# A Real-Time Image Enhancement System Using Depth From Edge

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*Abstract*— **In this paper, an efficient depth-aware image enhancement system is presented. The depth information and well-known depth-cue relative perception are used to enhance 2-D still images or videos. Image enhancement has been developed for decades in a lot of fields. However, conventional approaches deal with images in the 2D(x-y) projective plane. The information of z-axis is not used. In this work, an efficient and complete system composed of 1) reconstructing depth from edge and 2) depth-aware enhancement is presented. The information of the third dimension in 3D space is extracted and exploited. Finally, the computational discussion and the visual performance are also shown.**

***Keywords-component; depth-aware enhancement; depth genration; 2D-to-3D; depth perception***

## I. INTRODUCTION

Image or video enhancement is a process that is applied on images or videos to increase their visual performance to the viewers. Since now, techniques making images or videos with better visual quality for viewers have been developed in several decades. There are various enhancement algorithms in computer vision. It usually works on the post-processing stage of display systems.

Due to the difficulty of extracting depth information from general monoscopic images or videos, conventional approaches, like [5], [6], and [7], pay their attentions to enhancing them within the 2D projective plane, x-y plane. That means the depth information is not concerned. In these two years, researchers try to integrate more information for enhancement. Sara Hashemi et al. proposed a genetic approach for contrast enhancement in [8]. Bahman Zafarifar and Peter H. N. de With proposed a content adaptive approach for enhancement in [9]. The kinds of methods try to embed semantics implicitly or explicitly to image enhancement. Our approach focuses on another possible solution. In our previous work [1], a depth-aware achromatic enhancement method is proposed. It deals with images in 3D space than 2D x-y projective plane assuming depth information exists. In this work, we try to enhance color images and videos instead of achromatic images. The relation of depth information and displayed color images is required to be analyzed well for image or video enhancement. This is one of the challenges of this work.

In the other hand, in the most popular type of multimedia content, monoscopic color videos, extracting the depth information is a renewed interest in these years. All the possible depth cues from human perception, like depth from motion parallax, depth from defocus, etc. and depth from texture, are used to rebuild the depth information. H. Murata et al. provide a method called Computed Image Depth method [10] (CID), which divides a single image into several sub-blocks, and uses contrast and blurriness information to regenerate depth information for each block. Tsai et al. detected possible vanishing lines and used the vanishing point of a line to find the depth gradient of the scene in [12]. Park et al. used the blur property of low depth-of-field in optical physics to determine the distance from the focal plane in [11]. Staring from [13], motion parallax, one of the most important depth cues for human's depth perceptions is used. The methods work well when the used depth cues are stronger in the test images or videos. However, they are not so reliable when the chosen cue is weak in the image. Thus, generating a suitable depth map, especially for enhancement, is another challenge of our work.

In this paper, we focus on the depth map generation for enhancing and the analysis on the relation of depth and displayed images or videos for enhancement. This is organized as follows. In Section II, review of display system and problem statement is presented. The proposed framework for generating depth is provided in section III. Then, experimental results and computational discussion are given in Section IV. Finally, conclusion and summary are made in Section V.

## II. REVIEW OF DISPLAY SYSTEM

At the end of display, there are two main functional blocks. As in Figure 1, they are decoder and video post-processor. The input video stream provides a compressed video sequence, which will be decoded by the decoder. Then, the decoded video frame is processed by the video post processor.

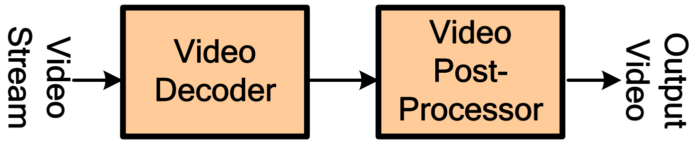


Figure 1. Simple flow of display system

Shengqi Yang, and Tiehan Lu mentioned that the video post-processor are divided into six pipeline in current display systems. They are de-interlacing, noise reduction, contrast enhancement, sharpness enhancement, and scaling. The pipeline order in detail is shown in Figure 2.

Considering the target of this work again, it is using the extra information in z-axis, i.e. depth, for image or video enhancement. Therefore, the framework of this paper is mainly on the third, the fourth, and the fifth stage of video post-processing pipeline.

## III. THE PROPOSED FRAMEWORK

According to the problem statement in section II above, our proposed framework can be shown as in Figure 4. First of all, a depth generation algorithm is applied. The generated depth map is then applied to contrast enhancement and color enhancement. This work also develops corresponding image enhancement algorithms for them.

This section will be divided into two parts. The first one is about depth generation. The other is about depth-aware contrast and color enhancement. Combing the two parts and conventional de-interlacing, noise reduction, and scaling, a depth-aware video processing pipeline is provided.

### 1. Depth Generation

As mentioned in section I, the depth map can be generated from many possible depth cues. Because of the depth map will be used by enhancement algorithms, the requirement of depth map for better visual quality is different from using it to reconstruct 3D scenes. The better depth cues for this framework are supposed to be stable in temporal axis, useful in more cases, and less side-effect for enhancement.

From the conditions above, Depth from motion parallax is not suitable because of temporal stability. Depth from texture and familiar size are also unsuitable because of the useful probability. Therefore, depth from defocus and geometric perspective seems to be more suitable.

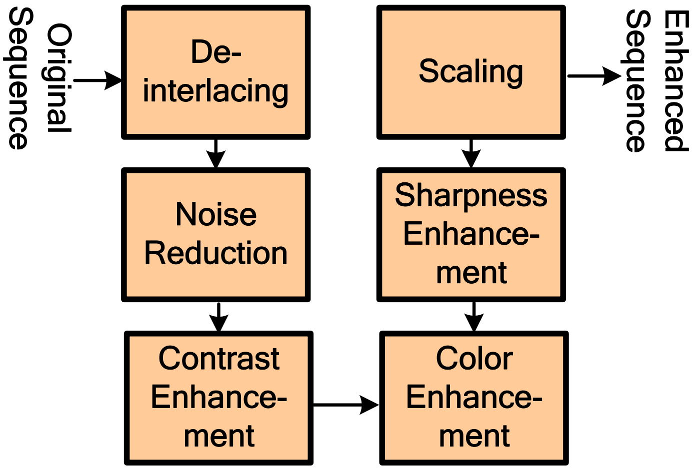


Figure 2. Conventional video post-processing pipeline in display system

In our experiment, using the depth cue of depth from defocus results in less side-effect for output enhanced sequences. Therefore, it is chosen as the reference depth cue in this framework.

Considering depth from defocus or edge, in [2] and [3], edge information is used for depth reconstruction. However, these methods are time-consuming. Here, we provide an efficient but robust method for depth from defocus. It includes edge (i.e. sharpness) detection and corresponding depth assignment as shown in Figure 3.

#### *1) Edge Detection*

We denote the edge map of the test image I by E. In our implementation, we choose Sobel filter as high frequency detection for computational concern.

#### *2) Depth Assignment*

In this sub-section, a fast weighted filter is adopted to assign depth. The weighting map $\hat{C}$ is selected with a probability map from E, i.e.

$$\hat{C}(x,y) = f\left(\left|\frac{E(x,y) - mean(\{E\})}{std(\{E\})}\right|\right) \quad (1)$$

where f is a probability distribution function of edge map.

Recalling the concept of depth from edge or defocus, pixels distant from focus plane will be vaguer. That means the edge strengths of the kinds of pixels are weaker. Assuming the edge map is normally distributed in each depth layer. The variance of edge strength will be larger when the location of the corresponding pixel is nearer to focus plane. Thus, the stronger edges are supposed to be more meaningful when mapping edge to depth.

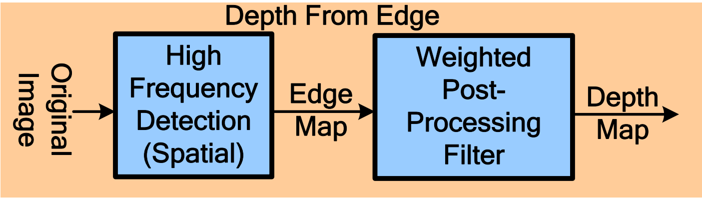


Figure.3 Our implementation of depth from edge.

Therefore, the probability distribution function f is suggested to be an increasing function. For both the computational concern and the quality of the depth map, f is selected as a biased inverse normal distribution, which is shown in (2).

$$f(x) = Normal_{0,1}(0) - Normal_{0,1}(x), \qquad (2)$$

where the $Normal_{0,1}$ means zero-mean and uni-variance normal distribution.

Then, the depth from edge, i.e. $D_{edge}(x,y)$, can be estimated by weighted low-pass filter with using color similarity and weighting map $\hat{C}$ in (3).

$$D_{edge}(x,y) = \frac{\sum_{(x_j,y_j)\in N(x,y)} \hat{C}(x,y) e^{-|I(x,y)-I(x_j,y_j)|} E(x,y)}{\sum_{(x_j,y_j)\in N(x,y)} C(x,y) e^{-|I(x,y)-I(x_j,y_j)|}} \qquad (3)$$

where N is a neighbor of (x,y)

Then, the depth is filtered by cross-bilateral filter as in [7]. So, the final depth map $D_{filtered}$ is shown in (4) and (5).

$$D_{filtered}(x_i) = \frac{1}{K(x_i)} \sum_{x_j \subset N(x_i)} e^{-\frac{|x_j - x_i|^2}{2\sigma_s^2}} e^{-\frac{|u(x_j)-u(x_i)|^2}{2\sigma_r^2}} D_{fused}(x_j), \qquad (4)$$

$$K(x_i) = \sum_{x_j \subset N(x_i)} e^{-\frac{|x_j - x_i|^2}{2\sigma_s^2}} e^{-\frac{|u(x_j)-u(x_i)|^2}{2\sigma_r^2}}, \qquad (5)$$

## 2. Depth-Aware Enhancement

As our previous work [1], the nearer part of the test images should be enhanced more in contrast and sharpness. For color enhancement, it is also suggested to be enhanced more. For computational concern, we modified the complex algorithm in [1] , depth-adaptive kernel-size enhancement in high frequency parts, to a simplified form in contrast enhancement.

For the enhancement part in the pipeline, the depth-aware video enhancement makes the video more vivid and more realistic. Three stages, contrast, color, and sharpness, are all adjusted to enhance the depth perception according to relative depth information.

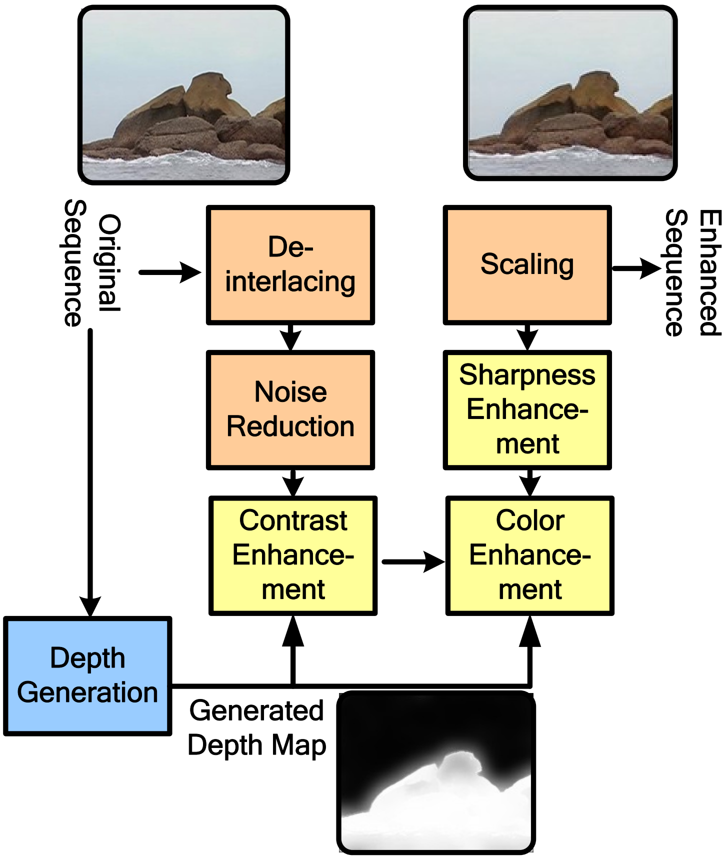


Figure 4. Our proposed framework for video post-processing pipeline in display system

### 2.1 Contrast enhancement

For contrast enhancement, characteristics of human depth perception on contrast are used[15]. The nearer, the contrast should be stronger. Therefore, contrast is enhanced by an increasing function of depth in (6).

$$Image_{contrast\_en}(x) = Image(x) + (Depth(x)) \times HPF(Image(x)) \qquad (6)$$

We apply simple linear increasing function of depth as the depth-aware enhancement for high frequency component in the input image frame. The enhancement provides a sharp contour and texture for nearer objects, which enhances depth perception.

### 2.2 Color enhancement

Similarly, objects that are further away have lower color saturation due to light scattering by the atmosphere [16]. This is caused from the characteristics aerial perspective. In (7) and (8), the total light to the viewer is composed of two parts. The first one is the light from object with exponential degrading as the increasing of depth. The other is the ambient light.

Figure 5. Generated depth and image enhancement result (a) test image (b) depth (the brighter, the nearer) (c) enhanced Image

The viewer actually sees the combination of the two light sources. For simplicity, the ambient light is supposed to be white in our algorithm. The further the object is, the weaker the saturation of the combined light is. Thus, the saturation can be also enhanced by an increasing linear function of depth in (9).

$$Light_{object}(depth) = c \times Light_{object}(0) * e^{-depth} \quad (7)$$

$$Light_{total} = Light_{object}(depth) + Light_{Ambient} \quad (8)$$

$$Saturation_{enhanced}(x) = Saturation(x) \times \left(\beta\left(Depth(x)\right)\right) \quad (9)$$

.

Thus, for color enhancement, the saturation channel of HVS color space can be adjusted stronger to represent the object is closer to the viewer. Therefore, saturation of image can be enhanced by an increasing function of depth. The relationship between scattering and depth can be modeled as an exponential function:

## IV. EXPERIMENT RESULT

Our experiment results are shown in Figure 5. The details are enhanced more compared to original image frame. In computation, our proposed system is about 30 fps @CIF in CPU (Core™2 DUO CPU E6850 @3.0GHZ.).

## V. CONCLUSION

In this work, an efficient depth-aware video post-processing pipeline at the end of display is presented. Compared to conventional video post-processing pipeline, our proposed frame work provides automatic depth generation and corresponding contrast and color sharpness enhancement with little computational overhead. One of our future work is optimization it in parallel structure for videos with higher resolution.

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