IPT-EGVE Symposium (2007)
B. Fröhlich, R. Blach, and R. van Liere (Editors)

Short Papers

Learning from Painting: Perspective-dependent Geometry Deformation for Perceptual Realism

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Abstract

Virtual environments and user interfaces in general can be improved by using the concept of Perceptual Realism, e.g. by means of non-photorealistic rendering techniques. The approach presented here follows a different path by reducing perceived geometric distortions, which typically occur for spherical objects while rendering scenes with a large angle of view. Learning from painting, we adopt the Renaissance painters' principle of using multi-perspective views and propose a perspective correction technique to overcome the mentioned problem. With it, three-dimensional transformations directly modify the geometry of particular objects within a scene to countervail their distortion during the rendering process. The approach results in an improved perceptual realism of the rendered images.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation–Viewing algorithms I.3.6 [Computer Graphics]: Methodology and Techniques I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

Due to the tremendous improvements in graphics hardware, more and more realism can be achieved for computer graphics images and interactive virtual environments. With the advent of non-photorealistic rendering techniques the question came into play how to create images and interfaces which better reflect and support human perception and viewing behaviour. The resulting computer graphics images are no longer aiming at accurate realism but at achieving so-called *Perceptual Realism*. Perceptual Realism in this sense means to take into account capabilities of human perception to obtain a better *feeling* of realism, sometimes to better solve a particular task. This is one of the goals of non-photorealistic rendering approaches. Our work presented here has a different focus to reach this goal. It is about the reduction of geometric distortions within computer generated images. These distortions especially occur for spherical, curved objects not being in the centre of the view plane while rendering scenes with a large angle of view. In addition, the phenomenon of a perceived distortion especially occurs with big screens or projections, where the user is standing close to the projected image. We approached this problem by studying the way how painters transformed three-dimensional scenes into two-dimensional paintings. This is described in the next section, followed by a short review of related work. In section 4 we introduce our approach and propose a perspective correction method to reduce geometric distortions.

2. Learning from Painting: An Art-based Approach

The traditional arts provide a number of techniques that could be useful for improving computer-generated images and interfaces especially of large displays. One reason for that is that Renaissance artists developed solutions for perceptual problems occurring on large canvases. This shall be illustrated with a specific example.

Figure 1 shows the picture "Neumarkt in Dresden von der Moritzstrasse aus" (original dimension 135 × 237 cm), which was painted by Bernardo Belotto called Canaletto in the middle of the 18th century. Although the picture seems to be made by a photo camera the perspective is incorrect in a mathematical sense. The main direction of view in this painting rules the size and depth of contained buildings and other objects. A deeper analysis reveals that the Frauenkirche, the

Figure 1: *"Der Neumarkt in Dresden von der Moritzstrasse aus", painting by Canaletto, 1749-51*

church seen in the right part of the image, was painted in a different way with its own perspective. The artist turned his view towards the church while he was painting. The result was an own image plane for the church building. That's why the picture employs a so-called *hybrid perspective* (cp. [Hoc01], [Gro05]).

If the picture would have been constructed exactly by the rules of central projection, the image would look different (see figure 2 or video). The tilting ellipses in the range of the dome are remarkable. Please note that the distortion is increased due to the main vanishing point not being in the centre of the image. In general, the visual impression seems to be not as natural as that of the original picture.

Figure 2: *Computer graphics reproduction of the painting in figure 1 (with one principal vanishing point for all objects)*

It is obvious that the artist changed the perspective of the church deliberately. His aim was to reduce distortions which otherwise would occur by projecting all image objects equally. In that case the image would possess a so-called *mono perspective*. The basic technique of painters was to look straight to object while creating a picture (cp. [Hoc01]), especially to the objects which were projected in a perceptually disturbing manner. The ambition to paint perceptually realistic images leads to multiple image planes and therefore multi-perspective views of a three-dimensional scene. See figure 3 or video for a corrected image rendered with our approach.

Figure 3: *Multi-perspective image rendered from three-dimensional model (one extra principal vanishing point for the church, one principal vanishing point for all other objects)*

As a consequence, the question arises, which objects of a 3D scene should be selected to be treated differently in rendering them with their own perspective. In [Gro05] three basic rules were derived from observations of using multi-perspectives in Renaissance paintings. The objects treated differently are:

1. *covered by a closed curved surface (convex)*. This means an organic structure, for example human bodies, spheres or columns.
2. *isolated and single*. Objects are often isolated in the composition or detached from other objects in the scene.
3. *exhibiting dialogical significance*. Objects often have a narrative relevance with regard to the painter's intention.

A user study of the authors supports these findings. The main goal of the survey was to analyse the viewers' reaction to a mono and a multi-perspective image of the same scene with regard to their perspective impression. A significant number of subjects indicated that the modified version of an image (with multiple perspectives) was the perspectively correct one. A correlation between the artistic multi-perspective techniques and the human perceptional habits could be detected. Especially spherical objects and their distortions influence the impression of the whole image. With regard to these foundations, a concept for an intelligent camera is presented in [GFZ06], which proposes several principles for creating perceptually realistic images. The work presented here can be seen as a specific solution for one of the concepts suggested in [GFZ06].

3. Related Work

The main question is how to create a computer graphics system which fulfils the need for multi-perspective rendering of a scene. There exists a main limitation for building such a system as formulated in [ZB95]: "It is impossible to construct a viewing transformation such that the images of all lines are straight and the images of all spheres are exact circles." Due to the fact that a single viewing transformation cannot fulfil the requirements, it is necessary to search for other possibilities to influence the results of the rendering process. Existing approaches in the field of non-photorealistic and non-linear rendering show two different principle solutions. Most of these are based on images, only few are directly using geometric data. Firstly, images could be assembled from images with different views. One example for it is the method presented in [Sin02], which uses different cameras and weight vectors to render the image. The points are projected to the different cameras depending on the influence on them which is defined in the weight vectors. The produced image is a composition of all camera views.

Secondly, 3D geometry modifications could be used for creating such images, as for example in [CS04]. This concept also operates with different cameras like the previous one. In contrast, the image is rendered by a single *boss camera*. The other cameras also called *lackeys* define a deformation on the scene objects. This means, the closer a lackey camera is placed to an object, the more this object is deformed towards the camera. It is obvious that the positioning of the lackey camera allows changing the perspective of the influenced objects. Other approaches, e.g. [RB98], use the virtual camera to create multi-panoramas from a 3D scene. Both methods have advantages and disadvantages, for example problems with shadow generation for raytracing.

4. The Perspective Correction

One advantage of the direct manipulation of object geometry is that standard rendering techniques can be used for creating images. This is one of the reasons why we decided for a method working with direct three-dimensional geometry manipulation. In the following, the perspective correction will be presented as a method for solving the problem of perceived geometric distortions in computer rendered images. A fundamental function of this algorithm is the reduction of distortions especially of spherical objects by using three-dimensional transformations. In contrast to artists, computer graphics offers the possibility to directly interfere with three-dimensional geometry. Thereby, rotation and shearing as two essential transformations will be applied to the object's geometry to imitate the painters approach. As a consequence, the geometry of particular objects within a scene is directly modified *a priori* to countervail their distortion occurring later during the rendering process.

The basic steps of our approach can be summarized as follows:

1. Determination of the object's position P_O in the local camera coordinate system.
2. Calculation of shear factors $sh_{x(z)}$, $sh_{y(z)}$ from that relative position

$$sh_{x(z)} = \frac{\delta x}{\delta z} \tag{1}$$

$$sh_{y(z)} = \frac{\delta y}{\delta z} \tag{2}$$

3. Calculation of rotation angles r_x, r_y

$$r_x = -arctan2(\delta y, \delta z) \tag{3}$$

$$r_y = arctan2(\delta x, \delta z) \tag{4}$$

4. Object rotation around x-axis and y-axis according to the rotation angles r_x, r_y
5. Object shear with a shear matrix based on the calculated shear factors

$$[S] = \begin{bmatrix} 1 & 0 & sh_{x(z)} & 0 \\ 0 & 1 & sh_{y(z)} & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Figure 4 sketches the main transformations of the perspective correction by using a two-dimensional example. As noted earlier these steps have to be performed both in the horizontal and vertical direction.

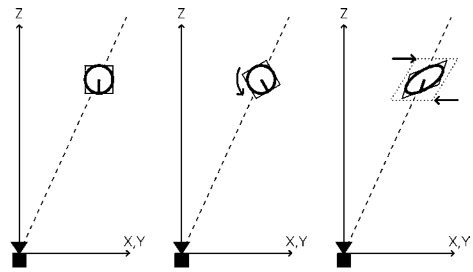

Figure 4: *Original object, rotated object, rotated and sheared object*

Given this algorithm, it is possible to create a formula which calculates the perspective correction for three-dimensional objects by using matrices common in computer graphics. Fundamental resources for developing a solving equation are object transformation matrices. This matrix represents the pivot's position and orientation and by this means the object in general.

The components of the formula presented below are the object transform matrix $[O]$, the origin point of object $[P]$, and the camera transform matrix $[K]$. According to the presented algorithm the modified object transform matrix $[O']$, the modified camera transform matrix $[K']$, the object's position relative to camera P_O, the shear matrix $[S]$, the rotation relative to local y-axis $[R_y]$ and the rotation relative to local x-axis $[R_x]$ have to be determined. Finally the corrected point $[P']$ could be calculated. The rotation part of the object transform matrix is replaced by the corresponding 3×3 identity matrix. Thereby only the actual object's translation is used in the calculation. That is necessary for shearing and rotation relative to the object's pivot.

$$[O] = \begin{bmatrix} r_1 & rs_1 & rs_2 & x \\ rs_3 & r_2 & rs_4 & y \\ rs_5 & rs_6 & r_3 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \rightarrow [O'] = \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The translation part of the camera is set to zero, therefore only the actual rotation of the object is used for the calculation. This allows shearing and rotating the object relative to camera orientation regarding the object's self rotation.

$$[K] = \begin{bmatrix} r_1 & rs_1 & rs_2 & x \\ rs_3 & r_2 & rs_4 & y \\ rs_5 & rs_6 & r_3 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \rightarrow [K'] = \begin{bmatrix} r_1 & rs_1 & rs_2 & 0 \\ rs_3 & r_2 & rs_4 & 0 \\ rs_5 & rs_6 & r_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Calculation formula:

$$[P'] = [O'] * [K'] * [S] * [R_x] * [R_y] * [K']^{-1} * [O']^{-1} * [P]$$

The following essential steps are involved in the perspective correction. First of all the shear factors are calculated in such a manner that the farer an object is away from the optical axis the more it will be sheared. Respecting the two-dimensional image plane, shearing has to be performed in the camera's local x-axis as well as y-axis. Figure 5 shows a sample scene rendered with a 100 degree angle of view. Applying this transformation reduces the distortions. Thereby, visual information for the object is lost. Take for example figure 5, where you are able to see more of the bottom side of the upper teapots and more of the top side of the lower teapots. The Result is a more perceptually realistic image, i.e. an image which more fulfils the human expectation of the object's shape (see figure 5). The focal length of the images in figure 5 is identical.

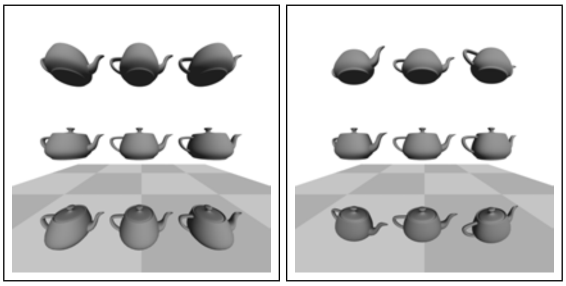

Figure 5: *Mono-perspective image, no transformation applied to the teapots (left), multi-perspective image, shear and rotation transformations applied to the teapots (right)*

5. Conclusion and Future Work

The fine arts provide a number of techniques which can be used for enhancing computer generated images, virtual environments and even other user interfaces. An important method in paintings is to use multi-perspectives to reduce distortion effects caused by linear projection. This paper presented an algorithm that reduces distortions in two-dimensional images based on 3D scenes. By applying an a priori geometry correction of mainly spherical and organic objects in a scene, they can be rendered in a more perceptually realistic manner using standard rendering pipelines.

One of the problems still to be solved is the automated detection of those objects in a scene, which are candidates for being rendered with their own perspective. In addition, we are currently investigating the application of the proposed method to an interactive real-time environment to improve the usage of three-dimensional user interfaces. An example for that idea is depicted in figure 6.

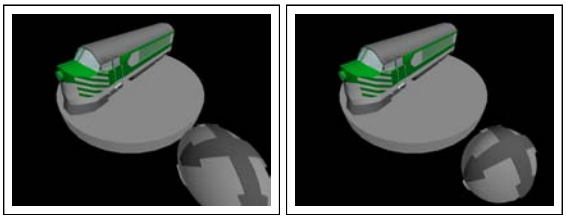

Figure 6: *The steering gizmo is being distorted in the mono-perspective image (left). Performing the perspective correction on the steering gizmo leads to a multi-perspective result with reduced distortions (right).*

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