3DNSITE: A networked interactive 3D visualization system to simplify location awareness in crisis management

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Context and motivations 1/2

- **New crisis of growing complexity**
  - The typical modern scenario
    - Dense population concentration
    - Complex architectural environment
  - Essential for public authorities to adopt proper decision support tools and crisis simulation systems

- **New collaborative approaches and technologies are researched in the IT**
  - Emergency operations handling
  - Agents, crisis managers training
  - Emergency procedures planning
Context and motivations 2/2

- **Complex scenario**
  - Important to simplify location awareness and remote navigation
  - Exploration of the near-3D data

- **Important data for the security domain**
  - Combination of detailed 3D model of the site with georeferenced aligned 2D images
  - Data sometimes already available or easy to acquire/update
  - *Eg. SfM pipeline: cheap to acquire and update, no specific hardware is needed*
3DNSITE system introduction

- **Client-server 3D visualization tool**
  - Streaming and visualizing large tridimensional hybrid data
    - 3D point-clouds or meshes
    - Related aligned images projected on the model

- **Included in a general training and decision framework for emergency operations**
  - Indigo system
  - Evaluated with real-world datasets and real users
Challenges

• Efficient and scalable distribution and visualization of the data
  – Different capabilities devices
  – Different performances networks

• Interactive frame-rates
  – Huge 2D/3D data (hundreds of images, massive 3D models coming from different sources, etc.)

• Fast and efficient navigation interface
  – Users not skilled with VR and 3D objects interaction
Related work 1/2

- Several solutions have been presented for maps browsing, 3D mobile navigation, etc.

- ...but only a few existing browsers support the joint navigation of mixed 2D/3D datasets
  - PhotoTourism [Snavely et al. 06] - PhotoSynth [Microsoft 07]
  - [Snavely et al. 08], [Vincent et al. 07], [Kopf et al. 10], [Goesele et al. 10]
Related work 2/2

• Our contribution
  – Unlike the mentioned 3D photo browsers our system exploits state-of-the-art multi-resolution representations of the 3D model
    • Huge 3D massive models can be streamed and visualized
    • Scalability over limited hardware and network resources
    • Free-point-of-view navigation at interactive frame rates
    • Based on **Adaptive Tetra-puzzles** [Cignoni et al. 04] and **Layered Point Clouds** [Gobbetti et al. 04]
  
  – View-dependent/output-sensitive method applied to the image cache controller
    • Combined with pre-computed 6D descriptors for the images supports a fast and efficient navigation interface
    • Completing the system scalability
  
  – Combination, enhancement and application of SoA methods in a peculiar web-based environment
    • Very positive feedback in terms of performance and user experience
Method: output-sensitive philosophy

- **We assume less data on screen** ($N$) **than in model** ($K >> N$)
  - Real-time data filtering problem
  - Best visualization at interactive frame-rates

- **We adopt this philosophy to access** the 3D model, the embedded images and for the user interface

![Diagram](image)

- **Limited bandwidth**
  (network/disk/RAM/CPU/PCIe/GPU/...)

- **Screen**
  - 10-100 Hz
  - $O(N=1M-100M)$ pixels

- **Storage**
  - $O(K=unbounded)$ bytes (triangles, points, ...)

- **View parameters, priority, etc.**
System overview

- Server side pre-processing
- Data distribution
- Client side 3D navigation
Server side pre-processing 1/2

**Input data**
- 3D models and related aligned images
  - SfM pipelines [Snavely 06]
  - Images to 3D alignment tools
  - GPS records

**3D model out-of-core pre-processing**
- A MR hierarchy over the samples is generated
  - reordering and clustering in fixed size patches
- The hierarchical structure is split in a index tree and a point cloud (or triangles) repository
- Dependencies between mesh modifications arranged in a DAG
- Variable resolution representations of the model are obtained performing a *cut* of the DAG

\[ D^* = D_0 \oplus g_1 \oplus g_4 = f_{0\infty} \cup f_{02} \cup f_{03} \cup f_{13} \cup f_{1\infty} \cup f_{4\infty} \]
Server side pre-processing 2/2

- **Images out-of-core pre-processing**
  - An image depth is computed using the related 3D model depth buffer
  - A 6D descriptor is computed for each image as a weighted average (customizable) of:
    - Time of shot / Shot position / Shot orientation / Image color distribution / Spatial color layout / Image depth
  - **Image ordering and priority among images are pre-computed from these descriptors**

- **Geographical spatial reference frame**
  - RANSAC method comparing image data (GPS, exif, etc.) with the estimated 3D positions

- **The geo-referenced 3D model is a kind of “skeleton” where pre-existent and new images are embedded**
Data distribution 1/2

- **3D model and images repositories are stored in a server**
- **Priority-based/multilevel cache system**
  - 3 levels: http, (disk), RAM, GPU
  - 2 basic cache instances (3D model and images)
  - Different thread for each level (e.g., blocking files and sockets)
  - Fixed size budget for each level (e.g., RAM memory budget 50% of the system memory, etc.)
Data distribution 2/2

- **3D data data blocks stored as VBO**
  - VBO downloaded and rendered according with the current view parameters
    - GPU memory optimization
  - http persistent connection
    - Improves bandwidth usage and reduces network latency

- **Images stored as JPG**
  - Pre-computed priority-based respect to the current image
  - Good compression
  - Wide compatibility with different devices
Client: mixed 2D-3D navigation 1/3

- **3D model rendering**
  - Model rendered as a kind of scenario “skeleton”
  - Performing real-time:
    - Selective (view-dependent) queries on the multi-resolution repository
    - Rendering by assembling and refining fixed size patches (thousands triangles/points)
  - Caching enables rendering with a single CPU call
  - Interactive frame-rate achieved
Client: mixed 2D-3D navigation 2/3

- **Images rendering**
  - Loading from network according with:
    - Current viewport
    - Image descriptor differences
    - Hardware capabilities
  - Images projected simulating their real shot parameters
    - Viewport parameters
    - Pre-computed depth
  - Focus on the real image appearance
    - Projection mode suggested by the system end-users
Client: mixed 2D-3D navigation 3/3

- **User interface**
  - 3D navigation
  - 2D image browser
  - Geo-minimap

- **Click-and-go**
  - According with the 6D image descriptors
  - Suggested images rendered according their 6D proximity with the current one
  - Free-point-of-view navigation

Interactive 3D navigation over the gas storage site of Geomethane in Manosque (France).
Results 1/3

- **Part of the Indigo framework**
  - “Innovative Training & Decision Support for Emergency operations”
  - Distributed architecture to simultaneous involve multiple actors
  - 3DNSITE integrates the global Indigo map capabilities adding a detailed, realistic and interactive 3D navigation for specific operational sites
  - Real end-uses and crisis managers involved
Results 2/3

- **Pre-processor module**
  - Data from SfM pipelines / In-house technology for 2D-3D alignment [Pintus et al. 11b]

<table>
<thead>
<tr>
<th>dataset</th>
<th>3D model</th>
<th>images</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>MSamples</td>
<td>Patches</td>
<td>Time</td>
</tr>
<tr>
<td>Geomethane 1.2GB</td>
<td>7.5</td>
<td>464</td>
<td>2m23s</td>
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<tr>
<td>Training building 151MB</td>
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<td>11s</td>
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<tr>
<td>Stockholm Tegelbacken 457MB</td>
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<td>196</td>
<td>59s</td>
</tr>
</tbody>
</table>

*Dominant value for the real cases is the shot position – For the training area is instead the shot direction*
Results 3/3

<table>
<thead>
<tr>
<th>User</th>
<th>Hardware performance</th>
<th>Network</th>
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<tbody>
<tr>
<td></td>
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<tr>
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<tr>
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<tr>
<td>Agent5</td>
<td>tablet</td>
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<tr>
<td>Agent6</td>
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<td>8</td>
</tr>
</tbody>
</table>

- **Client module**
  - Developed on the users profile (agents and managers)
  - Tested by real users
  - Scalability increase in importance for remote/tablet applications
Conclusions

- **Web-based system to interactively navigate a complex 3D environment during the evolution/simulation of a crisis**
- **Output-sensitive philosophy**
  - Combination and enhancement of already presented SoA methods in a web-based/crisis environment
  - It achieves scalability over limited network and hardware resources
  - It preserves a good interactivity
  - Integrated in the Indigo framework
    - Very positive performance measurements
    - Very positive user experience
- **Limitations and future work**
  - Dynamic dataset
    - 3D model
    - Images
    - Other data
  - Images streaming
Questions and contacts

- **CRS4 - Visual Computing Group**  
  [http://vic.crs4.it](http://vic.crs4.it)

- **ISTI-CNR - Visual Computing Lab**  
  [http://vcg.isti.cnr.it](http://vcg.isti.cnr.it)

- **Speaker: Giovanni Pintore**  
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- **The Indigo project**  
  [http://indigo-project.eu/](http://indigo-project.eu/)
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