An Effective Blending Method for Panoramic Images in Image-based Virtual Reality

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Abstract

Image blending is very important for image stitching with visible seams. An effective blending method for panoramic images in image-based virtual reality is proposed in this paper. The proposed blending method is a two-phase scheme. The histogram-based blending is first applied in the first phase scheme; and then in the second phase scheme, the weighted blending is used under the result of the first phase scheme. Seamless image stitching is obtained by using the proposed two-phase scheme of blending method. The concepts of the weighted blending and the histogram-based blending are included in the proposed blending method, thus the advantages of the weighted blending and the histogram-based blending are also obtained in the proposed blending method. Based on experimental results, the performance of the proposed blending method is better than the three basic blending schemes (the weighted blending, the adaptive blending, and the histogram-based blending). Besides application of image-based VR with the panoramic images, the proposed blending method would be further used in the panoramic video. Hence, the proposed method would be very useful for computer vision.

Keywords: blending, panoramic image, virtual reality, seamless, stitching.

1. Introduction

Virtual reality (VR) has become an interesting research for several decades. Based on building VR world, VR can be divided into two categories: geometry-based VR [1] and image-based VR [2]. The geometry-based VR first constructs 3D models of the real world objects, and then generates the VR objects by rendering 3D models, but building 3D models is tedious work and computationally expensive. On the other hand, the image-based VR builds panoramic images by stitching images of the real world and obtains the advantage of easy and fast VR world building and of having realistic views.

Besides application of image-based VR, representations of panoramic images have a wide application, e.g. panoramic surveillance, tele-conferencing, content-based video compression and manipulation, panoramic video, etc.

Panoramic image is a wide field of view (FOV) image, up to a full view of 360 degrees, and it can contain full information about the scene from given views. The generation of panoramic images can be described as follows: A sequence of images is first captured while rotating a camera from a fixed position about a vertical axis that approximately passes through the camera optical center. Each image in the sequence is then projected onto a cylindrical surface. The panoramic image is subsequently created by determining the relative overlapping region between adjacent images in the sequence and using image stitching for the sequence of images (see Fig. 1).

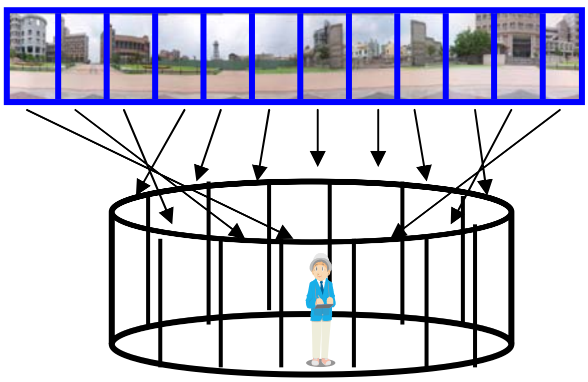
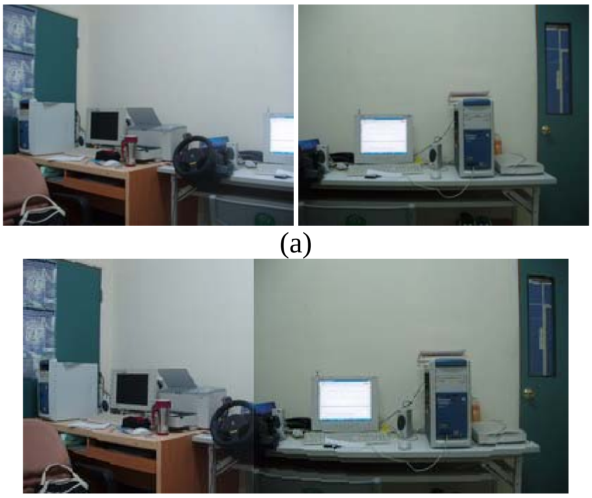


Fig. 1. View of the panoramic image in VR.

In image stitching of panoramic images, the detection of corresponding points of adjacent images is very important. The detection of corresponding points can be divided into two categories: template matching [3] and feature matching [4]. Methods based on feature matching compute the displacement of a small number of characteristic features, e.g. corner, edge, contour, etc. Methods based on template matching are the optimization of some similarity measure of the intensity of images. Once the corresponding points of consecutive images are detected successfully, the image stitching is performed based on the corresponding points of adjacent images to obtain panoramic images.

Ideally, the intensity of every image should be the same, but in reality this is not the case, e.g. change in exposure time, intensity decreases toward the edge of the image, significant intensity difference in the scene, etc. Hence, visible seams would exist in the result of image stitching, as shown in Fig. 2. So a good image blending is important to obtain the seamless images.



(a)

(b)

Fig. 2. Visible seam in image stitching.

The basic blending schemes can be divided into three schemes [5]: the weighted blending, the adaptive blending, and the histogram-based blending. Using the weighted blending, the intensity of the overlapping region of adjacent images can be smoothed successfully, but blurry scene would be attached under mis-stitching. However, the blurry scene and ghost would be detected and effectively removed by using the adaptive blending, but inexact scene would appear under mis-detection of ghost. For significant intensity difference, the intensity of the overlapping region can be effectively improved by using the histogram-based blending, but mis-adjustment of intensity varying function would cause over-exposure.

Many blending methods have been developed. For instance of using the weighted blending, Szeliski [6] uses the Levenberg-Marquardt method to estimate the homography matrix for aligning two overlapping images and to reduce visible artifacts and local misalignment, the method blends the overlapping area by a bilinear weighting function. The feather-based algorithm [7] was applied which uses averaging and interpolation functions to reduce intensity difference. Besides, for instance of using the adaptive blending, Brown and Lowe proposed a two-band scheme [8] based on the multi-band blending [9]. A low pass image is formed with spatial frequencies greater than 2 pixels relative to the rendered image, and a high pass image with spatial frequencies less than 2 pixels. The low frequency information is blended by using a linear weighted sum, and the high frequency information is selected from the image with the maximum weight. Li and Ma [10] also use the two-band blending in the proposed image stitching algorithm.

In this paper, an integrated method based on the weighted blending and the histogram-based blending is proposed to effectively smooth the intensity of the overlapping region of adjacent images. The proposed blending method is a two-phase scheme. The histogram-based blending is first applied in the first phase scheme; and then in the second phase scheme, the weighted blending is used under the result of the first phase scheme. Seamless image stitching is obtained by using the proposed two-phase scheme of blending method.

In the remainder of this paper, the basic blending schemes are briefly described in Section 2. In Section 3, the integrated method based on the weighted blending and the histogram-based blending is proposed. Section 4 presents experimental examples and evaluations of the experimental results. Finally, conclusion is made in Section 5.

2. The Basic Blending Schemes

Before image blending, the overlapping regions (corresponding points) of adjacent images are first detected for image stitching by using template matching. In this paper, the similar measure [11] is used to find the overlapping region of two adjacent images, and equation (1) is the formula of similar measure. The higher value r is, the better the similarity is. Hence, the highest value r is selected.

$$r=\frac{\sum_x\sum_y\left[f(x,y)-\bar{f}\right]\left[w(x,y)-\bar{w}\right]}{\left\{\sum_x\sum_y\left[f(x,y)-\bar{f}\right]^2\sum_x\sum_y\left[w(x,y)-\bar{w}\right]^2\right\}^{\frac{1}{2}}} \tag{1}$$

In equation (1), $-1\le r\le 1$, and $f(x,y)$ and $w(x,y)$ are the overlapping images; where $\bar{f}$ and $\bar{w}$ are the average of $f(x,y)$ and $w(x,y)$, respectively.

After image stitching based on overlapping regions, the image blending is used to smooth the intensity of the overlapping region. In this Section, three basic blending schemes (the weighted blending, the adaptive blending, and the histogram-based blending) [5] are briefly described.

2.1 Weighted blending scheme

The intensity of the point in overlapping region of image stitching is calculated as the percentage in the overlapping region against the adjacent images. A linear weighted function is used in the weighted blending scheme (as shown in Fig. 3).

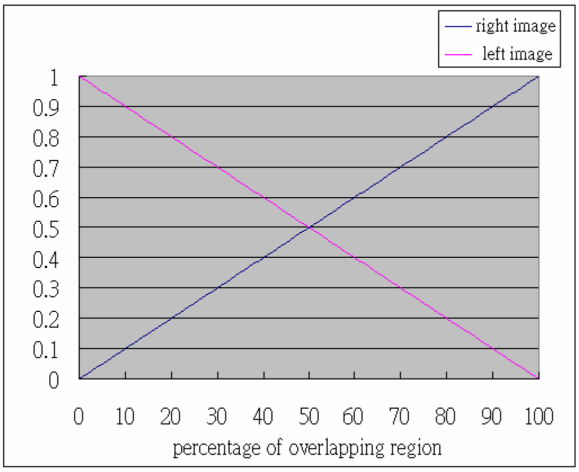


Fig. 3. The weighting map of the weighted blending method.

The diagram and the formula of the weighted blending scheme are shown in Fig. 4 and equation (2), respectively. In Fig.4, the point (a,b) in left image is in the overlapping region and the correspond point in right image is (x,y), where l_1 is the distance between point (a,b) and the left-side of overlapping region. And, l_2 is the distance between point (x,y) and the right-side of overlapping region.

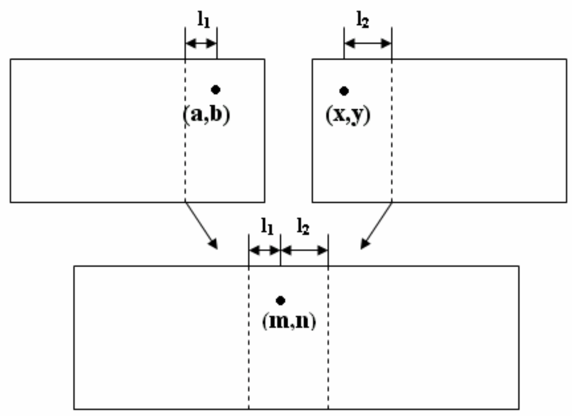


Fig. 4. The diagram of the weighted blending scheme.

$$color(m,n)=\frac{l_2}{l_1+l_2}*color(a,b)+\frac{l_1}{l_1+l_2}*color(x,y) \tag{2}$$

Using the weighted blending, the intensity of the overlapping region of adjacent images can be smoothed successfully, but blurry scene would be attached under image mis-stitching.

2.2 Adaptive blending scheme

In the adaptive blending scheme, the X-Y map of intensity of points in the overlapping region is first obtained, as shown in Fig. 5. In Fig.5, the X axis and Y axis are the intensity of left image and right image, respectively. For instance, the intensity of the point in left image is c_1, and the intensity of the correspond point in right image is c_2. Then, point (c_1,c_2) is marked in the X-Y map.

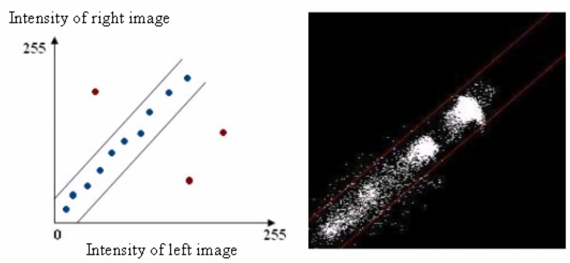


Fig. 5. X-Y map of the adaptive blending scheme.

Once all points in the overlapping region are successfully marked in the X-Y map, the adaptive region is defined as equation (3). If point (c_1,c_2) is inside in the adaptive region, then the intensity of the point is blended by using the weighted blending scheme; otherwise, the intensity of the point in the overlapping region is assigned as the bigger value of c_1 or c_2.

$$|c_1 - c_2| \le k \tag{3}$$

The blurry scene and ghost would be detected and effectively removed by using the adaptive blending, but inexact scene would appear under mis-detection of ghost.

2.3 Histogram-based blending scheme

Two adjacent images A and B would be blended based on an intensity varying function $F(c)$ varying from image A to image B in the overlapping region, as shown in Fig. 6. And, $F'(c)$ is the interpolation function of $I(c)$ and $F(c)$, as shown in Fig. 7. The intensity of the overlapping region in the images A and B is varied by using $F'(c)$ and $F'^{-1}(c)$, respectively, to obtain the consistent intensity. The image is subsequently divided into three parts based on center-line of the overlapping region, as shown in Fig. 8. For image A, $A'(c)$ is the interpolation function of $F(c)$ in region I and $I(c)$, $B'(c)$ is the interpolation function of $F(c)$ in region III and $I(c)$, and the intensity varying function in region II is the interpolation function of $A'(c)$ and $B'(c)$. Using the associated intensity varying functions, the adjacent images can be blended successfully.

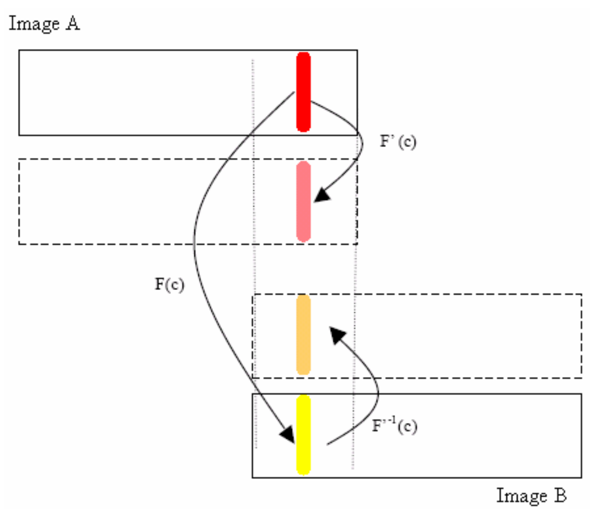


Fig. 6. Intensity varying function $F(c)$ [5].

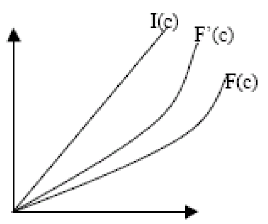


Fig. 7. Intensity varying function $F'(c)$ [5].

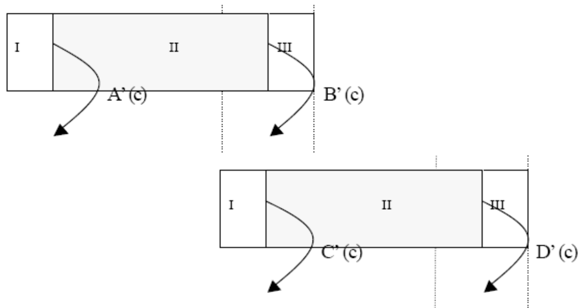


Fig. 8. Intensity varying functions in images [5].

For significant intensity difference, the intensity of the overlapping region can be effectively improved by using the histogram-based blending, but mis-adjustment of intensity function would cause over-exposure.

3. The Proposed Blending Method

An integrated method based on the weighted blending and the histogram-based blending is proposed to effectively smooth the intensity of the overlapping region of adjacent images. The proposed blending method is a two-phase scheme. The histogram-based blending is first applied in the first phase scheme; and then in the second phase scheme, the weighted blending is used under the result of the first phase scheme.

In the first phase scheme, the intensity of surrounding image in the overlapping region is balanced by using equations (4) and (5), and the diagram is shown in Fig.9.

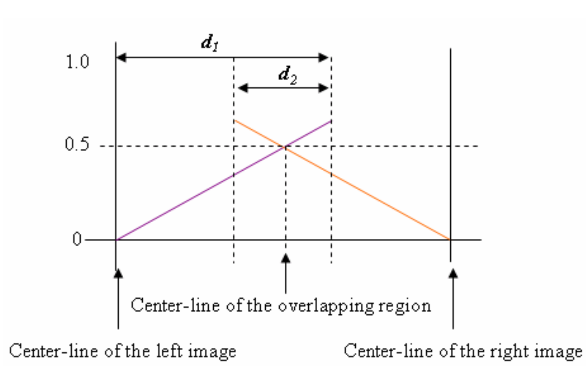


Fig. 9. The diagram of the first phase scheme of the proposed blendign method.

Let d_1 be a half of the length of the left image (or right image), d_2 be the length of the overlapping region, and $\Delta Q = \overline{f_1} - \overline{w_1}$, where $f_1(x,y)$ and $w_1(x,y)$ are the images in overlapping regions of left image and right image, respectively. $\overline{f_1}$ and $\overline{w_1}$ are the average of $f_1(x,y)$ and $w_1(x,y)$, respectively. In equations (4) and (5), $color(a,b)$ and $color(x,y)$ are intensity in left image and right image, respectively.

$$color(a,b) = -(\Delta Q/2)(l_1/L) + color(a,b) \quad (4)$$
$$color(x,y) = (\Delta Q/2)[(d_1 - l_1)/L] + color(x,y) \quad (5)$$
, where $L = 2d_1 - d_2$, and $0 \le l_1 \le d_1$.

In the second phase scheme, the intensity of the point in overlapping region is calculated as the percentage in the overlapping region against the adjacent images under the result of the first phase scheme. A nonlinear weighted function (sine function) is used in the weighted blending method (as shown in Fig. 10). Using the sine function as weighted function not one in Fig 3, the main reason is that the intensity of surrounding part in the overlapping region can be varied slowly. And, the diagram and the formula are shown in Fig. 4 and equation (6), respectively.

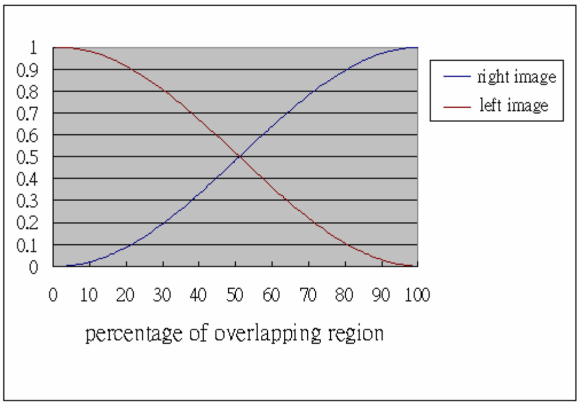


Fig. 10. The weighting map of sine function.

$$color(m,n) = \gamma_1 * color(a,b) + \gamma_2 * color(x,y) \quad (6)$$
, where
$$\theta_1 = \frac{l_2 \cdot \pi}{l_1 + l_2} \quad (7a)$$
$$\theta_2 = \frac{l_1 \cdot \pi}{l_1 + l_2} \quad (7b)$$
$$\gamma_1 = \frac{\sin(\theta_1 - \pi/2)}{2} + \frac{1}{2} \quad (8a)$$
$$\gamma_2 = \frac{\sin(\theta_2 - \pi/2)}{2} + \frac{1}{2} \quad (8b)$$

Using the proposed two-phase scheme of blending method, seamless image stitching can be obtained, and the intensity of surrounding image in the overlapping region can be also smoothed successfully. Besides, the intensity of the overlapping region with significant intensity difference can be effectively improved.

4. Experimental Results

In the following, the performance of the proposed method will be demonstrated and the experimental results will be compared with the three basic blending schemes. Experiments are conducted on a computer with Pentium 4 2.4GHz CPU, 512MB RAM based on BCB (Borland C++ Builder) 6.0 program.

All experiments in this section, image warping [12] is first applied with focal length $f = 50\,\text{mm}$ by projecting all of the images onto a common cylindrical surface. And, the similar measure based on equation (1) is used to find the overlapping region of two adjacent images. Image stitching is employed based on overlapping regions of adjacent images to obtain the panoramic images. Finally, intensity in the overlapping region is smoothed by using image blending.

There are three consecutive images in Fig. 11, and the results of image stitching are Figs. 12, 14, 16, and 18 by using the weighted blending, the adaptive blending, the histogram-based blending, and the proposed method, respectively, where the sizes of these stitching images are all 538×166. In Fig. 14 by using the adaptive blending, the adaptive region is defined as $k = 70$, and the intensity varying function $F(c)$ is selected as $I(c)$ in Fig. 16 by using the histogram-based blending.

A horizontal scanline of height of 145 pixels is used to obtain the intensity-scanline map of the stitching image. Figs. 13, 15, 17, and 19 are the intensity-scanline maps of Figs. 12, 14, 16, and 18, respectively, where the height of intensity-scanline map is 255.

Clearly, the intensity of surrounding image in the overlapping region is smoothed successfully by using the proposed method from the intensity-scanline maps of Figs. 13, 15, 17, and

19. And, the seams of adjacent images are invisible in Fig. 18. Hence, the performance of the proposed method is better than the three basic blending schemes.

Fig. 11. Consecutive three images.

Fig. 12. Result of using the weighted blending.

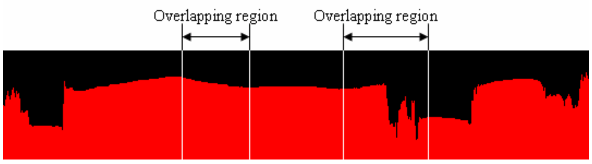


Fig. 13. Intensity-scanline map of Fig. 12.

Fig. 14. Result of using the adaptive blending.

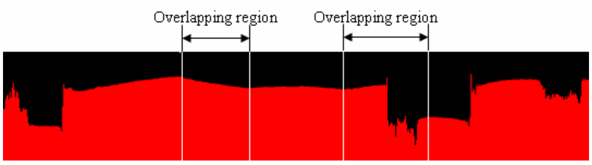


Fig. 15. Intensity-scanline map of Fig. 14.

Fig. 16. Result of using the histogram-based blending.

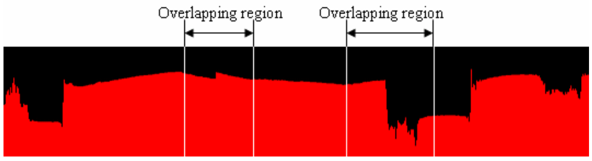


Fig. 17. Intensity-scanline map of Fig. 16.

Fig. 18. Result of using the proposed method.

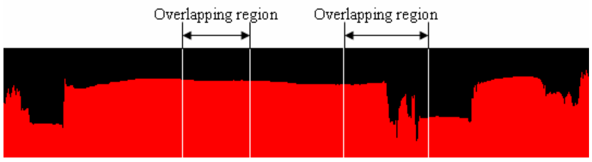


Fig. 19. Intensity-scanline map of Fig. 18.

The image-based VR is achieved by using the proposed blending method. First, a sequence of images is first captured while rotating a camera from a fixed position about a vertical axis that approximately passes through the camera optical center. In this paper, a camera is rotating horizontally at an interval of 30^0 to capture an image. Figs. 20 and 23 are the sequence of images of the outdoor scene and indoor scene, respectively. Figs. 21 and 24 are the 360^0 panoramic images of the outdoor scene and indoor scene, respectively. The sizes of Figs. 21 and 24 are 1608×169 and 1656×169, respectively. Finally, Figs. 22 and 25 are different viewpoints of VR in the outdoor scene and indoor scene, respectively, on the VR display by using image dewarping [12]. Especially, the significant intensity difference exists in the indoor scene, but the seams of adjacent images are invisible by using the proposed blending method.

5. Conclusions

An effective blending method for panoramic images is proposed successfully. The proposed blending method is an integrated method based on the weighted blending and the histogram-based blending. The proposed blending method is a two-phase scheme. In the first phase scheme, the histogram-based blending is applied to balance the intensity difference by using the proposed diagram (as shown in Fig. 9). And, in the second phase scheme, the weighted blending is used under the result of the first phase scheme, where a nonlinear function (sine function) is used as the weighting function (as shown in Fig. 10). The intensity of surrounding part in the overlapping region can be varied slowly by using the sine function as weighted function.

The concepts of the weighted blending and the histogram-based blending are included in the proposed blending method, thus the advantages of the weighted blending and the histogram-based blending are also obtained in the proposed blending method, such as the intensity of the overlapping region of adjacent images can be effectively smoothed, and the intensity of the overlapping region with significant intensity difference can be effectively improved.

The performance of the proposed blending method is demonstrated under the experimental results comparing with the three basic blending schemes. That is, the performance of the proposed blending method is better than the three basic blending schemes. Further, the 360^0 panoramic image with seamless image stitching is obtained in image-based VR. Besides application of image-based VR, the proposed blending method would be further used in the panoramic video. Hence, the proposed method would be very useful for computer vision.

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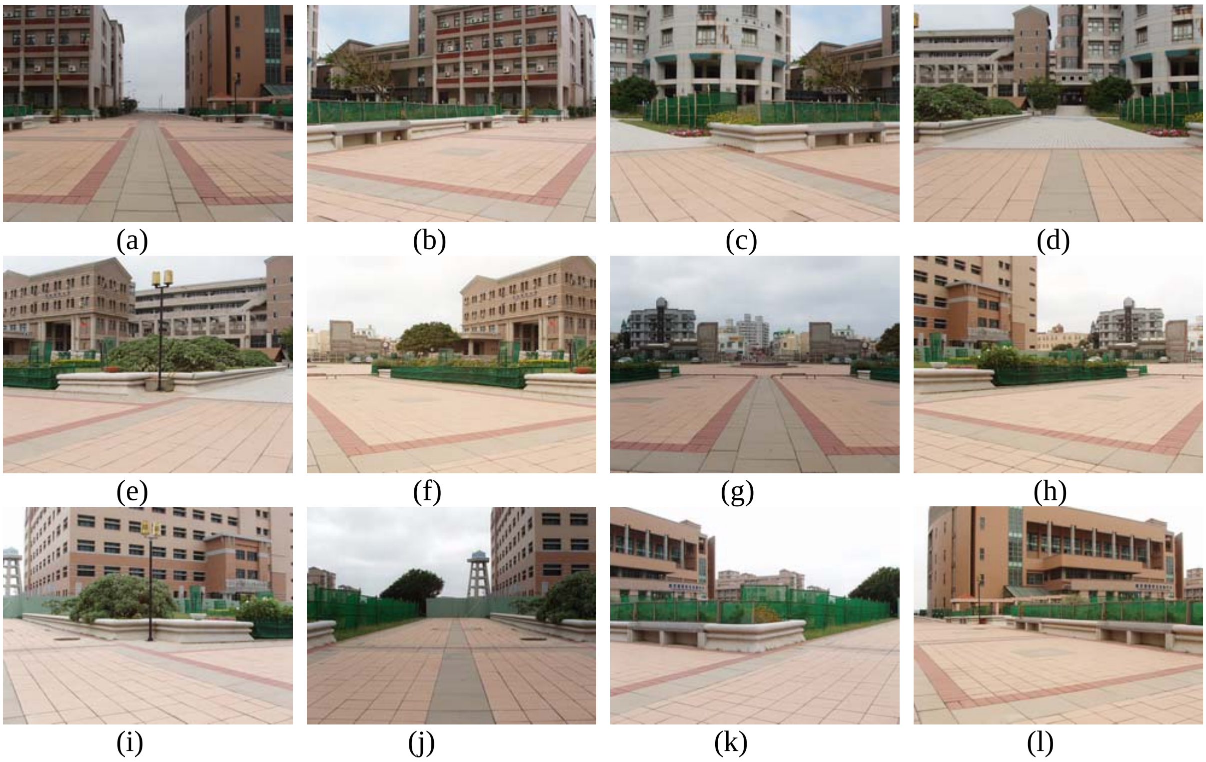


Fig. 20. A sequence of images of the outdoor scene.


Fig. 21. The panoramic image of the outdoor scene.

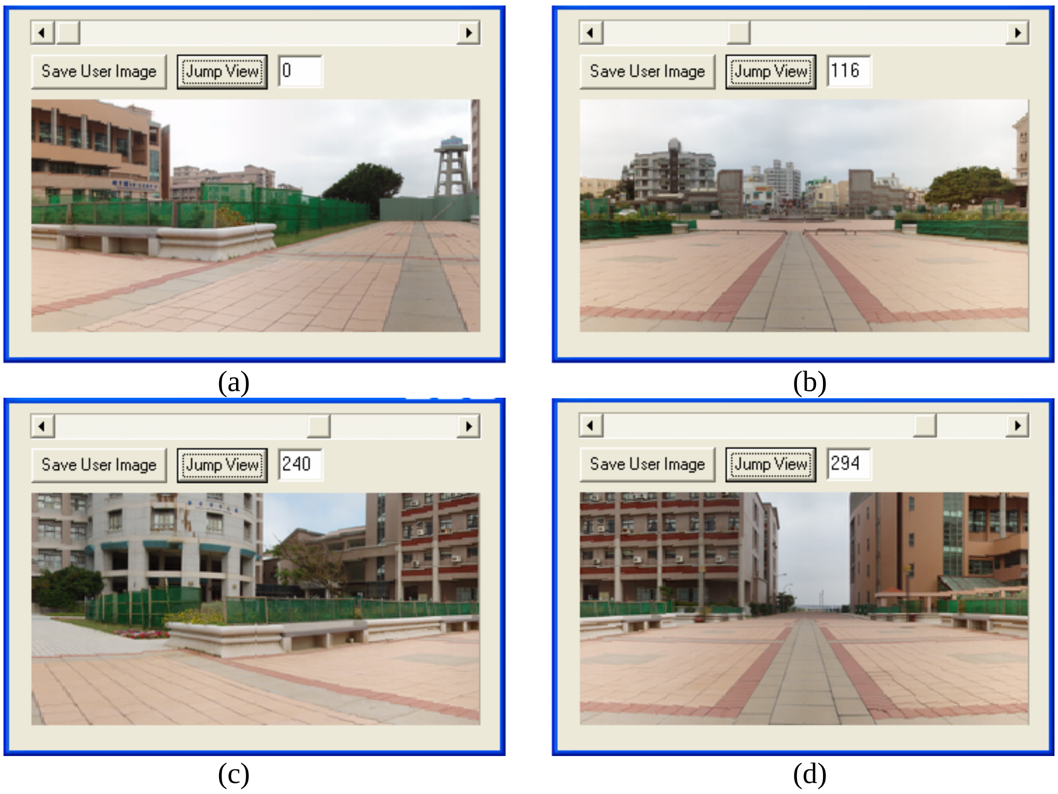
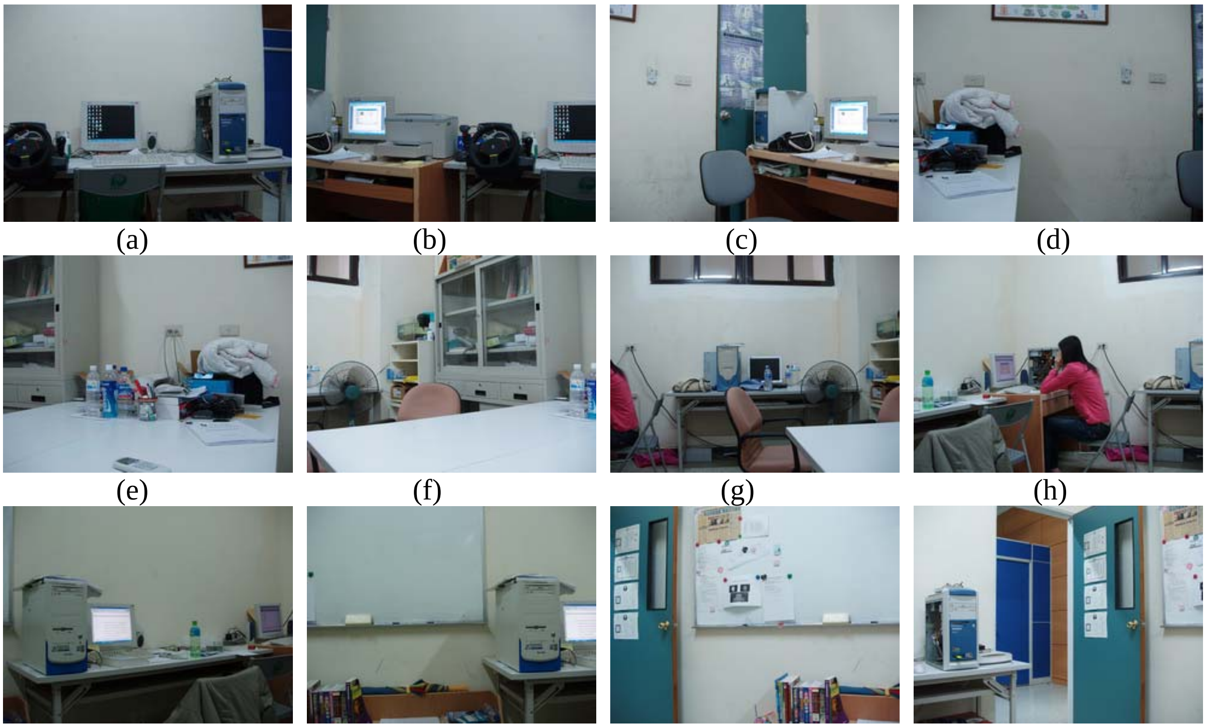


Fig. 22. Different viewpoints of VR in the outdoor scene.



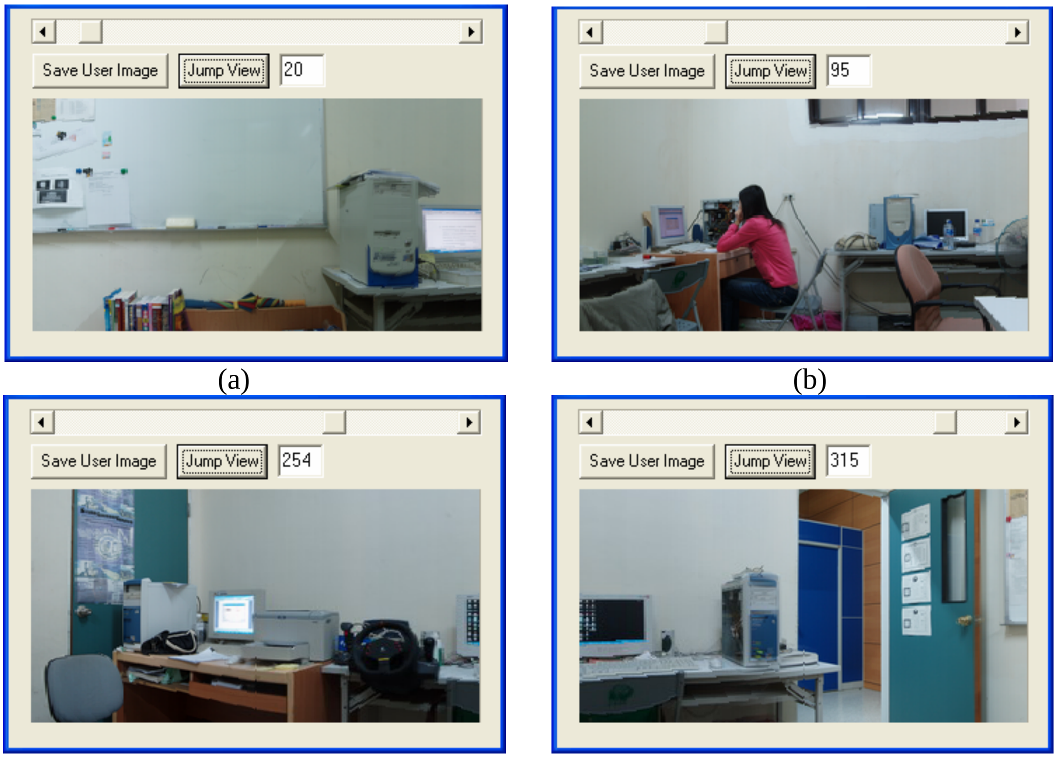
(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j) (k) (l)

Fig. 23. A sequence of images of the indoor scene.

Fig. 24. The panoramic image of the indoor scene.



(a) (b)

(c) (d)

Fig. 25. Different viewpoints of VR in the indoor scene.