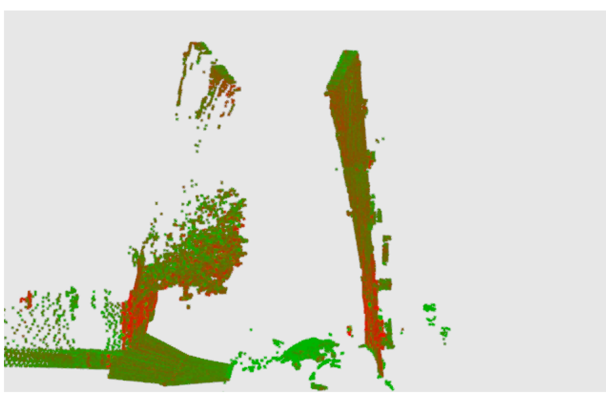
Moving LIDAR platform

- Horizontal LIDAR: street object and traffic monitoring

© DiFiLTON-ARC



- Tilted LIDAR: reconstruction of building facades



Lidar

Input point cloud frames (1,2,…,N)

Grid based segmentation of each point cloud (1,…N)

Point cloud registration

Merged cloud

Tree crown removal

Grid based re-segmentation and connected component analysis (merged cloud)

Large planar regions

Surface reconstruction

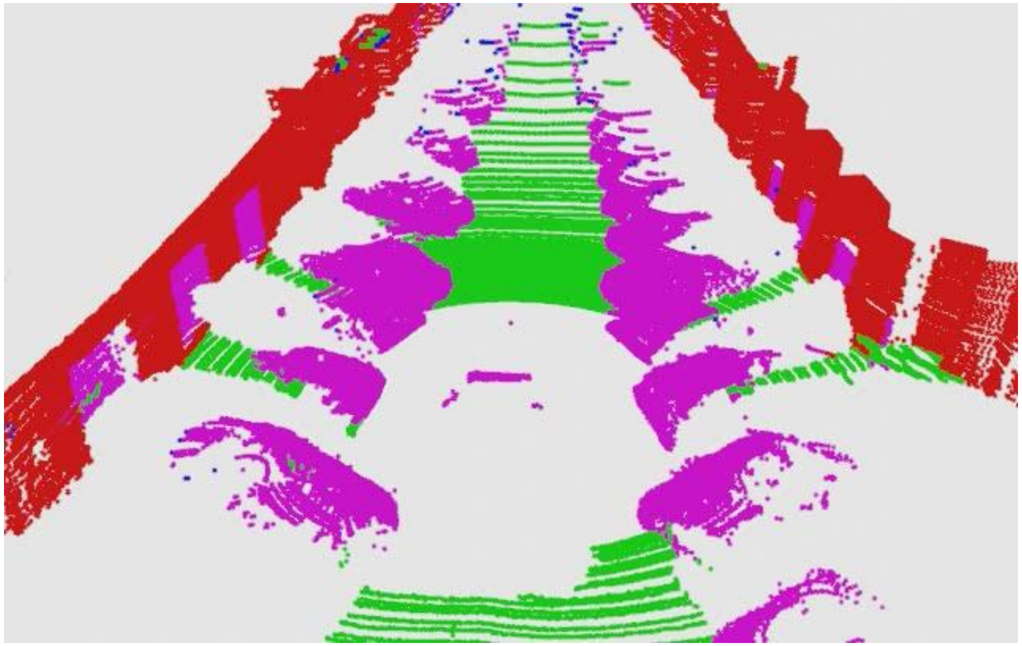
Other objects

Moving object detection and classification

Preprocessing – point cloud segmentation

- A grid based method.
  - Uniform grid defined in the 2D space along the ground.
  - The grid is segmented as an *image* first
  - Runs in real time.
- <u>Point classes:</u>
  - **Noise and sparse data:** grid cells with a few data points
  - **Ground surface**: cells of points with small elevation differences (used threshold: 25cm)
  - **Tall objects** (e.g. walls): cells with large elevation differences (more than 310cm) or large maximal elevation (used 350cm)
  - **Short street objects:** everything else (cars, pedestrians, street furniture, etc)

Street scene segmentation



Color codes:

- road
- wall
- vehicle+ street objs.

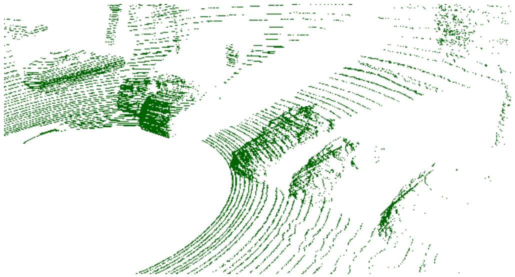
• O. Józsa, A. Börcs and Cs. Benedek: *"Towards 4D Virtual City Reconstruction From Lidar Point Cloud Sequences,"* **ISPRS Workshop on 3D Virtual City Modeling**, Regina, Saskatchewan, Canada, May 28-31, 2013, vol. II-3/W1 of **ISPRS Annals of Photogrammetry, Remote Sensing and the Spatial Information Sciences** pp. 15-20, 2013

•A. Börcs, O. Józsa and Cs. Benedek: *"Object Extraction in Urban Environments from Large-Scale Dynamic Point Cloud Datasets,"* **IEEE International Workshop on Content-Based Multimedia Indexing (CBMI)**, Veszprém, Hungary, June 17-19, 2013

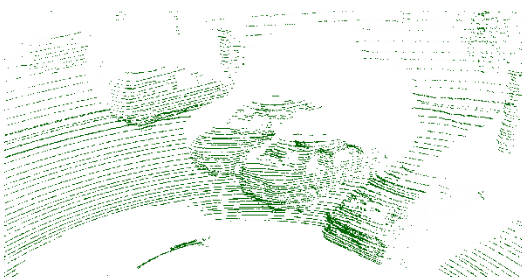
Registration

- Only the points in the Wall or Tall Static Object class are used.
  - Noise and dynamic data are removed
  - Reduced number of points
  - Remaining points are strong features
- Registration techniques
  - Normal Distributions Transform(NDT) – used for most of the following results
  - Trimmed Iterative Closest Point algorithm (TrICP, Chetverikov at all, ICV 2005) – alternative method used in some tests

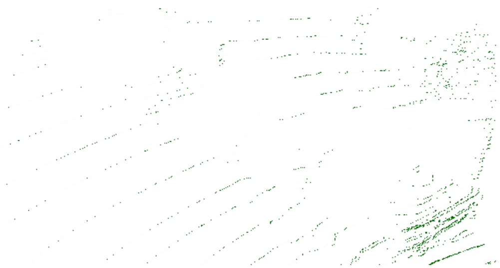
Registration: results



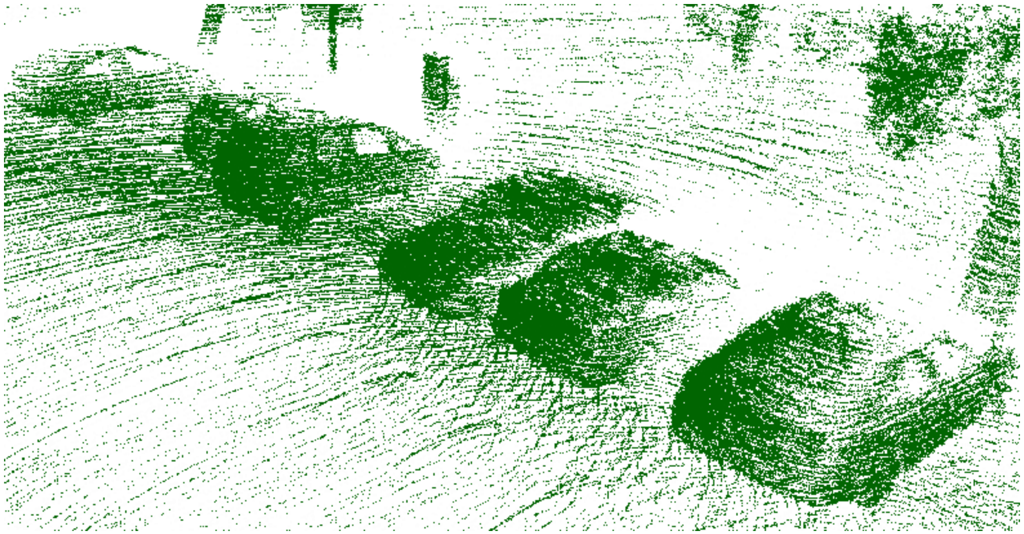
Frame #1



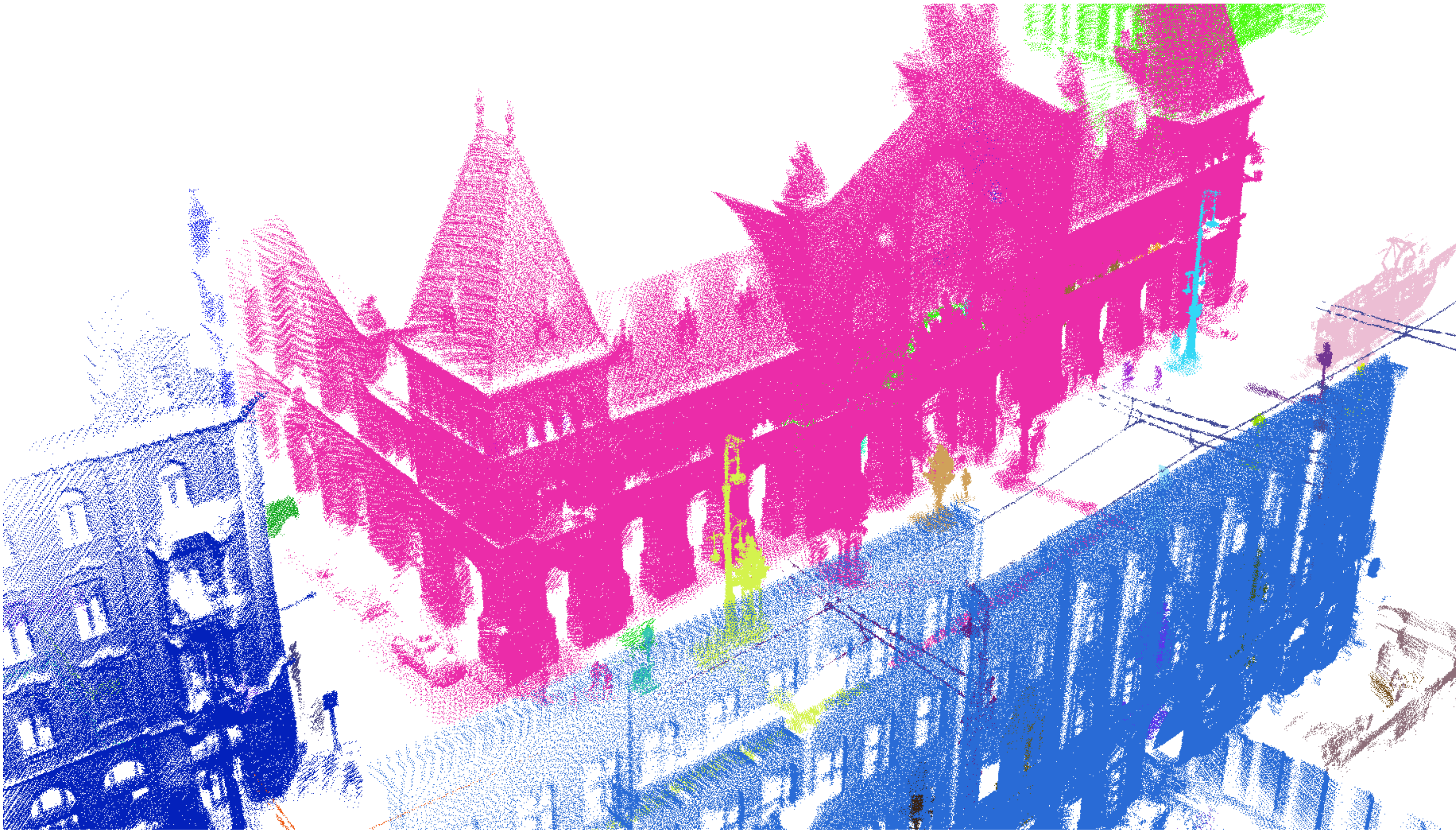
Frame #2



Frame #3



30 merged frames



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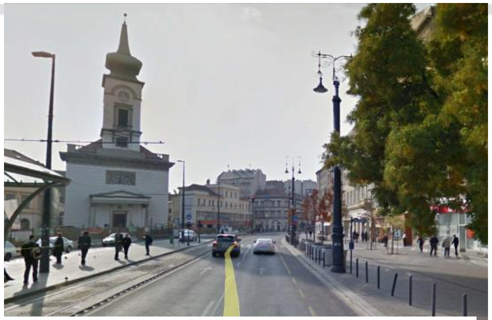
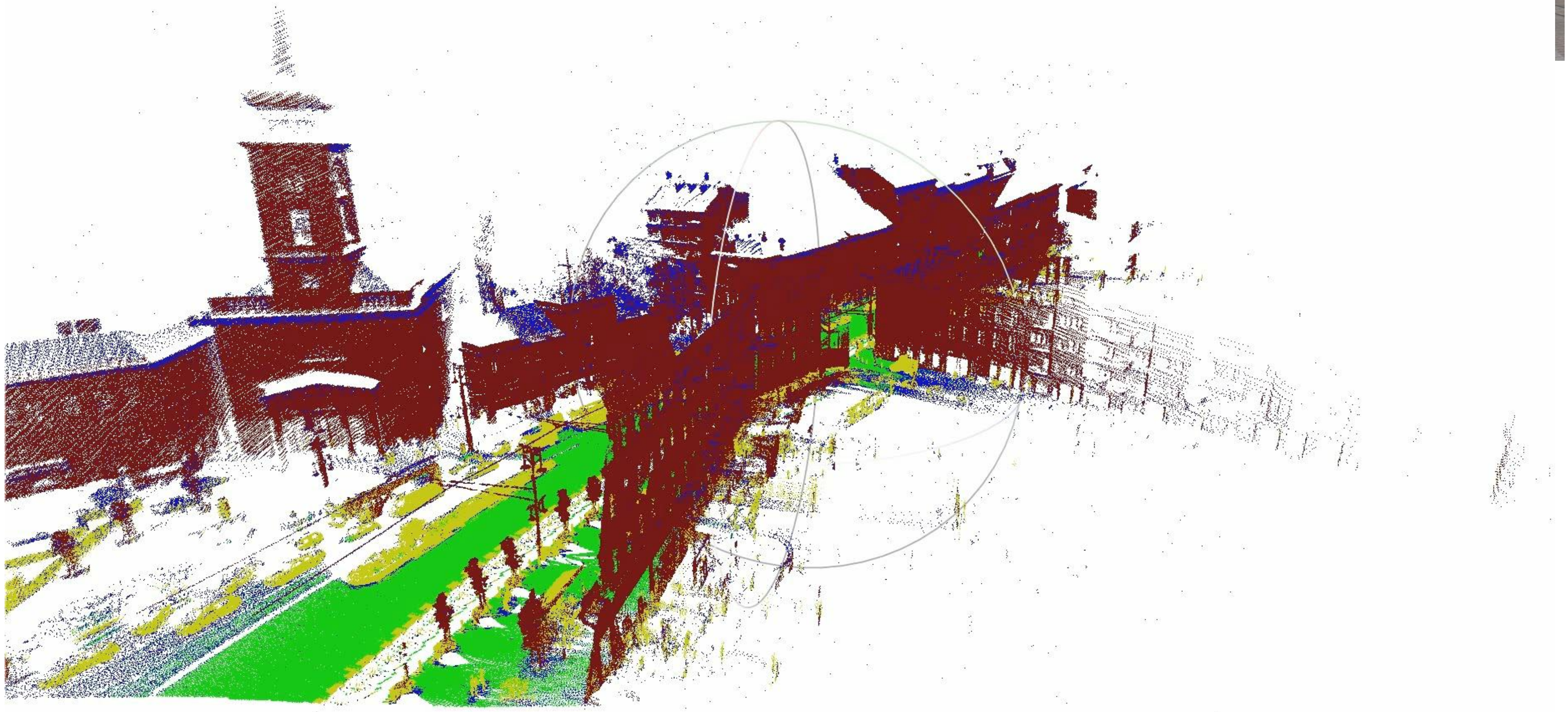
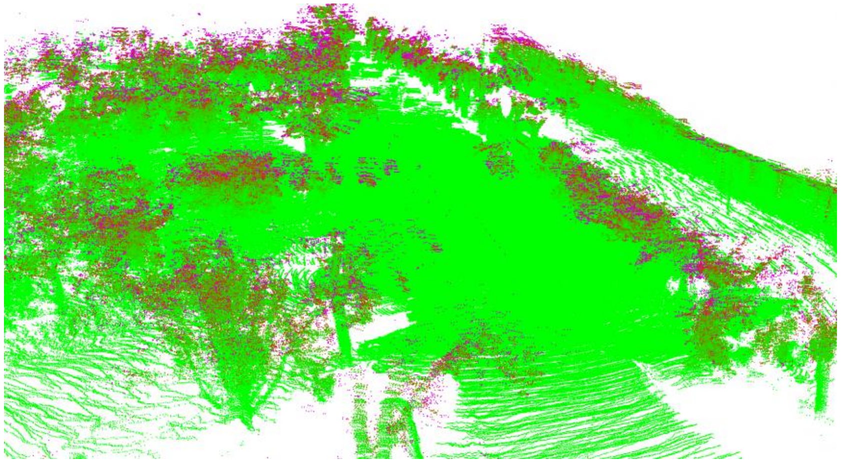
Kálvin square

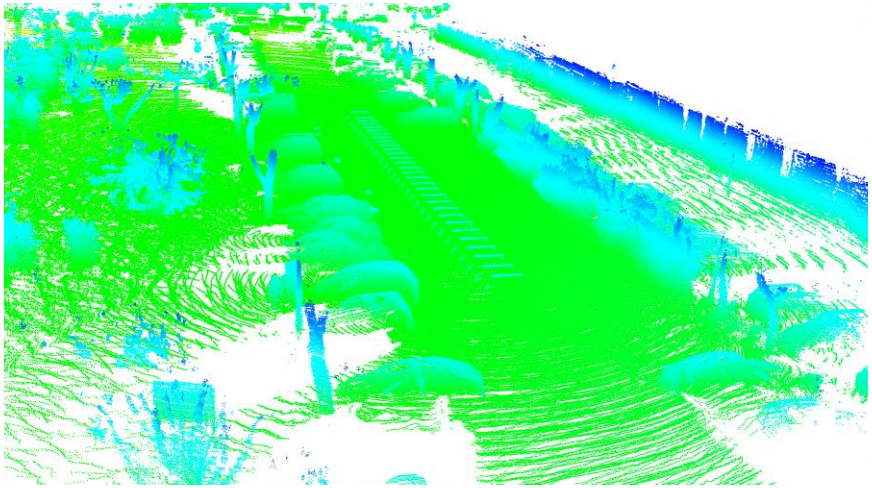




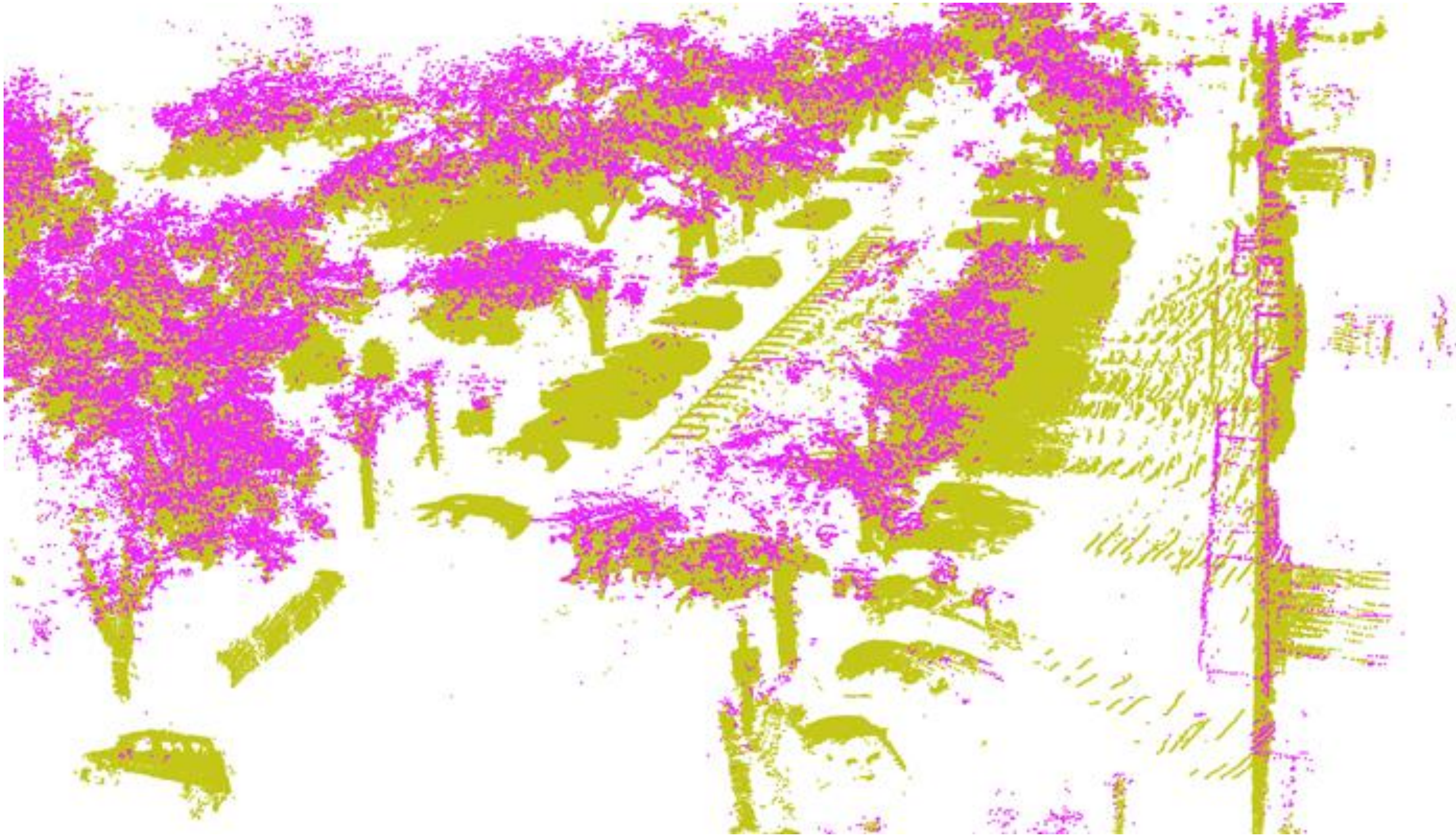
Tree crown removal

- Overhanging trees can corrupt the scene reconstruction as they may occlude facades
- Registered data is dense, thus sparse regions with large scattering (such as leafs) can be detected
- Overhanging tree crowns can be removed

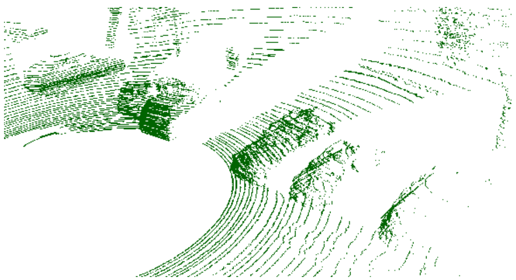




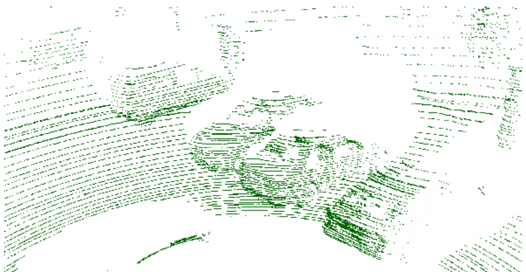
Result of upper vegetation detection



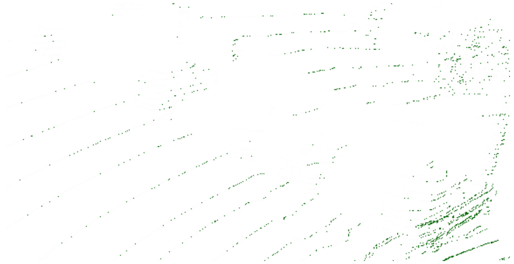
Vehicle detection



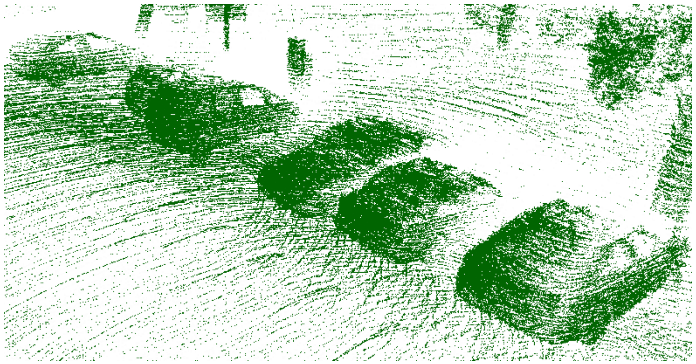
Frame #1



Frame #2



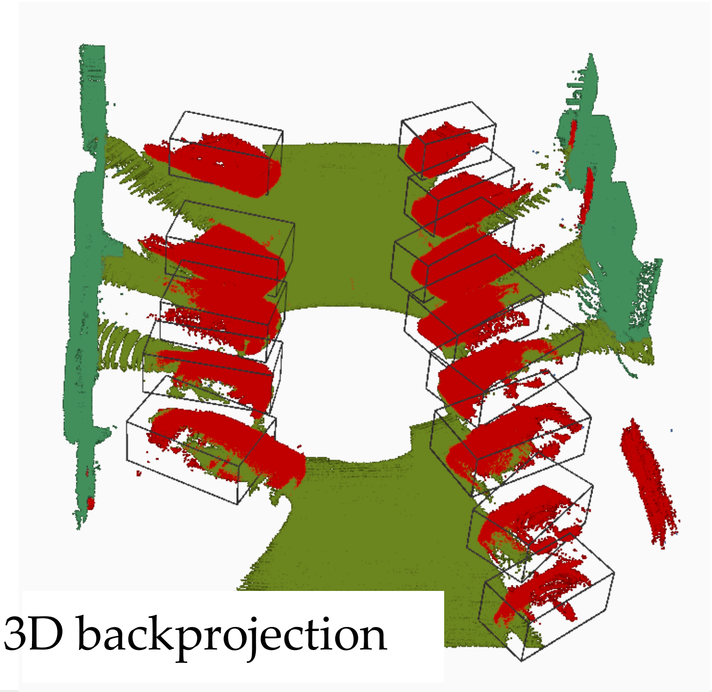
Frame #3



30 merged frames

- vehicles should be removed from the city models

2D recognition



3D backprojection

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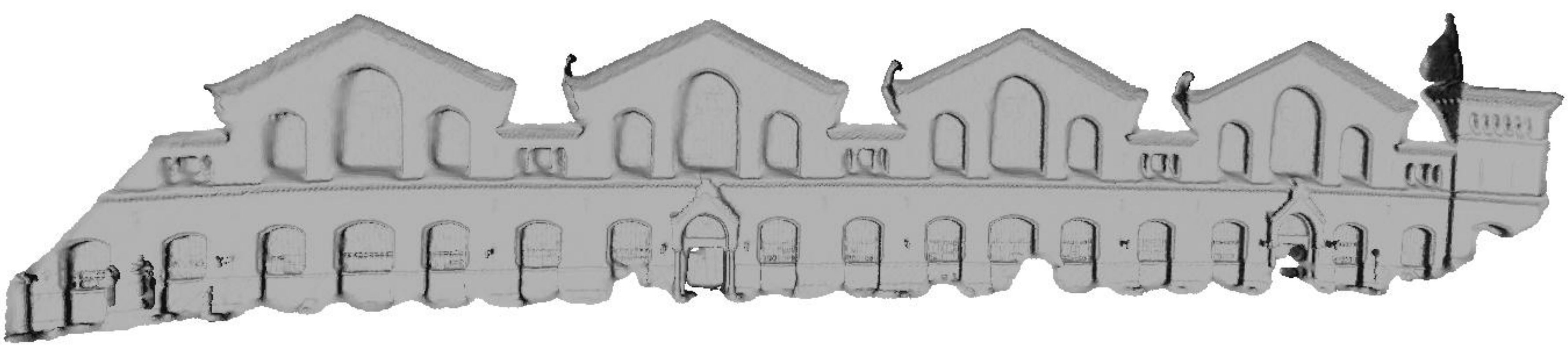
Surface reconstruction

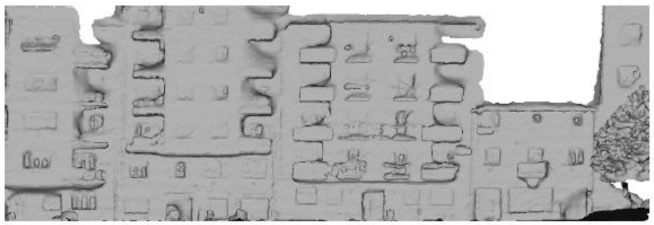
Poisson triangulation of the obtained point cloud

Figures: main and southeastern facades of the Great Market Hall

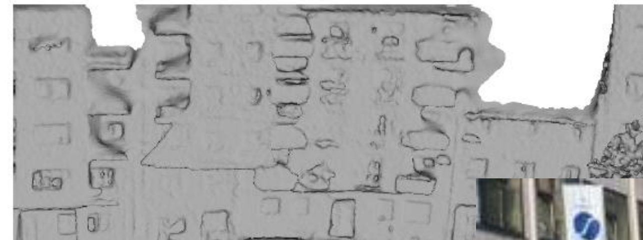


NDT vs TrICP

NDT

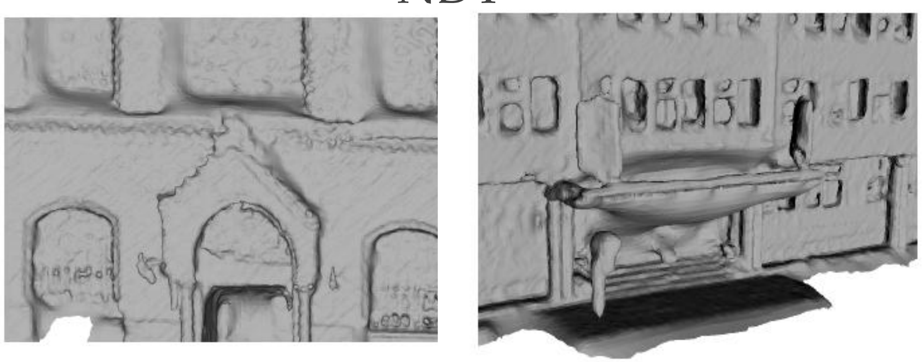


TrICP



- NDT is more robust for 'featureless' buildings (like offic

NDT

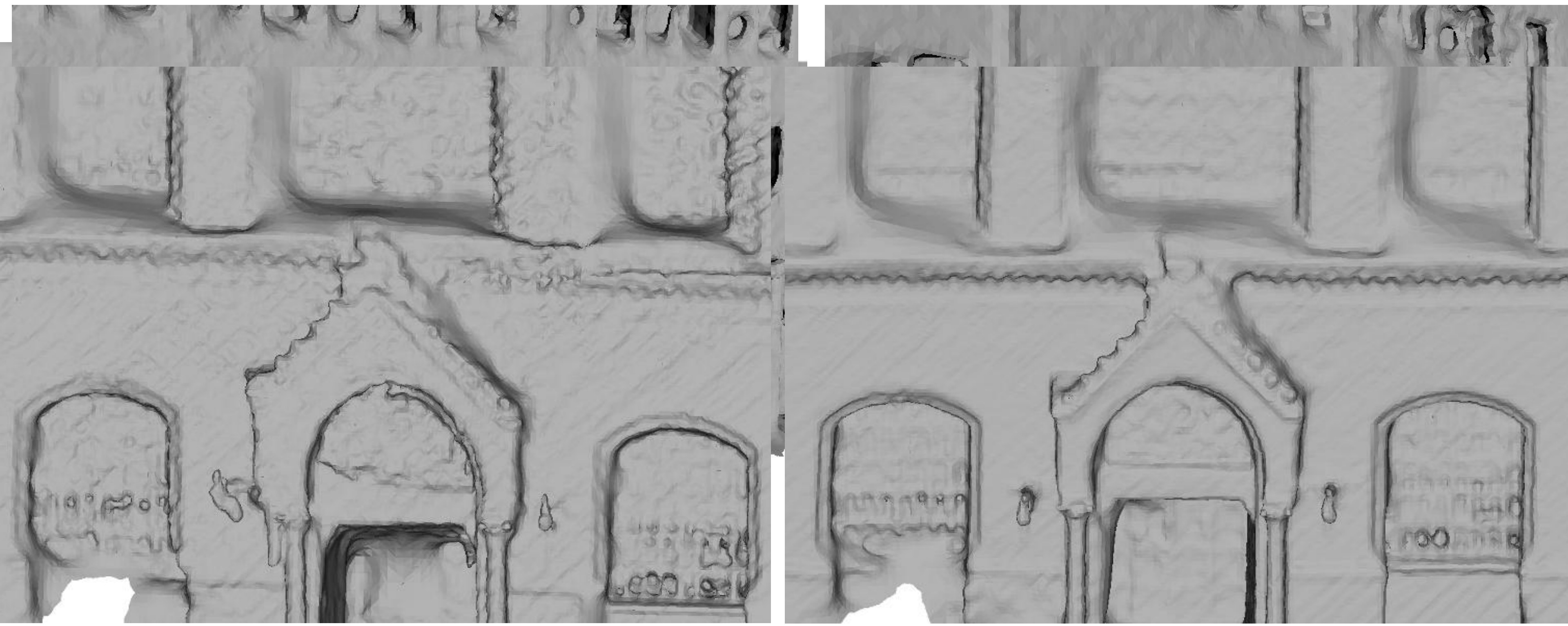


TrICP

- TrICP gives superior results for surfaces containing characteristic features.

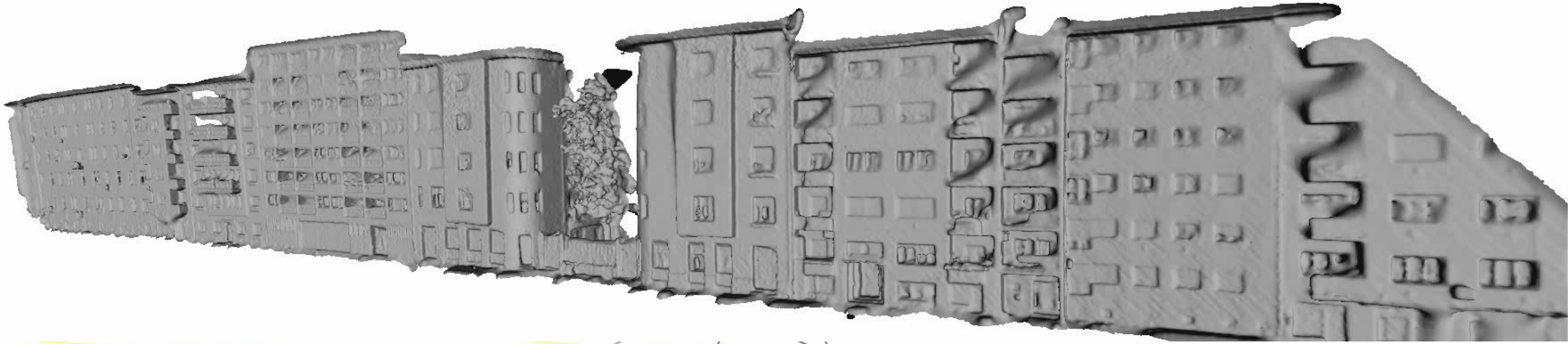
NDT vs TrICP

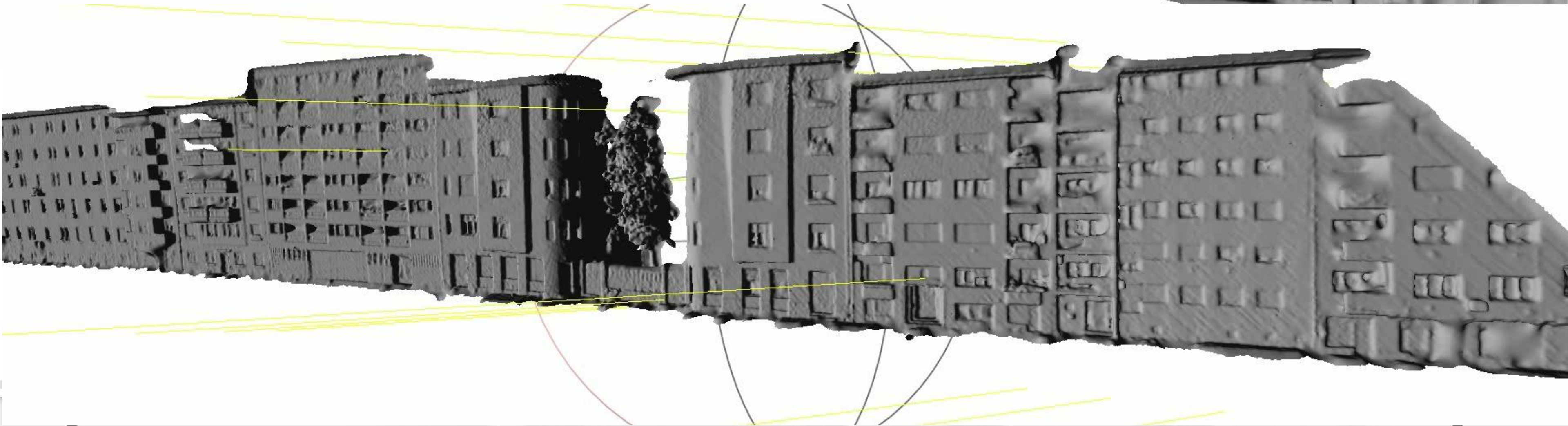
- NDT is more robust for 'featureless' buildings (like office houses)
- TrICP gives superior results for surfaces containing characteristic features.



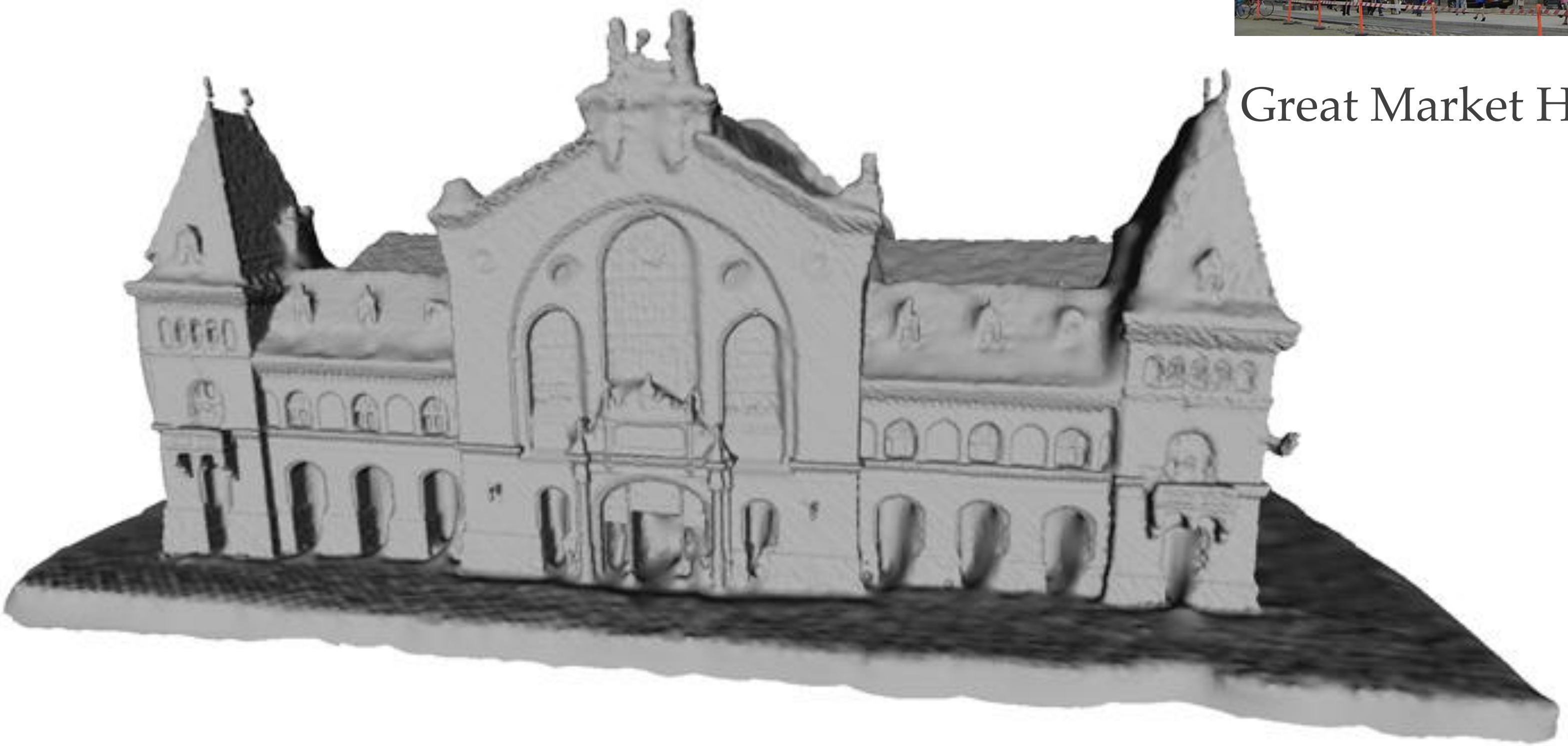
NDT TrICP

Surface models





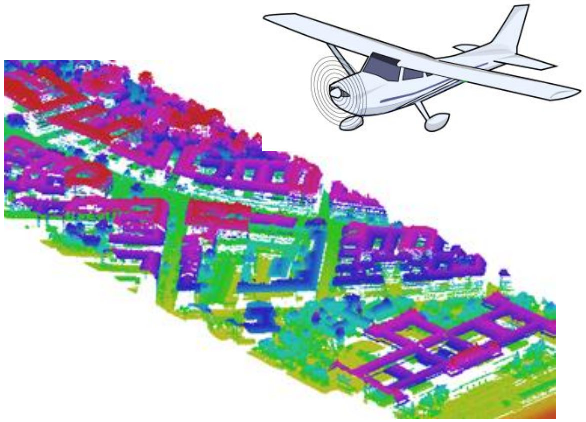
Surface + texture



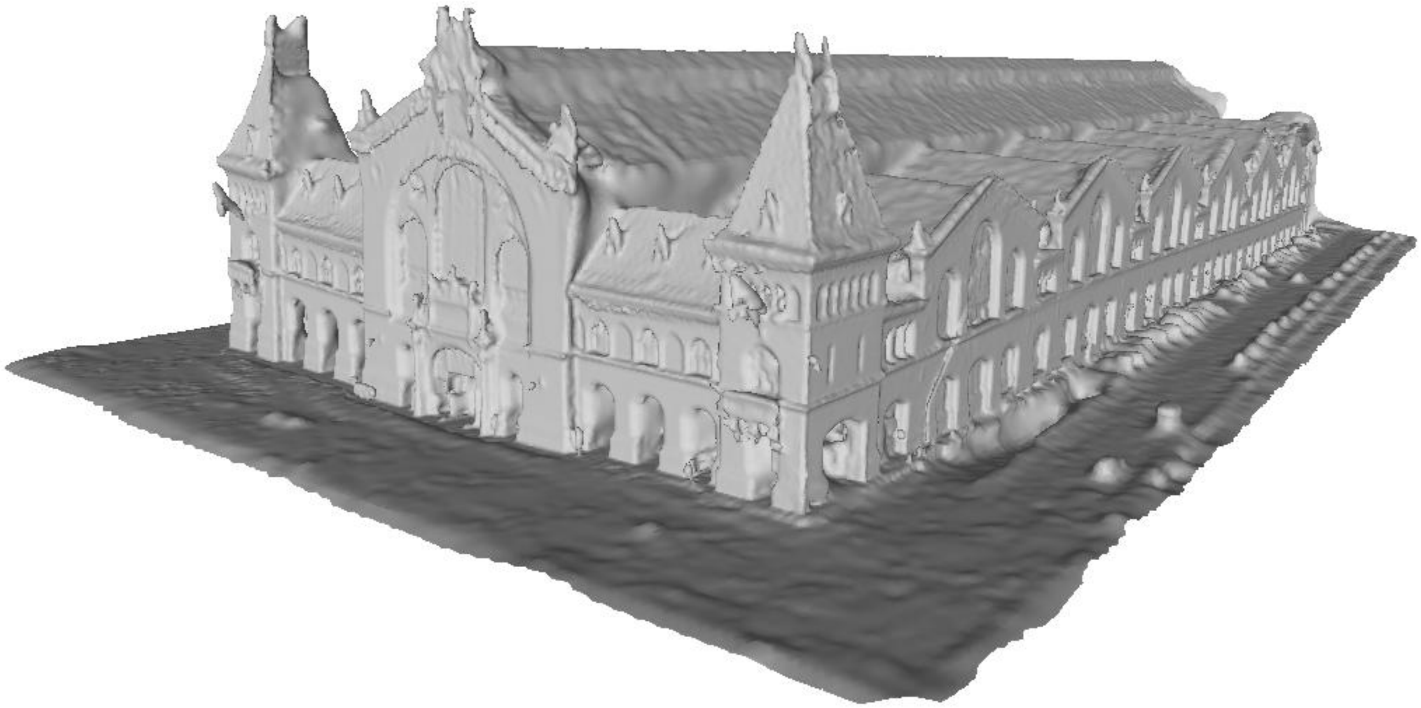
Great Market Hall, Budapest

Data fusion

- Roof (aerial) + facades (terrestrial scan)



Aerial scans © Infoterra Hungary Ltd



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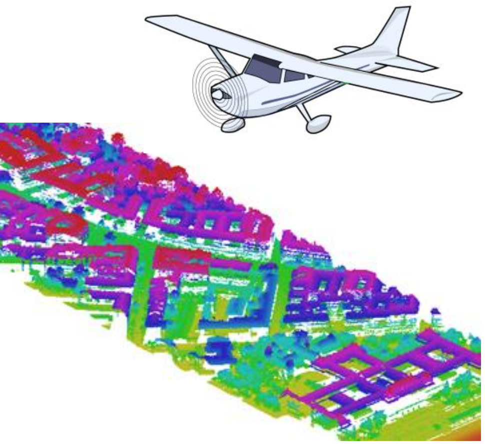

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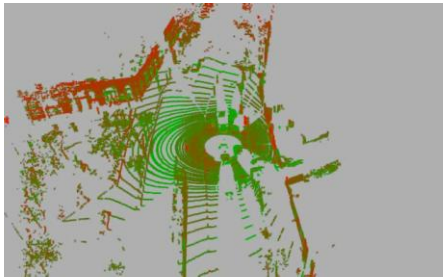

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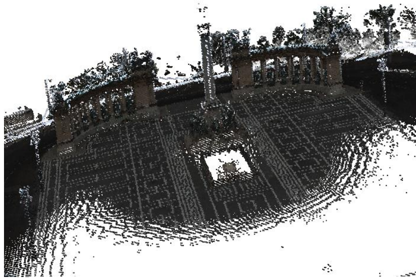
Multi-sensorial mobile mapping system



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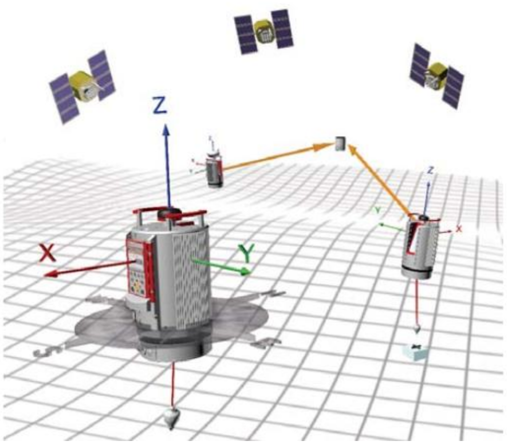
Terrestrial laser scanning



V-Line® 3D Laser Scanner RIEGL VZ-400

General figures	
Maximal range	2,000 m
Meas. rate up	400,000 meas/sec

150 m range evaluation	
Accuracy (vs. true value)	8 mm
Precision (vs. repeated meas.)	5 mm

	Vertical	Horizontal
Field of View	100°	360°
Max scan speed	240 lines/sec	150°/sec
Angle resol.	< 0.0015°	< 0.0005°

Output: colored point cloud!

Main terrestrial scanner brands

Zoller + Fröhlich
Imager 5010X

Riegl VZ-1000

Trimble X130 3D

Leica ScanStation C5

Faro Focus3D X 330

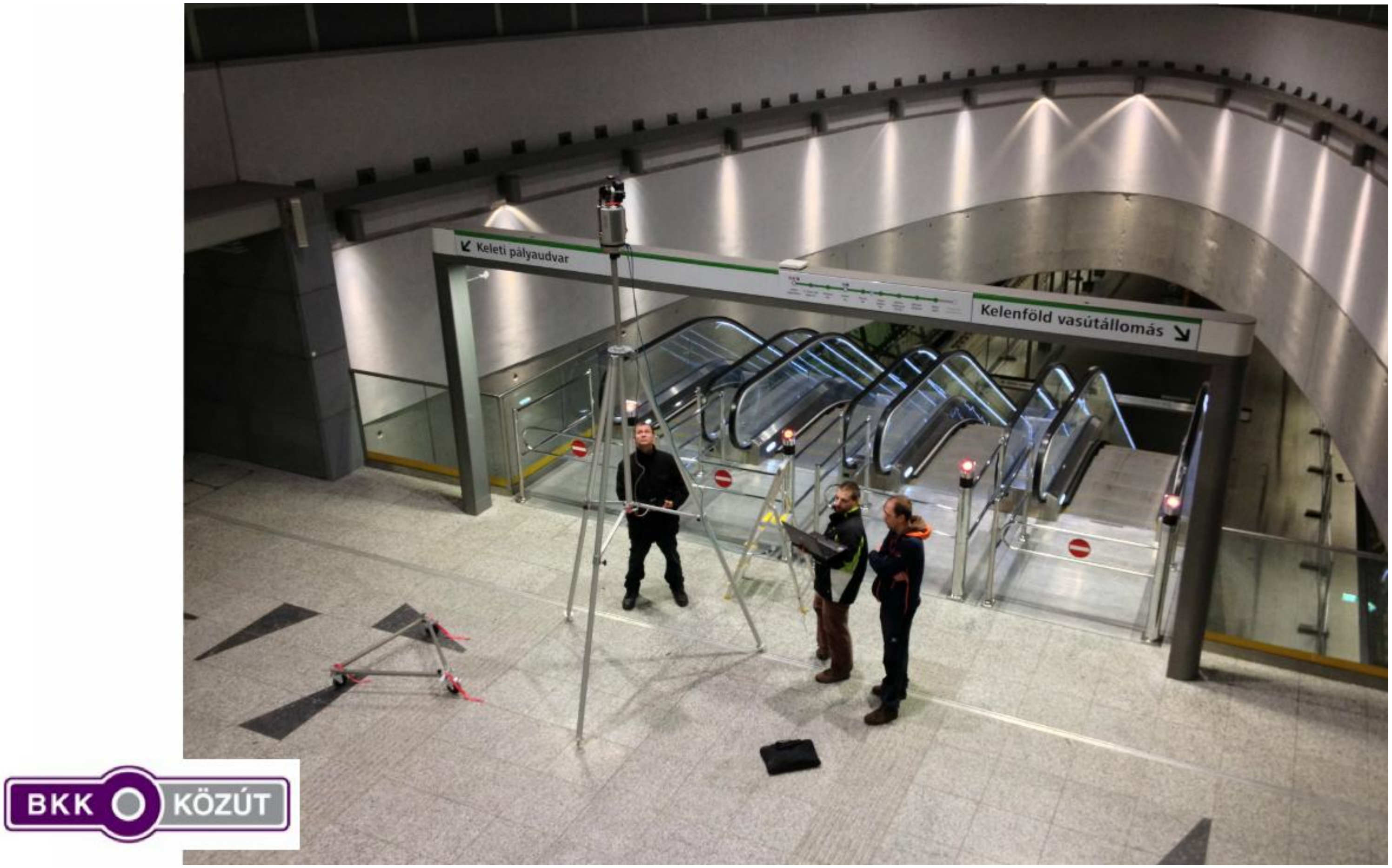
Topcon GLS-2000

Scanning with Riegl VZ-400 in Budapest

BKK KÖZÚT

Scanning with Riegl VZ-400 in Budapest

Scanning with Riegl VZ-400 in Budapest



Scanning with Riegl VZ-400

- Károlyi castle - Füzérradvány

BUDAPEST KÖZÚT

Heritage Survey - Wartburg

Heritage Survey - ArcTron

ArcTron 3D
Expertise in Three Dimensions

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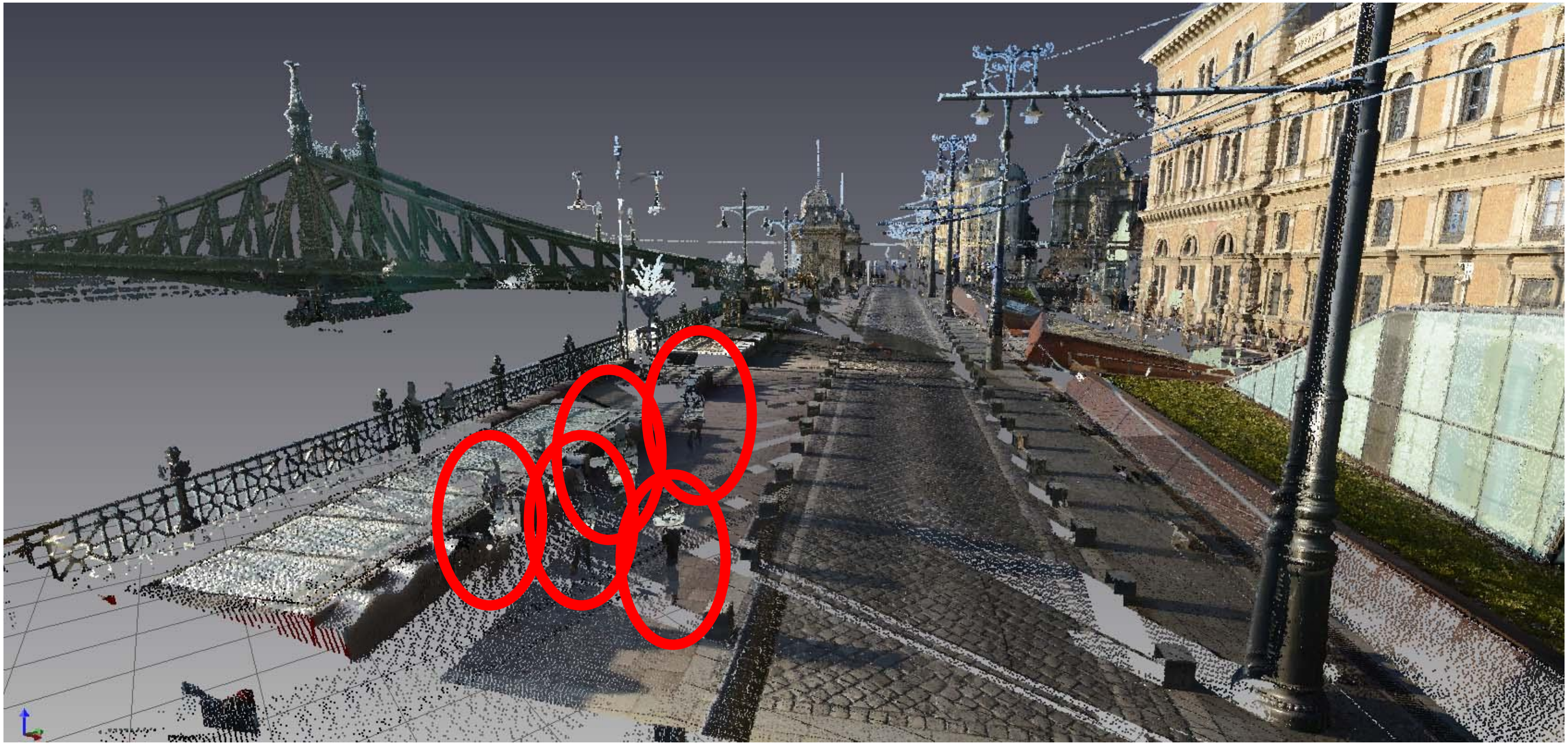
Ghost of moving objects…

Fővám tér Budapest

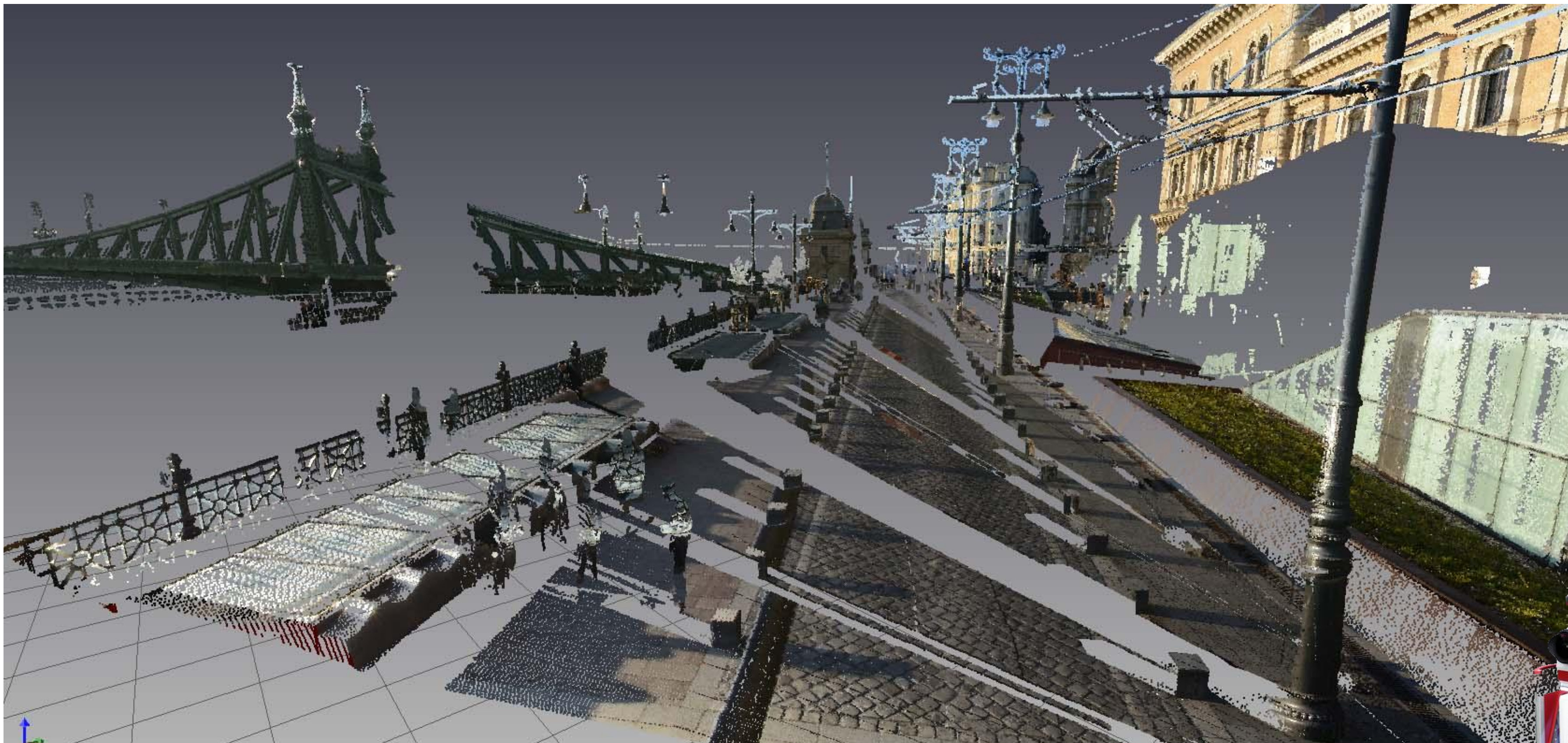


Various scanning positions

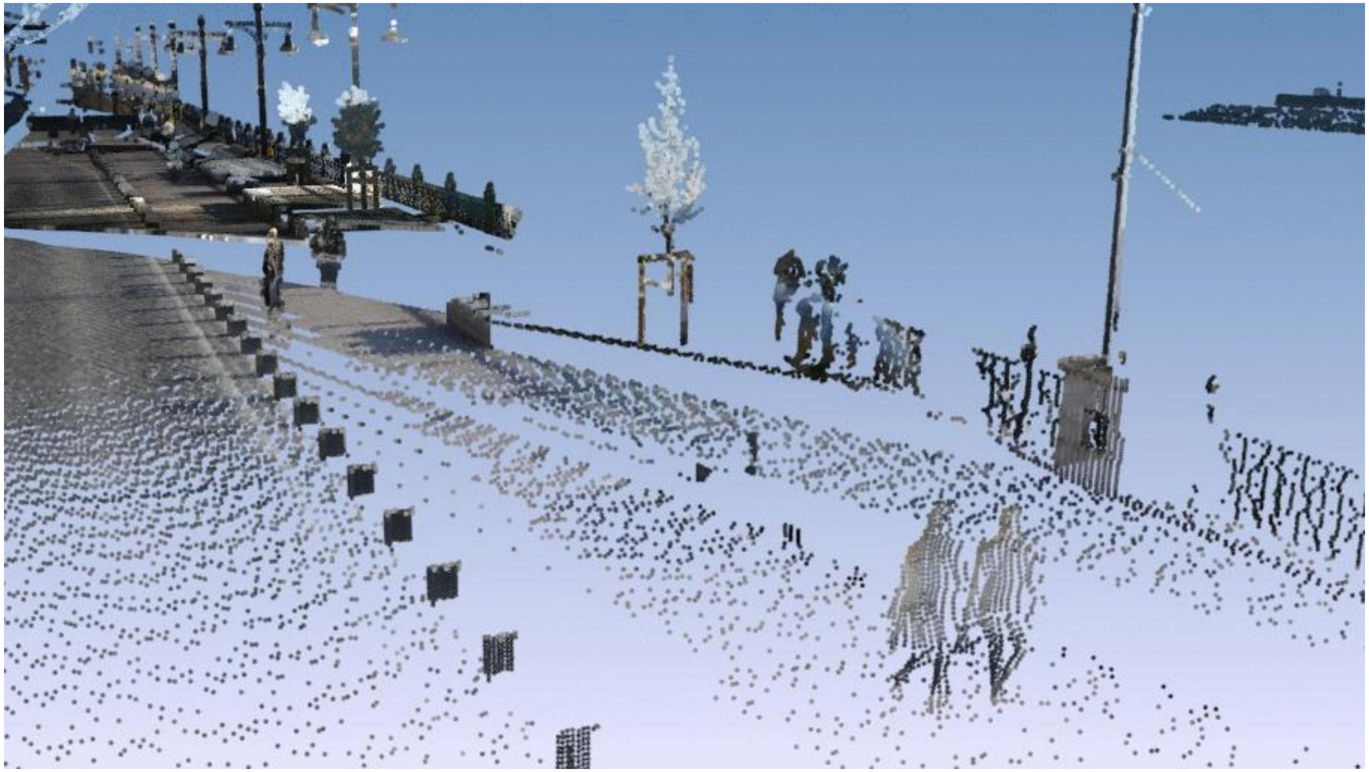
Fővám tér Budapest

Various scanning positions

Fővám tér Budapest



Removing ghost

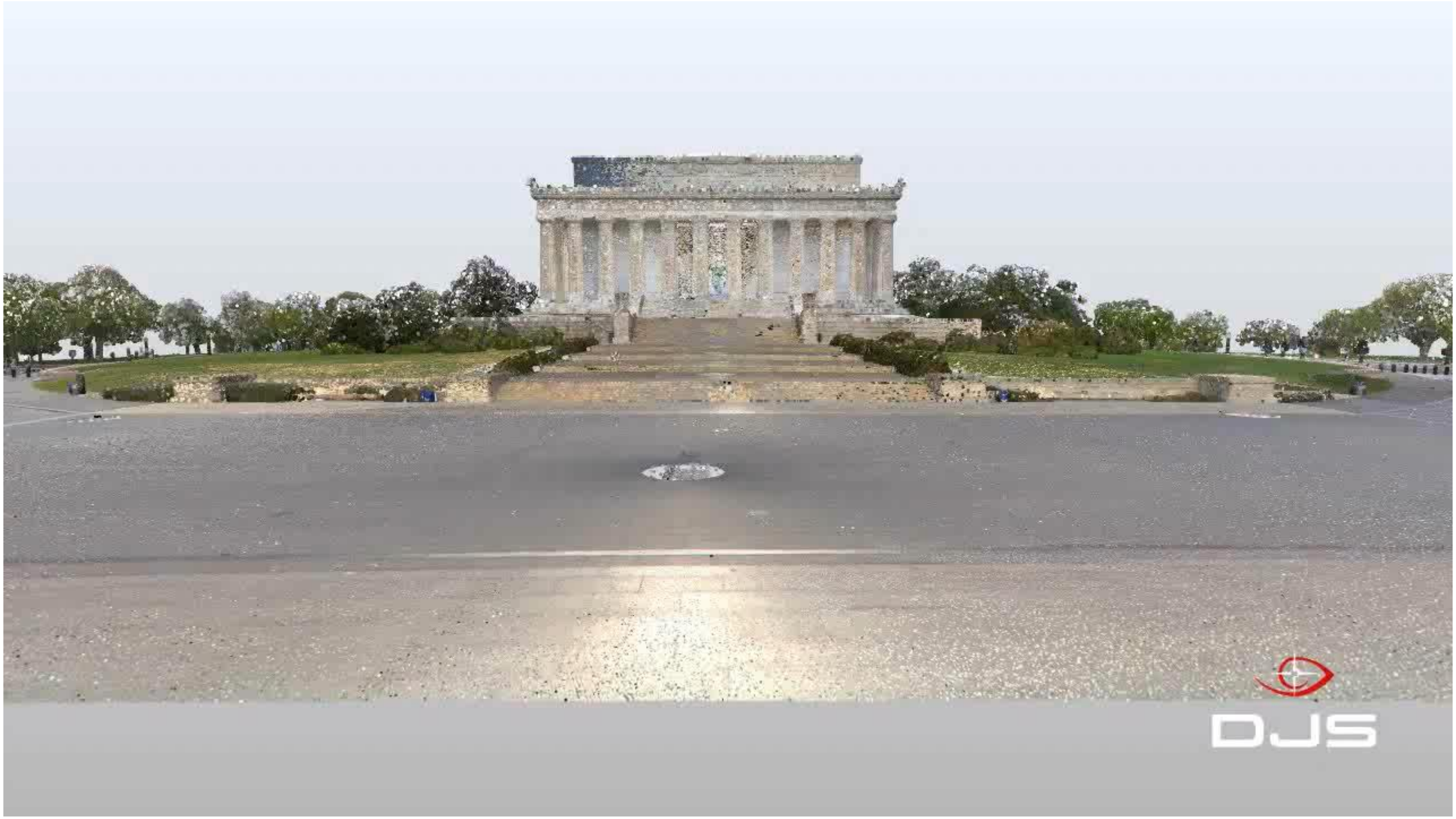


3D inpainting

- 3D inpainting: adaptive and automatic hole filling by local environmental information

http://www.djsscans.com/

Lincoln Memorial, Washington, DC

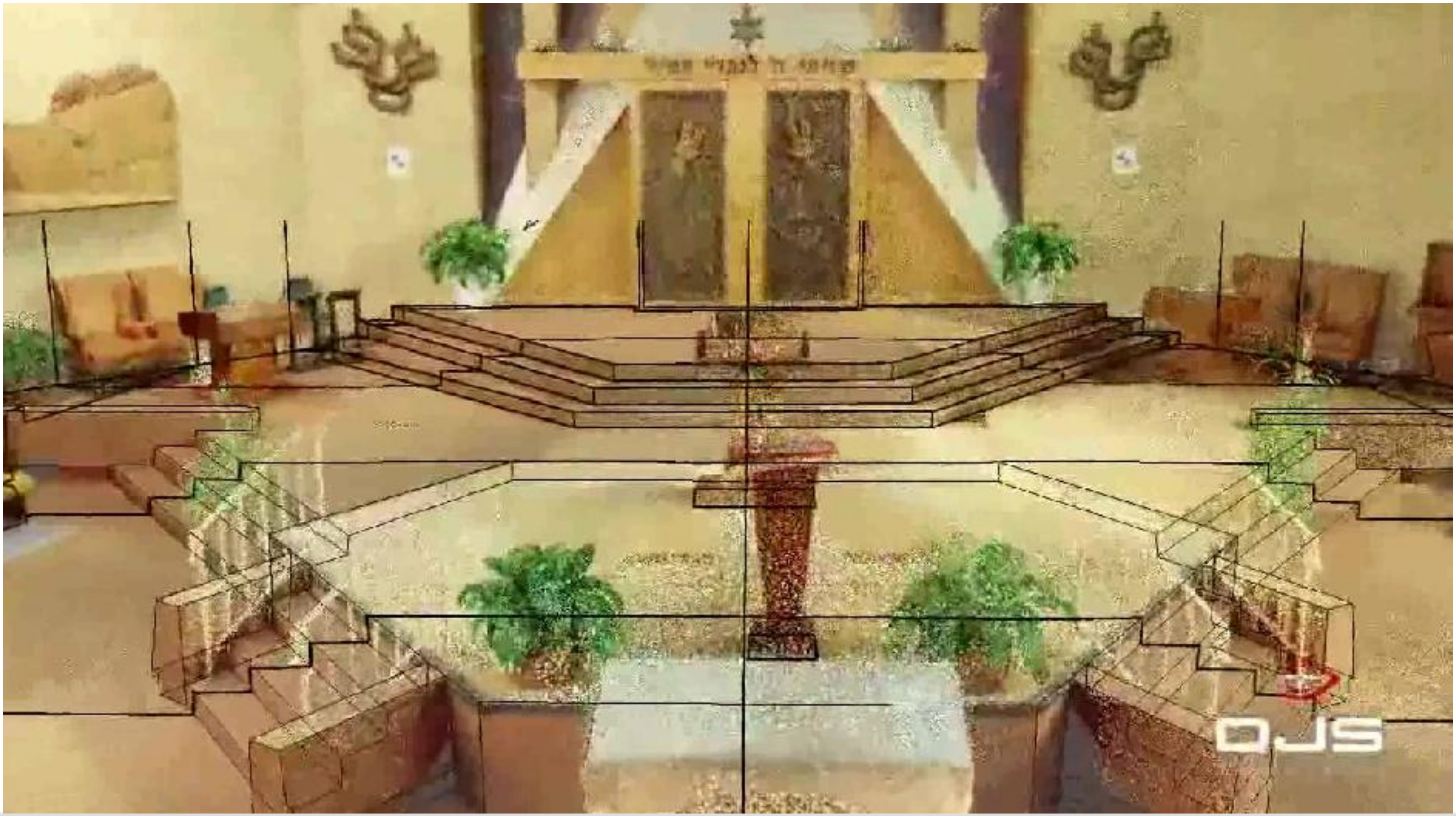


http://www.djsscans.com/

Mount Moriah Cemetery Gatehouse

http://www.djsscans.com/

Sons of Israel Synagogue, Cherry Hill, NJ



Mesh or point cloud rendering?

Pros and cons... what is the future?

- Mesh
  - Compact 3D scene representation
  - Compact surfaces
  - Couple of hundred thousand surface elements →quick rendering
  - All CAD & game engines can read and manage them
  - Realistic colored surface illusion via texturing
  - Limited accuracy
    - polygon approx: smoothness vs. control point fitting
  - Limited details (size of polygons)

- Point cloud
  - Points are dump... no meaningful scene representation
  - Independent points – holey surfaces
  - Couple of billion points → fast rendering is challenging
  - Limited management options in CAD & games engines
  - Realisitic color scenes by point cloud coloring with cameras
  - Very high accuracy
    - depends only on the accuracy of the scanner
  - Unlimited details

Future: We will need very high accuracy + unlimited details

Euclideon SolidScan

Video URL

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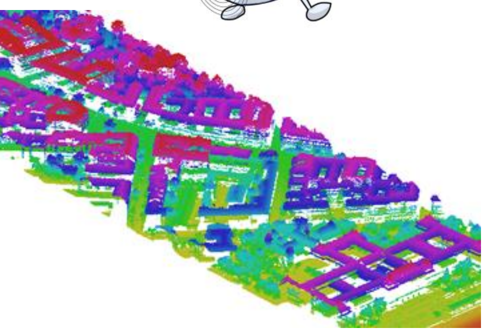
Outline

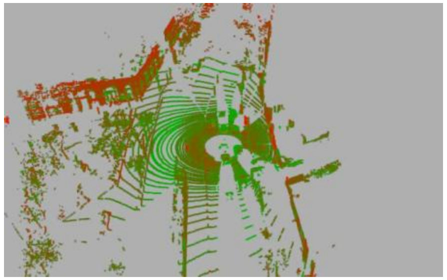
Aerial Lidar



AIRBUS
DEFENCE & SPACE

esa

Velodyne HDL 64-E
Car-mounted laser scanner



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Lidar based terrestrial mapping

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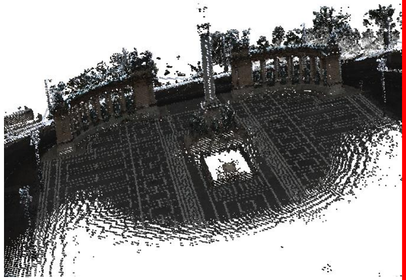
Multi-sensorial mobile mapping system



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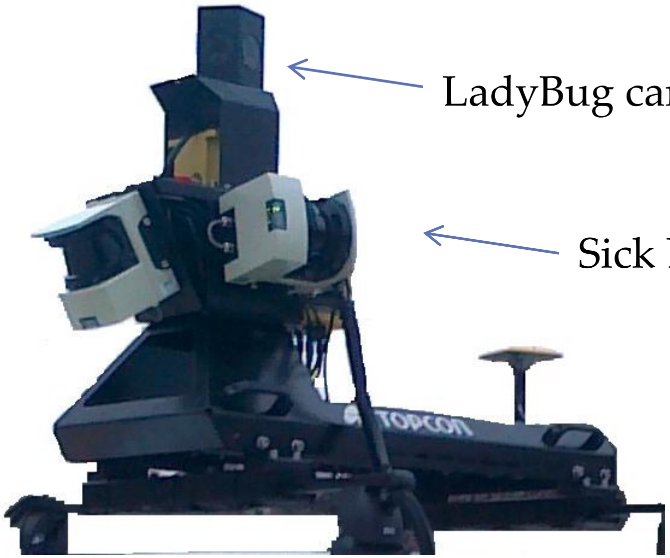
Mobile mapping system

- *Mobile mapping:* integrated array of time synchronised navigation sensors and imaging sensors mounted on a mobile platform.
  - typically photographic, radar, laser, LiDAR or any number of remote sensing systems.
- Output: GIS data, digital maps, and georeferenced images and video.

Mobile mapping: Topcon system



LadyBug camera

Sick Lidar

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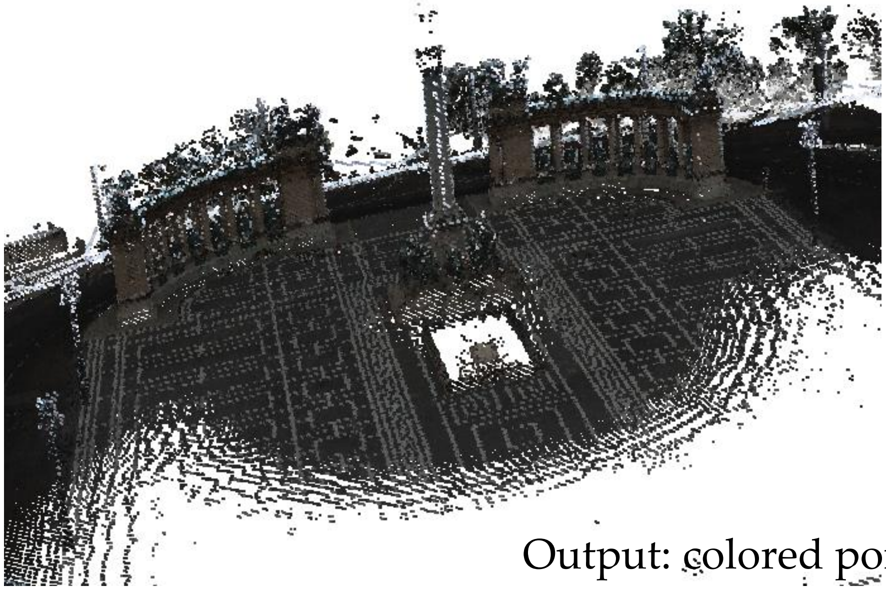
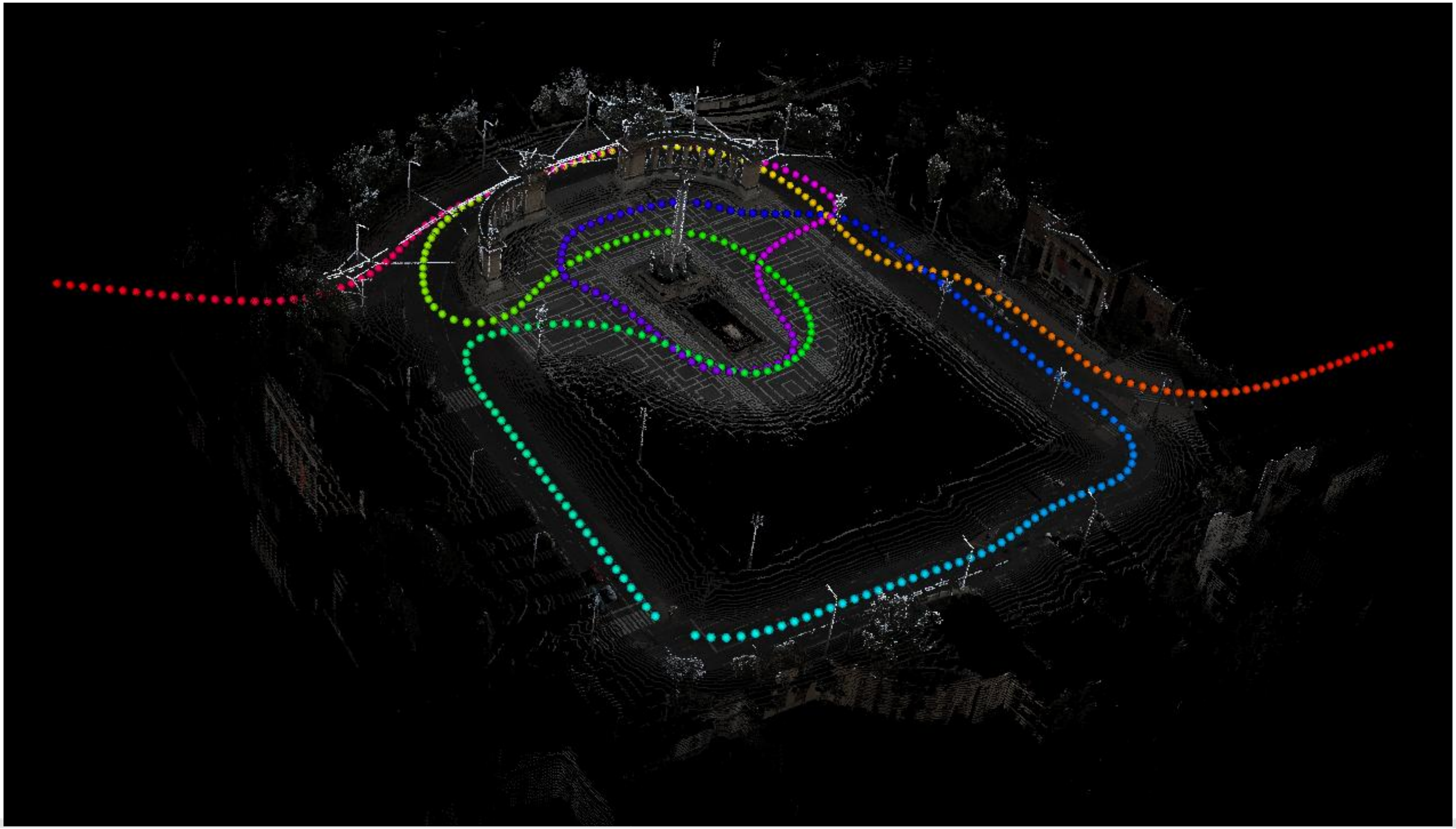


Output: colored point cloud + panoramic images

Vehicle trajectory

Dots: Ladybug camera image shooting points

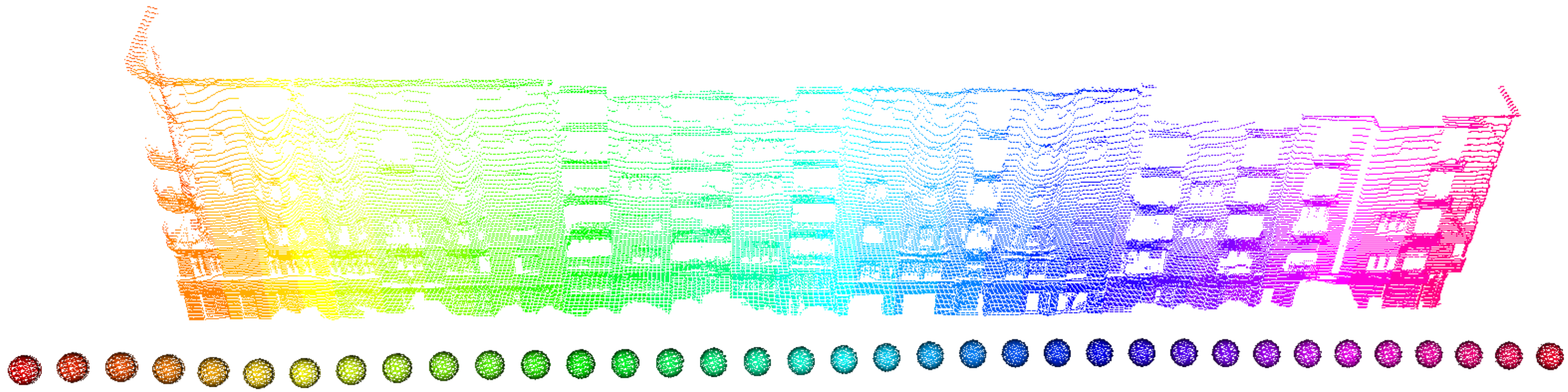


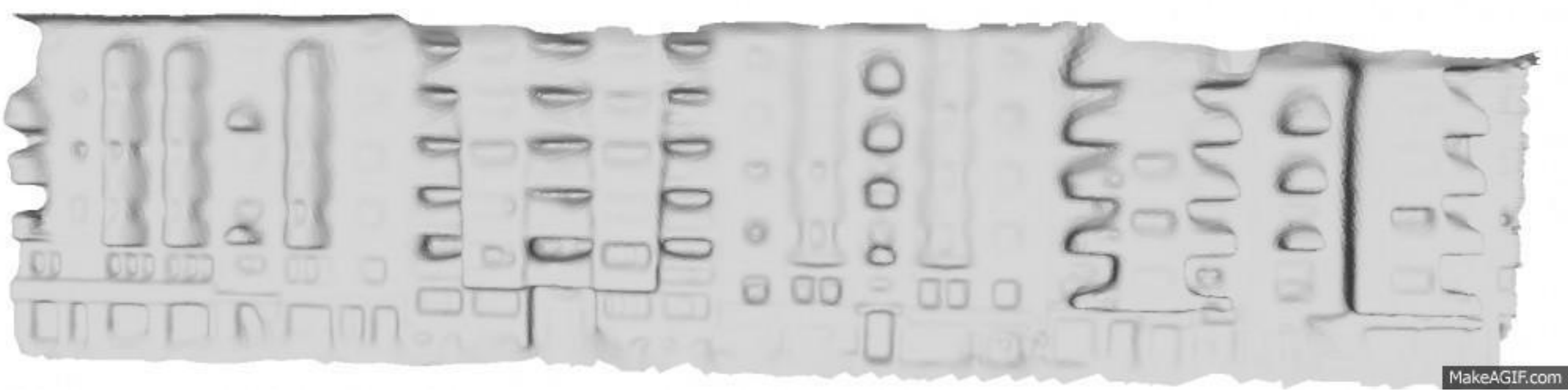
Ladybug panoramic image

Is it appropriate for mesh texturing?

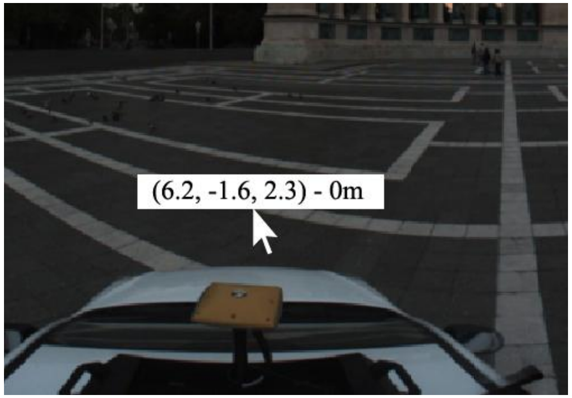
Image part perpendicularly visible from the shooting point

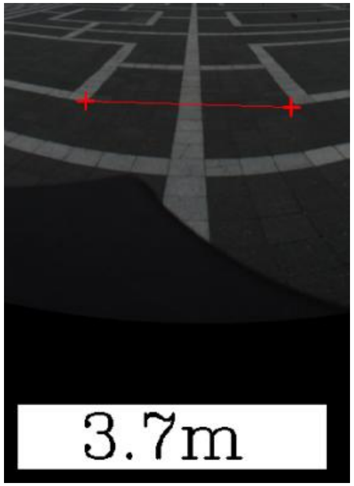
Topcon – facade reconstruction



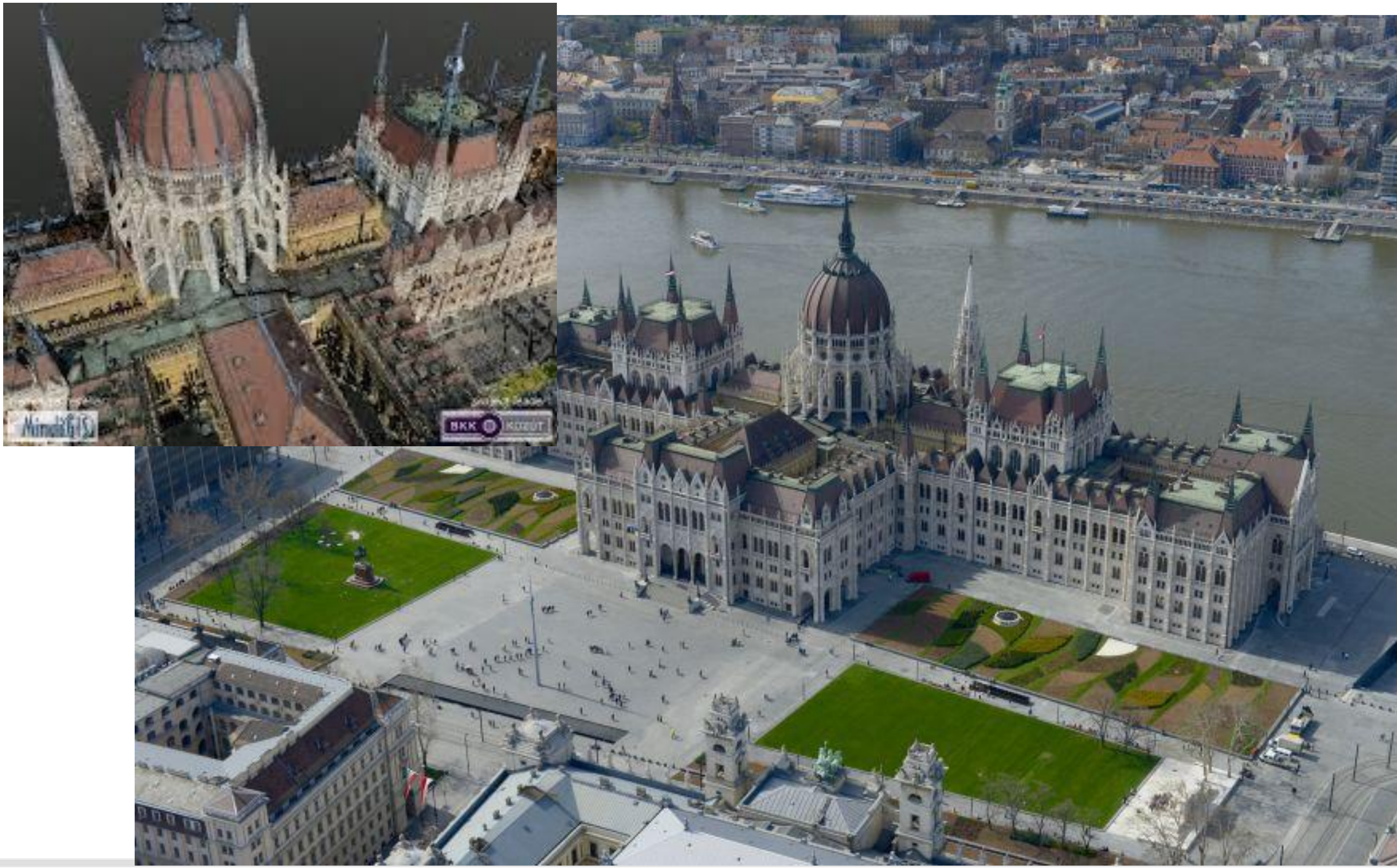


Distance measurement on panoramic images

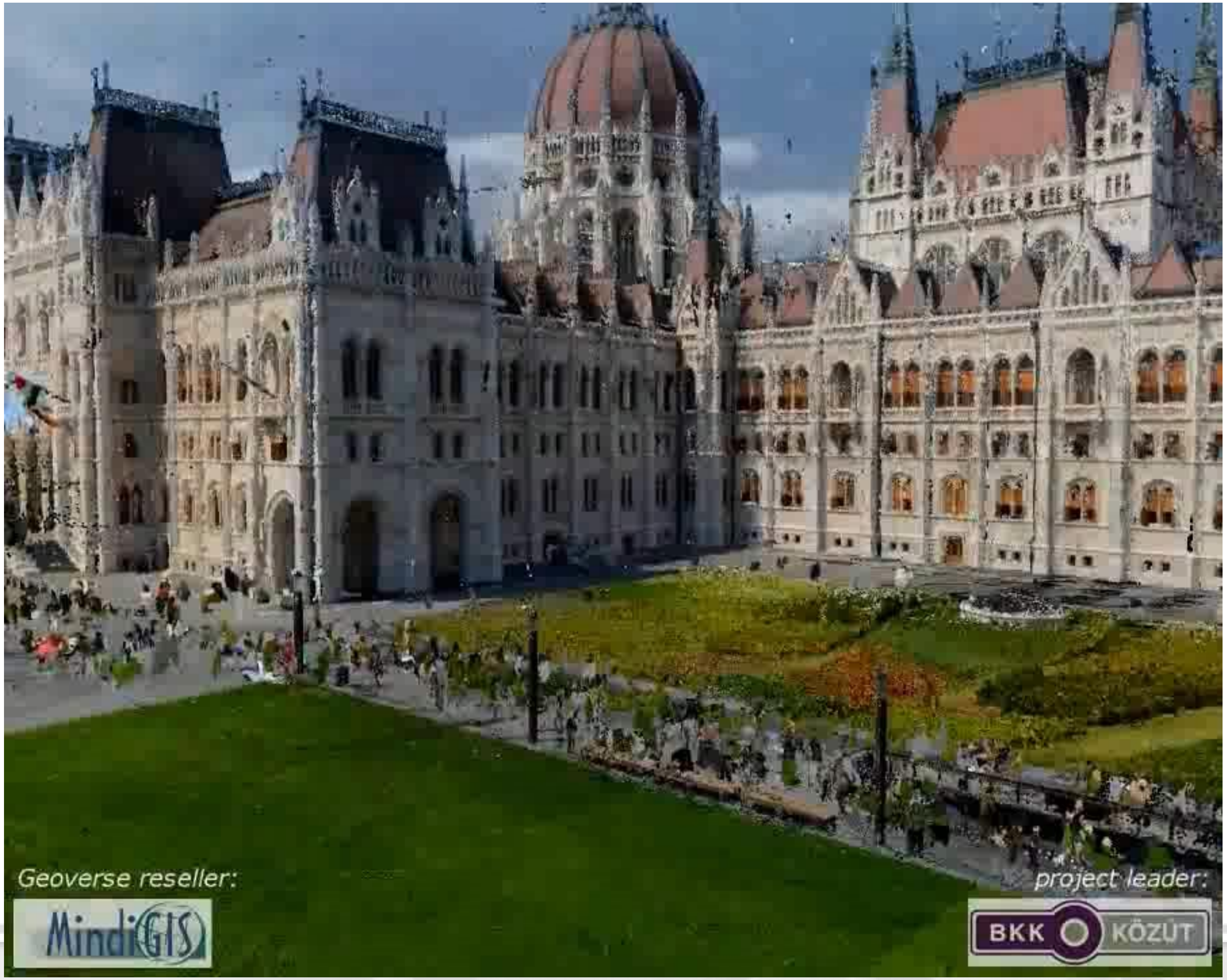




Mobile mapping: Riegl VMX-450 system



Parlament scanning: joint mobile + terrestrial



Video URL

Mobile mapping: only from vehicles?

Mobile mapping for pedestrians

Microsoft UltraCam Panther Backpack (link)

RiCOPTER

- high-performance multirotor **UAV**
- integrated **LiDAR**: **RIEGL VUX-1**
- airborne laser scanning
- overall weight of below 25kg
- 15-30 min. missions

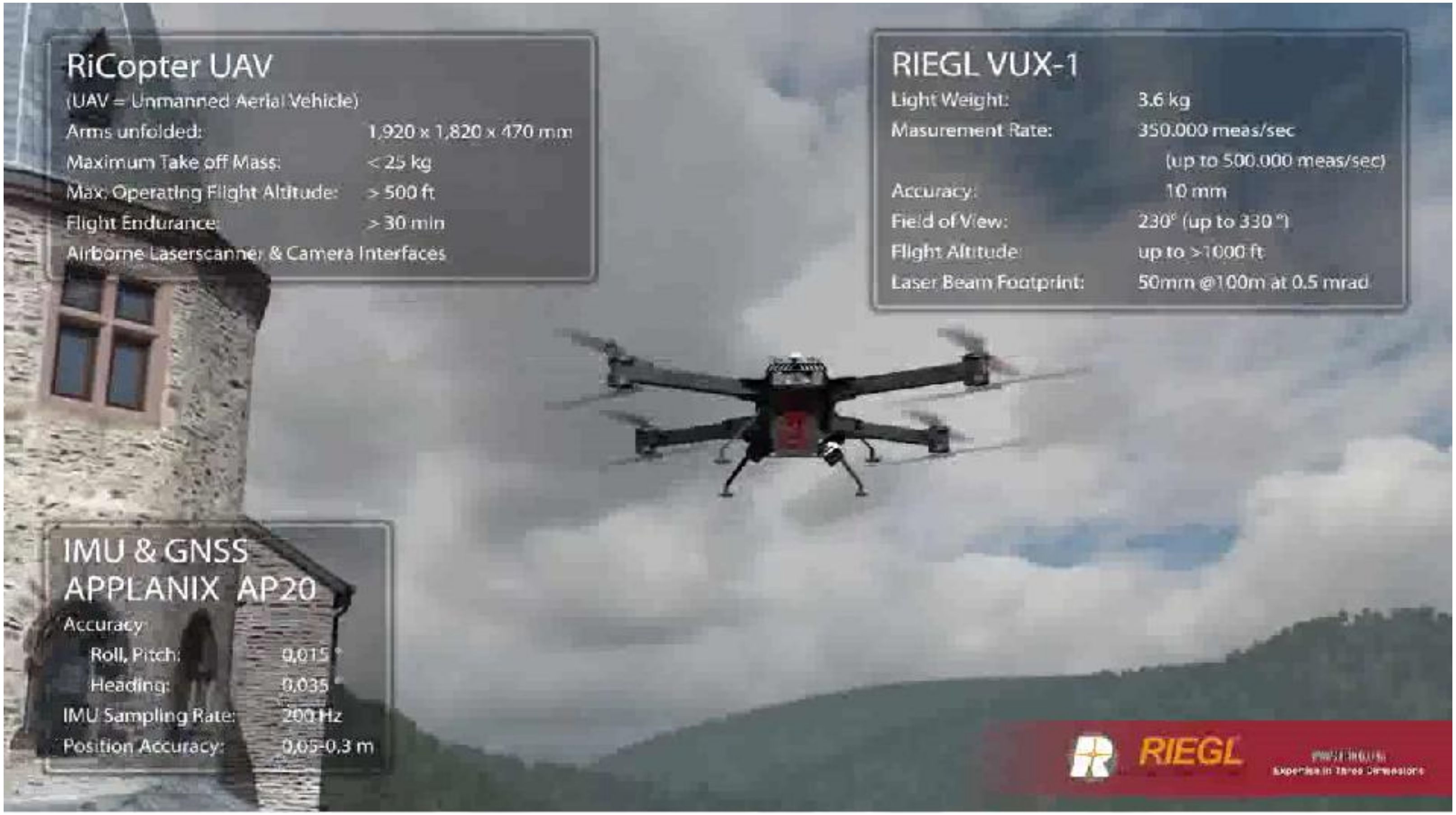
ArcTron 3D
Expertise in Three Dimensions

RiCopter case study

- UAV-based 3D Laser Scanning Documentation of **Vianden Castle** (Luxembourg)
  - Cooperation of **ArcTron 3D GmbH** and ***RIEGL* Laser Measurement Systems**
  - extremely high resolution 3D dataset from the castle
  - RiCOPTER flew **three missions** of approximately **15 minutes** each, proving its flight stability even under **very adverse wind** conditions.
  - Proof: "flying surveying robot" is able to conduct **very complex 3D inventories** in an **extremely short amount of time**.

http://www.arctron.de/en/gallery/

Scanning of Castle Vianden, Luxemburg (link)



i4D = dynamic 3D scenes

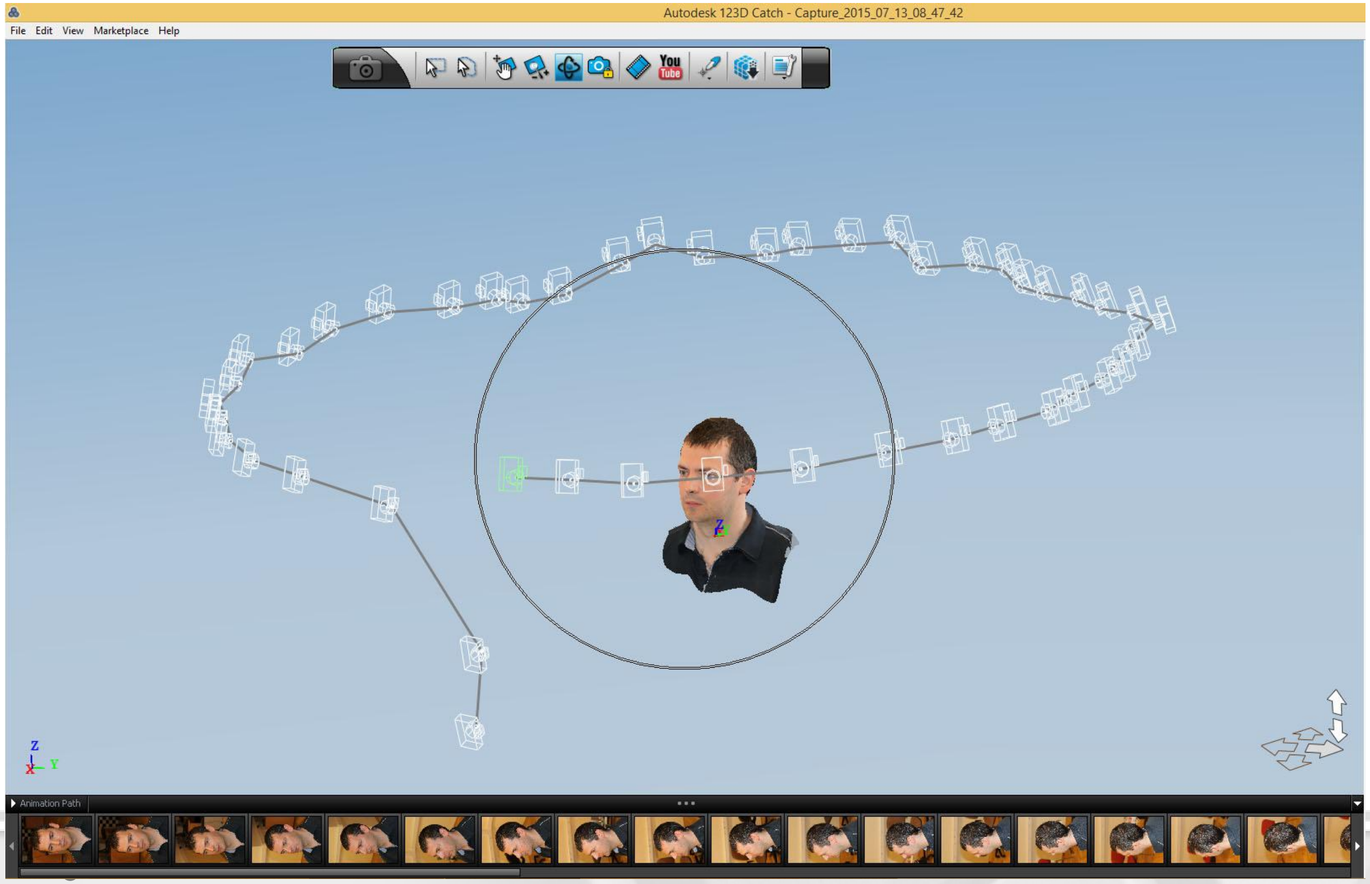
Moving avatar creation – 4D Studio

- A studio equipped with multiple calibrated video cameras
- Objectives
  - capture same scene from various viewpoints
  - create dynamic 3D models of moving objects

Panorama of 4D studio at SZTAKI, Budapest

Acquisition of static objects

- One or two cameras sufficient, but more views → higher accuracy
- Cameras (or scanner) can move around the object



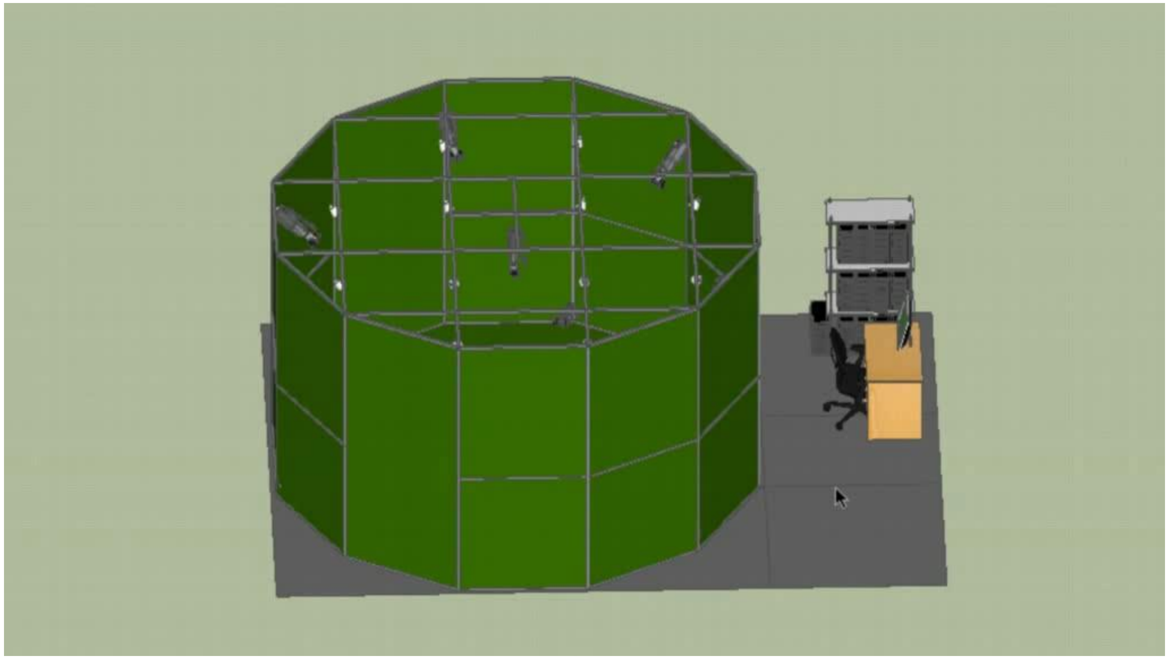
AUTODESK® 123D® CATCH

Acquisition of dynamic objects

- Dynamic objects
  - simultaneous images from multiple viewpoints → multi-camera system
  - fixed cameras
  - less views → lower quality
  - redundancy of sequence → higher accuracy

Hardware components

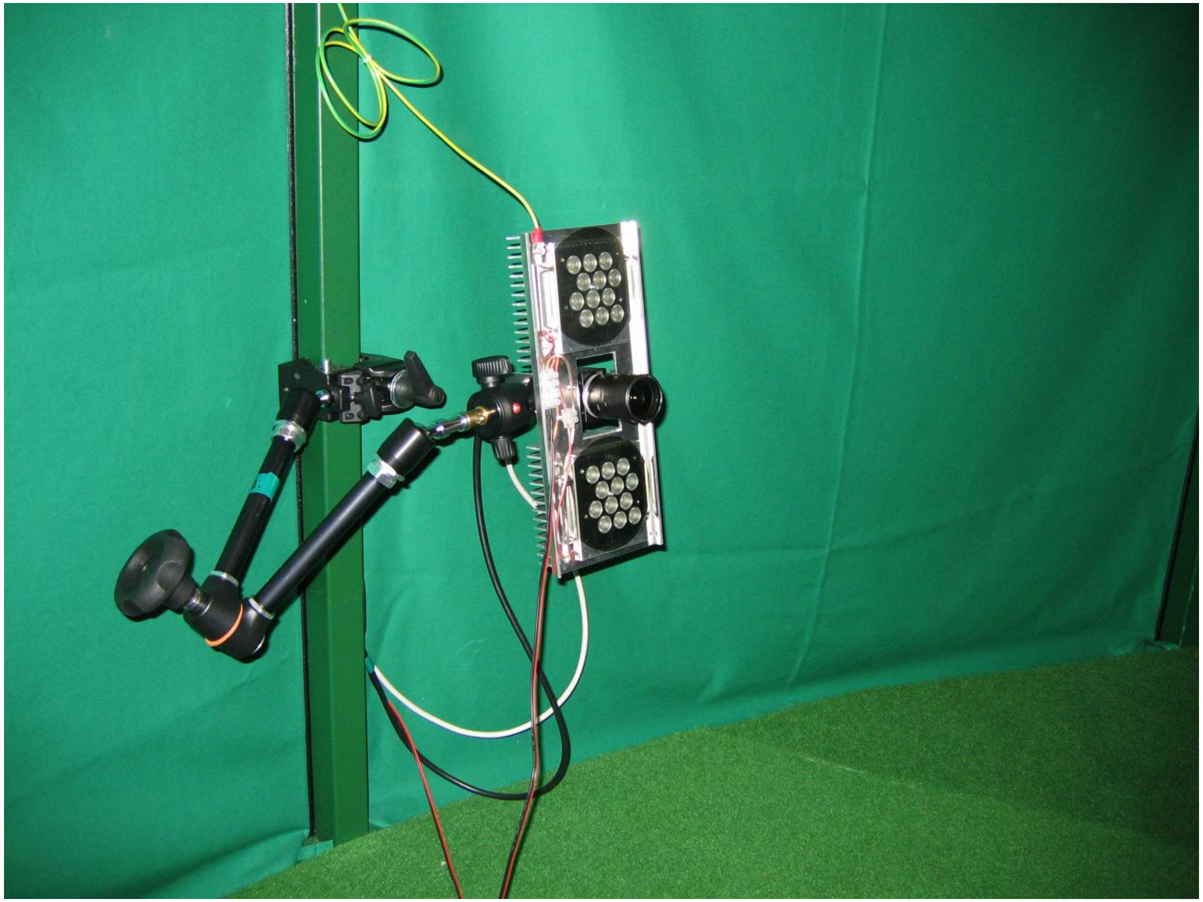
- Green box
  - cylinder with dodecagon base
  - massive, firm steel cage
  - 12 cameras uniformly around scene + 1 camera on top
  - green curtains and carpet → homogeneous background



Hardware components

- Cameras
  - wide-angle lenses
  - 1624 x 1236 pixels
  - 25 fps, GigE (Gigabit Ethernet)
- Lighting
  - light-emitting diodes (LEDs) set around each camera
  - can be turned on/off with high frequency
- Micro-controller
  - synchronises cameras and lights
    - opposite light turned off when camera takes picture
    - allows for more flexible configuration of cameras
- Computing power
  - 7 conventional PCs → 2 cameras per PC

Hardware components



Adjustable platform with video camera and LEDs mounted on cage

Software components

- Two main software blocks
- `Studio`
  - image acquisition software
  - → video recording
- `ModelMaker`
  - 3D reconstruction software

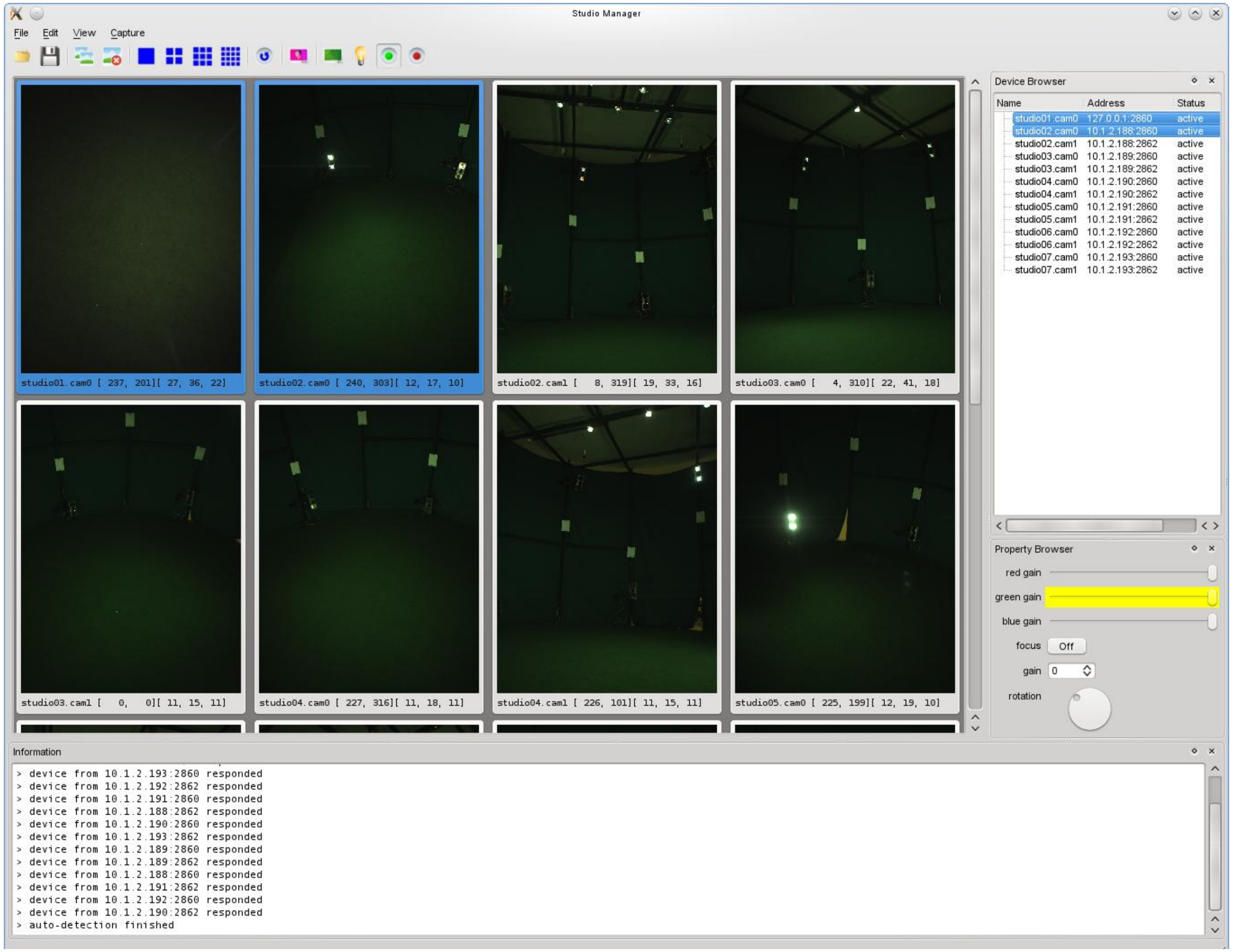
    → creation of dynamic 3D models
- Complete software system developed at SZTAKI
  - uses elements from OpenCV

Software components

- Selects cameras for acquisition
  - user can use a subset of cameras
- Configures cameras
  - focus, gain, white balance, etc.
- Calibrates camera system
  - intrinsic parameters of cameras (focus, lens distortion, etc.)
  - positions and orientations of cameras in joint coordinate system

  → extrinsic parameters
- Synchronises cameras and lights
- Captures synchronised multi-video sequences

Interface of image acquisition software



Camera system calibration

- Based on OpenCV routines (using method by Z.Zhang)
- Operator moves and shows 7×6 flat calibrating chessboard pattern to each camera
  - pictures taken for varying orientations of calibrating pattern
  - corners detected and identified unambiguously

  → intrinsic parameters of each camera

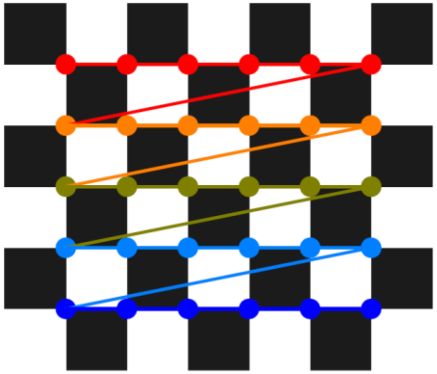
  → lense distortion parameters of each camera

  → relative positions and orientations (poses) of neighbouring cameras
- Chessboard pattern put on table and viewed by upper-row cameras

  → extrinsic parameters of upper-row cameras
  - relative poses of bottom-row cameras already known

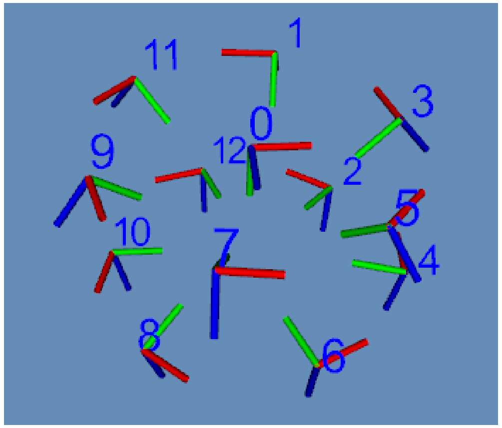
  → extrinsic parameters of all cameras

Camera system calibration



order of corners

showing chessboard



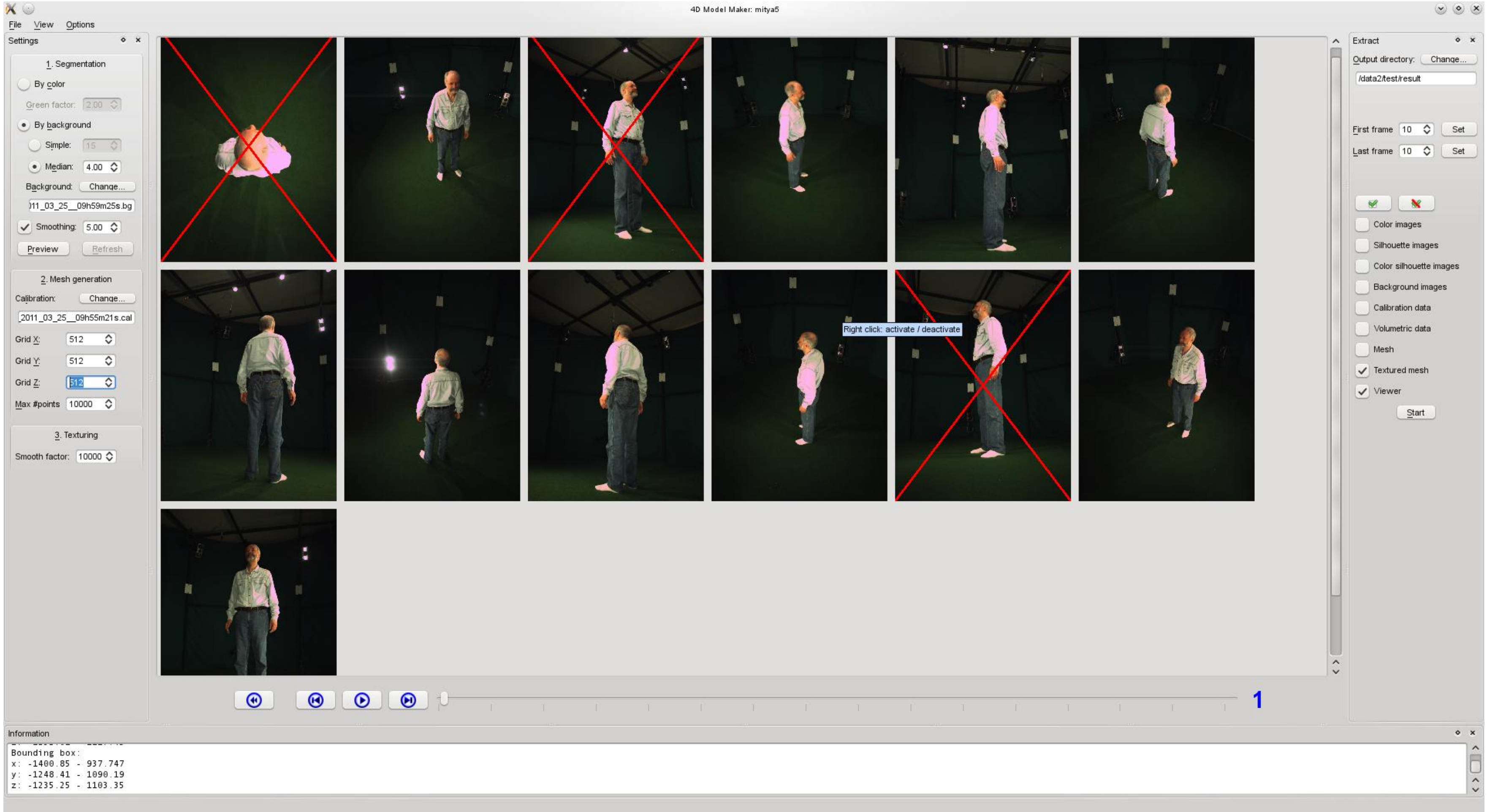
extrinsic calibration

- Asymmetric pattern is used to unambiguously identify corners under rotation
- Calibrating pattern is rotated to vary orientation
- Extrinsic parameters are defined in common coordinate system

Reconstruction software step-by-step

1. Extract **colour images from raw data captured**
2. Segment colour images to **foreground and background**
3. Create **volumetric model by Visual hull algorithm**
4. Create **triangulated mesh from volumetric model**
5. Add **texture to model**

Interface of reconstruction software

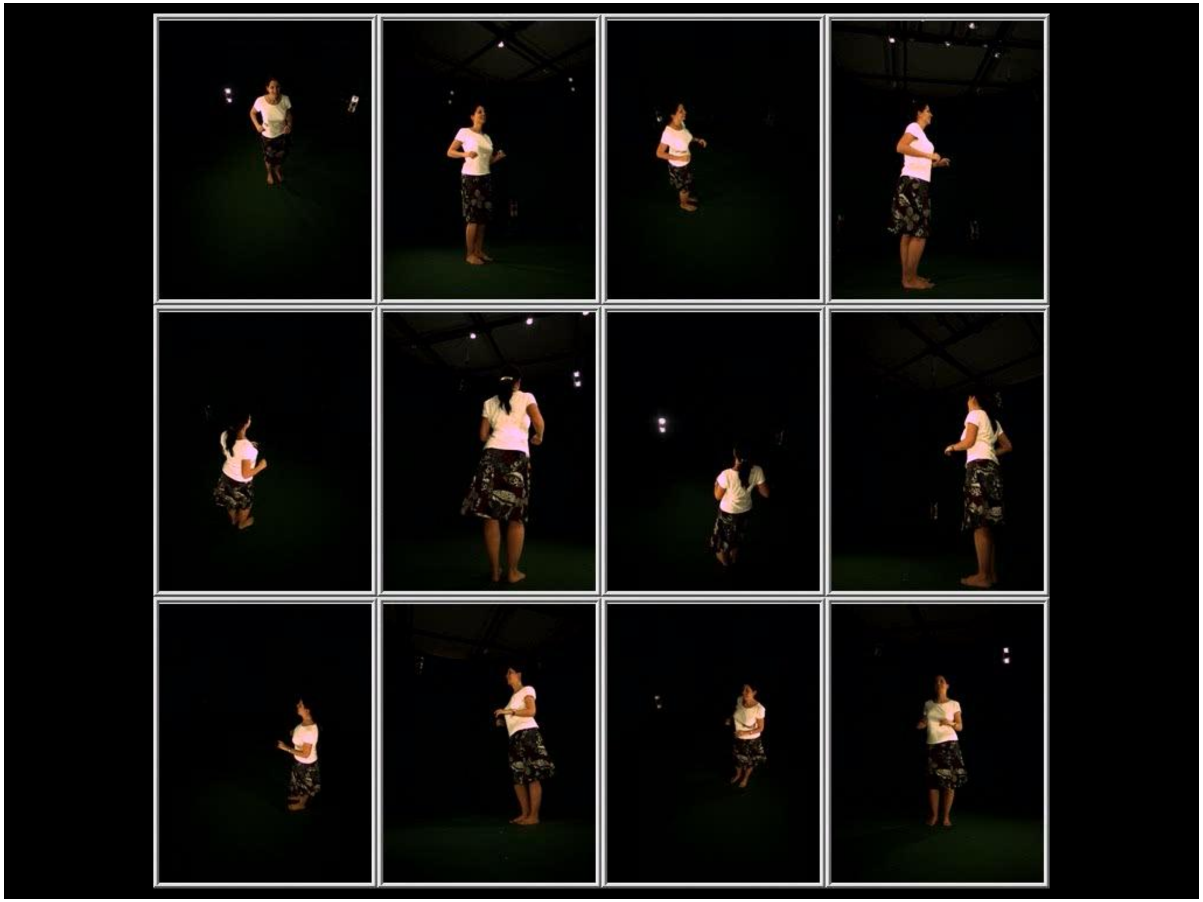


Reconstruction software step-by-step

- Basic configuration: each video frame is processed separately
  - temporal coherence has been addressed later (not discussed here)
- Binarises colour input images
  - assigns 0 to background, 255 to object
  - binary image provides **silhouette of object**
- Principles of segmentation
  - assumes that background is larger than object
  - reference background image obtained in absence of objects
  - input RGB image converted to spherical colour representation

  → improves robustness to illumination changes
  - difference between image and reference background calculated
  - object detected as outlier using robust outlier detection

Video illustration of segmentation



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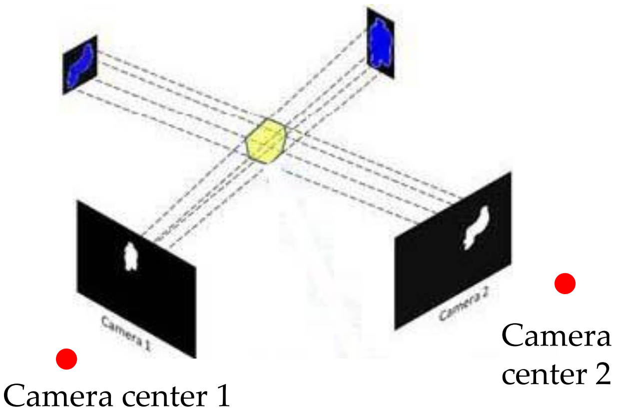
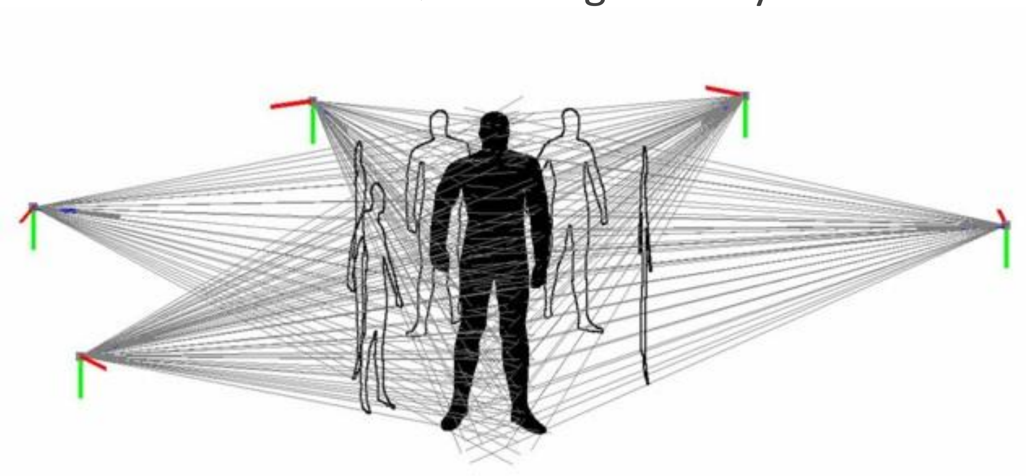
Creating volumetric model

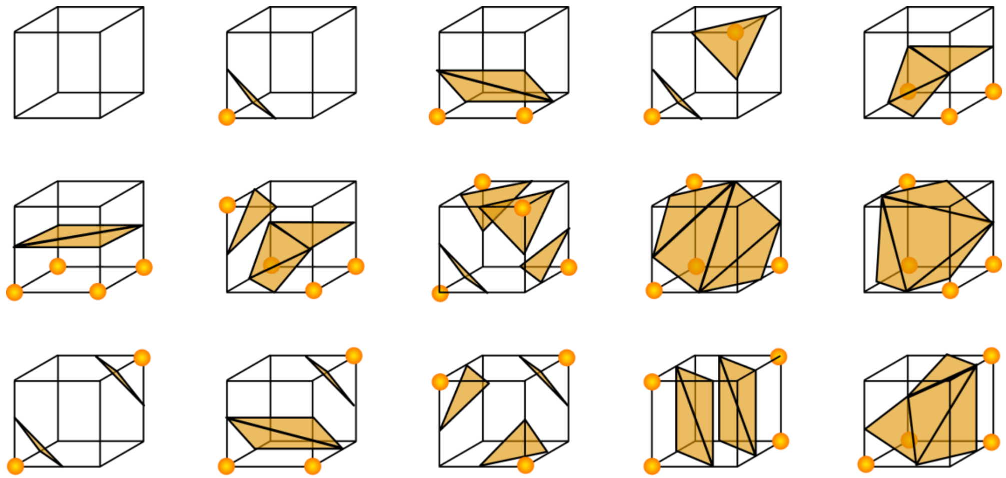
- Apply shape-from-silhouettes to obtain Visual hull
  - maximal volume consistent with given set of silhouettes
- Back-project silhouette images in 3D space
- Take intersection of generalized cones
  - this gives bounding geometry of actual 3D object
  → concave details may be lost
  - more cameras → better geometry





Triangulated mesh generation from volumetric data

- Use the standard Marching cubes algorithm
- For each voxel, take 8 neighbors → cube
- Determine the polygon(s) needed to represent the part of the surface that passes through this cube
- Post-processing: smoothing, decimation



Texturing the triangulated surface

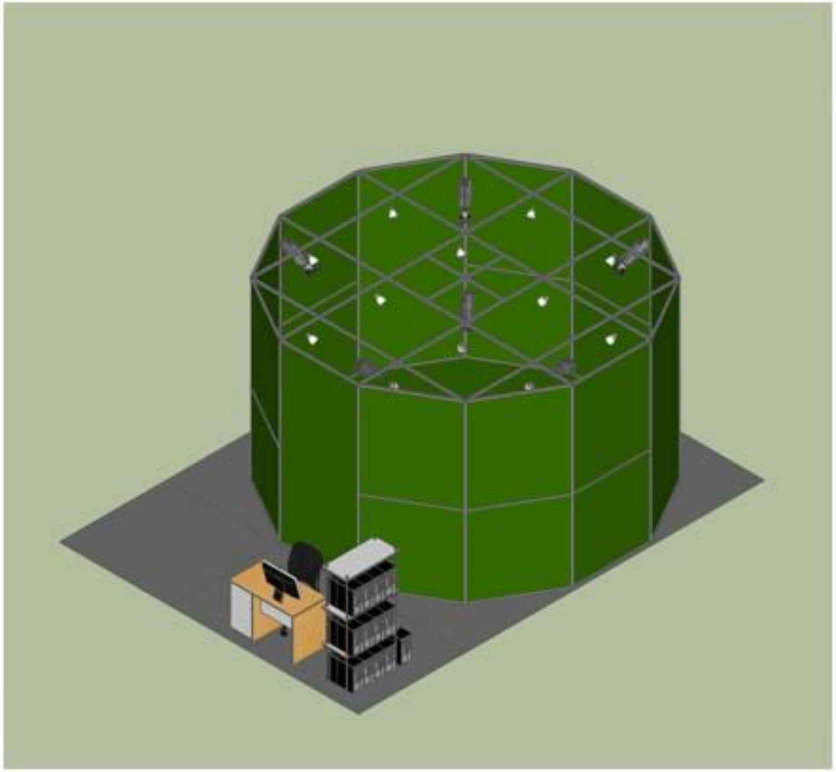
- For each triangle and camera, calculate measure of visibility
  - triangle is visible from camera
  - triangle normal vector points towards camera
- Form cost function with visibility and regularisation terms
  - regularise to reduce sharp texture edges between adjacent triangles

  → balance between visibility and smoothness
- Minimise the cost function using graph cuts

  → find best image for texturing the triangle
- Quality of texturing depends on precision of surface geometry
  - Visual hull and Marching cube may yield imprecise normals

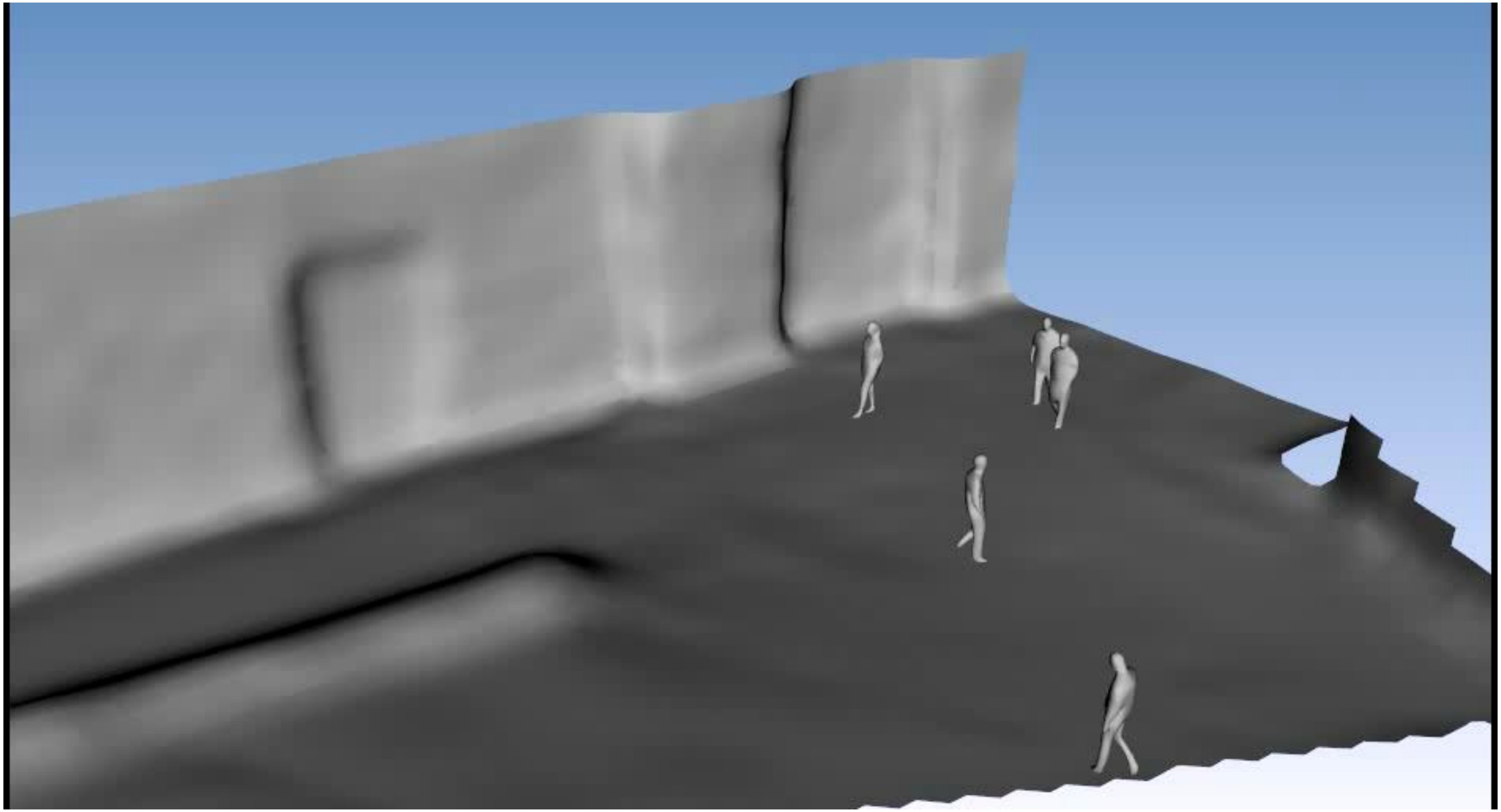
  → texture details may be lost or distorted

Virtual pedestrians - 4D studio



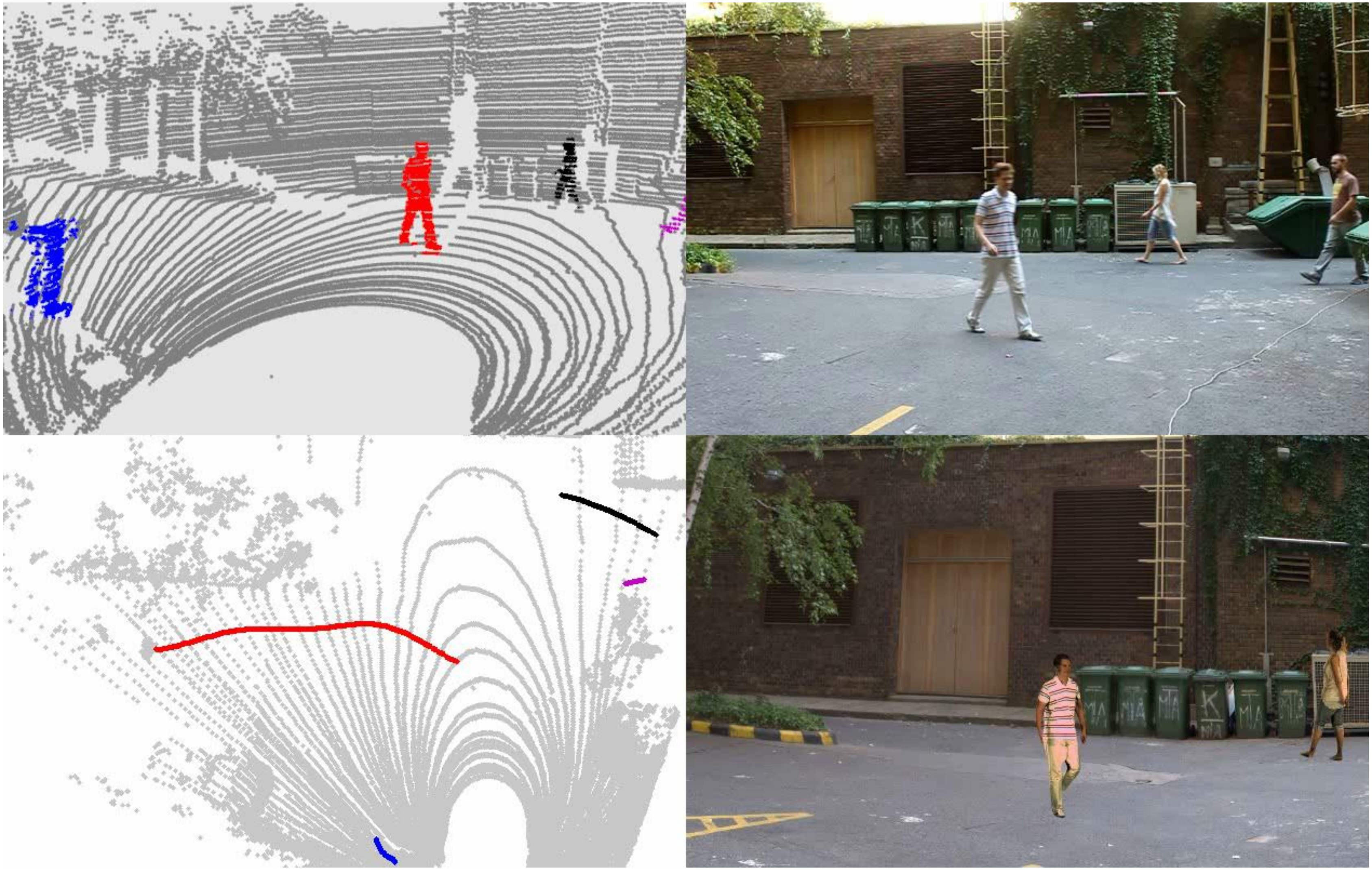
Video online available @ the i4D Projekt website

Output of the integrated model



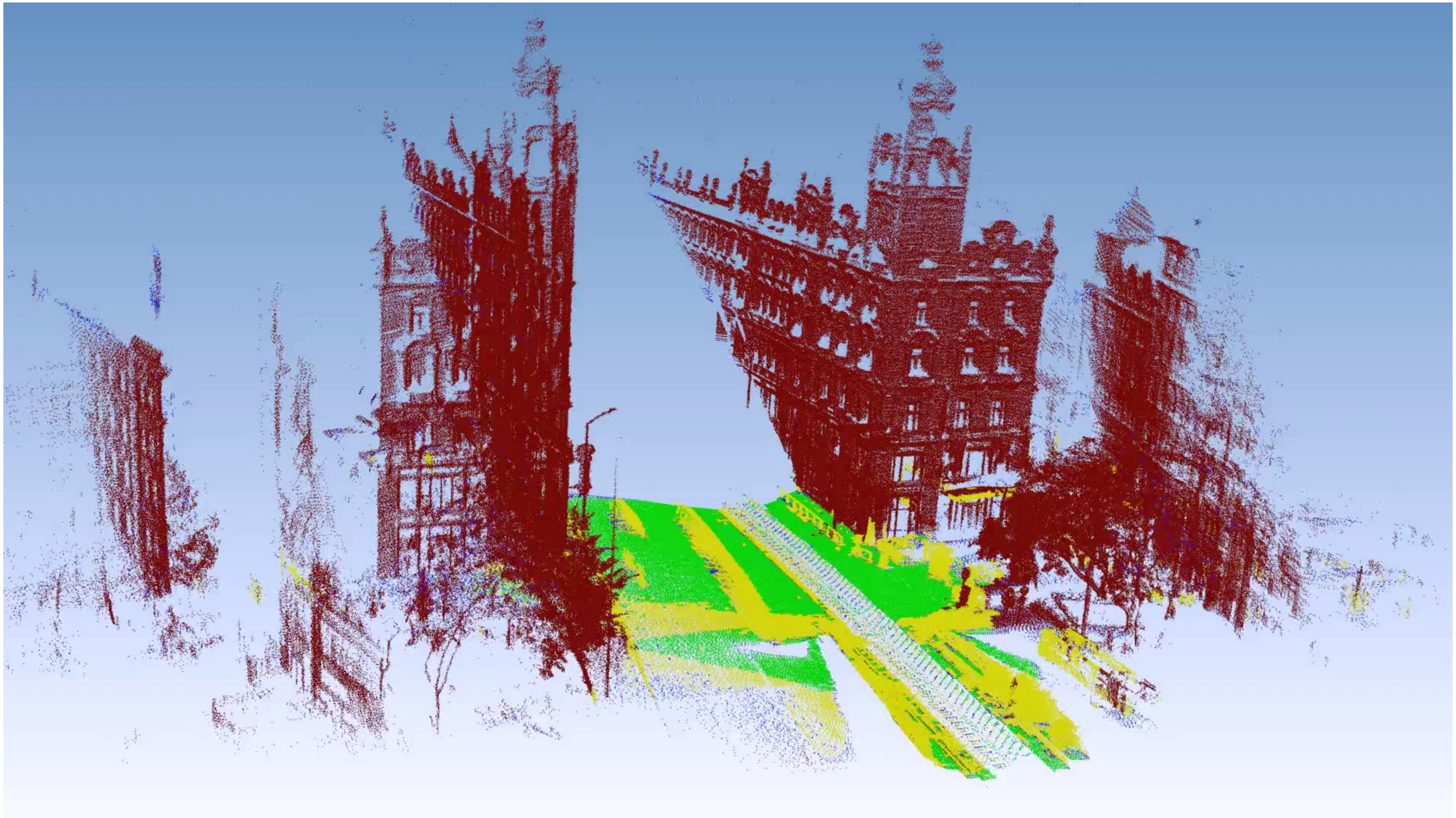
Video online available from the i4D Project website

i4D workflow



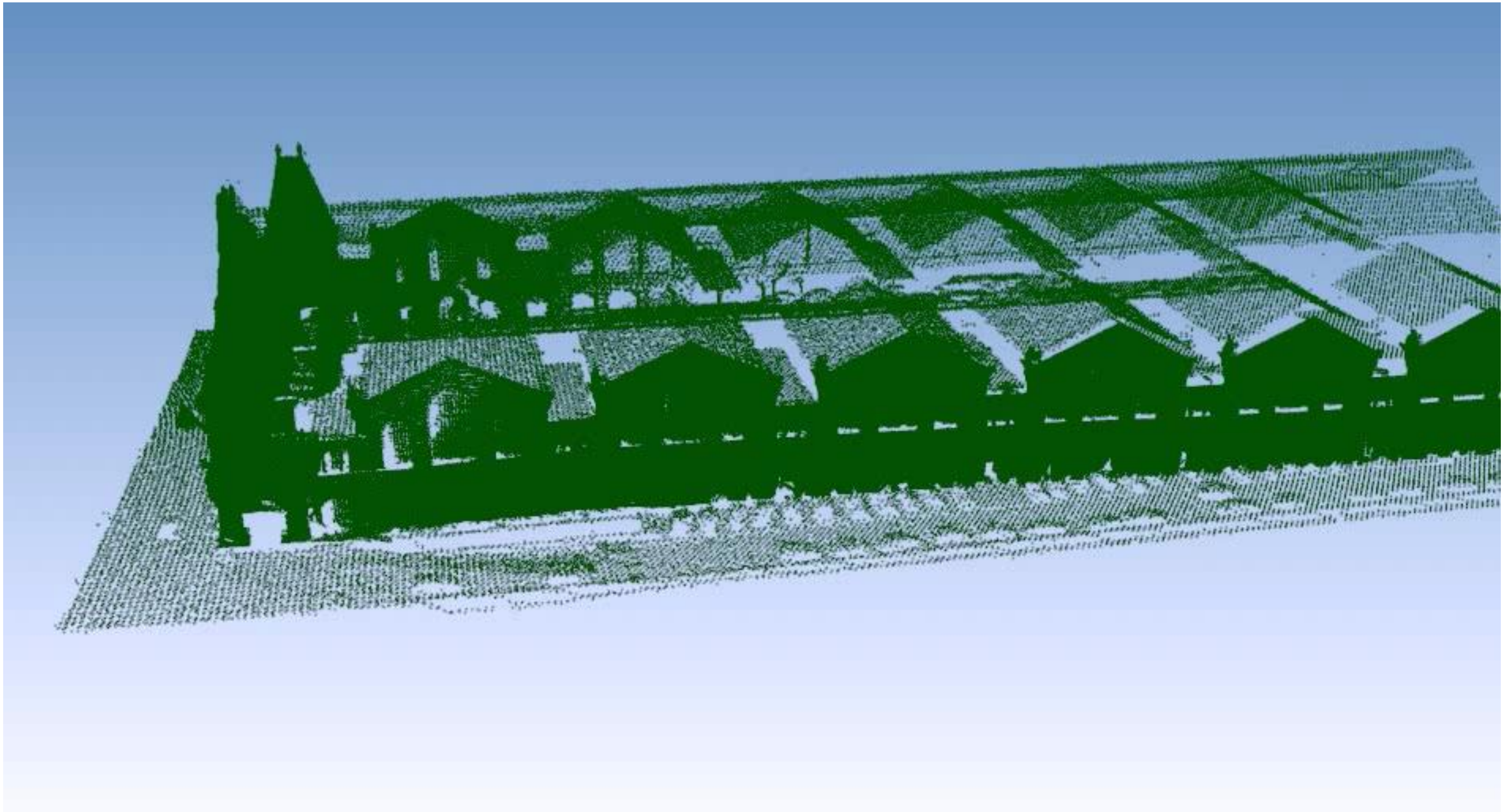
[Video online](#) available from the i4D Project website

Mixed reality



[Video online](#)available from the i4D Project website

4D scenario in front of the Great Market Hall



Video online available from the i4D Project website

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i4D - integrated 4D

Project of MTA SZTAKI

HOME | i4D SYSTEM | DEMOS | PUBLICATIONS | PRESS | PARTNERS | CONTACT

Introduction

The integrated4D (i4D) project encapsulates various R&D activities of the Distributed Events Analysis Research Laboratory (DEVA) of MTA SZTAKI. The main objective of the project is to design and implement algoritms and system prototypes for the reconstruction and visualisation of complex spatio-temporal scenes by integrating various types of sensor measurements, including outdoor 4D point cloud sequences recorded by car-mounted Velodyne HDL-64E or Riegl VZ-400/VMX-450 LIDAR sensor, and 4D models of moving actors obtained in an indoor 4D Reconstruction Studio. The main purpose of the integration is our desire to measure and represent the visual world at different levels of detail. In particular, we aim to achieve scientific contributions and provide innovative practical solutions in the following application fields:

Road scene understanding for driving assistance and autonomous driving: we are able to automatically interpret the LIDAR point cloud stream obtained from a moving platform, segment different point cloud classes, detect and recognize various field objects Read more...

4D virtual city reconstruction: based on our intelligent mobile mapping system, we are able to perceive a dynamic environment, create geometrically reconstructed and textured 3D scene models, meanwhile we detect and analyse various static and moving field objects which are replaced by fixed or animated studio objects in the systhetized 4D city models. Read more...

4D video surveillance: we jointly exploit various depth sensors and optical cameras, to achieve high level object detection and classification, multiple people localization and tracking, event recognition a biometric identification tasks. Read more...

Processing fused data of mobile mapping systems: protecting collective properties in urban environment: we develop automated algoritms for monitoring various public premises, including road quality assessment, surveys of road marks and traffic signs, urban green area estimation, traffic analysis. Read more...

History

The i4D work project was launched in 2012 as a joint mission of the Distributed Events Analysis Research Laboratory (DEVA) and the Geometric Modelling and Computer Vision Laboratory (GMCV), and funded by the Internal R&D Grant of MTA SZTAKI between 2012 and 2014. That time, Prof. Tamás Szirányi (DEVA) and Prof. Dmitry Chetverikov (GMCV) acted as research co-directors of the project, while Csaba Benedek and Zsolt Jankó led the technical developments from the Lidar and 4D Studio sides, respectively. Since the GMCV was closed in 2015, currently the DEVA Lab. operates the project with supervising both the Lidar and 4D Studio developments. Late 2014, the scope of the project was extended with research activities on Lidar-based road scene understanding, and with intelligent GIS development for measurements from mobile mapping systems (in collaboration with the Budapest Road Management Department)

Latest results

Like You and 24 others like this.

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Links

DEVA Laboratory:

DEVA homepage

Lab's datasheet

SZTAKI main page

i4D Demos:

Demo page

Publications

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Prof. Tamás Szirányi

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Visitors

533 24
240 21
84 14
51 14
44 11
36 10

FLAG counter

i4D Project website:

http://web.eee.sztaki.hu/i4d/

Thank you for your attention

- i4D Project team

Csaba Benedek

Zsolt Jankó

Attila Börcs

Bence Gálai

Balázs Nagy

http://web.eee.sztaki.hu/i4d/contact.html

Related publications of the i4D project

Download: http://web.eee.sztaki.hu/i4d/publications.html

- Cs. Benedek, ”3D People Surveillance on Range Data Sequences of a Rotating Lidar,” **Pattern Recognition Letters**, Special Issue on Depth Image Analysis, vol. 50, pp. 149–158, 2014
- A. Börcs, B. Nagy and Cs. Benedek: "Dynamic Environment Perception and 4D reconstruction using a Mobile Rotating Multi-beam Lidar sensor," Book chapter in **Handling Uncertainty and Networked Structure in Robot Control**, Springer, to appear 2015
- Cs. Benedek, B. Nagy, B. Gálai and Z. Jankó: "Lidar-based Gait Analysis in People Tracking and 4D Visualization", **European Signal Processing Conference (EUSIPCO)**, Nice, France, August 31-September 4, 2015
- A. Börcs, B. Nagy, M. Baticz and Cs. Benedek: "A Model-based Approach for Fast Vehicle Detection in Continuously Streamed Urban LIDAR Point Clouds," **Workshop on Scene Understanding for Autonomous Systems at ACCV**, Singapore, November 2014, vol. 9008 of Lecture Notes in Computer Science, Springer 2015
- A. Börcs, B. Nagy and Cs. Benedek: "Fast 3-D Urban Object Detection on Streaming Point Clouds," **Workshop on Computer Vision for Road Scene Understanding and Autonomous Driving at ECCV**, Zürich, Switzerland, September 2014, vol. 8926 of Lecture Notes in Computer Science, pp. 628-639, Springer 2015
- Cs. Benedek: ”A Lidar-based 4D scene reconstruction system,” (abstract & lecture) **SPAR Europe and European LiDAR Mapping Forum (ELMF)**, Amsterdam, The Netherlands, 2013