Using a shifted lens to achieve visual depth in facade projections more efficiently

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Abstract—This paper describes a method for creating spatial illusion projections in a simple yet efficient way. It uses the horizontal and vertical lens shift properties of a virtual camera in a 3D modelling software to produce a normalized image that can be subsequently mapped with a traditional mapping technique, as cornerpin keystone correction for instance, onto a real facade. Our calculations describe how to automatically derive horizontal and vertical shift values. The method was developed during the creation process of a series of projections created with the 3D modelling software “Blender”. [1]

Projections art; augmented reality; shifted lens photography

I. INTRODUCTION

During the last two decades the availability of projectors influenced different kinds of art like exhibition installations or street art as well as some daily life experiences like advertisement or party visuals. Regarding public projections, we observe the emancipation from its aforementioned origins towards an art on its own. At least it seems to be en vogue to decorate many kinds of festivals with public projections, especially in winter.

To use projections in a more architectural context it is not enough to merely map graphics on a surface. The architect has to begin from a different conceptual basis, treating the projection as the mapping of a facade onto another facade and then using the appropriate 3D techniques to create the desired spatial illusion.

Since spatial illusions are part of architectural visualization, the techniques an architect has to learn to map spatial illusion projections are of great use in daily visualization tasks. Projected facades might also open an architect’s mind on how to communicate a project and how it is perceived, because she or he needs to focus only on image creation of facades, thus, narrowing down the usually very complex problem space.

This paper reports a straightforward method for efficiently creating spatial illusion projections on single planar surfaces. While making use of standard 3D modeling and image transformation tools, it enables users to develop illusive projections, which cover some basic features of spatial augmented reality. [2] In the future, it might be daily routine to generate not only renderings of architectural projects but also game-like augmented reality models, which can be viewed through people’s smart phones and tablets. Starting to develop and use projection tools like the one described here may help shift the architects’ views on new visualization methods and consequently influence the development of the tools themselves.

II. RELATED WORK

A. The Art of Projection

Renowned artists like Gerry Hofstetter or Jenny Holzer work mainly with projected symbols to establish a dialog between the projection surface and the image being projected. This is very different from projection mapping, where the projection and its canvas are being mapped graphically and not only symbolically. Nevertheless they are very successful in their puristic manner.

On the streets projections are used as a tool to achieve some sort of subcultural publicity, documented mainly on websites. [3-5]

On light mapping festivals also interactive installations are shown, where either visual user tracking methods are applied, as Christian Schneider [6] did with his thermal camera driven projections. Other projections are being controlled by smart phones. [7]

Additionally, we should not disregard the large field of party visuals, which rely strongly on the music being played. Only if intended by the artist such projections make reference to or influence any architectonical qualities, e.g. with graphical patterns used like tapestries.

B. Spatial Illusions

With the appearance of Alhazen’s (~965 – 1041 AD) “Book of optics” [8] in the 14th century as an Italian translation, many renaissance artists in Florence started to adopt his theory of vision successfully in their paintings. Frescos that seek to evoke spatial illusions have been created ever since. While in the 20th century artistic demands may have shifted, there are still artists like Edgar Muller, who create spatial illusions painted directly on streets (figure 1).

What these illusions have in common is that they assume one viewpoint for which the illusion works perfectly. When looking at the painting from a different perspective, the result seems distorted and unrealistic. Spectators may still be able to guess what the painting was meant for – especially when they are close to the assumed viewpoint, since human visual perception is able to compensate the incorrect perspective to a certain extent; however the 3D visual effect will be lost.

Using a Shifted Lens to Achieve Visual Depth in Facade Projections More Efficiently

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C. Projection Mapping Techniques in Art

Projection mappings technically consist of distortions to map a projection onto the canvas object. Sometimes it is a combination of techniques but with some abstraction there is always a content creation phase, where the content is put in relation to the canvas object, and a final mapping step. This is where the projected image is being transformed, so its content fits perfectly onto the facade. The mapping methods are explained later in this section.

Only in few cases the content adapts to the projection surface in real-time. Mostly the content of the projection needs to be prepared. To make a projection react to an existing surface, it needs to be referenced in the content creation process already. This is usually done with a photograph or even a 3D model of the given façade.

1) Keystone Correction: When projecting an image onto a surface at a certain angle, the image will be skewed to a trapezoid. Since this effect mainly occurs with projectors that are placed on tables and are facing upwards, it is called a “keystone effect”, referring to the architectural keystones in arches that have the same trapezoidal form.

Software correction methods exist that transform the projected image in order to finally produce a straight rectangle. Those methods are based on the creation of a trapezoid image on a black background that mirrors the former trapezoid on the projection surface.

The correction methods built in most projectors allow for re-adjustment of only regular trapezoids. In order to correct the projected image for different kinds of distortions, a variety of computer software allows the user to adjust every corner of the image individually. This enables the projection artist to map his or her projection exactly on the screen surface, as he or she wants it.

2) Cornerpin keystone correction: To address the trapezoidal transformation, most software implementations [9-13] treat the image as a texture on a 3D mesh. One very simple way to transform this mesh is by bilinear interpolation of the position of every vertex in the mesh, once one of the four corners has been moved. Due to computer graphics relying mainly on triangular geometry, when mapped on a quad, a texture usually gets transformed in a way that is unexpected for the human eye. As shown in Figure 2, the quad needs to be subdivided into a mesh in order to down-size the triangles until they are not visible anymore.

3) Rasterized and Content-Aware Mesh Correction

With the mesh warp method all the vertices of a mesh can be mapped, and not only the four corner vertices. Simple methods [13] use a simple raster of vertices, which can be repositioned. A more complex solution, as implemented in the “Mesh Warp Server” [14] allows for importing the 3D mesh, project it into two dimensions, and then adjust a 2D mesh that is not regularly rasterized, but conforms to the image being displayed.

4) Photogrammetric Methods

While photogrammetric methods are mainly used in computer vision today, the basic research on the calculation of a camera’s parameters with only a single image at hand was done in the 1950s and 1960s under the term “photogrammetric research”. [15]

As the keystone correction is a straightforward method for mapping projections on a planar façade with a projector centred onto it, photogrammetric methods are only considered when the image is projected on more than one face.

Photogrammetric methods are also applied when mapping a virtual 3D object onto an image. In this case, photogrammetric algorithms are able to calculate the position, angle and lens distortion of a camera, using markers that are applied to the image. The same is applicable when mapping a virtual object onto a real object: the location, angle and lens distortion of the virtual camera coincides with the location, angle and lens distortion of the projector in the physical space.

Since the lens distortion can be modelled only approximately, the resulting image in most cases needs to be mapped with a second correction method in order for the mapping to be precise.
D. Spatial Augmented Reality

In contrast to traditional Augmented Reality, Spatial Augmented Reality (SAR) uses images that are integrated directly in the user’s environment, instead of images that are superimposed onto reality with Head-Mounted-Displays. [2] This means that SAR-images are projected directly onto objects with projectors. Projection Mapping therefore could be seen as an artistic kind of Spatial Augmented Reality.

De Miranda et al. [16] have created similar projections as presented in this paper. They used a projector to augment an x-ray vision directly on a wall. As their work is based on Raskar’s et al. shader lamps [17] and iLamps [18], the augmented view conforms to a viewpoint near the projector itself. It is intended to work for users who hold the projector in their hands. While Raskar et al. also provide a method to augment reflections and other material properties for different user viewpoints, the mapped geometry always conforms to the projection angle of the projector, as opposed to the method presented here.

The simulation of material properties has been developed by Aliaga et al. [19]. They are able to equalize the existing and apply new colours. This allows for projections onto real objects and enables Aliaga and his team to virtually restore antique vases using just light. To achieve this, the real objects are scanned with structured light 3D scanners. In order to obtain a very precise model of the object during that process, photographs are also applied as textures to the model.

III. Shifted Lens Method for Projections

A. Preconditions

The camera shift method suits very well the needs of a spatial illusion projection. As described in section II.B “Spatial Illusions”, this kind of projection requires the assumption of a viewpoint. In addition, the camera shift method describes a workflow with which to capture and render (animated) 3D models. Therefore it is only applicable for projections whose content is being created with 3D models, since this is considered as a simple but effective way of creating a spatial illusion. Furthermore it is presupposed that the projector is positioned more or less centric and orthogonal to the projection surface.

B. Development

The method was developed during the preparation for a Christmas projection mapping in fall 2010 (see figure 4). In order to project a virtual façade onto the real façade, a virtual model of the real façade has been created using photographs and plans of the building.

Thereupon the virtual facades have been modelled using scanned drawings of St. Katharine’s Church in Oppenheim [20] amongst others, which coincided approximately with the given real façade. As 3D modelling software we chose Blender, since it has a built-in Game Engine that would allow for interactive spatial illusions.

Lens shifting is a well-known technique in architectural photography as it used to prevent “converging verticals”, an often seen effect in photographs. The building in figure 4 seems to be tilted backwards, since its roof is farther away from the image plane than its base because the camera and therefore the image plane needed to be tilted backwards to frame the whole building. Human perception normally compensates this effect unconsciously, since we assume walls to be perpendicular.

Shift lenses allow the image plane to remain parallel to the subject as they are raised parallel to the image plane. This is how converging verticals are skewed to appear straight on a photograph [21].

![Figure 4 Mapped Projection, ETH Zurich, Christmas time 2010](image)

C. Setup

In order to create a spatial illusion, a virtual camera is positioned at the estimated viewpoint of a spectator. As shown on the left side of figure 5, a camera with no shifted lens captures an image as we know it: objects that are far away are smaller than close objects. But since the projector is located centric to the projection surface, the rendered image needs to be transformed to an image similar to the one on the right side in figure 5, where the most left and the most right column have the same size.

When applying a keystone correction to a rendered image in order to accomplish this transformation, the pixel resolution on the skewed side might get very low, depending on the viewing angle. To come around this, the resolution might be increased, with potentially a lot of wasted resolution and therefore wasted rendering time and energy consumption.

A better alternative is to shift the camera lens, which produces an image that is distorted in a similar way but with a different kind of distortion process. One of its main advantages is that the transformation is being applied BEFORE any image is rendered. Metaphorically speaking, the image is being distorted in the virtual camera’s lens, as it is the purpose of shift lenses also in physical world photography.

The shifted lens method could be described as a visual normalization process as well. It is possible to create images with exactly the same outline, while being captured from different viewpoints. The details on that will be covered in section F “Viewpoint Movement”.

Fore,
D. Lens shift method step by step

Put a camera in front of the virtual model, so that it faces the virtual model orthogonally. Then the camera is being moved to the estimated viewpoint of a spectator. To observe the transformation effect best, it is proposed to test this method with viewing angles that clearly distinguish from the orthogonal view. Once the camera is repositioned, instead of rotating the camera to face the virtual model again, the camera’s lens is shifted until the model appears in the camera’s view.

E. Focal length over camera distance

As we know from photography, it is possible to frame an object at different distances, if we have a camera with a zoom-able lens. This is so common that we might not even think about different distortions of pictures taken at different focal lengths. For spatial illusions, however, it is crucial to render the projected content with approximately the focal length of the human eye – 50mm on a camera with a 36mm sensor. As illustrated in figure 6, a different focal length leads to incorrect illusions, since the perspective lines of illusion and context don’t match in their direction.

The distance between the rendering camera and the virtual screen surface is ruled by the camera’s focal length and the size of the object being captured and not by the actual distance of the spectator to the screen object. As explained in section F “Viewpoint Movement”, using the camera shift method this distance is easily applied, since the camera’s location does not have to follow a circle around the object in order to keep the distance but is allowed to move parallel in front of it. The distance is calculated as follows [22]:

\[ dist = \text{object height} \times \frac{\text{image dist}}{\text{sensor height}} \]  

(1)

where image distance is the distance between image sensor and lens. Due to simplification or some irregularities in Blender’s implementation the image distance needs to be replaced with the focal length in Blender:

\[ dist = \text{object size} \times \frac{\text{local length}}{\text{sensor size}} \]  

(2)

where size is the maximum out of object width and height.

F. Viewpoint Movement

One major advantage of the camera shift method is its ability for camera movement, parallel to the facade, without any need for recalibration. While a not shifted camera would need a separate cornerpin keystone transformation for every new camera position, the shifting method frames the object always exactly the same (figure 7).

To achieve this throughout camera movement, the horizontal shift parameter of a Blender camera can be automated, which means calculated based on the position of the camera as follows:

\[ \text{shift}_x = \frac{\text{offset}_x \times \text{focal length}}{\text{distance} \times \text{sensor width}} \]  

(3)

Since the distance between virtual camera and facade is determined by the camera’s focal length, as mentioned in section 3.5, in order to augment a spectators viewing angle the camera must not only copy the viewing angle but keep the given distance towards the framed object.
As illustrated in figure 8 a constant distance results in a spherical movement of the camera around the subject to frame it from different viewing angles.

As we know from architectural photography (section 3.2) a camera with a shifted lens must remain perpendicular towards the subject. Therefore it is only allowed to move along a plane perpendicular to this very subject.

In order to adjust the projection, so that a passer-by standing close to the projection surface (figure 8) still perceives the projected image as a 3D structure (the illusion effect), we need to situate the virtual camera on point “A”. For a normal camera, point A is at the intersection of the extension of the viewing angle and the “constant-distance” sphere. In the case of a shifted camera, point A can be defined as a combination of the following: in the xy plane, it is the projection of the viewpoint onto the “constant distance” plane, while in the z direction it lies on the extension of the viewpoint angle. In general this leads to possible camera positions that either follow a sphere (camera not shifted) or a plane (camera shifted).

In order to calculate the vertical position of the virtual camera we use the approximation:

\[
\text{cam}_z = \text{orth.dist}_{\text{viewpt}} - \text{orth.dist}_{\text{cam}}
\]  (4)

This moves the camera downwards to the same amount as the viewpoint approaches the facade. Currently this method is restricted to the viewpoint being at a certain minimum distance from the wall, in order to avoid infinite values.

IV. Relevance

During the creation process of a projection the artist either on purpose or unconsciously studies very closely the facade that is being used as a projection surface. In case the projection is a facade, all the proportions, columns, capitals, window frames etc. have to be treated very carefully, because the projected and the existing architecture communicate directly with each other. Therefore, projections can be also used as a tool to visually communicate classical to modern architecture, and thus also to help laymen get into closer contact with architecture.

Besides, projections offer a special opportunity for an architect to look at architecture from a different point of view, using animation tools. Visual appearance is in this case much more important than constructive correctness and regulation strictness or well and precise designed floor plans. At the same time it is clear that the design produced in this way can be used only for visualization purposes; it is only a show, only light, not to be inhabited.

With the means of animation, architectural rhythms inherent to the repetition of visual elements (patterns) can be explored in combination with time by highlighting their relations.

One main feature of modelling classical architecture with animation tools in order to create facade projections is the didactical benefit. Architecture students learn a 3D modelling tool that focuses on 3D sculpting workflows, which means they acquire a different understanding of precision. At the same time, by digitally manipulating modern structures in order to use them as projection surfaces, they experience what i.e. gothic or roman design means in terms of form, structure or dimension, compared to modern design.

Projections can be used to visualize reconstructed facades in real scale. Nowadays they are often used to exhibit information on urban models that would otherwise be invisible and consequently hard to imagine. While such visualizations may be very impressing on urban models, they don’t have much success on a larger, 1:1 scale, since projections are only available publicly at night.

Being widely applied in the field of party visuals, colours and light can change the perception of a room or an urban space and influence people’s feelings, or create spatial illusions.

Supporting ephemeral activities like light festivals is a good way to keep people feeling proud about the city they inhabit or at least make them aware that somebody cares about it.

In a way similar to technical visualizations, projections can be used to visualize daily information, like the remaining minutes until a bus’s departure, or the number of available parking lots.

With augmented reality applications becoming more and more common, especially on smart phones and tablets, it is time to think about how architects could create content for and make use of such tools. The presented method enables them to do so with standard animation/modelling tools.
V. REFERENCES


