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LOW COST RENDERING METHOD FOR VIRTUAL FACTORY CONSIDERING INTERPOLATION OF OCCLUDED OBJECTS

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Recent technology of computer graphics and image processing enables us to realize the construction of real world on a computer with virtual reality (VR). However, easiness constructing the VR space is not enough for most of users. This is because the methods to construct the VR space require very high working cost or special instruments and skills. We are aiming to use virtual factory (VF) which is constructed on a computer and enables us to walk through it with the viewpoint of workers, as the user interface of ubiquitous maintenance environment. But the construction process of VF costs very much in traditional ways, as well as other VR spaces. To solve the problem, this paper adopts the image-based rendering (IBR), which uses some photographs and generates the image at another viewpoint by interpolation. An efficient IBR algorithm for the straight path is proposed, which is adequate for the use in the VF.

Keywords: virtual factory, virtual reality, image-based rendering, walk through, occlusion

1 Introduction

We are aiming to use virtual factory (VF) as the user interface of ubiquitous maintenance environment [1, 2], which is constructed on a computer and enables us to walk through it with the viewpoint of workers. Using VF, it is possible that the constructor of VR space can work intuitively by spatial programming such that he puts maintenance information or programs, which should be received by worker at the same place in real factory, into the VR space. To construct the VR space where user can walk through is useful for many fields, not only for industrial use e.g. virtual museum, architect model and so on.

In the construction of the VF, it is general to model the facilities in the factory as 3D objects and to locate them in VR space. But this process costs very much, because there are many objects in a factory and to model all of facilities requires large amount of operations. Thus, to construct the VF with real view on a computer is not so easy for general users. On the other hands, as computer becomes popular and more powerful, the demands of constructing VR environment on a computer will increase. In addition, at the viewpoint of person's privacy or company's secret, the construction should be done in person. Hence, the reduction of working cost for constructing VF is important issue. This paper adopts the image-based rendering (IBR) instead of traditional 3D modeling ways for the construction of VF with very low cost, which uses some photographs and synthesizes the image at another viewpoint by interpolation (Figure 1). With IBR, an user can easily construct the VR space. The user should prepare only some photographs along the passage which are taken by adequate intervals. As a result, it is not necessary to model the facilities in the factory as 3D objects nor to hold huge number of images at every place, so that we can easily reduce the cost.

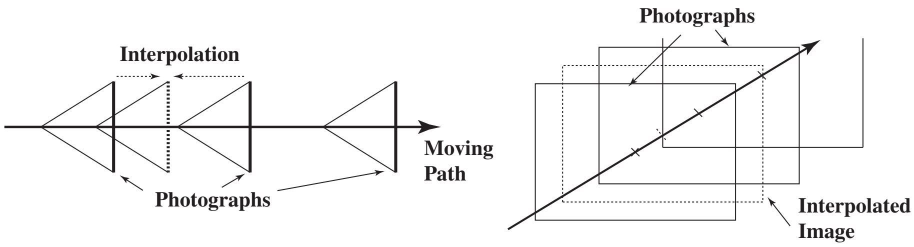

Fig. 1. Example of image-based rendering.

This paper's interest is only to synthesize images corresponding to the views of a worker in the factory. In factories, movable area for workers is restricted, therefore we should be able to synthesize the view only along the specific passages where workers are allowed to enter, which can be approximated by straight paths and rotary points.

Besides it, construction process should be easy enough to do by the workers themselves. That is, if construction method require special instruments and skill, it is hard to use at real field. For our purpose, the accuracy is not required so much comparing with stereo vision and so on. Therefore, our demand for IBR method is not exceeding accuracy of synthesis but easiness for users.

Based on these prerequisites, this paper discusses the existing IBR methods and proposes an efficient IBR algorithm, which is adequate for the use in the VF.

2 Existing IBR Methods and Their Problems

Image-based rendering is a method which synthesizes view of arbitrary position by interpolation from real photographs, without any 3D shape and position information of objects in the space. Its merit is that synthesized images by IBR have very real appearance. And it can reduce the cost for construction of VR space because it does not need 3D modeling process.

There are three motion types of viewpoint; left to/from right (perpendicular to line of vision), forward or backward (parallel to line of vision) and rotation. Consequently, there also exist corresponding three types of IBR method. In this paper, we call them as "LR-IBR", "FB-IBR" and "Rot-IBR", respectively.

QuickTimeVR [3] is the earliest IBR method and its type is Rot-IBR using panoramic image. But the position of viewpoint is not able to move to anywhere. Subsequently, "The lumigraph" [4] is proposed using "plenoptic function" [5] which holds the state of ray at arbitrary time, point and direction. All states of rays at all points are recorded as "light field" [6], and the view of arbitrary point can be synthesized from the light field. Kobayashi [7] also proposed an improved method with light field, but fundamentally this method requires very large number of photographs and huge storage space for preparing and keeping the light field, so costs very much. This method can work as all types of IBR.

On the other hand, Endo [8] proposed IBR method which can synthesize the view between two roughly parallel passages along which a set of photographs are taken at every defined intervals. This method generates interpolated image by the improved 2-phase View Morphing [9], so is LR-IBR and FB-IBR simultaneously. But this method needs the explicit indication of the corresponding points by human and requires large number of manually prepared layer images, to cope with occlusions. Consequently, working cost of this method becomes very high and the easiness of IBR is lost. Yamazaki's LR-IBR method [10] synthesizes images by morphing, and uses a filter [11] which detects corresponding points. This method can automatically find corresponding points but requires very long calculation time.

There also exist IBR methods already solved against occlusion, using space-time image, such as Katayama [12] or Halle [13] proposed. These methods are LR-IBR, but Katayama's method can work as FB-IBR if some additional photographs are taken. However, the area of synthesizable position along with forward or backward is quite narrow and requires diverse information about camera.

For our purpose, required IBR method is Rot-IBR and FB-IBR. Rot-IBR is used at the turning point (called "rotary"), and FB-IBR is used on the passage (called "path"). QuickTimeVR is adequate for our purpose in Rot-IBR, but there is no FB-IBR method whose cost is sufficiently low. And, a improved FB-IBR method with very low cost should be proposed.

The commonly heaviest difficulty of existing IBR methods is to cope with occlusions. This causes the increase of costs of existing methods, such as the requirement of manual operations, huge number of photographs and their recording storage. In the following sections, we investigate some peculiarities of FB-IBR and propose new FB-IBR method appropriate for our purpose.

3 Investigation of FB-IBR

We assume that we use only two images which are taken at any forward and backward position against target position where we are going to synthesize interpolated image, and also assume that all objects in the angle of camera are not moving.

3.1 Geometrical Relation between Images

When we want to synthesize an image at midway between some two positions by interpolation, it is necessary that we know the correspondence of each image's feature points. Generally epipolar line in epipolar geometry is used for this purpose.

In the case of FB-IBR, the light axis of camera is perfectly common i.e. both at image centers and same directions. Camera's moving direction is the same as light axis. Therefore, epipolar lines always appear from the center of image and take same directions on both two source images. Hence, extracting same scanlines radially from each image's center corresponds to extracting epipolar lines. Then, one point on one image's scanline must have corresponding point on another image's scanline of same position if there is no occlusion.

As a result, the interpolated image will be synthesized by generating enough number of scanlines which are extracted radially around the center.

3.2 Detection of Corresponding Color Segments

In the process of synthesizing interpolated scanlines, it is necessary to know which color segment on one scanline extracted from one image is corresponding to a color segment on another scanline extracted from another image; detection of corresponding color segments.

Detection methods of corresponding points for stereo vision [14, 15, 16] could be used for this purpose, treating the endpoints of color segments as feature points. However, IBR require not only feature points' correspondence but also all pixels' correspondence to synthesize image by interpolation. Thus, more suitable method is desired.

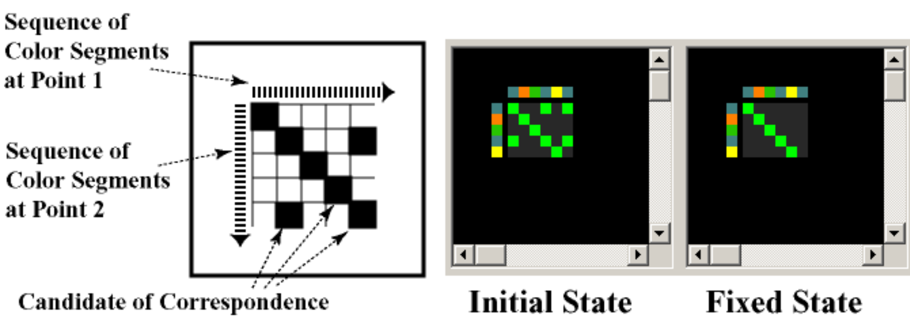

Fig. 2. Correspondence table of color segments

In FB-IBR, the appearing order of objects in the space becomes same between epipolar lines, if there is no occlusion. Then, we define a correspondence table of color segments (Figure 2). In this table, the sequence of color segments at backward point (we call this point "point 1" in the following) is assigned to the horizontal axis and the sequence of color segment at forward point (we call this point "point 2") is assigned to the vertical axis. Consequently, correspondence of color segments appears diagonal line from top-left of this table to right-bottom. Therefore, detecting correspondence is easy in FB-IBR. But if some occlusions happen, this diagonal order is broken. Hence, we need detection method of corresponding color segments which consider the disorder of correspondence sequence by occlusion.

3.3 Occlusion

There are four occlusion cases which can occur along the path from point 1 to point 2 (Figure 3): an object is

(a) visible at point 1, but hidden by another object at point 2

(b) invisible at point 1, but visible at point 2

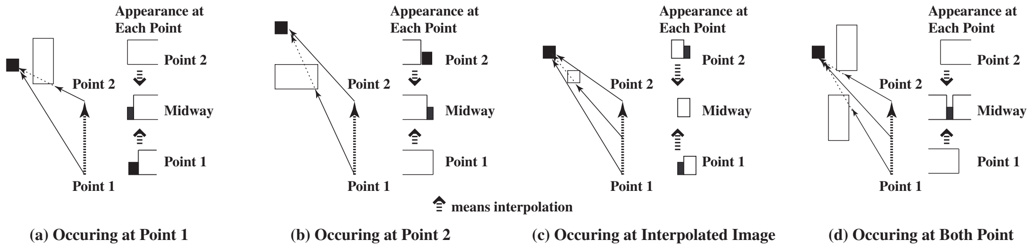

Fig. 3. Situations of occlusion

(c) visible at both points, but hidden by another object midway

(d) invisible at both points, but visible midway

Among these cases, it is impossible to cope with the occlusion in case (d). In this case, interpolated image becomes certainly incorrect. Therefore, only way to avoid this is to prevent this situation by taking photographs at appropriately selected points. In the case (c), we can properly synthesize the image by rendering closer objects later than far objects. Katayama's LR-IBR method [12] derives the objects' position relations from the objects' distance calculated by their apparent velocity on scanline (orthogonal velocity against line of vision). There exists a method which can calculate the objects' distance in the case which the camera moves forward or backward [17], and this could be applied to FB-IBR. But this method can calculate only feature points' distance. We require all pixels' distance in order to interpolate all pixels on the scanline, so postprocess is required to judge which velocity of a feature point is corresponding to the color segment's velocity. This postprocess should be very complex and causes increase of computational complexity.

Hence, this paper proposes improved FB-IBR method which works in very low cost, is easy to use by the constructor of VR space and can cope with occlusions appropriately. In the following sections, we call the occlusion of cases (a) and (b) "evident occlusion" and case (c) "latent occlusion".

4 Proposed Method

We assume that preprocessing such as camera's calibration and image segmentation are already completed.

After the preprocessing, scanlines are extracted radially corresponding to epipolar lines from each source image. Next, correspondence of color segments on the scanlines is detected. These color segments are drawn in the appropriately determined range along a scanline that is in the interpolated image, according to the correspondence. This procedure is made for every scanline, and interpolated image is finally synthesized (Figure 4). This is the outline of the proposed method.

Correspondence detection of color segments uses correspondence table described in the previous section (Figure 2). Correspondence of color segments appears as diagonal line from top-left to right-bottom of this table. If there are some occlusions, this diagonal order is broken (Figure 5). In the case of evident occlusion, a dislocation appears in this sequence. In the case of latent occlusion, a partial inversion of the order appears in this sequence.

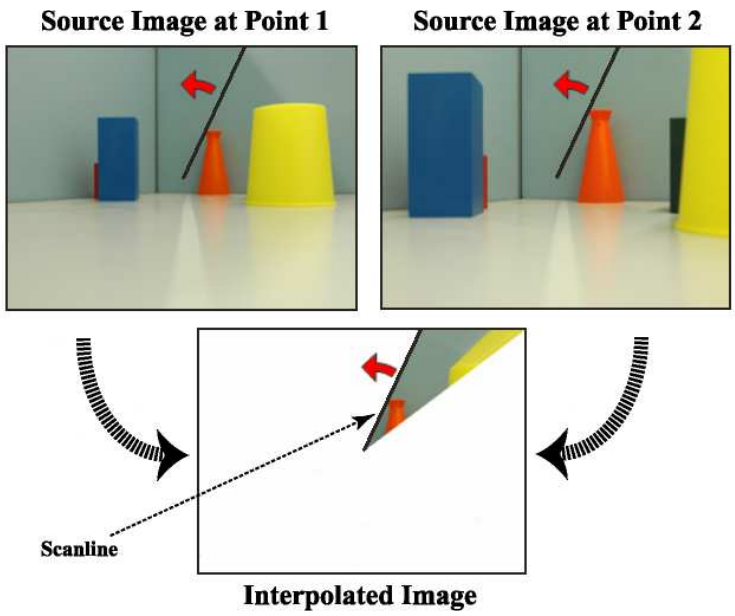

Fig. 4. Interpolation process

Correspondence detection algorithm for FB-IBR dealing with this disorder appropriately is presented as follows:

Correspondence Detection of Color Segments Algorithm for FB-IBR

```
All elements in the table which correspondence exists are marked as candidates;
Set probing point to top-left position of the table;
while (probing point is within the table) {
    if (a candidate exists at probing point) {
        Set detected candidate as fixed correspondence;
        Move probing point to the lower-right direction;
    }
    else {        // Otherwise, occlusion occurs here.
        if (candidates exist near the probing point on the same both row and column) {
            // This is latent occlusion.
            Set both detected candidates as fixed correspondences;
            Move probing point to the lower-right direction;
        }
        else if (a candidate exists near the probing point on the same row or column) {
            // This is evident occlusion.
            Set detected candidate as fixed correspondence;
            Move probing point to the fixed correspondence's position;
        }
        else
            Move probing point to the lower-right direction;
    }
    Remove candidates on the same both row and column of detected fixed correspondence(s);
}
```

Afterwards, interpolated scanline is synthesized, coping with occlusions appropriately. The basic idea is that we calculate proper position of color segments on interpolated scanline by Endo's formula [8] of interpolation for FB-IBR at first, and draw color segments at calculated position on interpolated scanline with appropriate colors derived from the source scanlines.

At first, the position of corresponding color segment's starting point and end point are calculated. The distance x_i of interpolated corresponding point from the image center on

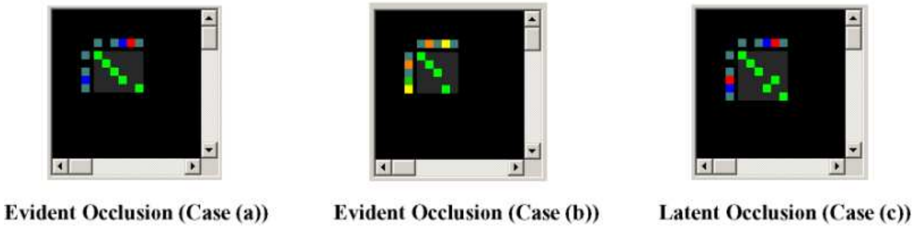

Fig. 5. Correspondence table with occlusion

interpolated scanline can be calculated by the following formula:

$$\frac{1}{x_i} = (1-p)\frac{1}{x_1} + p\frac{1}{x_2} \tag{1}$$

where x_1 is the distance from the image center on the extracted scanline at point 1, x_2 is the distance from the image center on the extracted scanline at point 2, p is the ratio of the distance from the point 1 to the viewpoint's position against the distance between the point 1 and point 2. This formula is applied to the starting point and end point of corresponding color segment, so that the segment's starting point and end point on the interpolated scanline is calculated.

Then, we can fill the section between the starting point and end point on the interpolated scanline by the corresponding color segment's color. The color of pixel at the position w, which represents the ratio of distance from the starting point against the distance between starting point and end point, can be derived from the color of pixel on the extracted scanlines by the following formula:

$$x_n = (1-w)s_n + we_n \tag{2}$$

where x_n is the position on the extracted scanline of point n, s_n is the position of starting point and e_n is the position of end point. The final color which should be put on the interpolated scanline is the average color between the color at the position x_1 and x_2 on corresponding extracted scanlines. This filling process should be iterated with changing the w from 0 to 1, and its step should be defined finely enough to draw all pixels. Thus, the interpolated color segments are drawn.

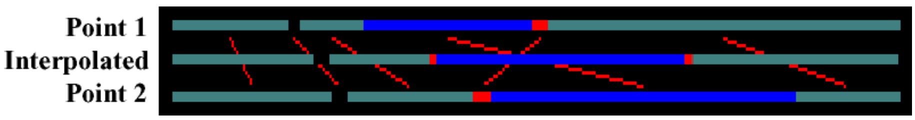

Fig. 6. Synthesis of interpolated scanline

Endo's interpolation method does not cope with occlusion itself (it needs manually prepared layered images corresponding to distance information of objects). Accordingly, we need to know the positional relation between color segments which are corresponding to objects, preparing for latent occlusion. Proposed method does not do any complex calculation at all which existing methods do, but determines appropriate rendering order using peculiarity of FB-IBR. Proposed method sorts the correspondence sequence of color segments by the appearing order at point 2 before interpolation process. The reason is that an object apparently overtakes another object on scanline in FB-IBR if latent occlusion occurs, so that nearer object must be outer position on the scanline of point 2. Then, drawing order on interpolated scanline is determined according to the order of correspondence sequence of color segment. Thus, in the case of existing latent occlusion, nearer object is automatically drawn at last and overwritten upon distant object's interpolated color segment. Though, this can correctly work only for small-scale latent occlusion, it is still effective because large-scale latent occlusion rarely occurs in FB-IBR. The reason is described in section 6.

When the interpolation with corresponding color segments is completed, if some disorders of the correspondence sequence on correspondence in the table exist, there are gaps which are not drawn with any color yet on interpolated scanline. Investigating the gap, and if the disorder corresponding to the gap is dislocation of sequence, it is caused by evident occlusion. In this case, the gap corresponds to the occluded object i.e. color segment which only appears in one source scanline therefore does not have a corresponding pair in another scanline. Accordingly, it should be filled by colors from color segment of occluded object. If the disorder corresponding to the gap has partial inversion of the order, it is caused by latent occlusion. In this case, the gap is corresponds to the background which can be seen during overlapping two objects. Accordingly, it should be filled by colors of color segment corresponding to probable background object. When all gaps are embedded, synthesis of interpolated scanline is completed and it should be drawn to appropriate position on interpolated image.

Above process is repeated, and synthesis of interpolated image is completed when this process is done for all radially extracted scanlines. Total interpolation algorithm is in the following:

FB-IBR Interpolation Algorithm:

```
Image segmentation;                                                   //assume this was already completed
for (all scanlines extracted from source image radially) {
    Correspondence detection of color segments between scanlines;                    //described previously
    Sort correspondence sequence by appearing order of point 2 (vertical axis);
    Calculate appropriate position for each corresponding color segments on
                                    interpolated scanline and draw it on interpolated scanline;
    for (all gaps on interpolated scanline) {
        if (the gap is by evident occlusion)
            Fill the gap with colors of non-corresponding color segments being
                                                held between both sides' color segments of gap;
        else if (the gap is by latent occlusion)
            Fill the gap with colors of color segment which is neighbour
                                                of gap and does not participate in the occlusion;
    }
}
```

5 Construction of Virtual Factory

This section describes the constructing and displaying process of virtual factory with the proposed method.

5.1 Constructing Process of Virtual Factory

The construction process is shown as below:

1. Define the paths and rotaries.

2. The constructor should prepare pictures along the paths and rotaries.

3. Assign pictures on the paths and rotaries. Pictures assigned to rotaries should be panoramic images.

The detail of each step is described below.

Definition of Paths and Rotaries At first, define the paths and rotary according to the structure of the factory (Figure 7). Rotaries are located at the points where worker can change the direction of view. The rotaries are connected by straight paths, according to the moving passage which workers can walk along.

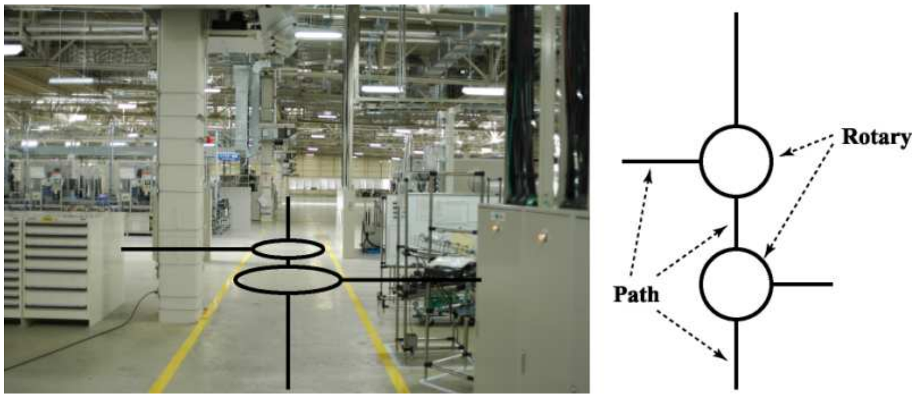

Fig. 7. Definition of paths and rotaries

Preparing Images along the Passage Next, the constructor should prepare the images which are taken along the passage (paths and rotaries).

At the rotary, we use the method proposed as QuickTimeVR which uses panoramic image. So the constructor should prepare panoramic image at the rotary.

On the path, we use the proposed method. The constructor should prepare the images taken with some interval. At one taking point, two images should be taken. One is forward directional along the path: camera's direction is parallel to the path. Another is backward direction along the path: camera's direction is parallel to the path, but reverse to first image's direction. This is because the path is bidirectional.

Assignment of Images to the Passages Taken photographs should be assigned to appropriate rotaries and paths. The constructor assigns an image to rotary or path (Figure 8). If an image will be assigned to path, the image's position (distance from starting point of the path) should be indicated at the same time. When the assignment is completed, we can now walk through the VF.

However, the number of taken images is not always enough to achieve the minimum quality of interpolation. The cause of this shortage is described in section 6. Consequently, we need to detect the shortage of images, and we tried to detect it automatically. The detecting method is also described in section 6.2.

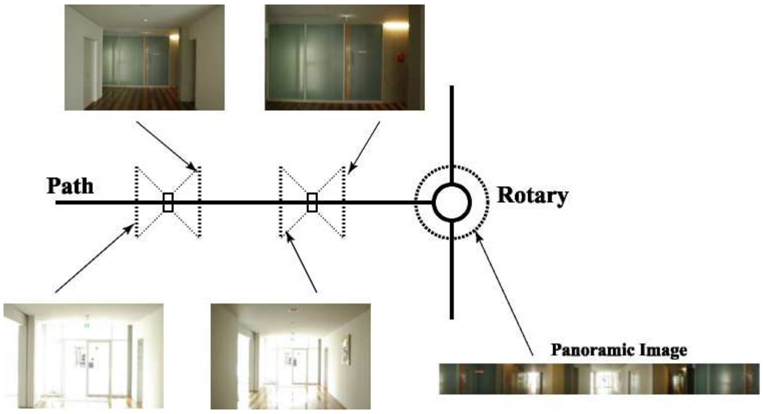

Fig. 8. Assignment of images to paths and rotaries

5.2 Displaying Process of Virtual Factory

The displaying process of VF is quite simple.

While the user walking around the VF, his view is synthesized and displayed by the system. At the rotary, required image is one panoramic image only and the system should acquire appropriate view by trimming it according to the direction of the user's view. On the path, the system should synthesize the view by the proposed method using two images which are taken at the nearest forward and backward point from the position of the user.

However, using the FB-IBR, the effective area of synthesized image is reduced, so we should trim away the defective edge of the interpolated image. This is because the objects being in outer area of the view at point 1 are out of the camera's angle at point 2. The detail and Specific example of this phenomenon are shown and discussed in section 6.

6 Simulation and Consideration

We examined proposed method to verify its effectiveness, especially for occlusions. Source images are photographs taken by digital camera, and image segmentation is manually completed in advance. Image size is VGA (640x480), and color depth is 24 bits (full color).

6.1 Basic Examination of the Proposed Method

The results of basic examination are shown in Figure 9. There are two source images which are taken at point 1 and point 2, and there are three interpolated images: 20%, 50% and 80% intermid in the middle from point 1. Actual photograph at 50% position from point 1 is also presented for reference. In this situation, latent occlusion occurs at the left side of the view and evident occlusion occurs in the right side.

The reason why the interpolation in near the border of image does not seem good is that the objects being in outer area of the view at point 1 are out of the camera's angle at point 2. Therefore this phenomenon is unavoidable. As a result, we need to trim away the border area of interpolated image, and we should also take photographs with wider angle lens. Occlusions are approximately represented well in interpolated images by proposed method. The objects' shape and size in interpolated image at 50% position are accurately consistent with the one's in the actual photograph at the same position.

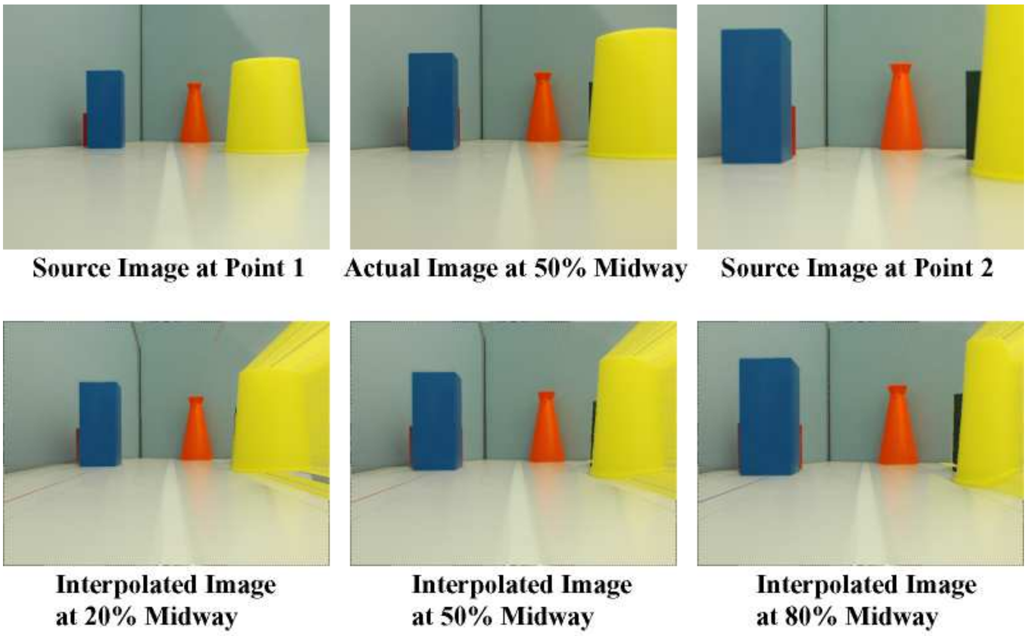

Fig. 9. Examined images (Source, interpolated and actual images)

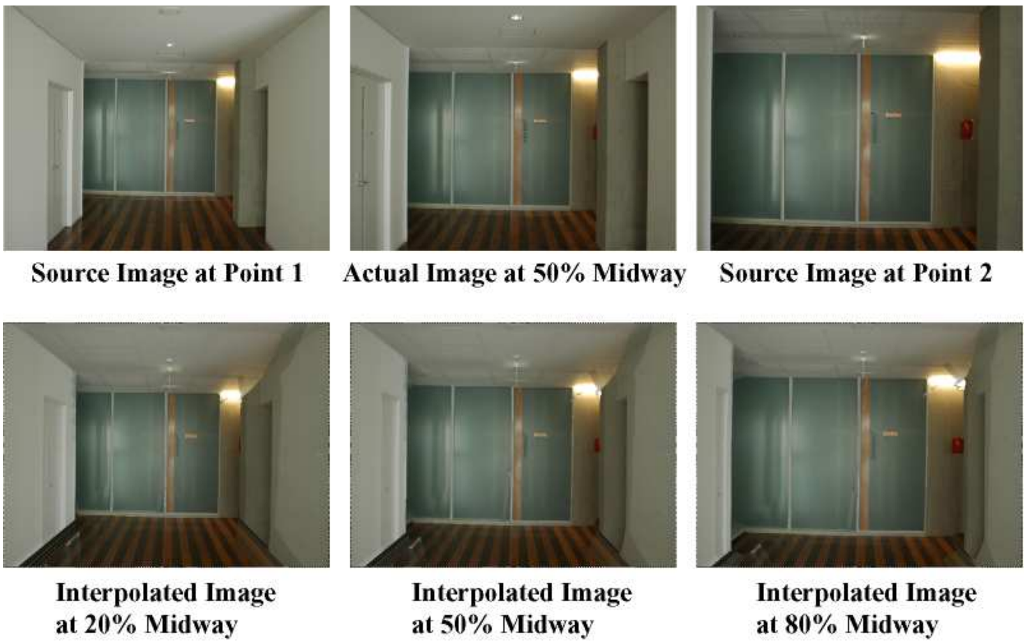

Fig. 10. Additional Examined images (Source, interpolated and actual images)

Additional examination is performed. Target is the corridor of actual building. The results of this examination are shown in Figure 10. There is a poster which is occluded at point 1 in the right side of image. In the interpolated image at 50% position, we can say the occluded poster represented appropriately by comparing with the actual view. Some objects such as door, light on ceiling and so on are not represented correctly. This is because those objects are out of camera angle at point 2.

It also turned out that latent occlusion will rarely occur in FB-IBR, through this examination. If latent occlusion occurs, the closer object overtakes the distant object from inside to outside for our viewpoint. Then, they should have enough apparent relative velocity to overtake. However, all objects have apparent velocity whose direction is certainly outwards in FB-IBR, so that the apparent relative velocity tends to be small. The nearer to the border of view angle, the larger apparent velocity the object has, but in this situation it is already out of camera's angle at point 2 if it has overtaken another object. On the other hand, near the image center, the objects' distance tends to be distant because there is a space where the camera can move into, so that apparent velocity tends to become small. Furthermore, apparent velocity near the center is naturally very small. Therefore the apparent velocities are too small near the center to overtake another object. Accordingly the large-scale latent occlusion rarely occurs there. As a result, correspondence detection method should have ability to cope with only small-scale latent occlusion in FB-IBR, thus proposed method is adequate for our purpose.

6.2 Practical Examination of the Proposed Method

We examined the proposed method at more practical situation, i.e. actual factory. Target factory is owned by DENSO Manufacturing Kitakyushu Co., Ltd. and manufactures parts of car engine. We tried to apply the proposed method to a passage in the factory.

The results are shown in Figure 11. Trimming of the interpolated image is required because of the reason described in the previous section. The trimmed interpolated image and actual image are shown in Figure 12: The trimming frame was defined according to the way described below. There are many objects around the passage and they form very complicated view. However, the synthesized view is plausible. Note the occluded object being right side of the images shown in Figure 13. The hidden equipment is correctly represented in the interpolated image.

The distance between the points where source images are taken is 3 meters. Additional results whose interval of taking point is 6 meters are shown in Figure 14. In this situation, the usable area of interpolated image is narrower than the case of 3 meters' interval. The ratio of effective area depends on the interval of the points where two source images are taken, so the constructor should define the interval of taking point according to the defined user's view angle (trimming ratio).

The worst case that effective area becomes the minimum occurs when the viewpoint is quite near to the point 1. Since the trimming ratio should be defined according to the worst case, we should check the interpolated image at point 1. If the trimming ratio is defined appropriately against the interpolated image at point 1, we can generate appropriate image for all position by using the trimming ratio. We call the interpolated image at point 1 'MFR (Minimum Field-of-view Reference) image'.

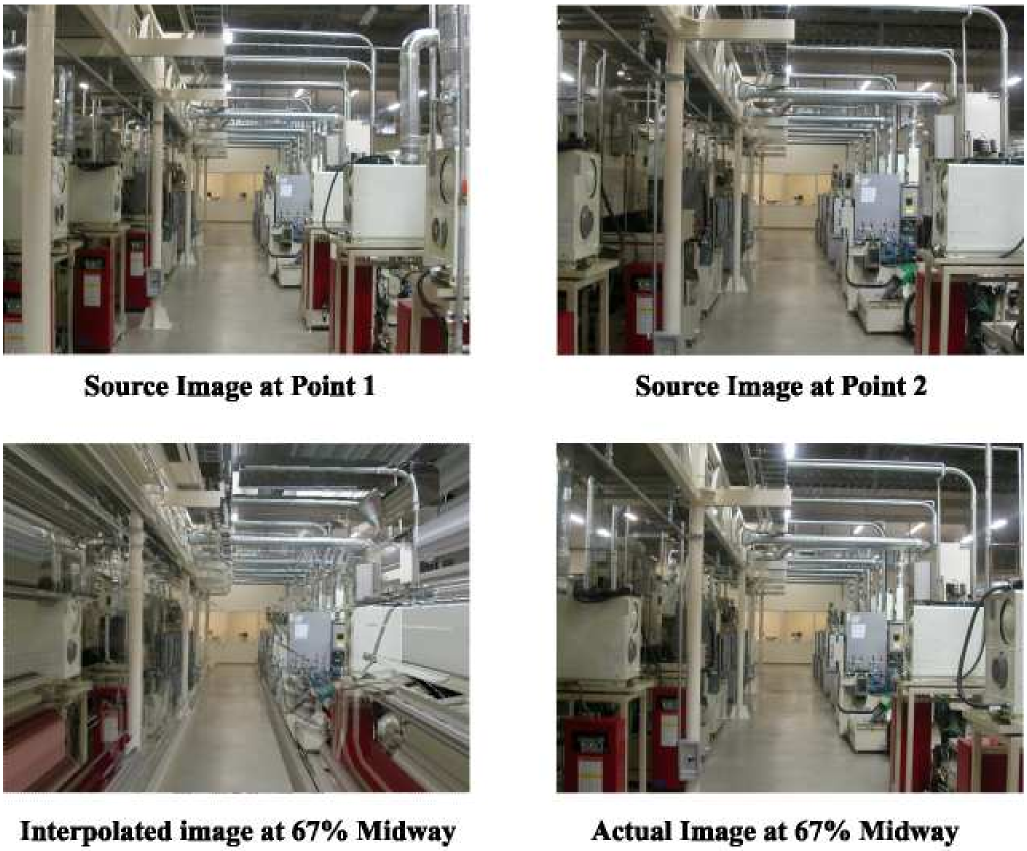

Fig. 11. Practical Examined images (Source, interpolated and actual images)

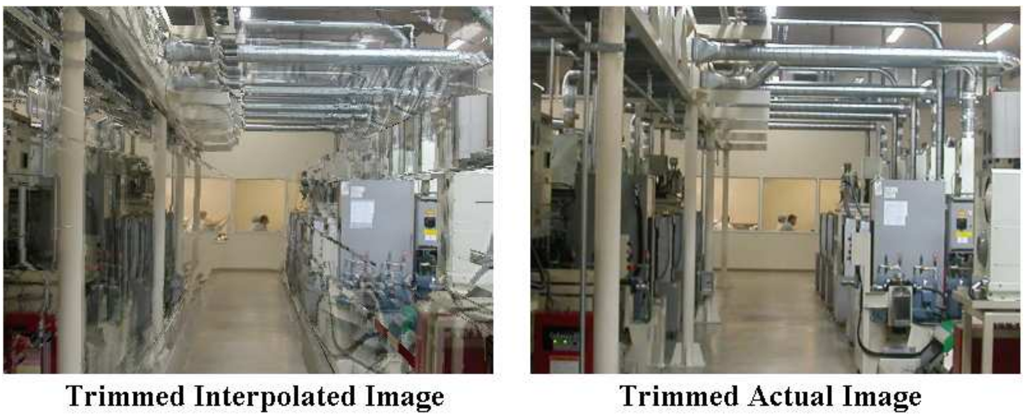

Fig. 12. Trimmed Images of Practical Examination

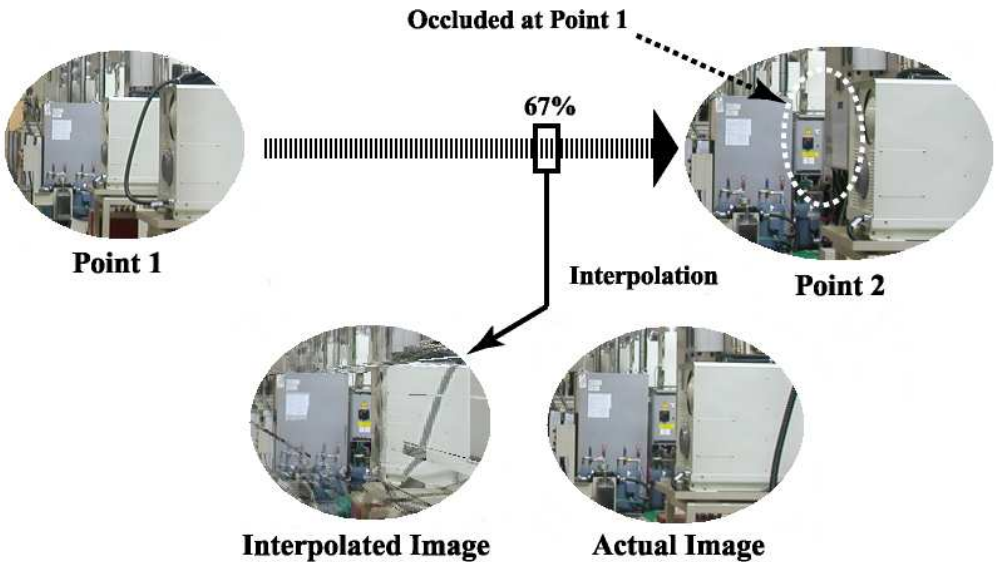

Fig. 13. Evaluation of Coping with Occlusion

The MFR image is shown in Figure 15. The outer area filled by one color indicates that interpolating this area is impossible because the objects which should be located there are out of camera angle at point 2.

The neighbor area with half transparent color indicates that interpolation can be done, but has possibility that the interpolation has some error. Since the objects (color segments) of this area are just on the border of camera angle at point 2, the outer position of color segment's edge is out of camera angle. Consequently, we can detect the correspondence of these color segments, but the size of interpolated color segments are probably not correct. However, the result of these areas' interpolation is not so bad and is quite plausible. This

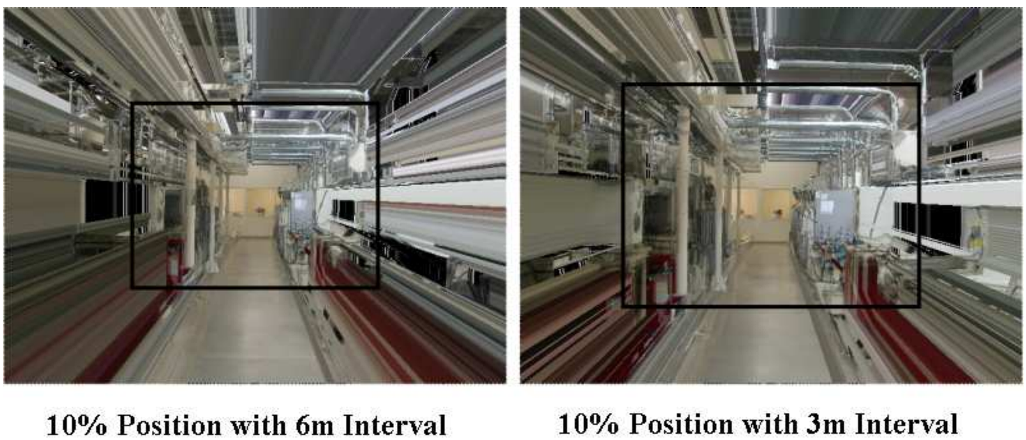

Fig. 14. Comparison of Interpolated Images with Different Interval

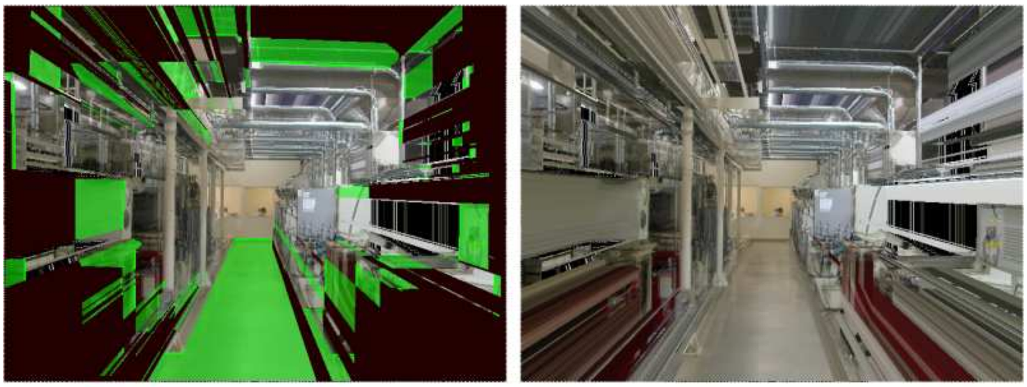

Fig. 15. MFR Image with 3m Interval

is because that the pixels of color segment have basically the same or quite near color each other, and evident error occurs at the outer edge of color segment. Therefore, we should trim the interpolated image at the position where is outer than the probable error color segment's inner edge and is inner than the probable error color segment's outer edge. In other words, the trimming frame should be located where most of the frame across the half or full transparent colored area indicated in Figure 16.

We tried to investigate the trend of average range of probable error area for each scanline and average range of evident error area for each scanline, by changing the interval. The results are shown in Table 1. It turned out that the evident error does not affect the feasibleness of trimmed image if we adopt the average range of probable error area as the trimming ratio. The example of trimmed image is shown in Figure 12. When the interval is the shortest (1

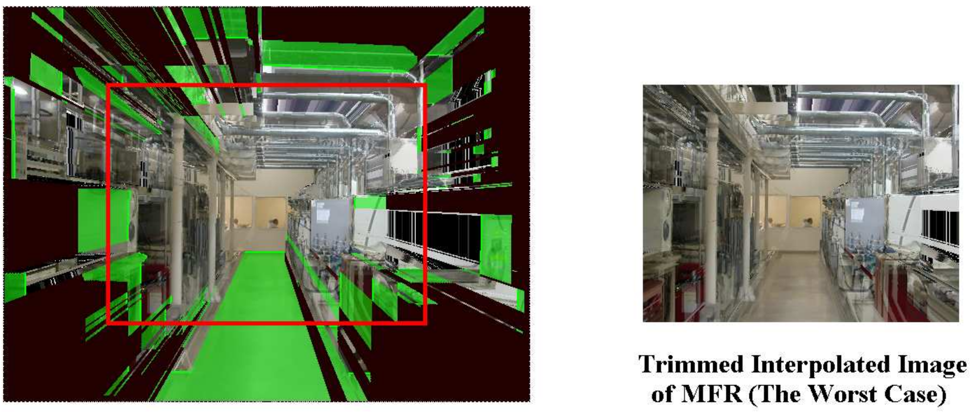

Fig. 16. Defined Trimming Frame and Trimmed Interpolated Image

Table 1. Usable area for trimming against interpolation error

Interval	1m	3m	6m
Average usable area against probable error	91%	76%	62%
Average usable area against evident error	69%	60%	49%
Average usable area against average of probable and evident error	80%	68%	55%

meter), the usable area is about 70% of original interpolated image. The usable area is reduced to 50% when the interval is increased to 6 meters. According to this result, we consider the appropriate interval exists between 3 and 5 meters in most cases. However, this is the worst case that most objects are located near the passage and camera. If most objects are far from the camera, we can get wider usable area because the objects located far from camera has less apparent velocity, i.e. evade getting out from the camera angle. Consequently, we can use longer interval in some cases.

Furthermore, since this inspection process of this examination described above can be done by computer only, we can use this procedure in order to verify the adequacy of interval automatically. When the source images are assigned to the path, the system checks the MFR images for all couples of neighbor source image. If the usable area is less than the trimming area which the constructor was defined, the system indicates to the constructor that the interval of those images is too long and retake additional photograph.

The usable area is affected by the state of image segmentation. This factor causes failure of interpolation, when the number of color segments is too few. In this case, each color segment has quite large area. As a result, one large color segment becomes the probable error segment. This situation can be seen in the Figure 15. The floor of the factory becomes one large color segment and is probable error area, because a part of the floor gets out from camera angle at point 2. Consider the extreme situation that only one simple wall exists in front of the worker. Then, only one color segment exists in the source image at point 2. In this case, the whole area of interpolated image becomes probable error, and the system will indicate retake. However, any retake can avoid this ill state, because the source image at point 2 still must be used.

To avoid this misdirection, if the camera is about to reach a rotary, we should stop to use the retake indication process. In some cases, it is possible that the interpolation does not work correctly due to the shortage of color segments. If this case occurs, we should use not only the IBR method but to introduce simple resizing method. Since the objects are in front of the camera and very near to the camera in such situation, simple resizing method can work properly.

6.3 Performance Comparison

Required time of rendering interpolated image by proposed method and each method which needs least manual operations (working cost) are shown in Table 2. In the proposed method, the rendering time does not contain preprocessing time, but the image used for proposed method is about 4.7 times as large as the others' one. In addition to that, the rendering time of Kobayashi's method does not contain the time for constructing light field and its color depth is shallow. And the existing methods require the huge number of images and storage capacities, or cannot cope with occlusions. The other methods requires special instruments

Table 2. Required processing time of each method

Method	Image Size	Colors	Images	CPU	RAM	Required time
Proposed Method	640x480	FullColor	2	Pen.IV 2GHz	512MB	**2.97 sec.**
Auto Morphing(Yamazaki)	256x256	FullColor	2	Pen.III 1GHz	768MB	**51.30 sec.**
Light FieldiKobayashij	256x256	256 Gray	2000	Pen.III 1GHz(Dual)	2GB	**1.38 sec.**

or processing by human's hand or inherently unusable as FB-IBR, so they are not usable for our purpose.

Hence proposed method is superior to existing methods.

7 Conclusions

We are aiming to use VF as the user interface of ubiquitous maintenance environment, which is constructed on a computer and enables us to walk through it with the viewpoint of workers. The construction process of the VF should be with low cost and easy enough for the workers themselves to do without any special instruments and skills.

This paper adopts the IBR and proposes an efficient FB-IBR algorithm, which is adequate for our purpose. Proposed method realizes low cost rendering and appropriately copes with occlusion in comparison with existing IBR methods, considering the peculiarity of FB-IBR. By the examination, the effectiveness of proposed method is verified. We are developing a robust image segmentation algorithm and implementing whole IBR system.

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