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PHYSICALLY-ACCURATE SYNTHETIC IMAGES FOR MACHINE VISION DESIGN

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Abstract

In machine vision applications, accuracy of the image far outweighs image appearance. This paper presents physically-accurate image synthesis as a flexible, practical tool for examining a large number of hardware/software configuration combinations for a wide range of parts. Synthetic images can efficiently be used to study the effects of vision system design parameters on image accuracy, providing insight into the accuracy and efficiency of image-processing algorithms in determining part location and orientation for specific applications, as well as reducing the number of hardware prototype configurations to be built and evaluated.

We present results illustrating that physically accurate, rather than photo-realistic, synthesis methods are necessary to sufficiently simulate captured image gray-scale values. The usefulness of physically-accurate synthetic images in evaluating the effect of conditions in the manufacturing environment on captured images is also investigated. The prevalent factor investigated in this study is the effect of illumination: the significance of ambient lighting effects on the captured image and, therefore, on camera calibration was shown; if not fully understood, these effects can introduce apparent error in calibration results. While synthetic images cannot fully compensate for the real environment, they can be efficiently used to study the effects of ambient lighting and other important parameters, such as true part and environment reflectance, on image accuracy. We conclude with an evaluation of results and recommendations for improving the accuracy of the synthesis methodology.

1. INTRODUCTION

For machine vision system applications such as part presentation, the accuracy of image gray-scale pixel values far outweighs image appearance [Lee, 1991]; in this paper, we present physically-accurate image synthesis as a rational basis for designing both hardware and software components of a vision system. This is a very complex task, since such systems consist of many parts and the most proficient systems are designed by considering the *integrated* hardware/software arrangement. Numerical simulation is a flexible, practical tool for investigating a large number of hardware/software configuration combinations for a wide range of parts.

Prior machine vision research includes the use of *photo-realistic* synthetic images as an aid in testing model-based vision algorithms [Wu *et al*, 1990]; however, these images were generated with the simple image synthesis algorithms available with most commercial CAD systems, which assumed idealized or nonphysical reflectance models, limited light source models and unrealistic camera optics. While the images obtained with these packages were useful in gaining some insight into algorithm performance, their usefulness was limited [Chen and Mulgaonkar, 1991]. These photo-realistic images were generated based upon work developed in the area of computer graphics, where appearance of the image to the viewer is generally the primary concern. Meyer *et al* [1986] modeled the generation of a physically-accurate synthetic image. In their model, the environment description includes the scene's reflective and emitting properties, in addition to geometrical information and is processed via a simulation based upon the *physics* of illumination, instead of the idealized or nonphysical reflectance and illumination models used to produce photo-realistic images.

It was, in fact, attempts to improve the realism of photo-realistic images that resulted in the development of highly accurate methods for calculating illumination, which supported the development of *physically-accurate* synthesis methods [Goral et al, 1984; Nishita and Nakamae, 1985; Sillion *et al*, 1991, Kajiya, 1986; Ward *et al*, 1988]. The use of such physically-accurate images in an iterative method for improved image understanding was proposed by Gagalowicz [1990]. Some researchers, while agreeing that understanding the illumination problem is important, felt that most physically-accurate synthesis methods were too computationally expensive to be useful in vision system design [Cowan, 1991]. Rushmeier *et al* [1992] have developed an efficient methodology for generating physically-accurate synthetic images that predict the gray-scale values of images captured by a computer vision system. Results from this research confirm that physically-accurate image synthesis methods, rather than those methods currently available with standard CAD packages, are