Every Color Chromakey

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1. Introduction

Image composition is very important to creative designs such as cinema films, magazine covers, promotion videos, and so on. This technique can combine images of actors or actresses in a studio and those of scenery taken in other places (Porter & Duff, 1984). Robust methods are needed especially for live programs on TV (Gibbs et al., 1998, Wojdala, 1998).

To perform image composition, objects of interest must be segmented from images, and there are a lot of studies about image segmentation (Fu1 & Mui, 1981, Skarbek & Koschan, 1994), e.g. pixel-based, area-based, edge-based, and physics-based ones. For example, Snakes (Kass et al., 1988) was proposed as an effective technique based on edge detection. However, there have not been developed practical methods which are accurate and automatic, while methods with high accuracy are proposed that are realized by human assistance (Mitsunaga et al., 1995, Li et al., 2004). Qian and Sezan proposed an algorithm that classifies the pixels in an input image into foreground and background based on the color difference between the input image and a pre-recorded background image (Qian & Sezan, 1999). The classification result is obtained by computing a probability function and the result is refined using anisotropic diffusion. However, the algorithm does not work well when foreground objects share regions of similar color and intensity with background. It has also restriction of requiring a stationary camera.

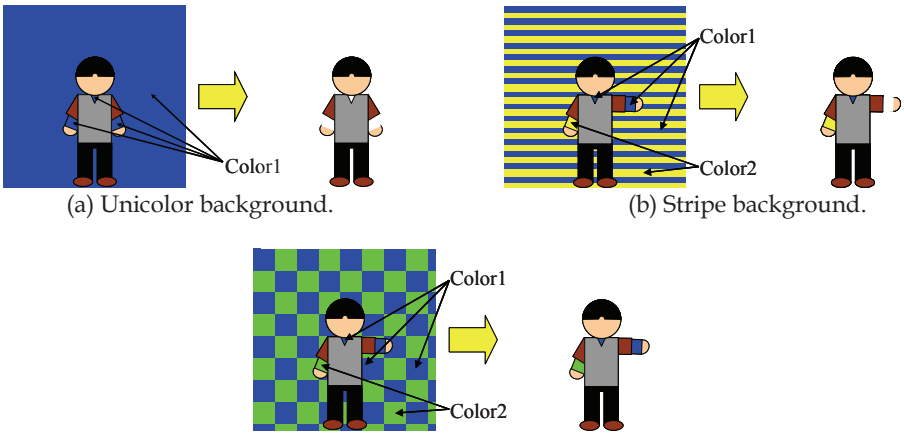
As to camera motion, Shimoda et al. proposed a method in which the background image alters accordingly as the foreground image is altered by panning, tilting, zooming and focusing operations of the camera (Shimoda et al., 1989). This method is a fundamental technique of virtual studios (Gibbs et al., 1998, Wojdala, 1998).

As a method that takes the advantage of three-dimensional information, Kanade et al. proposed a stereo machine for video-rate dense depth mapping that has a five-eye camera head handling the distance range of 2 to 15m using 8mm lenses (Kanade et al., 1996). Kawakita et al. proposed the axi-vision camera that has up-ramped and down-ramped intensity-modulated lights with an ultrafast shutter attached to a CCD probe camera (Kawakita et al., 2000). These systems can obtain the ranges from the camera to the objects in the scene and extract the objects from the images by using the range information. Yasuda et al. proposed the thermo-key extraction technique that measure thermal information for keys based on that the high temperature region is the human region (Yasuda et al., 2004).

However, since these systems consist of special devices, it is difficult for ordinary users to realize image segmentation by employing this information.
Chromakey, which is also referred to as color keying or color-separation overlay, is a well-known image segmentation technique that removes a color from an image to reveal another image behind. Objects segmented from a uniform single color (usually blue or green) background are superimposed electronically to another background. This technique has been used for long years in the TV and the film industries.
In image composition, the color $I(u,v)$ of a composite image at a pixel (u,v) is defined as:

$$I(u,v) = \alpha(u,v)F(u,v) + (1-\alpha(u,v))B(u,v) \tag{1}$$

where $F(u,v)$ and $B(u,v)$ are the foreground and the background color, respectively, and $\alpha(u,v)$ is the so-called alpha key value at a pixel (u,v) (Porter & Duff, 1984).
The color at a pixel (u,v) is the same as that of the foreground when $\alpha(u,v)$ equals to 1, and is the same as that of the background when $\alpha(u,v)$ equals to 0. In chromakey, it is very important to determine the alpha value exactly. Methods for exact estimation of the alpha value have been proposed in applications of hair extraction, transparent glass segmentation, and so on (Mishima, 1992, Zongker et al., 1999, Ruzon & Tomasi, 2000, Hillman et al., 2001, Chuang et al., 2001, Sun et al., 2004).
However, conventional chromakey techniques using a monochromatic background have a problem that foreground objects are regarded as the background if their colors are similar to the background color, and the foreground regions of the same color are missing (Fig. 1(a)).



(a) Unicolor background. (b) Stripe background.

(c) Checker pattern background.

Fig. 1. Region extraction with chromakey.

To solve this problem, Smith and Blinn proposed a blue screen matting method that allows foreground objects to be shot against two backing colors (Smith & Blinn, 1996). This method can extract the foreground region whose colors are the same as the background color. This alternating background technique cannot be used for live actors or moving objects because of the requirement for motionlessness within a background alternation period.

In order to solve the above problem, we proposed a method for segmenting objects from a background precisely even if objects have a color similar to the background (Yamashita et al., 2004). In this method, a two-tone stripe background is used (Fig. 1(b)). As to foreground extraction, the boundary between the foreground and the background is detected to recheck the foreground region whose color is same as the background. To detect the region whose color is same as the background, the method employs the condition that the striped region endpoints touch the foreground contour. If the foreground object has the same color as the background and has parallel contours with the background stripes, endpoints of the striped region do not touch the foreground contour. Therefore, it is difficult to extract such foreground objects (Fig. 1(b)). To solve this problem, we also proposed a chromakey method for extracting foreground objects with arbitrary shape in any color by using a two-tone checker pattern background (Fig. 1(c)) (Agata et al., 2007).

Basically, these two methods (Yamashita et al., 2004, Agata et al., 2007) only decide the alpha values as 0 or 1 discretely, and exact alpha value estimation is not considered. In other words, these methods mainly treat segmentation problems, not composition problems.

In this paper, we propose a new chromakey method that can treat foreground objects with arbitrary shape in any color by using a two-tone checker pattern background (Fig. 1(c)). The proposed method estimates exact alpha value and realizes natural compositions of difficult regions such as hair (Yamashita et al., 2008).

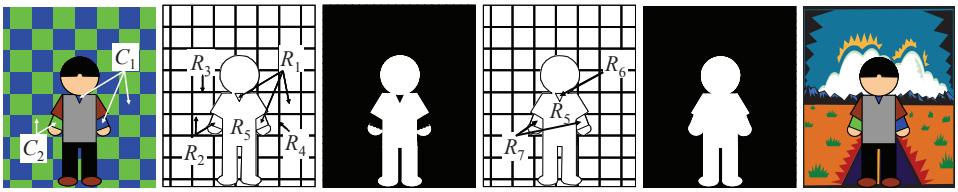
The procedure consists of four steps; background color extraction (Fig. 2(a)), background grid line extraction (Fig. 2(b), (c)), foreground extraction (Fig. 2(d), (e)), and image composition (Fig. 2(f)).

2. Background Color Extraction

Candidate regions for the background are extracted by using a color space approach. Let R_1 and R_2 be the regions whose colors are C_1 and C_2, respectively, where C_1 and C_2 are the colors of the two-tone background in an image captured with a camera (Fig. 2(a)). Then region R_i (i = 1, 2) is represented as

$$R_i = \{(u,v) \mid I(u,v) \in C_i\} \tag{2}$$

where $I(u,v)$ is the color of an image at a pixel (u,v).



(a) (b) (c) (d) (e) (f)

Fig. 2. Procedure. (a) Original image. (b) Region segmentation 1. (c) Foreground extraction 1. (d) Region segmentation 2. (e) Foreground extraction 2. (f) Image composition.

In addition to regions R_1 and R_2, intermediate grid-line regions between R_1 and R_2 are also candidates for the background. Let such regions be denoted as R_3 and R_4, where the former corresponds to horizontal grid lines and the other to vertical ones, respectively (Fig. 2(b)). The color of R_3 and R_4 may be a composite of C_1 and C_2, which is different from C_1 and C_2. Here, let C_3 be the color belonging to regions R_3, R_4 or foreground region, and we have the following description:

$$C_3 = \{I \mid I \notin (C_1 \cup C_2)\} \tag{3}$$

Figure 3 illustrates a relation among background regions R_1, R_2, R_3, R_4, and pixel colors C_1, C_2, C_3. It is necessary to estimate C_1 and C_2 in individual images automatically to improve the robustness against the change of lighting conditions. We realize this automatic color estimation by investigating the color distributions of the leftmost and rightmost image areas where the foreground objects do not exist as shown in Fig. 4(a). The colors in these reference areas are divided into C_1, C_2, and C_3 in the HLS color space by using K-mean clustering. Figure 4(b) shows the distribution of C_1, C_2, and C_3 in the HLS color space, where the H value is given by the angular parameter. The HLS color space is utilized because color segmentation in the HLS color space is more robust than in the RGB color space against the change of lighting conditions.

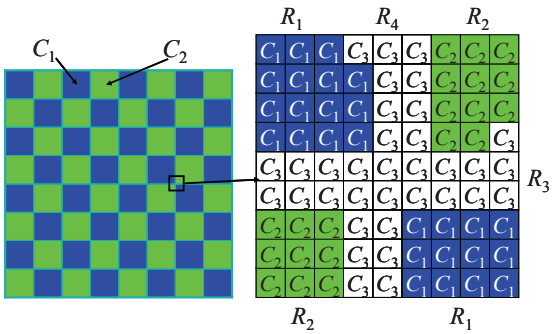
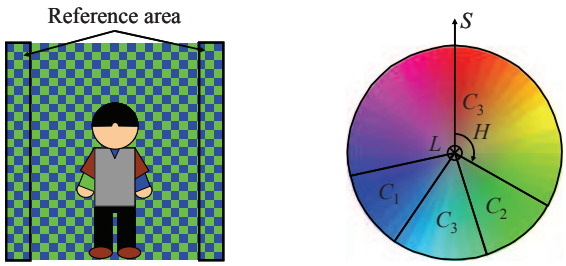


Fig. 3. Background regions and their colors.



(a) Reference areas. (b) HLS color space.

Fig. 4. Background color estimation.

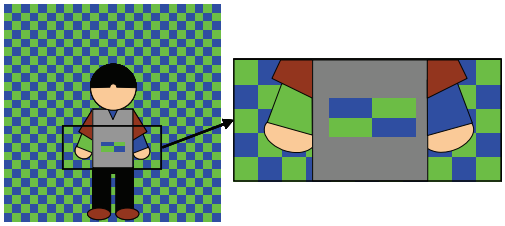


Fig. 5. Checker pattern in the foreground object.

Let H_i (i = 1, 2) be the mean value of the H values of C_i (i = 1, 2) in the reference areas, and let h_j (j = 1, 2, …, N) be the H value of each point in the image, where N is the total number of pixels of the image. Pixels are regarded as background candidate pixels if they satisfy the following condition, where T is a threshold:

$$|H_i - h_j| \leq T \tag{4}$$

3. Background Grid Line Extraction

Background grid lines are extracted by using adjacency conditions between two background colors. Background grid line regions R_3 and R_4 contact with both R_1 and R_2. The colors of the upper and lower regions of R_3 differ from each other, and also the colors of the left and right regions of R_4 differ from each other. Therefore, R_3 and R_4 are expressed as follows:

$$\begin{aligned} R_3 = \{&(u,v),(u,v+1),\cdots,(u,v+l+1) \mid I(u,v+1) \in C_3,\cdots,I(u,v+l) \in C_3, \\ &((I(u,v) \in C_1, I(u,v+l+1) \in C_2) \text{ or } ((I(u,v) \in C_2, I(u,v+l+1) \in C_1))\} \end{aligned} \tag{5}$$

$$\begin{aligned} R_4 = \{&(u,v),(u+1,v),\cdots,(u+l+1,v) \mid I(u+1,v) \in C_3,\cdots,I(u+l,v) \in C_3, \\ &((I(u,v) \in C_1, I(u+l+1,v) \in C_2) \text{ or } ((I(u,v) \in C_2, I(u+l+1,v) \in C_1))\} \end{aligned} \tag{6}$$

where l is the total number of the pixels whose color is C_3 in the vertical or horizontal direction.

However, if R_3 and R_4 are included in foreground objects, e.g. when a person wears in part a piece of cloth having the same checker pattern as the background as shown in Fig. 5, these regions can not be distinguished whether foreground or background. Therefore, we apply a rule that background grid lines should be elongated from those given in the reference area where foreground objects do not exist. If grid lines in foreground objects are dislocated from background grid lines as shown in Fig. 6, they are regarded as foreground regions. Elongation of the background grid lines is realized by the following method.

In the case of horizontal background grid lines, continuous lines exist at the top of the image as shown in Fig. 7 (a). At any part of the left and right reference area of the image, foreground objects do not exist. Therefore, it is possible to match any horizontal lines between the left end of the image and the right one by making correspondence from top to bottom one by one. We approximate the horizontal background grid lines behind the foreground object by applying a least mean square method to visible grid-line pairs.

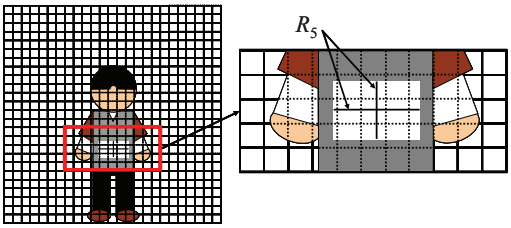
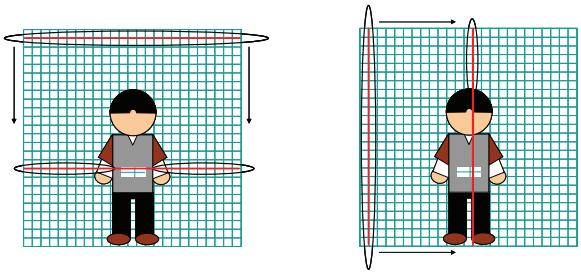


Fig. 6. Background grid line approximation.



(a) Horizontal line. (b) Vertical line.

Fig. 7. Background grid line estimation.

In the case of vertical background grid lines, continuous lines exist at the left and the right end of the image as shown in Fig. 7(b). However, if a foreground object is a standing person, it is not always possible to match the vertical lines between the top end of the image and the bottom one. In this case, we estimate the vertical background grid line behind the foreground object by applying a least mean square method only to the line at the top end of the image.

When applying a least mean square method to estimate either horizontal or vertical grid lines mentioned above, we should take into account the influence of camera distortion as a practical problem. Then we should fit higher-order polynomial curves instead of straight lines to the background grid lines. Here, we may have another approach; i.e. if we use a perfect checker pattern background consisting of squares or rectangles each of which has exactly the same shape, and a distortion-free camera whose image plane is set perfectly parallel to the checker pattern background, the background grid-line extraction procedure will become a very easy one. Comparing to this situation, our procedure seems to be elaborate, but it has such advantages as a camera with an ordinary lens can be used, the camera is allowed to have some tilt, and a checker pattern background which is somewhat distorted is available.

In this stage, all regions whose colors are same as the background are extracted as the background candidates, which may include mis-extracted regions as illustrated in Fig. 2(c). Those are regions which belong to the foreground object but have the same color as the background. As shown in Fig. 2(d), we define foreground regions whose colors are different from the background as R_5, and we define mis-extracted regions isolated from the

background and neighboring to the background as R_6 and R_7, respectively. These errors are corrected in the next step.

4. Foreground Grid Line Extraction

Background candidate regions corresponding to R_6 and R_7 should be reclassified as the foreground, although their colors are same as the background. This reclassification can be realized by adopting the following rules concerning to adjacency with background grid lines.

1. If there is a background region candidate that does not connect with the background grid line regions R_3 nor R_4, it is reclassified as the foreground region R_6 (Fig. 8, top).
2. If there is a background region candidate which has an endpoint of a background grid line in its inside, it is divided into two regions; one is a foreground region and the other is a background (Fig. 8, right). The dividing boundary of the two regions is given by a series of the interpolation lines each of which is a connection of neighboring background grid-line endpoints (Fig. 9(a), (b)). The region containing the background grid line is regarded as the background, and the other is regarded as the foreground region R_7.

Figure 9 illustrates the above 2nd rule. Background grid-line endpoints shown in Fig. 9(a) produce the dividing boundary as a series of interpolation lines as shown in Fig. 9(b).
By completing the above procedures, the image is divided into seven regions R_1 - R_7. Regions R_5, R_6 and R_7 are the foreground regions (Fig. 2(d), (e)). The contours of the foreground objects may not be exact ones, because the interpolation lines do not give fine structure of the contours owing to the simplicity of straight line connection. Therefore, we need to execute post processing for contour refinement which is realized by Snakes (Kass et al., 1988) (Fig. 10).

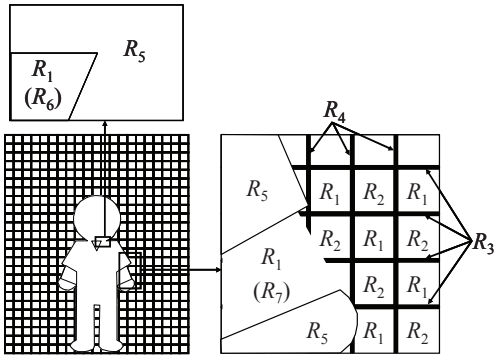
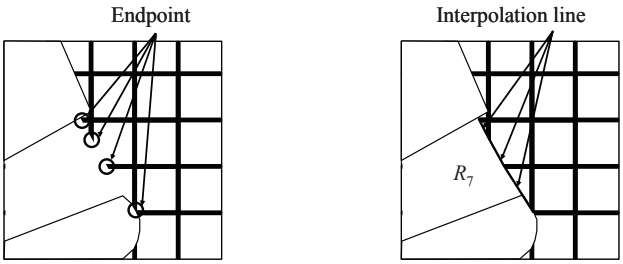


Fig. 8. Foreground region whose color is same as the background. Top: Inside the foreground (R_1 is reclassified to R_6). Right: Neighboring to the background (R_1 is reclassified to R_7).



(a) Background grid line endpoints. (b) Interpolation lines.

Fig. 9. Determination of region R_7.

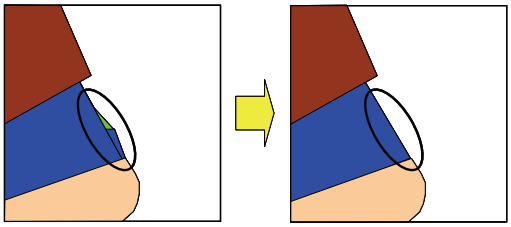


Fig. 10. Region extraction using Snakes.

Let $\mathbf{s}_i = (u, v)$ (i = 1, 2, …, n) be closed curves on the image plane (u, v), and we define Snakes energy as:

$$E_{snakes}(\mathbf{s}_i) = E_{spline}(\mathbf{s}_i) + E_{image}(\mathbf{s}_i) + E_{area}(\mathbf{s}_i) \tag{7}$$

where $E_{spline}(\mathbf{s}_i)$ is the energy to make the contour model smooth, $E_{image}(\mathbf{s}_i)$ is the energy to attract the contour model to the edge, and $E_{area}(\mathbf{s}_i)$ is the energy for the contour model to expand to fit to the reentrant shape (Araki et al., 1995).

These energies are defined as:

$$E_{spline}(\mathbf{s}_i) = \sum_{i=1}^{n} (w_{sp1} \,|\, \mathbf{s}_i - \mathbf{s}_{i-1} \,|^2 + w_{sp2} \,|\, \mathbf{s}_{i+1} - 2\mathbf{s}_i + \mathbf{s}_{i-1} \,|^2) \tag{8}$$

$$E_{image}(\mathbf{s}_i) = -\sum_{i=1}^{n} (w_{image} \,|\, \nabla I(\mathbf{s}_i) \,|) \tag{9}$$

$$E_{area}(\mathbf{s}_i) = \sum_{i=1}^{n} w_{area} \{u_i(v_{i+1} - v_i) - (u_{i+1} - u_i)v_i\} \tag{10}$$

where w_{sp1}, w_{sp2}, w_{image}, and w_{area} are weighting factors, respectively. $I(\mathbf{s}_i)$ is a function of image intensity on $\mathbf{s}_i$.

Therefore, $|\nabla I(\mathbf{s}_i)|$ is the absolute value of image intensity gradient. In the proposed method, $|\nabla I(\mathbf{s}_i)|$ is given by the following equations depending on what region the pixel belongs to.

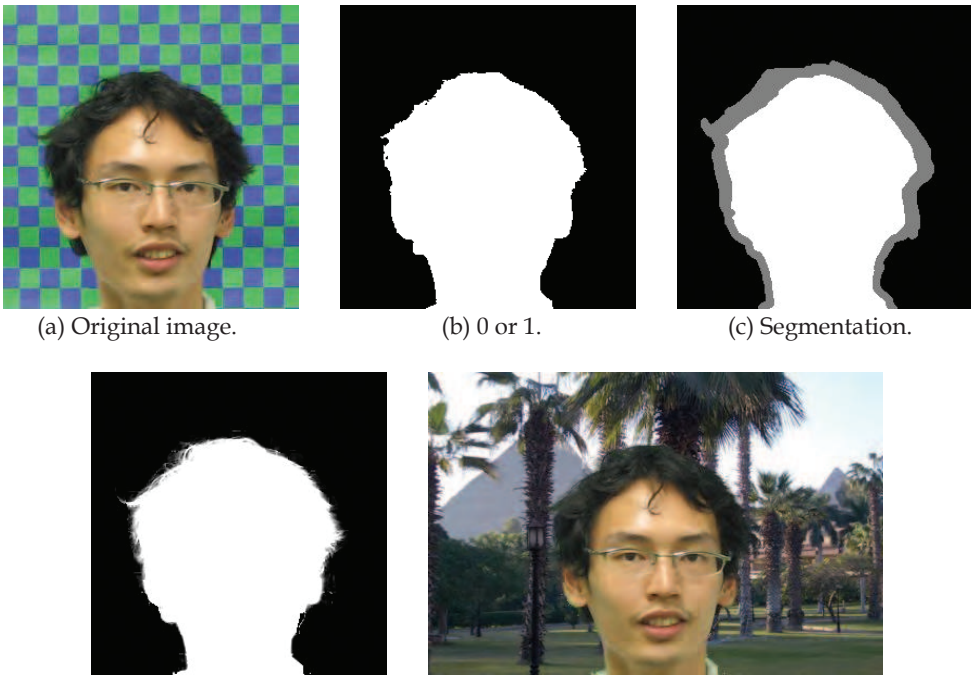
$$|\nabla I(\mathbf{s}_i)| = \begin{cases} |I(u_i+1,v_i)-I(u_i,v_i)|+|I(u_i,v_i+1)-I(u_i,v_i)|, & \text{if } (u,v)\notin R_3, R_4 \\ |I(u_i+1,v_i)-I(u_i,v_i)|, & \text{if } (u,v)\in R_3 \\ I(u_i,v_i+1)-I(u_i,v_i)|, & \text{if } (u,v)\in R_4 \end{cases} \tag{11}$$

Equation (11) shows that the contour model should not be attracted to the edges belonging to the background grid lines. The horizontal and the vertical background grid lines are regarded as edges that have large intensity gradients along the vertical and the horizontal directions, respectively. Therefore, we make directionally selective calculation of intensity gradients for pixels belonging to region R_3 or R_4 in Equation (11).

5. Image Composition

The extracted foreground image and another background image are combined by using Equation (1) (Fig. 2(f)).

The alpha values for the background pixels are decided as 0 (black regions in Fig. 11(b)), and those for the foreground pixels are decided as 1 (white regions in Fig. 11(b)) by using Snakes. It is important to decide binary alpha values for region extraction, however, alpha values of boundary regions between foregrounds and backgrounds are neither 0 nor 1. Therefore, we estimate alpha values by using Bayesian approach to digital matting (Chuang et al., 2001).



(a) Original image. (b) 0 or 1. (c) Segmentation.

(d) Alpha matte. (e) Composite image.

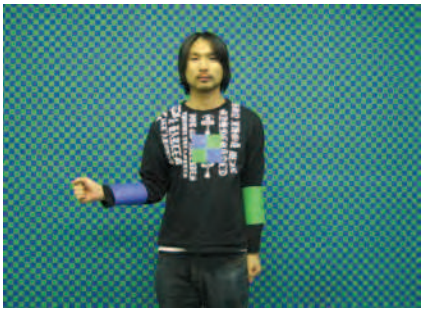
Fig. 11. Image composition.

Conservative foregrounds (white regions in Fig. 11(c)), conservative backgrounds (black regions in Fig. 11(c)), and unknown regions (grey regions in Fig. 11(c)) are segmented from the region extraction result by using foreground extraction results by Snakes.
Alpha value, in other words, opacity for each pixel of the foreground element, is estimated by using a modified Bayesian matting method that can extract same color regions with backgrounds (Fig. 11(d)), and a natural composite image is generated by using the opacity (Fig. 11(e)). Note that Snakes is essential to our method for deciding initial foreground regions and dividing image into three regions. Our method cannot work well without Snakes, because initial foreground contours is important for estimating opacity for same color regions with backgrounds.

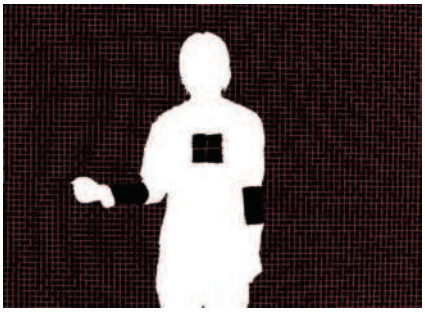
6. Experiment

Experiments were performed in an indoor environment. In the experiments, we selected blue and green as the colors of the checker pattern background, because they are complementary colors of human skin color and generally used in chromakey with a unicolor background.
The pitch of the checker pattern was 30mm x 30mm to interpolate the boundary of R_6 region precisely. Note that we have also compared the patterns of the background, e.g. triangle, quadrate, hexagon, and so on (Matsunaga et al., 2000). Checker pattern (quadrate) was selected from the simulation results of the optimization by considering the accuracy of foreground extraction (the numbers of the endpoints of region R_7 can be increased) and the computation time.
The sizes of still images were 1600 x 1200 pixels, and those of the moving image sequence were 1440 x 1080 pixels, respectively.
The threshold value T for a color extraction in Equation (4) was 20. The length l of regions R_3 and R_4 was 4. The weighting factors w_{sp1}, w_{sp2}, w_{image}, w_{area} for Snakes were 30, 3, 2, 1, respectively. In approximation of the background grid lines by a least mean square method, we used quartic equations to fit. All parameters were determined experimentally by manual search for optimal ones to give good results. These parameters were unchanged throughout the experiments.
The method has been verified in an indoor environment with a lot of people whose clothes were diverse in color.
Figure 12 shows an experimental result, where Fig. 12(a) shows a foreground image, Fig. 12(b) shows a background extraction result, Fig. 12(c) shows a foreground extraction result before contour refinement, Fig. 12(d) shows a foreground extraction result after contour refinement (Snakes), Fig. 12(e) shows opacity for alpha matte, and Fig. 12(f) shows a result of the image composition, respectively.
Figure 13(a) shows a composite result without alpha estimation and Fig. 13(b) (enlarged result of Fig. 12(f)) shows a result with an alpha estimation. From these results, it is verified that natural compositions of difficult regions such as hair can be realized.
Figure 14 shows the results of region extraction using a unicolor, a stripe and a checker pattern background, respectively. Figures 14(a), (b) and (c) are original images to segment,

where sheets of the same paper used as the background are put on the foreground person in order to confirm the validity of the proposed method. Figure 14(d) shows that the foreground regions whose colors are the same as the background color can not be extracted. Figure 14(e) shows that if the foreground regions have the same colors as the background and have parallel contours with the background stripes, they can not be extracted. Figure 14(f) shows that the foreground regions whose colors are the same as the background color are extracted without fail.



(a) Original image.



(b) Background extraction.

(c) Foreground extraction.

(d) Snakes.

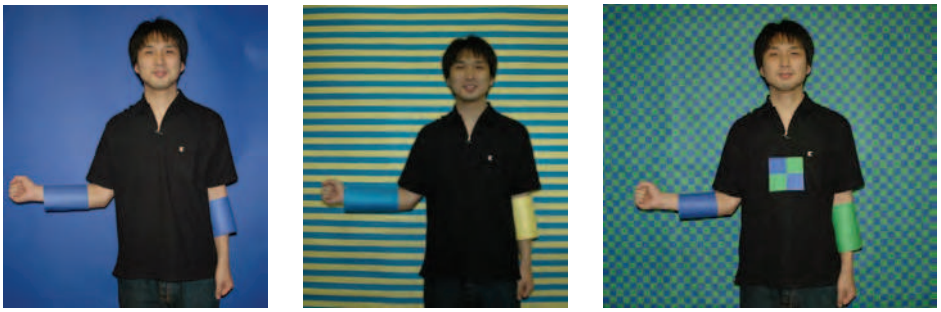
(e) Alpha matte.

(f) Image composition.

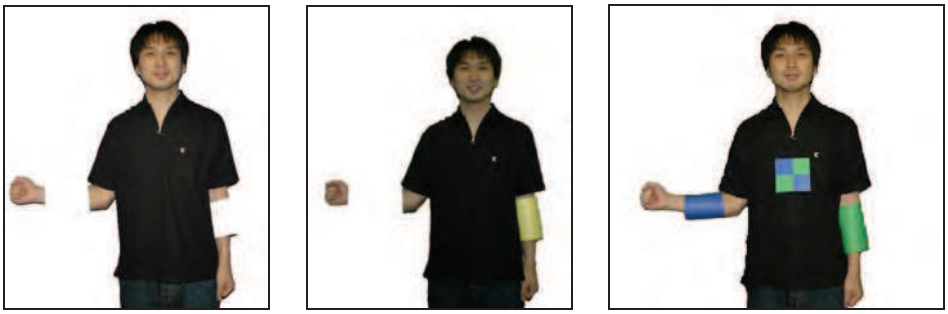
Fig. 12. Experimental result 1.

(a) Without alpha estimation. (b) With alpha estimation.

Fig. 13. Experimental result 2 (enlarged image of Fig. 12).



(a) Original image 1. (b) Original image 2. (c) Original image 3.



(d) Result image 1. (f) Result image 2. (g) Result image 3.

Fig. 14. Experimental result 3.

Figure 15 shows other experimental result. In Fig. 15(a), sheets of the same paper used as the background are put on the foreground person. In Fig. 15(b), same color checker pattern are put inside the foreground person. In Fig. 15(c), the foreground person holds his pelvis with his left hand, and there is a hole inside the foreground person. From these results, it is verified that foreground objects can be extracted without fail regardless of colors and shapes of foreground objects whose colors are same as the background colors.

(a) Same colors as background.

(b) Same color checker pattern as background.

(c) Hole (Person who holds his pelvis with his left hand).

Fig. 15. Experimental result 4.

Figure 16 shows results for a moving image sequence, where (a), (b) show foreground images, and (c) shows results of image composition, respectively.
From these experimental results, the effectiveness of the proposed method is verified.

(a) Original image 1. (b) Original image 2. (c) Composite image.

Fig. 16. Experimental result 5.

7. Conclusion

In this paper, we proposed a new chromakey method using chromakey with a two-tone checker pattern background. The method solves the problem in conventional chromakey techniques that foreground objects become transparent if their colors are the same as the background color. The method utilizes the adjacency condition between two-tone regions of the background and the geometrical information of the background grid lines.

Experimental results show that the foreground objects can be segmented exactly from the background regardless of the colors of the foreground objects.

Although our proposed method can work successfully, parameters for image processing should be determined automatically based on appropriate criteria to improve our method. When applying the method to a video sequence, we should take the advantage of interframe correlation. The parameters and the background grid-line geometry obtained in the first frame can be utilized in processing of succeeding frames so that the total processing time will be much shorter.

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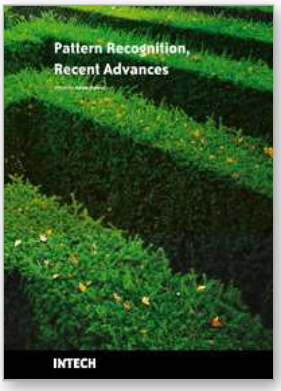

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