# Chapter 7

# Conclusion

Modern graphics accelerators present exiting opportunities for low-cost simulations on personal computers. There are, however, a number of limitations that must be kept in mind when implementing a simulation. These limitations reduce the accuracy of simulations and techniques must be implemented to work around them.

## 7.1 The use of OpenGL as a library for generating infrared scenarios

OpenGL was designed to generate visually pleasing images at real-time frame rates. The required resolution of the images are therefore limited to values that would lead to images that "look right". Infrared scene generation has much higher requirements for scene fidelity. Infrared parameters such as radiance, atmospheric transmittance and atmospheric path radiance can be implemented directly on OpenGL. It is also possible to include reflected energy from sources such as the sun in simulations. The main drawback is that the resolution of hardware limits the accuracy of the resulting images. The dynamic range is a limitation even on systems such as the SGI Onyx2 with an InfiniteReality engine [5]. Parameters such as the atmospheric transmittance and path radiance must be calculated separately, and do not use the rendering hardware that is normally used for generating visual images.

## 7.2 Limitations of using a personal computer as simulation platform

Colours on the personal computer were defined to yield images that are visually acceptable. The colour space was therefore limited to 3×8-bit colours. The maximum number of gray scales on a personal computer is 256, placing a severe limitation on the dynamic range of the resulting infrared image. The graphics co-processors are designed to deliver images at real-time frame rates, but although the frame rate is sufficient for infrared simulations, the dynamic range is too low.

## 7.3 Benchmarks

The benchmarks indicated that the GeForce card can render images at more than the required frame rate. It is not possible to read the rendered images from the frame buffer at the required frame rates, using the available OpenGL commands. Calculating an image using the super-resolution technique is also too slow for practical implementation. The matrix multiplications that are required to implement the atmospheric transmittance and path radiance calculations are too slow to calculate on-the-fly during real-time simulations.

## 7.4 Implementing a physically realistic simulation on a personal computer

Commercial-off-the-shelf (COTS) systems are limited in their ability to render accurate radiometric images at real-time frame rates, using only their native hardware graphics acceleration. This statement is also valid for very expensive graphics supercomputers such as the SGI Onyx2. In all the cases the reason is the difference between the dynamic range required for visually acceptable images and the dynamic range required for radiometrically accurate infrared images.

Implementing an infrared simulation on a COTS system requires a number of compromises. Rendering images of objects at close ranges can be accomplished to a high level of accuracy, as was shown in Chapter 4. These object images can then be translated to other distances using the super-resolution technique described in Section 6.4.1. The image of the target object can be scaled with the atmospheric transmittance and combined with a pre-calculated bitmap representing the atmospheric background.

The time required to read an image from the frame buffer into the personal computer's main memory and the time required for matrix multiplications are major bottlenecks, reducing the simulation's frame rates. These bottlenecks must be removed before a real-time simulation can be successfully implemented. It is possible to do this by sampling the video card's analog outputs and performing the matrix multiplications on an external digital signal processing card.

It is therefore possible to generate physically realistic infrared images on a personal computer at real-time frame rates, given that techniques can be implemented to eliminate the problems with memory bandwidth and processing power on a personal computer.

## 7.5 Contribution

The study showed that it is possible to generate infrared imagery on a personal computer, as opposed to the expensive hardware normally used for this task. The task was accomplished by extending OpenGL to the infrared band through the mapping of infrared parameters to OpenGL. The mapping of infrared parameters to OpenGL can be inaccurate and techniques were developed to limit the errors. The techniques used are described in the article by le Roux *et al.* [23]. The technique to extend the dynamic range of SGI machines, as suggested by

Olsen *et al.* [6], was extended to a personal computer. A technique was suggested that would enable the generation of accurate infrared imagery on a personal computer. A summary of the work included in this dissertation was presented at the AeroSense 2001 conference [24].

## 7.6 Future Work

The biggest hardware problem with implementing the rendering on a personal computer is the speed with which data can be read from the graphics card to the PC's main memory. The focus of future work will therefore have to be to increase the speed at which data is read into the PC's memory. This can be done either by sampling the display card's video output or improving the current DMA (direct memory access) rates. A further possibility is to increase the part of the rendering that is done in software in the PC's main memory. This would become more feasible with the continued increase in processor speeds. A form of distributed rendering, where parts of the image are rendered on different computers, would also increase the frame rate. This would present new challenges in transferring the image data at the required frame rates.