Photo-Realistic Graphics for Emergency Lighting Visualisation

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Abstract

In an emergency situation it is vital that people are rapidly able to identify the exits. This is particularly important when the visibility of the signs can be significantly reduced, for example in a smoke filled room. There are several factors which contribute to a sign's visibility: the colour of the sign, luminance, size of letters, the location of the sign in the room and of course how engulfed the room is with smoke. It is also important to determine the visibility in clear and dark conditions. This paper describes a visualisation system under development which uses photo-realistic computer graphics techniques and parallel processing to provide an interactive tool for emergency lighting designers. The system will enable designers to investigate different positioning and illumination of emergency lighting under a variety of environmental conditions.

1 Introduction

The two major contributors to the number of deaths in a fire are smoke and panic. In a fire, carbon dioxide and carbon monoxide gases are produced, as well as other lethal gases from burning furniture, carpets, etc. These gases form several minutes before any flames develop (hence smoke detectors are used instead of temperature-sensing devices in fire-alarms for private households). Panic often causes people to behave in an illogical and irrational manner. People usually remember the way they came in, for example the main entrance, and thus proceed along that route as a means of escape in an emergency situation. This happened during the fire in Munich in 1973 [2] when 3000 teenagers were gathered in a hall with eight emergency exits plus the main exit. Two girls were crushed and several others injured as the majority of the crowd attempted to leave through the main exit. The other emergency exits were hardly used. In an emergency situation, it is therefore vitally important that people are aware that other exits are available. This may not result in a nice, optimal division of people amongst the emergency exits, but it should help prevent a crush at any individual exit.

One important factor in enhancing peoples' awareness is to make emergency exit signs as visible as possible. Standards have been provided for the size of letters, text and whether the exit sign should be illuminated internally or not [14]. Experiments have been performed to establish the brightness of signs, luminance of different colours and configuration for exit signs under different conditions [7]. Such experiments are expensive, difficult to control and should be used as a last resort if needed.

Computer graphic techniques have been used for a number of years to "construct" virtual environments on computers. It is possible, therefore, to recreate a site on a computer and provide the viewer with an accurate representation of the internal illumination under a variety of conditions. In order to gain the maximum insight into possible visibility within the three dimensional space, the user should be able to navigate through this computer representation of the site. This process will be enhanced by the photo-realism that can be provided by the computer model including realistic illumination and the presence of environmental factors such as smoke, dust or fog. Natural motion is an important component of visual simulation and thus, it is essential that such a navigation system is interactive, responding immediately to the operator's directions [1].

Previous research of photo-realistic image synthesis techniques on sequential computers has demonstrated that the computational effort required to produce the images precludes the critical interactive nature of the envisaged system [15]. However, the application of advanced parallel processing methods should allow the interactive visualisation of the building interiors under emergency conditions and thus further our understanding of emergency lighting requirements [4, 11].

2 Photo-Realism

In all image synthesis techniques, the fundamental step is computing the amount and nature of the light from the three-dimensional environment which reaches the eye from any given direction. This computation is carried out by simulating the behaviour of the light in the environment and thus, the greater the correlation between the simulation and the physical world, the greater the realism that can be achieved. However, in the physical world, the lighting, reflection and scattering effects are very complicated, and although the behaviour of light as a form of radiant energy has been extensively studied and mathematically modelled [10], the prime problem that still must be addressed is solving the simulation based on these mathematical models in reasonable times.

2.1 Particle Tracing

Monte Carlo particle tracing has been proposed as a method to simulate accurately light propagation through an environment [15]. Particles or energy packets are shot out from their respective emitter in different directions and their history tracked as they propagate through the environment including any participating medium. The particles move in straight lines between collisions and they do not influence one another. This last condition allows the behaviour of a relatively small sample of particles to be used to represent the whole [9]. On collision with an object two things may happen:

- the particle is absorbed, thereby loosing its energy and travelling no further; or,
- the particle is reflected, thereby changing its direction and energy. The particle's new direction is determined by the incoming direction from which the particle hits the receiver and the bidirectional reflectivity distribution function, *brdf*, of the receiver surface.

The particle continues its travel through the environment until it is absorbed or a decision is taken to end a particle's flight, for example, if it is no longer making a significant contribution to the environment's illumination.

If we assume that there is no change in emissive behaviour of the light sources in the scene over a period of time, an energy equilibrium is established in which the rate at which particles leave surfaces is the same. This flux of particles for an area is used to determine the area's brightness. The colour of an object is defined by the distribution of the wavelengths among the outgoing particles from the object's surface. Hence, in particle tracing illumination is found by determining the particle flux per unit area at different wavelengths for each surface of every object in the environment.

In particle tracing a finite number of particles is used in the simulation. Particles are assigned a light source in such a way that the probability of their being associated with a more powerful light source is higher than being associated with a less powerful one. Having assigned a particle to a light source, the position on the emitter surface, its wavelength and its initial direction are also decided using probability distribution functions. In order for this algorithm to account for emitting participating media, such as flame, particles may also be allocated at different positions in an emitter volume.

As the path of a particle is traced, it may now either hit an object or be influenced by a participating volume. If the particle hits a non absorbing surface its energy, or "weight", is reduced by a factor of ρ and accordingly this fraction is added to the brightness of the reflecting surface. On reflection the particle is given a new direction depending on its incident angle and the *brdf* of the surface. When a particle's weight falls below a threshold, it no longer contributes significantly to the illumination of the environment. Statistical methods are used to determine whether the particle should terminate its travel or be allowed to continue with increased weight, known as *Russian roulette.*

If a particle is found to interact with the participating volume the scattering / absorption albedo, that is the proportion of the incoming light that is scattered or absorbed, is used to decide the type of interaction. If the particle is to be absorbed, its energy is lost and it travels no further. However, if the interaction type is scattering then the flux of the volume is updated according to the energy of the particle and a new direction is determined for the particle.

The question is now: how many particles do we need to trace in order to obtain accurate estimates of the flux for each surface in the environment? After some time an equilibrium will be established where the number of particles leaving an emitter surface and hitting surfaces in the environment is said to be constant. A further contribution of a finite number of particles sampled will not change the brightness of the surfaces significantly. Previous research has shown that a million particles is sufficient for an environment with 661 surfaces with a non-participating medium [15]. For the same environment filled with non-absorbing isotropically scattering gray medium with a scattering coefficient of 0.1, 10 million particles were sufficient. It was also shown that, compared to the radiosity method, the particle tracing method produced highly satisfactory results [15]. Another important factor is that the particle tracing method will be superior in processing time with increasing number of surfaces. This is due to the fact that the Monte Carlo method is inherently capable of handling far more complex 3D-configurations with greater simplicity, flexibility and speed [9].

2.2 Participating Media

In many graphics applications and methods it is assumed that light travels through a non participating medium, normally clear air or a vacuum. For a great majority of synthesised images, this is a satisfactory assumption. However, in some situations it is necessary to include the participating media such as fog, smoke, dust, humidity or clouds, to provide the required level of realism within the images. A medium affects light due to:

Augmentation arises due to emission in the medium or as a result of light scattered in from other directions, also referred to as inscattering [6]. This means that a particle's strength is increased by contributions from emissions in the medium or by other particles from other directions.

Attenuation is due to absorption and scattering. Absorption occurs when the light ray hits a particle of the medium and its strength is reduced to zero, or its path is terminated. With scattering some radiation is reflected, while the remaining portion will penetrate into the medium where some of this remaining radiance may be absorbed, transmitted or undergo multiple internal reflections or refractions.

The particle tracing method is able to accurately simulate the physical propagation of light within the environment, and can be used for complex scenes including the interaction of environmental factors including light emitters such as flames, light absorbers such as soot clouds, or light scatterers such as dust or smoke [15].

To restrict the spread of fire and smoke within an environment, ventilation, for example: open doors, windows, etc, should be kept to a minimum in order to decrease the supply of oxygen and hence, the spread of flames [12]. A fire without ventilation, or very little ventilation, will fill a room or building with smoke from the ceiling downwards, that is a greater concentration of smoke will exist the higher up we move in the environment. It should also be mentioned that vents located in the roof are used in the removal of smoke and heat to ease both evacuation and the fire fighters job [13].

In our model we assume a closed environment, and that at a given height the density of smoke and all the optical factors (scattering albedo and extinction coefficient) are the same. The environment is therefore divided in parallel horizontal three-dimensional planes, as shown in figure 1. The volume in each plane has the same density of smoke and also the same optical factors. This means that our model is an all-pervading non-homogeneous absorbing/scattering medium with an increasing density as we increase the height.

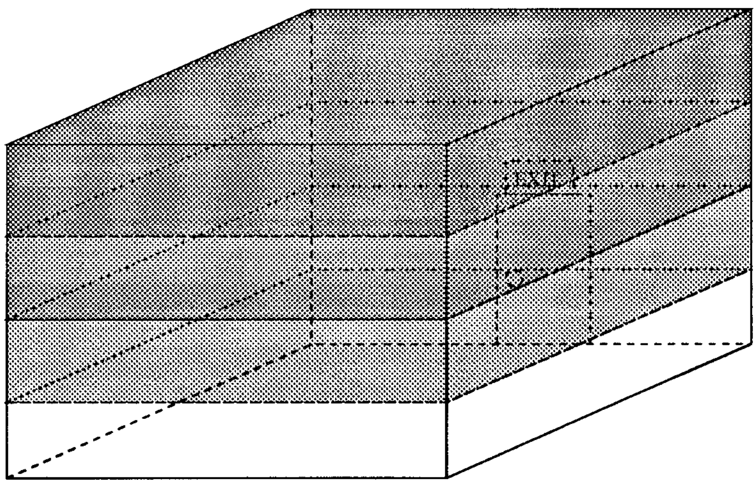

Figure 1: Different levels of smoke density in an environment

2.3 Implementation

The implementation that has been adopted is based on the methodology developed by Pattanaik [15]. This method models participating volumes in the following ways:

All-Pervading Volume: Models a homogeneous absorbing/scattering medium occupying the whole environment of interest. All points of interest in the environment lie within this volume and have the same extinction coefficient.

Volumes bounded by Quadric Surfaces: Models a homogeneous medium enclosed within quadric surfaces.

Data set: Models a unit cubical volume in a discretised form. A 3D array defines the optical properties with each element holding the value of extinction coefficient, scattering albedo and emission strength if the object is an emitter.

The Monte Carlo particle tracing method has the following algorithm for dealing with participating medium:

For each particle repeat steps 1 to 6 below:

1. Choose a wavelength for the particle by sampling the cumulative emission spectrum. In the presence of multiple light sources choose the emitter from which the particle will originate by sampling the emitter strength distribution at the chosen

wavelength. Choose the position on the emitter at which the particle originates by position sampling the emitter surface geometry or the emitter volume.

2. Update the outgoing particle flux at the emitter.

3. Choose the direction in which the particle is emitted by sampling the directional emission distribution function.

4. Repeat steps (a) to (c) below until the particle is absorbed.

   (a) Find the nearest surface along the particle path, and find its path length

   (b) Find the path length for the interaction with the participating volume, if any

   (c) if the path length found in (b) < path length found in (a) then

```
{
 //Particle interacts with the volume
 Sample the scattering/absorption albedo distribution
 to decide on the type of interaction.
 If the interaction type is scattering then
   {
    Update the outgoing flux of the volume.
    Assign scatter direction by sampling the directional
    scattering distribution or phase function.
   }
}
 else
 //Particle interacts with the surface
 {
  Sample the reflection/absorption albedo distribution
  to decide on the type of interaction.
  If the interaction is reflection then
  {
   Update the outgoing particle flux on the reflecting
   surface.
   Assign reflection direction by sampling the surface
   bidirectional reflection distribution function.
  }
 else
 Russian Roulette is ''played'' to whether to terminate
 the particle or let it go with increased weight.
 }
```

In order to increase the speed of tracing the particle, the method uses space subdivision of the environment. This means that the scene is divided into a three dimensional array of cells. Each cell is then further divided into a finite set of voxels.

3 Parallel Processing

Until sufficient particles have been traced, the accuracy of the solution will improve as the number of particles considered is increased, that is, the more particles used, the "more realistic" the result. Naturally, the computation time associated with the particle tracing method depends on this number of particles. Experience, based on a sequential implementation of the particle tracing method, has shown that even for relatively simple environments the number of particles that have to be considered in the simulation can be of the order of a few hundred thousand. On the single processor machine this can amount to many minutes and even hours of computing time [16].

The paths of the particles through the environment may be traced independently and then the resultant fluxes combined to produce the global illumination. It is this independent path tracing that suggests that the particle tracing method is suitable for implementing in parallel. However, using the particle tracing method to visualise complex scenes introduces certain characteristics which complicates its solution on multiprocessor systems.

Many thousands of data objects may be required to accurately model the sites including the participating media. The data requirements are thus far larger than can be accommodated locally at each processor in a multiprocessor system. It is necessary, therefore, for the processors to fetch data from remote parts of the system during the course of their computation. The latency in acquiring a data item which is not available locally can be significant [5].

The concept of *data sharing* may be used to cope with very large data requirements [3]. Data sharing allocates every data item an unique identifier. This allows a required item to be "tracked down" from somewhere within the system, or from secondary storage if necessary. The size of problem that can now be tackled is, therefore, no longer dictated by the size of the local memory at each processor, but rather only by the limitations of the secondary storage.

In the particle tracing method, the order in which the data objects are required is unknown as this depends on the probability distribution function of the surface with which a photon has most recently interacted [15]. If a requested data object is available at a processor's local memory, then there is no delay. If not, then the object must be requested from elsewhere in the system. Once the object is found it can be returned to the requesting processor. The time delay in acquiring a data item which is not available locally can be significant. Techniques such as profiling, caching and multi-threading, must be introduced in order to reduce this delay time [5].

Profiling enables some knowledge of the data requirements to be determined in advance [8]. This entails a preprocessing stage in which the computation is performed using a coarse approximation of the desired resolution of the problem. This profiling can thus provide each processor with an estimate of the number of time each data item is referenced, but unfortunately still does not quite give the order of reference. The information that is obtained by profiling does allow the data kept at a processor to be biased in favour of that which is most often referenced.

Caching algorithms have been used to attempt to satisfy the data requests locally. When combined with profiling, such techniques can significantly reduce idle time caused by data fetching [8].

Multi-threading uses more than one thread of execution at each processor. That is, each processor is responsible for computing the path of more than one photon concurrently. Now, although one computation may be suspended awaiting a remote data item, the other threads may still be able to continue. Previous work has shown that the use of multiple threads on each processor can significantly improve system performance, but there is a limit to the maximum number of threads that can be used [5].

3.1 Communication Protocols

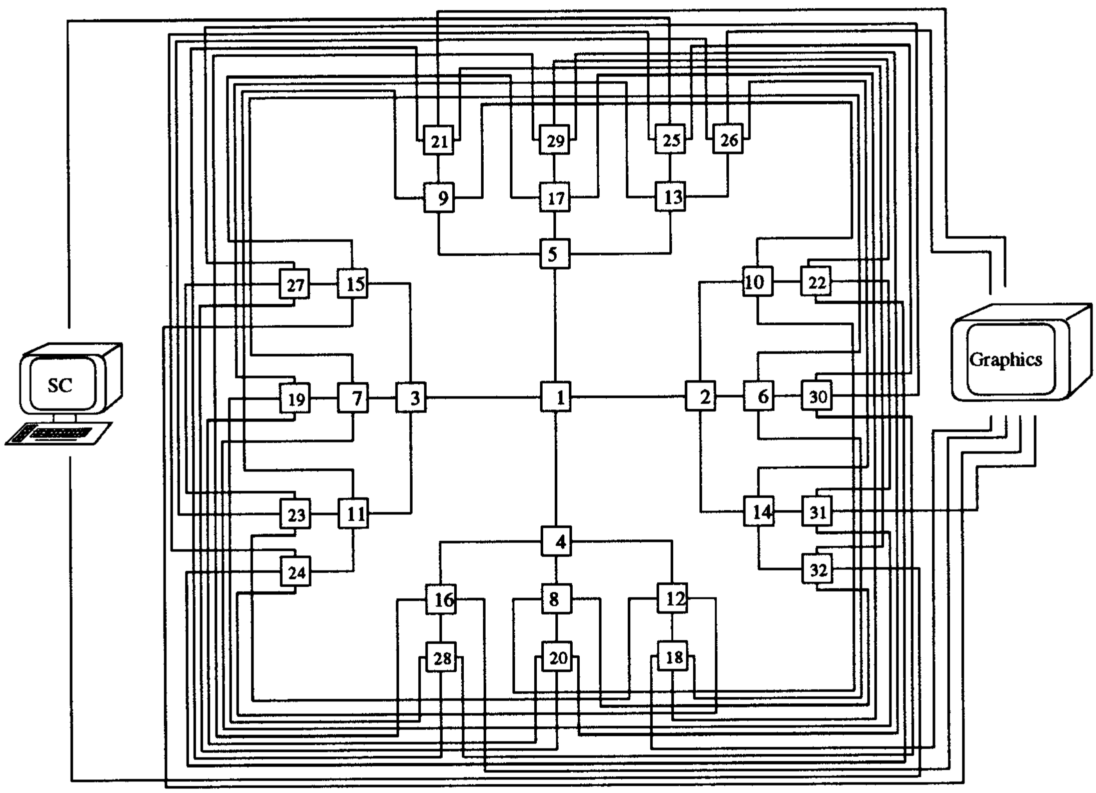

Figure 2: 32-processor AMP for visualisation

Communication overheads may also be reduced by efficient communication protocols. The solution of problems, such as the particle tracing method, which require global communication between all processors benefit from a communication scheme which reduces the distances messages have to travel between processors which are not directly connected. As the number of processors in the multiprocessor systems are increased to achieve the desired interactive nature of the system, communication overheads have an increasing impact on overall system performance and may limit the scalability of the system unless effectively tackled. Minimum path configurations have been shown to be successful in this respect [3]. Figure 2 shows the 32-processor minimum path (AMP) configuration which is used to reduce communication overheads.

4 Conclusion

A computer visualisation system can enable designers to investigate the placement and illumination levels of lighting within a site. Such a system must be flexible, allowing designers to alter the scene parameters and view the results immediately. To fully appreciate the modelled environment, the computer images should be of photo-realistic quality and include participating media such as smoke and flame.

On completion, the system described here will allow designers to determine the optimal placement and intensity of the emergency lighting. This should ensure that people are easily able to determine the nearest exit in an emergency and thus help alleviate panic.

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