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# ARTISTIC STEREO IMAGING BY EDGE PRESERVING SMOOTHING

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## ABSTRACT

Stereo imaging is an important area of image and video processing, with exploding progress in the last decades. An open issue in this field is the understanding of the conditions under which the straightforward application of a given image processing operator to both the left and right image of a stereo pair preserves the stereoscopic perception. In this paper, we explore this problem with application to artistic imaging and we prove that, unlike other methods, artistic operators based on edge preserving smoothing have this desirable property. We also present a novel multiresolution artistic operator, purposely designed for stereo images, which enhances the perception of three-dimensionality by means of a depth driven local scale control.

**Index Terms**— Stereoscopy, artistic imaging, edge preserving smoothing, multiresolution analysis

## 1. INTRODUCTION

Artistic imaging and non photorealistic rendering are important tasks in image and video processing [1]-[8]. The most widespread artistic operators are based on temporal coherence [2], multiscale algorithms [3], anisotropic filters [5], and covariance analysis [6]. In [8], a simple and effective artistic operator based on Edge Preserving Smoothing (EPS) is proposed, observing the fact that paintings tend to have sharper edges and less texture than photographic images.

However, at the best of our knowledge, the existing techniques have not been designed to work with stereoscopic images [9], [10]. In particular, the straightforward application of an artistic operator to both the left and the right image of a stereo pair would result, in many cases, in a partial or complete loss of the three dimensional (3D) perception (Fig. 1). Therefore, designing artistic operators specifically for stereo images deserves special attention.

The main contribution of this article is two-fold: (i) we show that EPS applied to stereo images still produces stereo

images, which implies that EPS-based artistic imaging can be straightforwardly extended to stereo images. (ii) we propose a novel multiresolution artistic operator, purposely designed for stereo imaging, which with deploys an adaptive

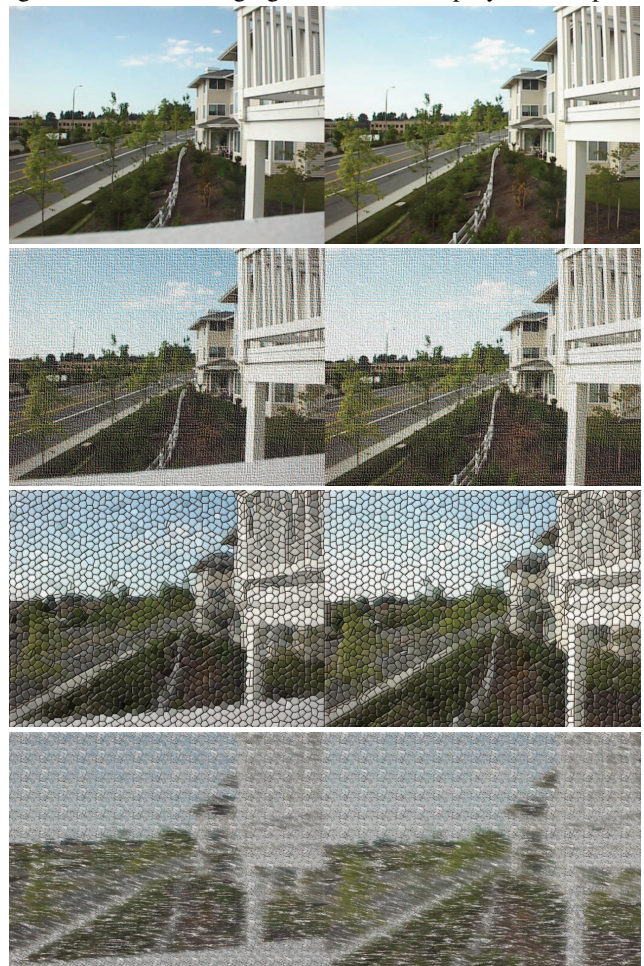


Fig. 1. From top to bottom: A stereo input image and the output of the artistic filters, «Canvas», «Mosaic», and «Impressionism» available in the commercial software Gimp. The processed images result in a considerably attenuated stereoscopic perception, especially for the last one.

scale control mechanism based on the depth map. It is based on the assumption that foreground objects are visually more salient than the background. Therefore, based on the depth map, the former are rendered with a higher degree of detail with respect to the latter.

## 2. STEREO IMAGES

Stereo images and videos [9], [10] have been widely studied in the recent literature because stereoscopic viewing is one basic and popular way to perceive a scene in 3D, which is by rendering the perception of depth. In general, 3D perception is based on various depth cues such as illumination, relative size, motion, occlusion, texture gradient, geometric perspective, disparity, and many others. However, a very effective depth perception sensation is obtained by viewing a scene from slightly different viewing positions. From a physiological point of view, given a scene in the real world, 2-D slightly different scenes are projected on the retina of each eye. This implies that the 3D depth information is lost at this stage. Then, the primary visual cortex in the brain fuses the stereo pair by means of a stereopsis and a prior knowledge on the 3D world. Therefore, humans can perceive the depth starting from the 2D images on the retina of each eye. When 3D imaging systems try to mimic the behavior of the human visual system, the role of the eyes is taken over by stereo cameras that capture a scene from slightly different positions. The depth information can be obtained using stereo vision techniques by means of the disparity, the relative displacement of the stereo camera as well as its geometry.

Roughly speaking the systems used to display stereo images present alternatively to the left and right eye two slightly different images in such a way that the human visual system gets a perception of depth. More in details the 3D rendering systems can be classified as either autostereoscopic or stereoscopic displays. Autostereoscopic displays do not need any special viewing glasses, but the viewing angle is not very wide. On the other side, stereoscopic displays require viewing glasses such as red-and-blue lenses or polarized glasses, but they are more affordable than autostereoscopic displays and they can be used in commercial theatre as well as in a home environment. These systems allow the left and right images to be projected onto a screen with different polarization or colours. Among the stereoscopic systems it is worth citing the active systems where liquid crystal shutter glasses, which are synchronized with a display, are used.

## 3. PROPOSED ALGORITHM

In this section, we present the proposed operator for artistic imaging, which is an evolution of the algorithm presented in [8]. We first present the operator in Section 3.1 for the single scale case, and we extend it to a multiscale context in Section 3.2.

### 3.1. Single scale operator

The proposed approach to EPS consists in dividing a circular region around each pixel  $\mathbf{r} = (x, y)$  in  $N$  equal sectors, over which we compute weighted local averages  $\mathbf{m}_i$  and local standard deviations  $s_i$ , with  $i = 1 \dots N$ . It can be shown that EPS can be achieved by considering a weighted average of the values of  $\mathbf{m}_i$ , with weights that are decreasing functions of the standard deviations  $s_i$  [8].

Formally, let  $\mathbf{I}(\mathbf{r}) = [\mathbf{I}^{(L)}(\mathbf{r}), \mathbf{I}^{(R)}(\mathbf{r})]^T$  be a stereo image, where the color images  $\mathbf{I}^{(L)}(\mathbf{r})$  and  $\mathbf{I}^{(R)}(\mathbf{r})$  are its left and right components. We indicate by  $\mathbf{I}_h^{(p)}(\mathbf{r})$ , with  $h = 1, 2, 3$  and  $p = L, R$ , each color component of  $\mathbf{I}^{(L)}(\mathbf{r})$  and  $\mathbf{I}^{(R)}(\mathbf{r})$  in a given color space.

The local averages  $\mathbf{m}_i^{(p)}(\mathbf{r})$  are computed by convolving  $\mathbf{I}^{(L)}(x, y)$  and  $\mathbf{I}^{(R)}(\mathbf{r})$  with  $N$  weighting functions  $w_i$  whose support defines the sectors  $S_i$ .

$$\mathbf{m}_i^{(p)} = \mathbf{I}^{(p)} * w_i, \quad w_i = g_\sigma \cdot (U_i * g_{\sigma/4}) \quad (1)$$

with:

$$g_\sigma(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \quad U_i(r, \vartheta) = \begin{cases} N, & i - \frac{1}{2} < \frac{N}{2\pi}\vartheta < i + \frac{1}{2} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Fig. 1 shows the weighting functions  $w_i$  for the case  $N = 8$  sectors.

The standard deviations  $s_i^{(p)}(\mathbf{r})$  are computed as follows:

$$s_i^{(p)} = \sqrt{\sum_{h=1}^3 \left[ \left( I_h^{(p)} \right)^2 * w_i - \left( I_h^{(p)} * w_i \right)^2 \right]} \quad (3)$$

Finally, the output  $\Phi_q^{(p)}(\mathbf{r})$  of the proposed operator is

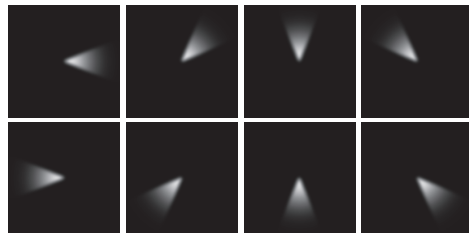


Fig. 2. The eight weighting functions  $w_i$  used in the proposed operator.

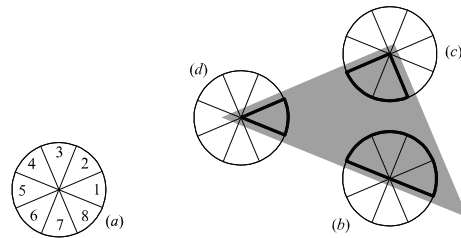


Fig. 3. Sector selection in various situations: (a) homogeneous (texture) area, (b) edge, (c) corner and (d) sharp corner. The sectors selected to determine the output are delineated by a thick line.

computed as follows:

$$\Phi_q^{(p)}(\mathbf{r}) = \frac{\sum_i \mathbf{m}_i^{(p)}(\mathbf{r}) [s_i^{(p)}(\mathbf{r})]^{-q}}{\sum_i [s_i^{(p)}(\mathbf{r})]^{-q}} \quad (4)$$

We observe that  $\Phi_q(\mathbf{r})$  is a weighted average of the local averages  $\mathbf{m}_i(x,y)$ , with weights equal to  $s_i^{-q}(x,y)$ . For positive values of  $q$ , more importance is given to the values of  $m_i$  that correspond to smaller values of  $s_i$ . This behavior is illustrated in Fig. 3. On areas that contain no edges (case *a*), the  $s_i$  values are very similar to each other, therefore the output  $\Phi_q$  is close to the average of the  $m_i$  values. The operator behaves very similarly to a Gaussian filter, thus texture and noise are averaged out and the Gibbs phenomenon is avoided. On the other hand, in presence of an edge (case *b*), the sectors placed across it give higher  $s_i$  values with respect to the other sectors. If  $q$  is sufficiently large (for instance,  $q \geq 4$ ) the sectors intersected by the edge ( $S_5 - S_8$ ) give a negligible contribution to the value of  $\Phi_q$ . Similarly, in presence of corners (case *c*) and sharp corners (case *d*), only those sectors which are placed inside the corner ( $S_6, S_7$  for case *c* and  $S_1$  for case *d*) give an appreciable contribution to value of  $\Phi_q$  whereas the others are negligible.



Fig. 4. From Top to bottom: A stereo image, and output of the single artistic operators proposed in section 3.1 for  $\sigma = 1.4$  and  $\sigma = 3$ , respectively, and of the multiscale operator of Section 3.2.

### 3.2. Depth driven scale control

The output of the operator presented in Section 3.1 strongly depends on the value of  $\sigma$  of the Gaussian kernel defined in (2), which determines the size of the brush used for painting. However, painters normally use brushes of different sizes on different areas of the painting, depending on the degree of detail that is desired for each object. Therefore, it is worth to develop a multiscale operator, for which the value of  $\sigma$  is adaptively computed across the image. In this context, a key role is played by the choice of the function  $\sigma = \sigma(\mathbf{r}) = \sigma[\mathbf{I}(\mathbf{r})]$ , which determines how the value of  $\sigma$  changes from pixel to pixel.

In this paper we assume that the visual attention of observers is more focused on foreground objects rather than in the background. Therefore, we compute  $\sigma(\mathbf{r})$  from the depth map  $d(\mathbf{r})$ , which indicates the spatial distance of each object from the camera. The depth  $d(\mathbf{r})$  is usually estimated  $d(\mathbf{r})$  from  $\mathbf{I}^{(L)}(\mathbf{r})$  and  $\mathbf{I}^{(R)}(\mathbf{r})$ , by measuring the distance  $\Delta(\mathbf{r})$  between each point  $\mathbf{r}$  in the left image and the corresponding point in the right image.

For the sake of simplicity, we have chosen  $\sigma(\mathbf{r})$  to be a linear function of  $\Delta(\mathbf{r})$ :

$$\sigma(\mathbf{r}) = \sigma_{\min} + \frac{\sigma_{\max} - \sigma_{\min}}{\max_{\mathbf{r}} \Delta(\mathbf{r}) - \min_{\mathbf{r}} \Delta(\mathbf{r})} [\Delta(\mathbf{r}) - \min_{\mathbf{r}} \Delta(\mathbf{r})] \quad (5)$$

with  $\sigma_{\min}$  and  $\sigma_{\max}$  determining, respectively, the minimum and the maximum size that are allowed for the brush. With this choice of  $\sigma(\mathbf{r})$ , nearer objects are rendered with more detail than farther ones, in agreement with the above mentioned assumption about visual saliency.

## 4. RESULTS AND CONCLUSIONS

In this section we present and comment some experimental results related to both the single and multiscale operators discussed in this paper, in comparison with other existing techniques. All the images presented in this article are available full size, together with a wider range of examples, at [www.cs.rug.nl/~imaging/stereoDSP09](http://www.cs.rug.nl/~imaging/stereoDSP09).

Fig. 4 Shows the left and right channels of a stereo image (First row) and the output of the single scale proposed operator for (second row)  $\sigma = 1.4$  and (third row)  $\sigma = 3$ . Larger values of  $\sigma$  result in less detailed rendering and correspond to larger brush strokes. In the fourth row, we see the output of the multiscale operator described in Section 3.2, where the displacement map  $\Delta(\mathbf{r})$  has been estimated by means of the algorithm proposed in [11], [12]. For an extensive review of the methods available in literature the reader can refer to [13].

We can observe that the multiscale algorithm here proposed renders different areas of the image at different levels of detail. In particular, the foreground hills contain more detail, whereas the farther objects in the background are less

detailed. This gives rise to a pop-out effect of the nearer object which enhances the perception of three-dimensionality.

In Fig. 5 we compare the output of the proposed single scale algorithm with other EPS (namely, Kuwahara [14] and bilateral filtering [15], and morphological area open-closing [16]) and the «Oil-painting» filter that is available in commercial software such as Gimp. With an appropriate stereo projector, it is possible to observe that, both the proposed operator and the other EPS do not give rise to significant loss of three-dimensionality, whereas in the images obtained with Gimp the stereoscopic perception results a bit flattened.

To summarize, in this paper we have shown that, unlike several other approaches, artistic imaging based on EPS can be straightforwardly applied to stereo imaging, without introducing significant loss in terms of stereoscopic perception. We have also proposed a novel multiresolution artistic operator, which deploys an adaptive depth driven scale control. It renders nearer objects with more detail than farther ones, thus producing a pop-out effect of the foreground with respect to the background, which enhances the perception of

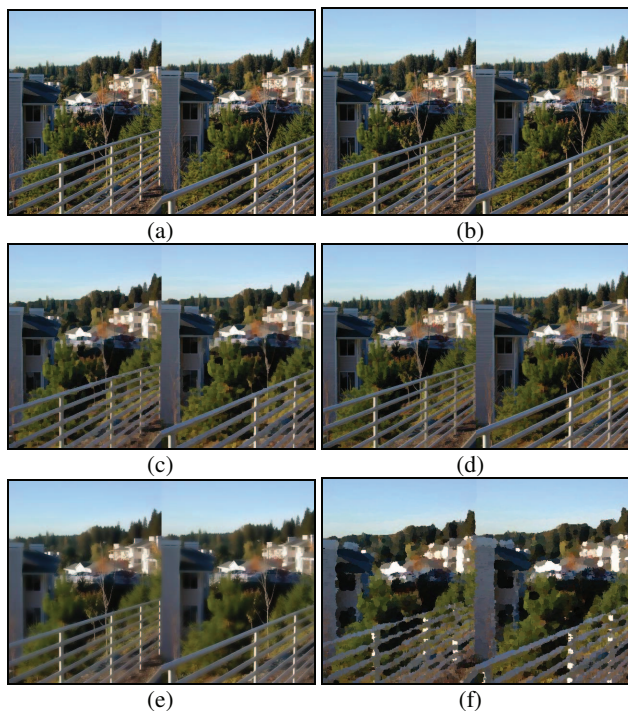


Fig. 5. (a) Input image. Outputs of (b) the proposed operator, (c) the Kuwahara operator, (d) morphological area open-closing, (e) bilateral filtering, and (f) the oil-painting artistic effect deployed in commercial software such as Gimp. Unlike the EPSs, the last operator shows less preservation of the stereoscopic depth three-dimensionality.

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