Dynamic anamorphosis

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Abstract

In this paper we define the concept of dynamic anamorphosis. A classical or static anamorphic image requires a specific, usually a highly oblique view direction, from which the observer can see the anamorphosis in its correct form. This paper introduces dynamic anamorphosis which adapts itself to the changing position of the observer so that wherever the observer moves, he sees the same undeformed image. This dynamic changing of the anamorphic deformation in concert with the movement of the observer requires from the system to track the 3D position of the observer's head and the recomputation of the anamorphic deformation in real time. This is achieved using computer vision methods which consist of face detection/tracking of the selected observer and stereo reconstruction of its 3D position while the anamorphic deformation is modeled as a planar homography. Dynamic anamorphosis can be used in the context of art installation, in video conferencing to fix the problem of the missing eye contact and can enable an undistorted view in restricted situations.

1. Introduction

In this paper we define the principle of dynamic anamorphosis which adapts itself to the changing position of the observer in such a way that he always sees the image in its correct un-deformed form. First, we introduce the classical principle of anamorphosis. Next, we extend this principle to dynamic anamorphosis. Later sections describe in some more detail the required technical background for implementing a system which uses dynamic anamorphosis. Computer vision methods are used to determine the 3D position of the observer's head. The anamorphic deformation of the displayed image is computed as a planar homography. In Conclusions we discuss possible user scenarios for dynamic anamorphosis.

2. Anamorphosis

Anamorphosis or anamorphic projection was discovered in art in the late fifteenth century both as a challenge and as a confirmation of the rules of linear perspective which were discovered at the same time [5]. Classical linear perspective is based upon the Euclidean paradigm that light travels in straight lines and when light reflected from an object intersects a planar surface an accurate representation of the original object is reflected on that surface. While we normally look at images frontally from a limited range of viewing angles, the viewer of an anamorphic image must usually be at a radically oblique angle to the picture plane to see the anamorphic image undistorted. The anamorphic image looked at up front is in such cases usually so distorted as to be unrecognizable.

Figure 1: The Ambassadors by Hans Holbein, 1533, Oil on oak, 207 × 209 cm, National Gallery, London.

Probably the most famous example of anamorphosis in art history is the 1533 painting *The Ambassadors*, by Hans Holbein (Fig. 1). On the bottom of this painting appears a diagonal blur which appears as a human skull when viewed from the upper right [12]. Therefore, anamorphosis was traditionally used to depict subjects

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one was reluctant to represent directly such as erotic, occult or otherwise controversial imagery. Probably the first known anamorphosis is from Leonardo de Vinci's Codex Atlanticus (1483–1518) and shows the face of a child [12].

Somewhat later, in the sixteenth century, other types of anamorphosis were developed, such as the so-called cylindrical anamorphosis which requires a cylindrical mirror to observe the image correctly. Famous, for example, is a cylindrical anamorphosis of Jule Verne's portrait drawn by the Hungarian artist István Orosz. The image looks up front as a shipwreck in an arctic landscape. By placing a cylindrical mirror on the sun depicted in the image, Jule Verne's face suddenly appears. Due to the ease of producing anamorphic images using computer graphics they appear now often in newspapers and magazines. Anamorphic images are even produced as pavement art [2]. Special examples of anamorphic projection are also images which are projected on slanted surfaces (pavements, ceilings) but appear undeformed.

Since the appreciation of anamorphic images requires an "eccentric" viewing point as opposed to a "normal" or orthogonal viewing point, anamorphosis is a term popular with many postmodern theorists used mainly as a metaphor for the relativity of vision or the subjectivity of human experience [12]. Anamorphosis serves as a model for the concept of the gaze, which suggests that visual appreciation rather then passive "looking" requires active "observing" [8, 14].

To appreciate an anamorphic image requires indeed from the observer that he positions himself precisely in the right spot and directs his gaze in the right direction as opposed from the "normal" or "centric" vision [1] where the viewer sees himself at the center of the world and as he moves, the center of the world moves with him and the world surrounding him stays coherent. To view an anamorphic image one has to transform an oblique and non-uniform focal plane into a coherent, two-dimensional image which is sometimes facilitated by viewing with one eye or with half-closed eyes [5]. This enables the dissociation of the image from the screen or the supporting surface and the anamorphosis re-forms itself [12]. Viewing "normal" pictures from an oblique angle does not result in a distorted picture since human perception can automatically compensate for the distortion using the principle of shape constancy. Straying away from the right viewpoint of an anamorphic image, on the other hand, can quickly deteriorate the effect.

3 How dynamic anamorphosis works

To see a static anamorphic image one has to position oneself in the right spot and then view the image in the right direction. Since we plan to project the anamorphic image using a video projector which is connected to a computer, we can reshape the anamorphic image whenever the observer moves in such a way that the re-formed image stays for the observer the same. To achieve this constancy of the re-formed anamorphic image one has to track the position of the observer in real-time and then according to the established position pre-deform the projected anamorphic image in real time so that it appears un-deformed from that particular view point. If traditional anamorphosis requires an accurate, often "eccentric" viewpoint, this installation uses anamorphosis to separate the human spatial orientation from the visual cues and can thus provoke a crisis in the visual faculty—wherever the observer moves in space, he sees the same re-formed image.

A somewhat similar concept involving imagery that adapts to the position of the viewer is described by Steve Mann [10]. The observer wears special eyeglasses that track where the person is and then the system generates stabilized images on displays to sustain the illusion of a transparent window showing the subject matter behind the display in exact image registration with one would see it if the display were not present.

3.1 Localization of the observer

To drive the anamorphic projection we need to know the position of the observer. The most unobtrusive technology to determine the position of objects in a given scene is provided by computer vision. We use a face detection method to determine the position of the user's face in the pictorial plane. By using two or even more cameras and the principle of stereo reconstruction of distances we can further determine the position of the user's head in 3D space. Face detection is now a mature technology and methods such as the one developed by Viola and Jones [13] can run in real-time. The most difficult problem in stereo reconstruction is the correspondence problem—to find for a given point in the left image the corresponding point in the right image [7]. Since the number of possible matches goes into thousands of points this is a computationally intensive task. The correspondence problem in this particular case will be solved by finding faces in both images first. Next, only correspondences between faces needs to be established.

Face detection can be performed based on several cues: skin color, motion, facial/head shape, facial appearance, or a combination of these parameters. Most successful face detection algorithms are appearance-based. The processing is done as follows: An input image is scanned at all possible locations and scales by a subwindow. Face detection is posed as classifying the pattern in the subwindow either as a face or a nonface. The face/nonface classifier is learned from face and nonface training examples using statistical learning methods.

For our purpose we used the AdaBoost [13] learning-based method because it is so far the most successful in term of detection accuracy and speed. AdaBoost is used to solve the following three fundamental problems: (1) learning effective features from a large feature set; (2) constructing weak classifiers, each of which is based on one of the selected feature set; and (3) boosting the weak classifiers to construct a string classifier. Weak classifiers are based on simple scalar Haar wavelet-like features, which are steerable filters. We use the integral image method for effective computation of a large number of such features under varying scale and location, which is important for real-time performance. Moreover, the simple-to-complex cascade of classifiers makes the computation even more efficient, which follows the principles of pattern rejection and coarse-to-fine search. In the case if the cameras are placed laterally we use an extended Haar feature set for dealing with out-of-plane (left-right) rotation.

With the proposed face detection method we get the location in the image plane of all the present faces regardless of their position, scale, orientation and age. To improve the detection in the case of low illumination we also use near-infrared cameras, which are invariant to illumination and capture the temperature of the body. For head tracking we must detect the faces in every frame. To improve the tracking we use addition clues such are motion, skin color or near-infrared image.

To locate the 3D position of the detected faces in the scene we use the stereo paradigm. Most stereo reconstruction methods are based on a punctual correspondence, but they are inefficient in most realistic contexts [11]. We approach the stereo matching problem as a matching between homologous faces, instead of point matching. The main idea is to determinate a unique disparity value for the whole face region and no longer for individual pixels. After we detect the position of faces in both stereo images using the above described face detection method we construct a graph for each image where face blobs are represented as nodes in the graph. To find homologous faces in both stereo images we perform graph matching. A bipartite graph matching between the two graphs is computed in order to find for each face blob in the left image the corresponding face blob in the right image. Using the horizontal displacement between the corresponding face blobs, the position and other calibration parameters of the stereo cameras, we can computer the 3D position of each face in the scene.

The computational process is simple and fast since we consider only complete face regions. The result is robust in a realistic context, because an integral measurement of the disparity for the whole face region can mitigate some local and global fluctuations between the stereo image pair.

3.2 Anamorphic deformation

Recent computer-controlled video projection systems have one or more built-in cameras to provide a visual feedback that can automatically compensate for the so called "keystone" deformation. The keystone deformation can be represented in the most general way as a planar homography mapping points in the projector plane onto the screen plane, corresponding to a 3-degrees of freedom alignment (pan, tilt, screw) [3]. To eliminate the effect of the keystone, its associated homography can be estimated and used to suitably pre-deform the image being displayed.

The same homography can be used to make a "virtual anamorphosis" so that the image is intelligible only for observers looking at the screen from a particular viewpoint [3]. The authors call this functionality directional vision and compare it to directional audio. We use this homography to deform the projected image of the face in such a way that it looks undeformed from the viewpoint of the observer.

4 Applications of dynamic anamorphosis

The first application of dynamic anamorphosis was in the context of an art installation where the subject of the projected image is a human face looking straight ahead. People are very sensitive to the direction of the eye gaze. Our eyes express our emotions and intentions and they help us direct attention. Cultural norms dictate when, for how long and in what situations it is appropriate to gaze into another persons eyes. We can determine very accurately if somebody is actually looking at us. Eye gaze is important in conversations and the lack of proper eye contact in videoconferencing systems is a serious limitation of such systems [4]. When a participant in a videoconference watches the images of other participants on the video monitor he cannot look into the camera at the same time even if the camera is placed just above the monitor.

In the installation the face with the eye gaze turned directly ahead will meet the eyes of the installation user. Due to the viewpoint-sensitive anamorphic deformation the projected face in the installation will stare at the installation user wherever he moves. There will be no way to escape it's gaze. This should be for most installation users a rather unnerving situation. On a symbolic level the installation epitomizes the personification of ubiquitous video Surveillance systems [9]. Instead of a static image a short video loop of a face gazing straight ahead can be used such as the Big Brother from the film after George Orwell's novel 1984. Figure 2 shows the transformed frame of video clip, when the user views it under 30° angle from right.

The installation requires a dark room with the video projection over an entire wall so that the only visible

Figure 2: The transformed image of the Big Brother from the film after George Orwell's novel 1984.

cues seen by the user are given by the projection. The video clip used for projection should feature a human face with the eye gaze directed straight ahead. The light reflected back into the room from the projected image must sufficiently illuminate the scene that face detection can be performed.

Since the installation can truly be experienced only by a single user the entrance to the room with the installation should be controlled. Another possible scenario for the exhibition would allow several people in the audience. Of course, only one of them must somehow be selected for the virtual anamorphic experience using either face recognition or some other distinguishing feature used for stereo matching. Other people in the room could enjoy the projection which will be deformed from their viewpoint or they will try to move into the position from which the anamorphosis will re-form itself.

Other uses of dynamic anamorphosis can be envisioned related either to fixing the problem of the missing eye contact in video conferencing or how to enable an undistorted view of visually conveyed information in restricted situations.

5 Conclusions

We introduced the concept of dynamic anamorphosis which enables an undistorted view of an image from almost any position. Classical or static anamorphosis forces the observer to find the special viewpoint from which the anamorphic image is re-formed. Dynamic anamorphosis instead disassociates the geometric space in which the user moves from the visual cues he sees, since wherever the observer moves, he sees the same image.

The principle of dynamic anamorphosis was initially developed for an art installation where a human face with the eye gaze directed straight ahead to meet the eyes of the installation user was selected for the projected image. For the real-time tracking of the observer's face we use computer vision methods. The 3D position of the face in turn also determines in real-time the homography that deforms the anamorphic projection in such a way that the projected face that the observer sees is constantly gazing towards him.

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