VISUALIZATION ASPECTS IN THE MERCW PROJECT

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ABSTRACT

The MERCW project focuses on the study of chemical munition dump sites in the Baltic Sea and Skagerrak area. Through focused site investigations an assessment will be made of the ecological risks related to the dumped warfare for the marine ecosystem and people. One of the objectives of the project is to illustrate the results from the risk assessment using innovative visualization techniques.

Our aim is to develop technology to interactively analyze and explore data that is collected, simulated, and used in the project, in order to support decision-making, risk analysis, and emergency plans. The data to be considered will include detailed bathymetric maps of the sea bottom, different scalar fields defined on the 3D water volume (e.g. temperature, salinity, and concentrations of poisonous substances) as well as vector fields (e.g. sea currents). In order to achieve this goal we will apply and enhance well-established methods of terrain, volume, and flow visualization. Special emphasis will be put on fast techniques that exploit the parallel computing power of current graphics processing units (GPUs). In addition to common visualization techniques, stereo rendering in virtual environments, such as PowerWall and CAVE, will further enhance the perception and understanding of complex 3D phenomena.

1. INTRODUCTION

The MERCW (Modelling of Ecological Risks Related to Sea-Dumped Chemical Weapons) research project, started in 2005 and funded by the European Commission under the Sixth Framework Programme, aims to carry out focused research and technology developments on chemical munition dump sites in the Baltic Sea in order to model the transport pathways and migration spreading of toxic agents in marine sediments and the marine environment. The final goal is to assess the ecological safety for the ecosystem and people of the coastal states.
near the dump sites. To properly analyze the ecological risks related to sea-dumped chemical weapons, data and analysis generated by a variety of independent disciplines need to be integrated. The project comprises a team of experts in marine geology, geophysics, oceanography, toxicology, modelling, and visualization, enabling a skilled use of front-line technologies, which will allow carrying out this project in a well integrated and tightly focused way. The partnership consists of 10 major European and Russian research institutions.

To illustrate and explain the results from the risk assessment we will use innovative visualization technologies. Visualization of different scenarios will allow to present the information in an optimum way, making the results also comprehensible for non-specialists, which should eventually help to make decisions regarding environmental protection measures.

The aim of visualization in the MERCW project is to develop a unique system, which will combine the capabilities and flexibility of a 3D geographical information system (GIS) with the latest advances in the fields of terrain, flow, and volumetric visualization. The integration of several key features of recent visualization solutions in a common framework with an intuitive 3D interface should make our system a useful tool for decision makers, environmental scientists and many more potential users. Our easy-to-use visualization tool will allow representing a wide range of data and making it available within the course of the MERCW project, in a way suitable for both GIS experts and non-specialists.

After a short description of the different types of data that are to be visualized in the project we will give an overview of recent work on related scientific visualization areas, followed by detailed description of user requirements for the integrated interactive 3D visualization solution for the MERCW project.

2. INPUT DATA FOR THE MERCW VISUALIZATION SYSTEM

In order to specify the requirements for our visualization system, we first have to consider the different types of data that will be available to us in the course of the project.

- Detailed bathymetric maps of the sea bottom. This will include already available datasets with digitized topography of the Baltic Sea (e.g. IOWTOPO [Seifert et al. 2001] and SRTM30_Plus [Becker and Sandwell 2004]), as well as more detailed data for certain areas, which should be acquired during the MERCW project.
- Different scalar fields defined on the 3D water volume (e.g. temperature, density, salinity, and concentration of poisonous substances), both measured and simulated.
- Vector fields (e.g. flow velocities describing sea currents).

For geographic as well as other georeferenced data or metadata the ESRI shapefile format [ESRI Shapefile Description] is the most widely used standard format, recommended by the European Environment Agency (EEA) [EEA GIS Guide]. Therefore, it is an essential requirement to have the ability to load ESRI shapefiles with GIS data of all kind into the visualization system and project the contained shapes, if desired, to the terrain surface. This will allow augmenting the bathymetric data with several layers of vector data containing e.g. mapped graphs of data measured during the project as well as textual information about the sites or findings.
3. PREVIOUS WORK ON RELATED VISUALIZATION AREAS

3.1. GEOGRAPHIC INFORMATION SYSTEMS AND TERRAIN VISUALIZATION

The classic way to manage and visualize possibly large amounts of geographical data is a geographic information system (GIS). Until recently most GIS systems could only visualize information in two dimensions and such 2D GIS systems are still widely used by geographic information professionals and much of the research and development still lies in the traditional map-based approach [Brooks and Whalley 2005]. An example for such a widely spread 2D GIS system, although being extended to some 3D functionality now, is ESRI ArcGIS [Li et al. 2001].

Recent advances of the graphics hardware contained in recent PCs enable the use of highly interactive high-quality 3D visualization techniques, supporting the user in the understanding of the visualized processes. Now 3D GIS gets more popularity due to advances in 3D graphics hardware and efficient terrain visualization algorithms, and several 3D GIS applications or related 3D visualization solutions have been successfully utilised in the field of oceanography and oceanic flow simulation, e.g. Fledermaus [Mayer et al. 2000], GeoZu3D [Ware et al. 2001, Arsenault et al. 2004], GeoNav3D [Arsenault et al. 2003, Plumelee et al. 2004], GeoVR [Huang and Lin 1999], GeoVRML [McCann 2002], X-VISION [Keen et al. 2001], and Vis5D [McClurg et al. 1999].

For the handling of large data sets, such as the ones to become available in the MERCW project, more advanced techniques for the visualization of the terrain data such as level-of-detail (LOD) algorithms are required. One of the first 3D GIS system using such techniques was the Virtual Geographic Information System [Lindstrom et al. 1997], a system, which is based on triangulated irregular networks (TIN) and continuous level-of-detail rendering methods [Hoppe 1996, Hoppe 1997, Lindstrom et al. 1996]. However, only gradually advanced techniques for handling large-scale datasets are entering the area of 3D GIS, also driven by the popularity of recent whole earth visualization tools such as Google Earth and NASA World Wind.

Multiresolution methods for fast terrain visualization with viewpoint adaptive resolution are still an active area of research. Since giving a complete overview is beyond the scope of this paper, we refer to recent surveys [Lindstrom and Pascucci 2002, Pajarola 2002] and only discuss the solutions most closely related to our work. One can differentiate between two main groups of approaches for the efficient processing and display of terrain datasets.

The first class consists of methods that employ regular, hierarchical structures to represent the terrain. The most established methods here make use of triangle bintrees and quadtrees [Lindstrom et al. 1996, Cline and Egbert 2001], restricted quadtrees [Pajarola 1998, Gerstner 1999], RTINs [Evans et al. 2001], and edge bisections [Lindstrom and Pascucci 2002]. These structures facilitate compact storage due to their regularity, as topology and geometry information is implicitly defined.

Approaches of the second class use more general, mainly unconstrained triangulations. They include data structures like Multi-Triangulations [Puppo 1996], adaptive merge trees [Xia and Varshney 1996], hypertriangulations [Cignoni et al. 1997] and the adaptation of Progressive Meshes [Hoppe 1997] to view-dependent terrain rendering [Hoppe 1998]. Evans proved [Evans et al. 2001] that triangulated irregular networks are able to reduce the number of necessary triangles by an order of magnitude compared to regular triangulations since they adapt much better to high frequency variations. However, in order to capture irregular refinement or simplification operations and connectivity, a more complex data structure is
needed. To alleviate these drawbacks, either Delaunay triangulations [Floriani and Puppo 1992, Rabinovich and Gotsman 1997] or a modified quadtree structure have been used to represent irregular point sets [Pajarola et al. 2002].

3.2. FLOW SIMULATION AND VISUALIZATION

To visualize acquired as well as simulated vector field data in the MERCW project, especially the sea current data, we are going to apply and develop suitable techniques of flow visualization.

Flow visualization is one of the most studied subfields of scientific visualization, because it has a wide range of applications, including oceanography, meteorology, aerodynamics, medical visualization and computational fluid dynamics. There are numerous different approaches for flow visualization. Most of them can be classified either as an approach based on the extraction of certain flow features, or as a dense texture-based visualization technique, or as a method based on particle tracing. For the many different methods falling into the first two classes, we refer to the recent surveys [Post et al. 2003] and [Laramee et al. 2004], respectively.

Methods based on particle tracing visualize the flow by tracing the movement of particles emitted into a flow field. This movement is either rendered as an animation over time, or the trajectories of the particles are visualized as streamlines. An alternative to streamlines are stream ribbons, which additionally show the local rotation of the flow field. Each of these solutions has its advantage: while a single image is more meaningful using streamlines or stream ribbons than in direct particle visualization, the latter technique has the advantage that it reveals the speed of the flow more clearly.

Fig. 2: Two stages of flow visualization using GPU-based particle system. 51633 particles are rendered in real-time with over 100 fps on an AMD Athlon XP 3000+ CPU with a NVIDIA GeForce 6800 Ultra graphics card.

The technique of particle tracing in general seems to be specifically suited for the visualization requirements of the MERCW project since it is also a very convenient method to visualize the movement of sediment and the spreading of toxic compounds.

Previous implementations of particle systems, including those contained in 3D GIS applications [Arsenault et al. 2004], allowed the tracing of up to 10.000 particles at interactive
speed. However, this might be insufficient for complex simulations. The bottleneck of these previous approaches lies mainly in the time required to transfer the resulting particle positions from the flow simulation to the graphics card for the visualization. A very recent approach [Krüger et al. 2005] eliminates this bottleneck by performing both, the simulation and the visualization of the flow, directly on the graphics hardware (GPU). This was made possible by the programmability of recent GPUs; and due to the high parallel computing power of these GPUs, also the time required to perform the flow simulation is reduced using this technique, allowing to simulate and visualize up to 1,000,000 particles in real-time. An open issue is yet the implementation of more complex models for the simulation of flow and particle movement, as required in the project, on the GPU.

4. AN INTEGRATED VISUALIZATION SOLUTION FOR THE MERCW PROJECT

During consultations with the project partners as primary users of our visualization system, the possibilities and potentials of an integrated visualization solution for the project were discussed and the features expected from the system were specified. Thereby the following main requirements were determined.

4.1. USER REQUIREMENTS FOR THE MERCW VISUALIZATION SYSTEM

- **Georeferencing**
  During the project, many different types of data and information will be gathered and produced. This includes geophysical, hydrographical, geochemical, and biological data acquired on research cruises as well as data produced by toxic compound migration and bioaccumulation modelling. Most of these data, especially those gathered during site investigations, can be associated to certain sites or areas of the Baltic Sea region.

  To simplify data sharing and management, it would be desirable to have the ability to get a quick overview over the available data and visualize them in a common environment. Therefore, our visualization system should be aware of the geographical locations associated to the available data (so called georeferences) and take them into account when combining data from several sites into a common visualization.

- **3D geographic information system (3D GIS)**
  While for many purely geographical applications most data can be adequately represented by 2D maps, in the MERCW project many of the acquired and modelled data is inherently 3D, e.g. the geophysical surveys and the hydrographical measurements to be performed, as well as the 3D diffusion model used for toxic compound migration modelling. Therefore, the users of our system need to have the ability to visualize available georeferenced data in 3D.

- **Handling of large-scale data sets using level-of-detail (LOD) techniques**
  In the MERCW project, large-scale data sets covering the whole Baltic Sea region have to be visualized, and sometimes they have to be combined with highly detailed data from certain areas. In particular, the already available low-resolution bathymetry data from the Baltic Sea acquired by satellite altimetry should be combined seamlessly with the higher resolution bathymetry data of certain areas that will be acquired by ship depth soundings during the MERCW project. This requires adequate level-of-detail (LOD) visualization techniques.
We are going to base our system on a high-performance and high-quality terrain visualization engine, which incorporates a very efficient continuous level-of-detail approach, enabled by the use of recent computer graphics techniques [Wahl et al. 2004].

- **Integration of 2D shape data and metadata into the 3D GIS**

  As mentioned above, the ability to load and visualize ESRI shapefiles with data of different kind is an essential requirement for our system. Contrary to recent 3D GIS applications, the shapes will not be approximated by fixed resolution textures, but directly visualized as vector data with maximum avoidance of aliasing artefacts [Schneider et al. 2005], resulting in a largely improved visualization quality.

  It is also desirable to have the ability to edit GIS data directly in the 3D visualization system and to save it back to the shapefile. This will allow to some extent to analyze and manage the data directly from the visualization system without switching back to GIS editors. These capabilities, when combined with the MERCW data management system, can also provide a valuable tool for the risk assessment in the project.

- **Integration of volumetric data into the 3D GIS**

  A simple, yet effective way to visualize the volumetric data acquired during the MERCW project (e.g. 3D scalar fields or the so-called pseudo-3D seismic data) in a 3D GIS is to embed vertical or horizontal cross-sections of the volume into the 3D visualization [McClurg et al. 1999, Ware et al. 2001]. The combination of these cross-sections with the bathymetric data of the Baltic Sea and possibly additional 2D data facilitates the user’s orientation in the data and the classification of the data in the 3D context. In case of real 3D data it is further helpful if the user has the ability to determine the slices through the volume, which are to be visualized, interactively.

  Especially when multiple cross-sections of a volumetric data set are to be visualized simultaneously or when seismic data below the sea bottom should be explored, an adequate use of transparency in the visualization is required such that the user’s view to these data is not unnecessarily obstructed. Transparency further plays an important role in advanced volume visualization techniques.

- **Flow visualization**

  To visualize the sea currents as well as the spreading of toxic substances, e.g. the dispersion of pollution ingoing to the sea from a river runoff, adequate techniques of flow and particle visualization are required.

  Therefore, the visualization system should include a flow visualization module, which will allow to visualize complex flow fields above the seabed using the particle tracing method. By the exploitation of the programmable graphics processors contained in recent PCs, hundreds of thousands of particles can be traced in real-time, which is far more than in recent 3D GIS solutions such as GeoZui3D [Arsenault et al. 2004]. The explanatory power of the real-time visualization will be further increased by the use of advanced rendering techniques such as streamlines and stream ribbons [Kipfer et al. 2004, Krüger et al. 2005].

- **Integration of simulation modules from the modelling of sediment dynamics and Computational Fluid Dynamics (CFD).**

  The advanced fluid dynamics and sediment transport models that are going to be developed in the MERCW project should be integrated directly into the visualization system as far as possible, such that they can be explored interactively in the 3D GIS context. The direct integration of these models into the visualization system can be an important factor for the model evaluation as well as for the risk assessment in the MERCW project.
• **Usability in a Virtual Reality (VR) environment**

In addition to common visualization techniques, stereo rendering in virtual environments, e.g. in a PowerWall or CAVE set-up, will further enhance the perception and understanding of complex 3D phenomena. Stereo rendering provides an additional depth cue, very helpful for the orientation in the 3D environment and the insight into the visualized data.

• **Database integration**

In order to provide advanced data query functions and allow the possibility to quickly update or extend the data it would be desirable to remove ourselves from the text file based paradigm of 3D graphics and try to integrate 3D spatial data into a database management system that will allow us to fuse spatial and aspatial data thus enabling interactive querying [Brooks and Whalley 2005]. Many researchers, e.g. [Li et al. 2001], are starting to address this issue but a definitive solution is not yet available.

### 4.2. USER INTERFACE

An important factor for the usability of our visualization system is an intuitive graphical user interface (GUI), which will include the following properties:

• Several navigation possibilities.

• In particular, users should be allowed to change scale easily by zooming in and out as they can do in traditional 2D GIS systems.

• A mini-map, which gives the user an overview over the entire terrain and the current camera location [Brooks and Whalley 2005].

• For a more detailed spatial overview and easy 2D navigation, it would be desirable to have the possibility to instantly switch to a top-down view of the current area.

• The ability to navigate to a location directly by inputting map coordinates or by clicking on the desired destination points on the terrain or mini-map.

• Because of the shallow nature of the Baltic Sea, which has an average depth of only 55 meters, it would be desirable in some situations to improve the user’s perception of the sea depth by suitable visualization techniques. For this purpose several methods come into question:
  
  − One possible solution is to let the user interactively select the vertical scaling of the bathymetric data, as supported in many 3D GIS applications.
  
  − Another possibility is to use exaggerated specular lighting to improve the depth perception, especially when navigating through the 3D environment.
  
  − Furthermore, the classical method of a 2D GIS to visualize contour lines could also be helpful in a 3D visualization to improve the depth perception.

• The ability to import and display all relevant 2D map-based data including symbolised structure data [de Kemp 2000]. It should be possible to add and remove separate data layers easily.
Fig. 3 shows an example of the terrain visualization application GUI [Schneider et al. 2005] with some of the features mentioned above. The application implements several navigation modes. The user can navigate using mouse or navigation controls (buttons and sliders) (1), specific to each navigation mode. The terrain data is augmented with several layers of georeferenced data stored in shapefiles. The list on the left (2) allows to turn on or off the visualization of certain information, such as paths shown in red (3) or names of the mountain peaks as well as their altitudes (4). The top-right rectangle contains the mini-map (5), which simplifies orientation as well as navigation.

5. CONCLUSION

We are developing an integrated visualization solution that should fulfil all the aforementioned different visualization requirements of the MERCW project. Our aim is to combine the capabilities and flexibility of a 3D geographical information system with the latest advances in the fields of terrain, flow, and volumetric visualization in a common framework with an intuitive 3D interface. Recent advances of the graphics hardware contained in commodity PCs enable the use of highly interactive high-quality visualization techniques that simplify its usage and support the understanding of the visualized processes.

6. ACKNOWLEDGEMENTS

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7. LITERATURE


31. Matthew Plumlee, Roland Arsenault, Rick Brennan, and Colin Ware. The CCOM Chart-of-the-Future project: Maximizing mariner effectiveness through fusion of marine &


