UNSEEN VISIBLE WATERMARKING FOR COLOR PLUS DEPTH MAP 3D IMAGES

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ABSTRACT

Unseen visible watermarking (UVW) is a novel data hiding scheme that imitates real-world watermarks and maintains advantages of both visible and invisible watermarking. One important feature of UVW is that specific extraction module is not required during watermarking decoding. The UVW for 2D image is studied based on imaging functions, e.g. gamma-correction in LCD monitors. On the other hand, due to the great success of 3D movies and low-priced 3D display devices, 3D contents are booming up in recent years. In this work, we propose a UVW for color plus depth map 3D images in which the watermark extraction is realized by changing of the rendering conditions. Under normal rendering conditions, the watermarked cover can be perceived exactly the same as the original one. Limitations and future extensions of the proposed 3D UVW are also addressed in this work.

Index Terms— Watermarking, Unseen Visible Watermarking (UVW), Depth-Image-Based Rendering (DIBR), Color plus Depth Map 3D Image

1. INTRODUCTION

The watermarks in real world applications, such as bills, are usually invisible or un-disturbing under normal viewing conditions. When the viewing conditions are changed, e.g. viewing the bill against light sources, the hidden watermark pattern is revealed. Figure 1 illustrates the authentication flow of real world watermarked bills.

UVW is a novel data hiding methodology [1, 2] for auxiliary information transmission via visual contents. UVW is inspired by real world watermarking which assembles both benefits of visible and invisible watermarks. The watermarked cover shows imperceptible distortion with respect to the original cover under normal viewing conditions, which is the major advantage of invisible watermark. The extraction of visually meaningful watermark pattern is realized by off-the-shelf imaging function, e.g. gamma-correction, of legacy LCD monitors and examined by human eyes without the aid of specific decoding module, which is the main benefit of visible watermark.

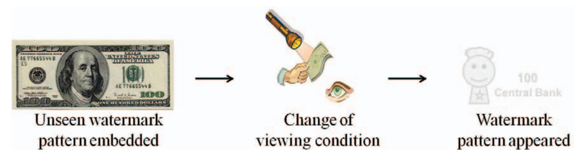


Fig. 1. The authentication process for watermarked bills.

On the other hand, 3D multimedia is becoming more and more popular in recent years. The great successes of 3D movies in Hollywood and the advance of 3D display technologies further flourish the growth of 3D multimedia applications. There are emerging studies of invisible watermarking schemes for 3D multimedia [3–5].

However, the research works on UVW for 3D contents are near to none in the literatures. The investigation of UVW for 3D contents can fill up the missing part of the researches on 3D content watermarking. Figure 2 illustrates the framework of the proposed UVW scheme for color plus depth map 3D images. The embedded watermark pattern is extracted by changing of rendering conditions where the explicit watermark extractor is not required. Furthermore, we analyze the non-linear property of the rendering process with which the proposed UVW scheme can accomplish zero distortion virtual view image synthesis under normal rendering conditions.

Section 2 describes the background knowledge of depth-image-based rendering (DIBR). Section 3 analyzes the non-linear property of the rendering process and the embedding flow of the proposed UVW scheme. Section 4 shows the experimental results of UVW extraction and the robustness against the JPEG compression attack. Section 5 compares the UVW schemes for 2D and 3D images and Section 6 concludes this work.

2. BACKGROUND OF DEPTH-IMAGE-BASED RENDERING (DIBR)

With the advance of 3D display technology, there are emerging auto-stereoscopic multiview 3D displays which can provide 3D viewing experience for multiple users without wear-

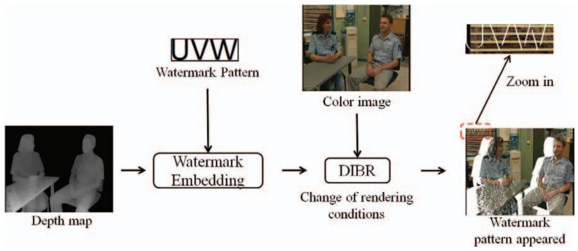


Fig. 2. The proposed UVW scheme for color plus depth map 3D images.

ing specific glasses. As a result, a 3D format that is capable of synthesizing arbitrary numbers of views with constant bit rate is a must for nowadays 3D displays. The color plus depth map 3D image is a 3D format that can decouple the representation of captured data and the data in displaying [6]. The color plus depth map 3D image is an efficient 3D format that is able to generate multiple virtual views and the required storage bit rate is lower than that of stereo and multiview 3D images [6–8]. The color plus depth map 3D image or its variation is expected to be one of the major 3D formats for future 3D multimedia applications [6].

Based on the color plus depth map 3D image, the virtual view image is synthesized by shifting the color image pixels horizontally. The horizontal shifting distance is the disparity d which can be derived as [6]:

$$d = f \cdot t_x \cdot \frac{I_z}{255} \cdot \left(\frac{1}{Z_{near}} - \frac{1}{Z_{far}}\right) + \frac{1}{Z_{far}}, \quad (1)$$

where f is the focal length, t_x is the inter-pupils distance between two eyes, and I_z is the intensity value on depth map. Z_{near} is the near clipping plane and Z_{far} represents the far clipping plane in the 3D scene.

During the rendering process, the dis-occluded regions will appear as holes in the virtual view image. The hole-filling problem can be dealt with post processing schemes [7, 8] which is beyond the scope of this work; therefore, we skip the detailed descriptions here.

3. UVW FOR COLOR PLUS DEPTH MAP 3D IMAGE

Similar to the UVW scheme for 2D images [1, 2] that utilizes the non-linear property of gamma-correction to acquire both the advantages of invisible and visible watermarks. We analyze and apply the non-linear property of DIBR to embed UVW into the color plus depth map 3D images.

3.1. The Non-linear Property in DIBR

We analyze the effect of embedding watermark pattern into depth map for DIBR in this subsection. The watermark embedding modifies the depth map with ΔI. The original DIBR in Eq.(1) will be changed as:

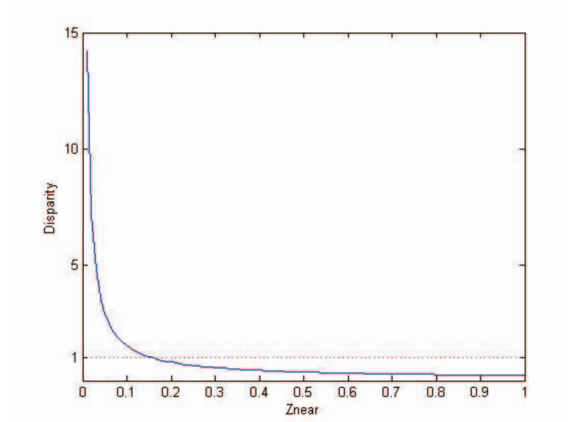


Fig. 3. The non-linear relation between Δd and Z_{near} where $\Delta I = 1$, $t_x = 36$,$f = 1$ and $Z_{far} = 18$ in Eq. (3)

$$d + \Delta d = f \cdot t_x \cdot \frac{I_z + \Delta I}{255} \cdot \left(\frac{1}{Z_{near}} - \frac{1}{Z_{far}}\right) + \frac{1}{Z_{far}} \quad (2)$$

The Δd is introduced by adding the ΔI in the depth map. By subtracting Eq. (1) from Eq. (2), we can get the following representation:

$$\Delta d = f \cdot t_x \cdot \frac{\Delta I}{255} \cdot \left(\frac{1}{Z_{near}} - \frac{1}{Z_{far}}\right) \quad (3)$$

Eq. (3) illustrates a non-linear relation between Δd and Z_{near}. Figure 3 shows the non-linear relation between Δd and Z_{near}, where f, t_x and Z_{far} are fixed. Under normal rendering conditions, e.g. $Z_{near} \geq 1$, the value $\Delta d < 1$ has no effect on the virtual view synthesis process. On the other hand, by changing the rendering condition, e.g. setting $Z_{near} < 0.1$, we can extract the watermark pattern since $\Delta d > 1$.

3.2. The Embedding Flow

The depth map embedding flowchart is depicted in Figure 4. We choose the farthest regions for conducting watermark embedding because the change of rendering conditions, e.g. setting $Z_{near} < 0.1$, will increase the disparity value drastically for the whole image. Embedding the watermark pattern into the farthest regions can avoid the situation that the disparity value is overflowed, i.e. the corresponding disparity is greater than the width of the cover image, when we want to extract the watermark pattern.

We embed the watermark pattern into the depth map where the benefits are two-fold. First, the depth map is mainly used for rendering process. The users will not perceive the depth map directly in normal usage. Second, as

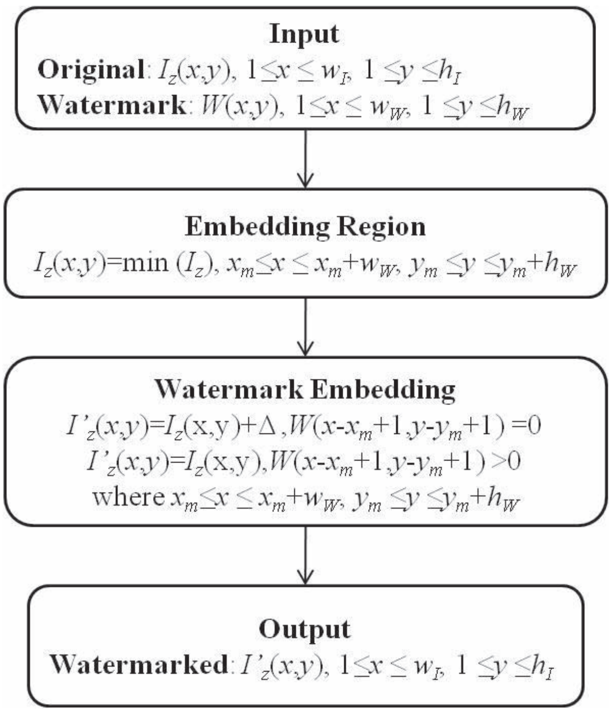
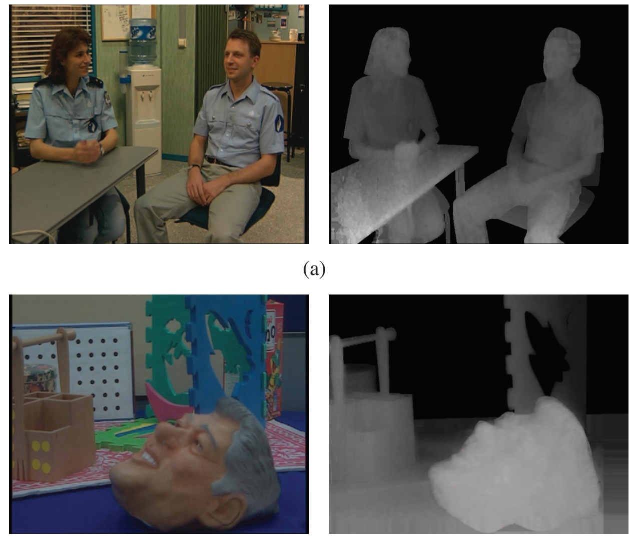


Fig. 4. The embedding flowchart of the proposed 3D UVW scheme.

derived in Section 3.1, $\Delta d < 1$ under normal rendering conditions guarantees that the virtual view synthesis image is kept intact. Different to the small distortion introduced by the UVW scheme for 2D images, the proposed UVW scheme for color plus depth map 3D images can even achieve zero distortion with respect to the original data.

4. EXPERIMENTAL RESULTS

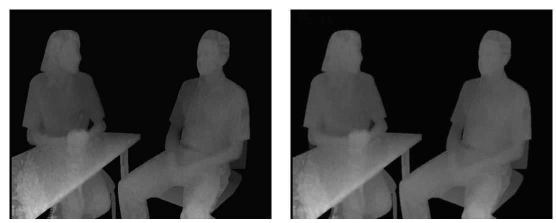
Figure 5 shows the color plus depth map 3D images used in our experiments. The resolution is 720×576 pixels for both color image and depth map. The test data *Interview* and *Orbi* are obtained from HHI (Heinrich-Hertz-Institut) [7]. We set $f = 1$, $t_x = 36$, $Z_{far} = 18$ during the experiments. We set $Z_{near} = 1$ for normal rendering conditions, and $Z_{near} = 0.1$ is used for watermark extraction. Figure 6 shows the original and the watermarked depth maps where the difference is imperceptible. The extraction process is simulated by software in our experiments. However, there are 3D display technologies, e.g. Philips 3D Solutions, which are capable of adjusting the parameters of the rendering process. It is our belief that the proposed UVW scheme for color plus depth map 3D images can also be utilized on the 3D display devices in the near future.



(a)

(b)

Fig. 5. The test data (a)*Interview*, and (b) *Orbi* used in our experiments.



(a) (b)

Fig. 6. (a) The original depth map, and (b) the watermarked depth map for the test data *Interview*

4.1. The UVW Extraction

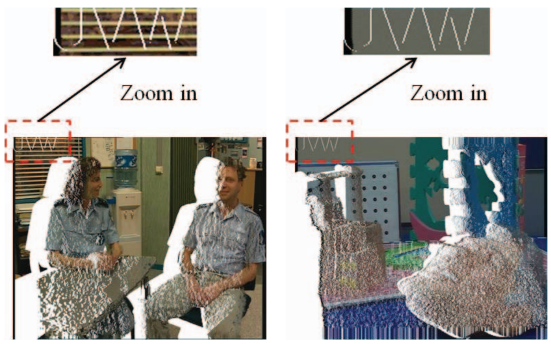
Figure 7 illustrates the UVW extraction results of the test data *Interview* and *Orbi*. The watermark pattern is appeared in a form of horizontal shifting gap, i.e. $\Delta d > 1$. The synthesized virtual view image shows that the disparity value d is increased drastically for the whole image when we change the rendering condition for extracting the watermark pattern.

4.2. Robustness to JPEG Compression Attack

We evaluate the robustness of the proposed UVW scheme against the JPEG compression attack. Figure 8 shows the UVW extraction results based on the JPEG compressed depth map where the compression ratio is up to 67. The extracted watermark pattern is distorted when the depth map is JPEG compressed. However, the semantically-meaningful watermark pattern is still recognizable by human eyes, which matches the characteristics of visible watermarks.

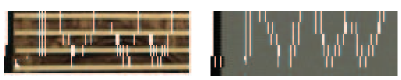
Table 1. The comparison between UVW schemes for 2D and 3D images

Characteristics	UVW for 2D	UVW for 3D
Explicit Extractor	Not required	Not required
Fidelity	Imperceptible	Zero distortion
Embedding regions	Dark regions in color image	Far regions in depth map



(a) (b)

Fig. 7. The UVW extraction of test data (a)*Interview*, and (b) *Orbi*



(a) (b)

Fig. 8. The UVW extraction results based on JPEG compressed depth maps which the data size is $\frac{1}{67}$ of original uncompressed depth maps for the test data (a)*Interview*, and (b) *Orbi*.

5. THE COMPARISON BETWEEN UVW SCHEMES FOR 2D AND 3D IMAGES

Table 1 lists the characteristics of UVW schemes for 2D and 3D images, respectively. As expected, the explicit extractor is not needed for both schemes. The UVW for color plus depth map 3D images can even accomplish zero perceptual distortion in the synthesized image, as detailed in Section 3. The embedding regions of the proposed UVW are the far regions in the depth map. The far regions in the depth map are more generic than the dark regions in the color images that are used in UVW for 2D images. The far regions may also be the textured regions in the corresponding color images where the watermark pattern appears in the textured regions of the test data. By utilizing the additional features of 3D images, e.g. depth map, the 3D UVW scheme can be more flexible and can even introduce zero perceptual distortion under normal viewing conditions.

6. CONCLUSIONS

In this work, a novel UVW scheme for color plus depth map 3D images is proposed, in which the embedded watermark pattern is extracted by changing the rendering conditions, e.g. changing the value of Z_{near}. We analyze and utilize the nonlinear property of rendering process (i.e., DIBR) to achieve zero perceptual distortion for virtual view image synthesis under normal rendering conditions. The embedding regions of the proposed UVW for 3D images are the far regions in the depth map which is more flexible and generic than the dark regions used in UVW for 2D images. The research on UVW is still in its infancy stage, especially for 3D contents. This work introduces the preliminary step toward the novel applications of UVW to 3D multimedia contents. There is still a large room for investigation and improving various UVW schemes for 2D and/or 3D images, of course, these kind of explorations is one of our future research directions.

7. REFERENCES

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