Exploring and Measuring Presence of 3D Effect in a Classical Painting

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Abstract—Our 3D world is not only perceived by our binocular vision but also pictorial cues of a single image can trigger a 3D perception which has been understood for centuries and are used in our classical paintings. The modern 3D display technology achieves a 3D perception by fusion of several images captured from different points of views in an interlaced image and using optical means. Observing a painting, as a single image, from different points of views only reveals different 3D information when the da Vinci stereopsis technique is used where the modern technology uses optical means to achieve the same effect.

In this paper we present novel methodologies to measure 3D effects of a classical painting, the youngest Madonna “Nativity” in Kulenovic collection in Karlskrona Sweden. In our methodologies a single image is observed from different points of view using high resolution camera whereas a viewer a pair of such images is considered to measure the 3D perception. Using computer vision theories we proof the methodologies and analyze the results. We have measured and compared different types of single images with respect to their pictorial cues. The result shows that the methodologies are useful in more understanding of da Vinci stereopsis technique which can open new era for new sort of 3D display.

Keywords—Da Vinci stereopsis; pictorial cues; 3D effect; classic painting

I. INTRODUCTION

Our 3D world is perceived by our binocular vision. However the 3D perception is not limited to have two views of a scene. We have also ability to grasp the 3D content from certain cues of a single image. These cues, known as pictorial cues, stimulate a depth perception [4], which have been understood for centuries and are used in our classical paintings since Renaissance time, such as Raphael’s ‘School of Athens’ (1510), Leonardo Da Vinci’s Mona Lisa’s Smile (1517) and so on.

The modern 3D display technology has brought a new method in perceiving 3D content where an interlaced image is generated by fusion of several images captured from different point of view of a scene. When the interlaced image is shown by optical means to viewers, two different images can be seen in several zones. Although a 3D perception can be stimulated by the interlace method or by the pictorial cues in a single image, however the interlaced method offers different 3D content information from different point of views which is not feasible with pictorial cues in single images.

Some of paintings, mostly classical ones, make different impression of 3D content when they are observed from different point of views. The stimulation of 3D perception in these paintings can be explained by the concept of Da Vinci stereopsis. As far as they are considered as single images and not viewed by any optical means, some justified questions possibly can be arisen. Is it possible to experience the same viewers’ impression by capturing images? Is it possible to quantify such impression? In this paper we present several quantification methods which will help us to analyze and answer such mentioned questions.

This paper is organized as follows. In the second section, the pictorial cues and Da Vinci stereopsis phenomena are discussed which can explain the stimulation of the depth perception from single images. A depth perception model is proposed in the third section. The fourth section presents the measurement setup. The results and measurement analysis are presented in section five and six. Finally, we summarized and discussed our work in this paper in section seven.

II. DEPTH PERCEPTION IN SINGLE IMAGES

The depth perception is the visual ability to perceive the world in three-dimensions and distinguish the distance of an object [1]. In single images the stimulation of depth perception can be explained by pictorial cues or Da Vinci stereopsis concept.

In everyday perception of our surrounding world we get help of different cues which seems to be processed together in the brain. Some of these cues are related to our depth perception and are used by artists to create a sense of depth. Three major cue classes (binocular, Da Vinci stereopsis and monocular) contribute to the depth perception and within each classes there are several subclasses of cues. The cues involved in the depth perception are show in the figure1.

The depth cues in the single images can be pictorial cues [1] or Da Vinci Stereopsis cues [9] which are observed by two eyes. The binocular cues stimulate a depth perception by observing two images where each image is only seen by one eye [2, 3 and 10]. The binocular cues as present of parallax disparities in the two observed retinal images cause the depth
sensation. The parallax disparities refer to the objects which are in overlapping region of a scene seen by the two eyes. They also refer to points within objects that are well defined, such as edges. The binocular cues in absence of parallax disparities but present of shadows in the two observed retinal images may also cause the depth perception [15]. The shadows can be defined as regions in an image which have abrupt luminance and color changes but are neither edges nor boundaries. The da Vinci stereopsis cues in single images, as a phenomenon, have a close relation to binocular cues of shadows stereopsis in two images [9]. In binocular observation of the da Vinci Stereopsis cues, the entire observation region is not seen by two eyes. Assuming the observed region has a distinguishable background and foreground objects, when part of the background is occluded by the foreground objects, some regions are seen only by one eye which are called monocular regions [6] [12]. The monocular regions left out the use of parallax disparity cues in these regions of the observed two images. However the monocular regions can contribute to stimulation of a depth perception if they are adjacent to e.g. shading region, texture or color differences area [9]. The perceived depth is quantitative in nature [12]. The perceived depth of a monocular point increases with increasing its separation from occluding edge.

The figure 2 describes four basic types of Da Vinci stereopsis cues [8]. The black thick line represents the occluder and the non-circle color area is the representative marker for visibility area either for the left eye (LE) as blue or right eye (RE) as red. Each colored area is seen only by one eye as the monocular region. In three types of Da Vinci stereopsis cues, shown in figure 2; occlusion; aperture; and camouflage, the boundaries of the background and foreground are rigid and independent of any angle of scene view. However in the phantom type of such cues shown in figure 2d, shadows as non-apparent luminance edges cause phantom surfaces to generate monocular regions which in their turn they stimulate a depth perception. Apparently the boundaries of the background and foreground become non-rigid and dependable to angle of scene view [13, 14].

In some of classical paintings, shadows technique as the phantom type of Da Vinci stereopsis cues have been used to stimulate the depth perception in the viewers. The pictorial cues are widely used in painting and photographing to stimulate or to enhance the human’s 3D perception. However, a painted portrait has strong limitation to evoke any depth perception caused by its 2D physical shape. Generally the depth information is associated to a real one when the information is changing by point of views. This expectation is arisen from the observation of real physical 3D objects. However, the paintings with monocular pictorial cues do not stimulate real depth information and the information remains the same by change of view point. In other hand implementing Da Vinci stereopsis cues, such as phantom ones, can stimulate real depth information. This has been seen in some of classical paintings in which it makes an impressive reaction on the viewers.

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III. DEPTH PERCEPTION MODELING

Human observers are sensitive to the size changes of an object when the object distance is changing. The relationship between the size and distance can be found by modeling the human eye.
The human eye can be modeled by a pin-hole camera model shown in figure 3; when an object is seen from certain distance. Accordingly it yields

$$\frac{P}{R} = \frac{D}{k}$$

(1)

where P, R, D and k are size of the object, size of the retinal image, the distance of the object from the eye and the eye’s focus length respectively. The focus length k is very small in comparison to the object distance to the eye D, thus the size of object can be approximated by

$$P \approx RxD.$$  

(2)

For objective measurement of the eye observation a camera can be used in which an object with size of P can be measured as

$$P \approx fxD.$$  

(3)

where f is the camera focal length. When the object changes its distance to the camera, the relative depth perception can be measured by

$$\frac{d_2}{d_1} = \frac{p_2}{p_1}$$  

(4)

where $d_1$, $d_2$, $p_1$ and $p_2$ are the distance of the object and size of the object in two positions.

IV. MEASUREMENT SETUP.

The youngest Madonna “Nativity” portrait is a classical painting in Kulenovic collection in Karlskrona Sweden. The naked eye observation of the portrait reveals real depth information by majority of observers which makes the portrait interesting for experimental measurement. The experiment setup is shown in figure 3. A camera, Canon 450D with resolution of 4272 by 2848 was placed in six different positions parallel to the portrait along a straight line. The interval of camera positions was 5.5 centimeters, and the camera positions were aligned with a distance of 1.45 meters to the portrait to capture the whole portrait in each position. Each positioning of the camera was done using a laser distance measurement instrument, Bosch DLE 40, to obtain parallel positioning of the image plane to the portrait surface. The camera height in each position was arranged in a way that the middle of portrait and the image plane were aligned vertically.

V. MEASUREMENT RESULTS

On each of six captured images, hundred points were selected manually, shown in figure 5, where to each point a label number was assigned. Each correspondent point in the images received the same label number. For selection of correspondent points in six images, each image was zoomed and the same perceptual position was marked and assigned to the label number. All connections of each two points in each image generated 4950 line segments. Each line segment represented a size of object. A certain label number was assigned to each line segment in conjunction to the connection points in a way to generate 4950 correspondent lines in each image.
the same in all six images. However the position of selected points on each two subsequent images is changing which is shown in the figure 8.

The length ratio of correspondent lines on each two subsequent images are shown in the figure 7 which is indicating significant changes in the relative depth perception in each two subsequent images, according to equation 4. The relative depth perception is not changing homogenously in each two subsequent images, as shown in the figure 8. To visualize the most significant correspondent lines, those which had a length ratio of less than 0.9 or bigger than 1.1 were selected in two subsequent two images; the result is shown in figure 9.

VI. MEASUREMENT ANALYSIS

On the portrait manually hundred points were selected which were realizable correspondent corner points in all six captured images. The selection of each correspondent corner point was done by zooming on the captured images and by careful inspection of corner area. The figure 10 shows the selection of one of these correspondent corners. The position changing of correspondent points varies differently and the small fluctuation in changing values can reasonably be caused by error in the procedure. However the significant position changes of correspondent points, as shown in the figure 8, can only be explained by implementation of shadow technique in the painting. The histogram analysis of the images proved that the pixel intensity values in the captured images have very small changes where envelop of histograms remained the same. This argues that the shadows on the portrait, as non-apparent luminance of edges, had affected the image capturing, sampling and quantization procedure, and caused the small intensity value changes in different capturing positions. The blind implementation of correspondent lines showed beneficial because the visualization of most significant length ratio of them revealed unexpected results, shown in the figure 9, which can verify reasonable 3D information area on the portrait.

Figure 6: The histograms of six images of the portrait

Figure 7: The length ratio of correspondent lines in each two subsequent images.

Figure 8: Position changing of selected points in each two subsequent images.

VII. DISCUSSION AND CONCLUSION

In this paper, novel methodologies were presented to measure 3D effects of a classical painting, the youngest Madonna “Nativity” in Kulenovic collection in Karlskrona Sweden. A relative depth perception model was proposed and the portrait was captured from different point of views. We showed that the shadow technique was present in the portrait and its 3D effect can be explained by phantom type of Da Vinci stereoscopic phenomena. The 3D effects could be measured by length ratio of correspondent lines. The results show that 3D effect on such classical paintings is not only a perceptional phenomenon, but also thanks to their measurement it is possible to arrange a topological map. The fully understanding of the mechanism behind the topological map generation by implementation of shadow technique can open new era for new type of 3D display.
Figure 9: The most significant correspondent lines which had a length ratio of less than 0.9 or bigger than 1.1 were selected in two subsequent two images. As row wise and from top left, the most significant correspondent lines are shown in blue in each subsequent images and starting with first and second images.

Figure 10: Marking of correspondent points are demonstrated. Six corners in six images are marked where the corner area in each image is zoomed. The point position is shown on the left image.

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