VIRTUALFIRES A Virtual Reality Simulator for Tunnel Fires

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ABSTRACT

The VIRTUALFIRES (Virtual fire emergency) simulator is presented, that allows to train fire fighters in the efficient mitigation of fires in a tunnel, using a computer generated virtual environment. This is a cheap and environmentally friendly alternative to real fire fighting exercises that are currently carried out and that involve burning fuel in a disused tunnel. The simulator can also be used to test the fire safety of a tunnel and to ascertain the influence of mitigating measures (ventilation, fire suppression etc.) on the fire safety level. The simulator is developed with financial support from the European community under the IST (Information society technology) program and combines the simulation of fires using advanced CFD software and the visualization of smoke, toxicity levels and temperature. Two versions are being developed: One using a head mounted display and a laptop, the other using a CAVE virtual environment together with a supercomputer. Both display systems have some advantages and disadvantages. The presented HMD version requires moderate computing power and can show realistic fire and smoke distribution, but the user is not fully immersed in the scene due to the limited field of view. The CAVE version gives a realistic impression of emergency situations in tunnels, because of its room-sized high resolution 3D video and audio environment. The VIRTUALFIRES simulator can be tested by the participants during the conference.

Key words: tunnels, virtual reality, CFD simulation

1. INTRODUCTION

A Virtual Real Time Fire Emergency Simulator (VIRTUALFIRES) has been developed using techniques of virtual reality. In the simulator, the observer is able to visualise the fire and smoke development and the transport of heat and toxic combustion products inside a tunnel and walk or run through the virtual structure in the same way as through a real tunnel. The simulator uses and accesses a database, which contains the results of three-dimensional transient combustion (Computational Fluid Dynamics - CFD) simulations for particular tunnel geometries with associated safety installations, particular fire hazard scenarios, etc. CFD-results can be displayed as a fixed installation in a CAVE virtual environment and as a portable installation using a PC and a head-mounted display (HMD). Two systems are developed: one where the CFD simulation is pre-calculated, stored into a database and then displayed and another where it is carried out in parallel to the visualisation. In the first system the user will be able to move through the data but will not be able to change the characteristics of the simulation, for example the ventilation characteristics. In the second system the user may change the properties of the simulation while the data are displayed. The VIRTUALFIRES system will be a unique system that can be used for assessing the fire safety of tunnels, for training of rescue personnel and for planning rescue scenarios and will be able to replace or supplement real fire tests. The end users of this system will be rescue organisations such as the fire brigade and police, tunnel operators and government organisations concerned about tunnel safety. The system can be used for making an objective assessment of the fire safety of existing European tunnels. It can also be used for training drivers on how to behave in the case of a fire emergency in a tunnel.
2. DESCRIPTION

The layout of the software is depicted in Figure 1. At the heart of the system is the CFD simulation software ICE, which uses the Lattice Boltzmann method [1] to compute the air velocity, temperature, pressure and smoke density at a cell point due to a fire.

![Figure 1: Layout of the VIRTUALFIRES software](image)

The “smoke density” is an artificial quantity, which varies between 0 and 1. The smoke production is taken to be proportional to the CO and CO2 standardized production curves provided as input. It must be pointed out that smoke is a result of fuel rich combustion and the modelling via standardized curves is only an approximation. However, a real combustion model requires input data, which are normally not available and the calculation is very time consuming.

The storage and retrieval of the calculated CFD-data and the states of all objects that are involved in a simulation-run is handled by the Database Manager module. This component serves as the communication layer between the simulation front end and the database server back end. Currently it transparently supports the MySQL 4.0.15 open source SQL server, but is adaptable to any other SQL server.

The communication between the CFD solver and the storage layer is done by the data manager Controller module. This module has been integrated into the Covise VR-environment [2] and also handles all requests from the user interface. As there are normally limited interaction capabilities inside a CAVE environment, a new PDA-based graphical user interface has been developed. This GUI allows the user to specify the mission he/she wants to examine, change simulation parameters and restart a simulation. The major advantage of this solution is that this navigation tool can also be used outside the CAVE with the PC-based VR environment without any changes to the simulator, because it is integrated into the network communication layer inside the simulator.

Within the project also some new visualization techniques have been developed. This was necessary as currently available ones where not sufficient for the system, mainly for 2 reasons:

1. They were to slow to handle the amount of the data produced by the CFD to update the rendering in real time
2. They were not capable of rendering photo realistic fire and smoke
These visualization methods were integrated as plugins for the Cover renderer and can be managed from the user interface. The photo realistic rendering of smoke is done by a fast volume rendering approach which takes advantage of the availability of programmable shader functions on modern graphics boards. This way frame rates around 25fps for the volume rendering of the CFD-results are possible on normal PC hardware. To achieve a photo realistic rendering of fire a fractal 3D texture is applied to the regions of the flames. As CFD results are too coarsely spaced compared to the fast visual fluctuations of a flame front, this behaviour is interpolated by the fractal texturing process until the availability of the next CFD result.

3. CAPABILITIES

3.1. Visualisation

At the current development stage the simulator is able to perform simulation runs for predefined missions. The results can be visualized in 3D on the HMD or the CAVE environment. Navigation in space is supported by a space mouse device and also navigation in time is possible by a simple “VCR-like” graphical user interface. Within this user interface the user can create and define new missions, edit existing ones and start new calculations. The visualization system shows these new results as soon as they are available on the database server.

The following visualization methods are already available on most platforms:

1. Line integral convolution (Figure 2)
2. Streamlines (Figure 3)
3. Isosurfaces (Figure 4)
4. Billboard method for realistic smoke visualization (Figure 5)

![Figure 2: Line Integral Convolution](image-url)
Figure 3: Streamlines

Figure 4: Isosurfaces
3.2. **Real time CFD Simulation**

Computer programs are usually sequential meaning that their execution is done by only one processor. The computational time varies extremely from a few seconds up to several weeks. Especially in the second case speeding up the computation is of particular interest. One can rely on the steady increasing performance of processor technology or try to parallelise computer codes. The idea of parallelisation is to spread the workload to several processors and therefore speed up computation. The ultimate objective of the Virtual Fires system is to perform real time simulations of tunnel fires in a concurrent VR environment. Since in general CFD calculations are very CPU demanding, it is not possible to perform this on today's single processor systems. Therefore, the parallelisation of the Lattice Boltzmann code ICE is a must to achieve the aforementioned objective.

There mainly exist two classes of parallel programming paradigms:

- The shared memory paradigm consists of sharing data through a common memory by using compilation directives. This paradigm allows using parallel machines without major changes to the sequential code, but becomes inefficient for larger numbers of involved processors due to memory bandwidth limitations or in inhomogeneous environments.
- The distributed memory paradigm consists in distributing the data to the processors to share the work load. Processors requiring information located in another processor have to communicate through messages. As the messages are sent over a network connecting the processors the amount of communication should be minimal. The distributed memory model requires much more programming effort but leads to more efficient codes and can be even used for cluster solutions.
In view of the available hardware and the requirements to the program it was decided to use a distributed memory parallelisation. Distributed memory systems are characterised by a high scalability and the large physical memory available normally. The performance is influenced by the balance between CPU speed and network speed and depends heavily on the programmer. In the MPMD (multiple program - multiple data) programming model each processor executes its own program. The communication between the processors is performed by sending and receiving messages. A subroutine library which contains functions for sending and receiving messages. The data distribution and communication must be explicitly defined by the programmer. Although it is probably the most difficult approach to parallel programming it is selected due to the following reasons:

- It promises the highest performance on distributed memory systems with a large number of processors.
- It is the most portable approach.
- The programmer has all freedom to optimise communication.

There are a few message passing libraries available, but for VirtualFires the Message-Passing-Interface (MPI), the de facto standard, is used for portability. A full description of the MPI standard is given in [3] and [4]. Up-to-date information can be found on the web site of the MPI forum [5]. The VirtualFires project uses a Linux Cluster located at KTH in Sweden. The performance of the code is tested with two different configurations:

1. Test case A consists of 60,000 computational cells and is the most representative for the current use of ICE within the Virtual Fires project
2. Test case B consists of 250,000 cells

Figure 6 shows the speedup factor for the different configurations. For large problems (Test case B) the speedup factor increases linear to the number of processors. For small problems (Test case A) the performance breaks down if more than 8 processors are involved due to the relative increase of communication compared to calculation. Investigations are being performed to optimise the communication so that a real time simulation can be achieved.

![Figure 6: MPIce on Lucidor](image-url)
4. EXAMPLES

For demonstration purposes some popular fire incidents have been calculated with the simulator. These datasets also serve as a base for the verification of the system. The calculated dataset consists of different ventilation scenarios for the Mt. Blanc tunnel in France and the Gleinalm tunnel in Austria. Both tunnels where examined with their former ventilation system and also with the improved ones after the reopening. Example of fire simulations is given in Figure 7. Also a typical subway station in Dortmund has been analysed. In Figure 8 the temperature distribution inside the station during a fire incident on a subway train is shown. Together with the calculation of smoke spread this kind of simulation is important for the fire fighters to plan their missions inside these stations and to verify that their strategies are efficient.

Figure 7: Mt. Blanc Tunnel

Figure 8: Subway Station Dortmund
5. CONCLUSIONS
A simulator was presented which allows fire men to perform virtual training exercises with a head mounted display or in a CAVE environment. The simulator also allows to assess the fire safety of existing tunnels and can be used as a tool for designing new tunnels. A prototype of the system will be available in May 2004 and it is expected that the system will be marketed world wide.

6. ACKNOWLEDGEMENTS
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7. REFERENCES


