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Augmented Reality for Urban Simulation Visualization

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***Abstract*—Visualizations of large simulations are not only computationally intensive but also difficult for the viewer to interpret, due to the huge amount of data to be processed. The case of urban wind flow simulations proves the benefits of mobile Augmented Reality visualizations, both in terms of selection of data relevant to the user and facilitated and comprehensible access to simulation results.**

***Keywords*-Scientific Visualization; Augmented Reality; Numerical Simulation; Urban Airflow; Geographical Information Systems (GIS)**

I. Introduction

The development of scientific computing including numerical simulation and interactive 3D visualization has today become an essential tool in many applications including industrial design, studies of the environment and meteorology, and medical engineering. The increasing performance of computers has played an important role for the applicability of numerical simulation but has also led to a data explosion. At present, the use of simulation software and the interpretation of visualization results usually require dedicated expertise. The large amount of data available leads to two problems for the end-user, which are discussed in this paper. On the one hand, handling and selection of the appropriate data requires a suitable user interface. On the other hand, the amount of perceptible information is limited, and thus visualizations of large data sets need very intuitive methods to be understandable.

Geographical Information Systems (GIS) are playing an increasing role for urban planning [1]. Their improved accuracy joined with the increasing performance of computing systems are making accurate large scale urban simulations feasible. In this paper we present the results of the joint work with the city council of Karlsruhe for simulations in an urban environment as an illustrative example setting, with focus on the advantages of mobile Augmented Reality visualization of large numerical simulations. The proposed visualization methods do not only serve as a technology for solving problems of large scale data visualizations but also open the path to making results of numerical simulations accessible to decision makers and to the citizen at large, both from the technical and the comprehensional perspective. The general availability of smartphones and tables equipped with GPS, cameras and graphical capabilities fulfills the technical requirements on the client side for implementing the presented visualization methods, which allows for an intuitive exploration of large scale simulations. The ongoing standardization process of GIS for city modeling in the CityGML consortium enable standardized simulation and visualization services for world-wide use based on the presented methodology in future.

The novel approach of providing scientific results on mobile devices presented as in this paper was developed in the *Science to Go* project in the Apple Research and Technology Support Programme (ARTS) aiming to deliver numerical simulation on the spot.

II. Related Work

The Touring machine [2] was one of the first mobile solutions for augmented reality illustrating the potential of enhancing real life images in real-time for exploration of the urban environment. The approach was to display information overlays on the camera image which is still popular in augmented reality applications of today [3], [4]. The availability of dedicated graphical processing units on mobile devices have led to augmented reality visualizations of 3D objects [5] as they have been found beneficial in laboratory setups [6]. The use of augmented reality visualization for environmental data is presented in the HYDROSYS framework [7], providing a method to combine measurements and simulation data with geographic information. The conceptional need for combining simulation results with data from geographic information systems is also a driving force for the CityGML project [1], which has applications to natural disaster management. The augmented reality visualization of urban air flow pheonomena in an indoor virtual reality laboratory setting based on physical mock-up building blocks is presented in [8].

III. Methodology

The integration of scientific visualizations into real world camera images is demanding from the perspectives of data preprocessing, mobile device positioning and the actual augmented reality visualization. The difficulties arise from the need to combine real-world and virtual geometries aligned with each other, and then to incorporate scientific visualizations of results from numerical simulations in the resulting image.

Simulating a phenomenon with a numerical method requires the computational domain to be determined. In our approach,

Figure 1. Photo-realistic building in the Karlsruhe 3D city model

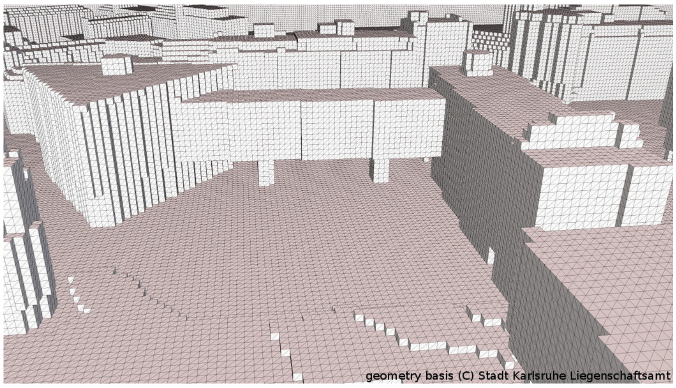

Figure 2. Computational geometry based on the Karlsruhe 3D City Model

the real world is represented by virtual city-models which are converted into mesh data using sophisticated preprocessing techniques well known in the context of bio-medical simulations (see e.g. [9], [10]). Based on a mathematical model for airflow, a finite element CFD simulation is then set up and run using the HiFlow^3 simulation software [11]. Using accurate position and orientation of camera images based on sensor fusion techniques as discussed and illustrated in [3], a consistent Augmented Reality visualization of the simulation results can then be produced.

The proposed visualization methods for interaction with large numerical simulation on mobile devices are based on a client-server framework where specific demands have to be taken into consideration.

A. Preprocessing

The "3D-Stadtmodell Karlsruhe" [12] was started in 2002 as an improved database of geographic information to meet the demands of the urban administration. It consists of several data sets of varying purpose, coverage, accuracy and detail, starting with a terrain model without buildings, and including large brick models for the cityscape, up to a photo-realistic model, as seen in Figure 1. The city model is currently progressing towards an integration into a CityGML [1] based representation.

Since none of the models were created for use by numerical simulation software, extensive pre-processing steps are necessary. In general two or three models have to be combined to create a suitable computational domain, as seen in Figure 2. Special care was necessary to deal with model enhancements that had been made mainly for visual effects. For instance, there were closed window planes in garages facing the outside world on both sides with zero width, which are very significant for wind flow simulations around buildings. Although such irregularities could be avoided by imposing strict conditions on the city models, in general we cannot expect available city models to conform to these conditions, since they were originally created for visual planning. To avoid problems arising from these kinds of artifacts, an emphasis was put on the use of robust and performant region growing methods that are well known from medical applications such as for the realistic computational fluid dynamics simulations of the nose and lungs (see e.g.[9], [10]).

Another challenge for enabling widespread use of simulation in urban environment is the non-availability of highly accurate city models. This condition can be weakened to the availability of high resolution models in the main areas of interest, since widely available low accuracy models are sufficient for the necessary peripherical simulation in the surrounding area. In spite of the varying detail of the models, the very accurate geographic alignment offers the opportunity for an automated data source selection and preprocessing workflow.

B. Simulation

The instationary Navier-Stokes equations are solved in a sufficiently large computational domain surrounding the area of interest with suitable artificial boundary conditions for assumed wind flow conditions. At the walls of buildings the velocity is set to zero.

The model is formulated as an initial boundary value problem for the velocity $\vec{u}\,(\vec{x},t)$ and the pressure $p\,(\vec{x},t)$ in Equation 1.

$$
\begin{aligned}
&\partial_t \vec{u} - \nu \Delta \vec{u} && \\
&+ (\vec{u}\cdot\nabla)\,\vec{u} + \nabla p = 0 && (\vec{x},t) \in \Omega \times (0,T)\ , \\
&\nabla \cdot \vec{u} = 0 && (\vec{x},t) \in \Omega \times (0,T)\ , \\
&\vec{u} = \vec{u}^{in} && (\vec{x},t) \in \Gamma_{\text{in}} \times (0,T)\ , \\
&(-\mathcal{I}p + \nu \nabla \vec{u}) \cdot \vec{n} = 0 && (\vec{x},t) \in \Gamma_{\text{out}} \times (0,T)\ , \\
&\vec{u} = 0 && (\vec{x},t) \in \Gamma \times (0,T)\ , \\
&\vec{u}\,(\vec{x},0) = \vec{u}_0\,(\vec{x}) && \vec{x} \in \Omega\ .
\end{aligned}
\tag{1}
$$

The parameter ν in this model is the kinematic viscosity, which is assumed to be constant over the entire domain. An artificially high value was used to keep the Reynolds number small for the computations that are illustrated in Figure 3. The visualization is based on the open source packages VTK [13], ParaView [14] and HiVision [15].

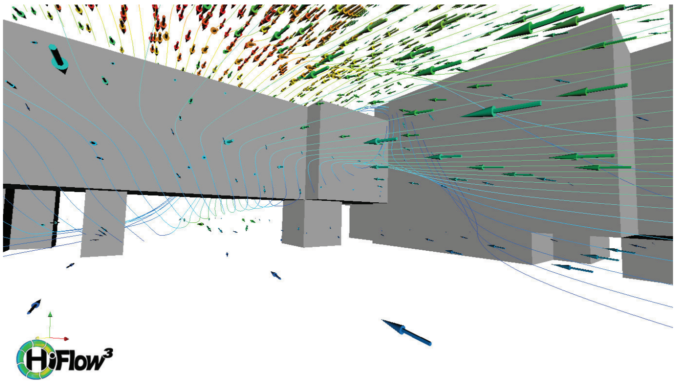

Figure 3. Numerical simulation results of urban wind flow

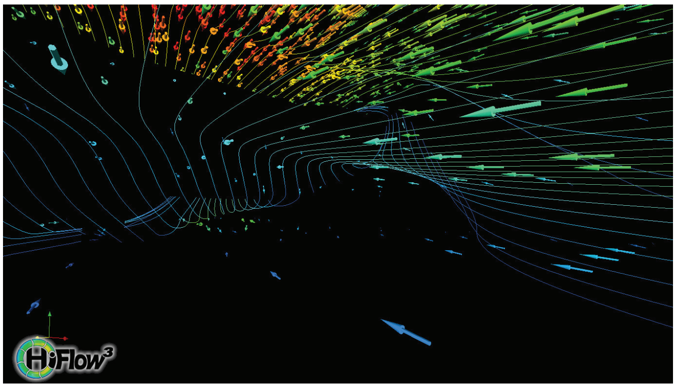

Figure 4. Masked numerical simulation visualization

Figure 5. Enhanced augmented reality visualization

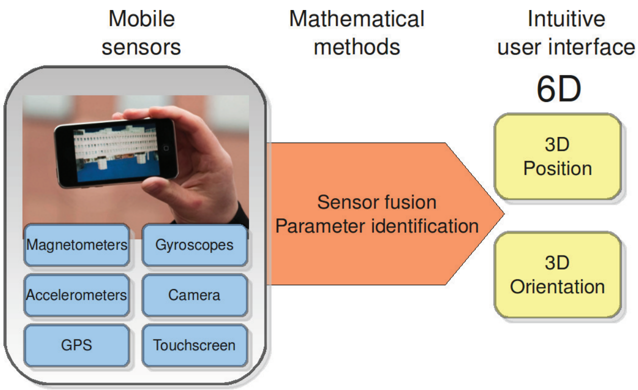

Figure 6. Mathematical methods enable intuitive user interfaces

C. Augmented Reality Visualization

The visualization method is based on the accurate alignment of the viewer's position and the orientation of his camera view with the three-dimensional city model and the numerical simulation. Beside the accurate localization, the methodology of reality augmention is also of high relevance for the comprehensibility and credibility of the visualization. In the setup considered here only the graphics representing the flow field are to be embedded in the real-life image, and therefore the city model and the computational mesh should not be visible. Yet, the simulation results that are covered by buildings in the city model must be removed from the image. Therefore, the occluded simulation results are masked by the city model which itself remains invisible leading to a masked visualization as displayed in Figure 4, where the transparent areas are left black.

The masked visualization can then be composed onto the camera view leading to the augmented numerical simulation visualization in Figure 5 which was extended with the computational domain for illustration. The resulting image is very informative and gives insight into the simulation results. Since the displayed part of the simulation coincides with the viewer's position, the data selection is most intuitive and the full simulation can be explored by simply wandering around in the computational domain.

D. Interaction and User Interface

The interaction and the user interface is crucial for usability and comprehension. The proposed model is to present the mobile device as a window to the Augmented Reality and the results of the numerical simulation. This leads to challenges as outlined in [3] that can be addressed using sophisticated mathematical methods such as filtering, simulation and parameter identification. Only the increasing computing power available in modern mobile devices such as smartphones and tablets enable the use of such costly algorithms in real-time leading to haptic user interfaces.

The camera view in space is defined by six parameters, the three-dimensional position and the three viewing angles. Therefore at least six dimensions of sensor data is needed to control the user interface. Besides GPS, the latest generation of mobile devices contain spatial accelerometers as well as spatial magnetometers as a minimum. Taken together, they provide the six degrees of freedom in sensor data, enabling a new approach to an intuitive interface, which can be improved by any other additional sensors such as gyroscopes or camera based marker detection. Figure 6 illustrates that this step covers the real-time fusion of various sensor readings to gain the position and orientation information that is the basis for the Augmented Reality visualization.

Interaction with a numerical simulation consists not only of moving around and changing the view; it is highly desirable

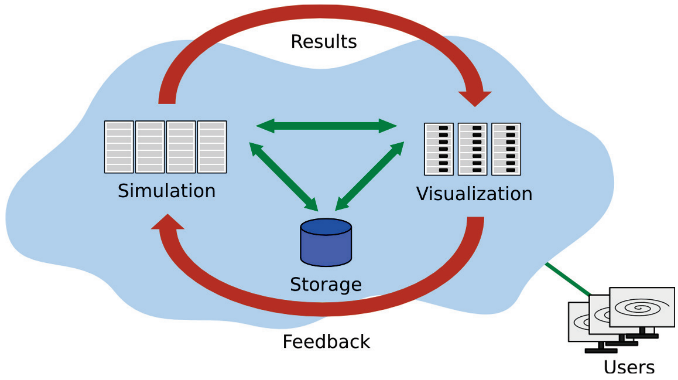

Figure 7. Interaction model

to also offer access to visualization parameters, such as what quantities are displayed, the method used, and maybe to enable changing some simulation parameters. From the view of the user interface, the touchscreen interfaces of modern mobile devices offer endless possibilities for manipulation of visualization and simulation parameters. Another crucial issue is the interactivity that is offered to the user: the presented visualization needs to be updated frequently, but is limited by the available network bandwidth.

E. Client-Server Framework

In general, the computation of large scale simulations and their visualizations need dedicated hardware and infrastructure, and is therefore traditionally only available to a small group of experts. The proposed visualization method overcomes this drawback by a client-server approach where the display, data selection and user interface is on a mobile device, but the actual simulation results and visualization remains on a high performance server infrastructure. The clients are connected to the visualization service on the servers by wireless or cellular networks as illustrated in Figure 7, which are limited by the available bandwidth. In a direct image transport a refresh rate of several frames per second is feasible on UMTS networks. Additional compression methods leading to higher refresh rates using significantly lower bandwidth are currently being developed by the authors in the framework of the newly starting European Project *MobileViz* in collaboration with industrial partners.

For widespread use of the simulation and visualization models, the necessary computing power can be provided by a cloud service, delivering the service of simulation and visualization on demand. The versatility and modularity of HiFlow^3 combined with the automated robust pre-processing of 3D city models and parallelized rendering servers for scientific visualization are the basis for a versatile and reliable service.

IV. Conclusion

In this paper we have presented a novel visualization method for large-scale scientific computing illustrated by the example of urban air flow simulation. The use of mobile devices opens the path to intuitive access to and interaction with numerical simulations that are highly comprehensible due the embedding in to the real-life camera view as Augmented Reality visualizations. By this, results of numerical simulations will be available to decision-makers and citizens, raising the impact and improving the communication of scientific results. The presented methods are backed by a client-server framework and offer business models for simulation and visualization on demand in a cloud-based setup.

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