Segmentation with Invisible Keying Signal.

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Abstract

Croma keying *is the process of segmenting objects from images and video using color cues. A blue (or green) screen placed behind an object during recording is used in special effects and in virtual studios. The blue color is later replaced by a different background.*

Blue screen is an example of chroma keying *where the keying signal is chroma difference.*

A new method for automatic keying using invisible signal is presented. The advantages of the new approach over conventional chroma keying include: (i) Unlimited color range for foreground objects. (ii) No foreground contamination by background color. (iii) Better performance in non uniform illumination. (iv) Features for generating refraction and reflection of dynamic objects.

The method can be used in real-time and no user assistance is required. New design of Catadioptric camera and a single chip sensor for keying is also presented.

Keywords: Segmentation; physics based vision; Vision with graphics

1 Introduction

Chroma keying is used in video and movie production for replacing the background in special effects and in virtual studios applications and for hiding objects.

Through this article we shall refer to the objects of interest as the *foreground* and to the objects that we want to exclude as the *background* regardless of their actual position in the scene.

In order to express transparency and very thin objects (such as hair) fuzzy separation of foreground and background is done. This fuzzy separation is usually coded as a gray scale mask image called *an alpha channel* or a *matte*.

The chroma keying process is illustated by fig 1. The forground objects is places in front of a blue (or green) screen.

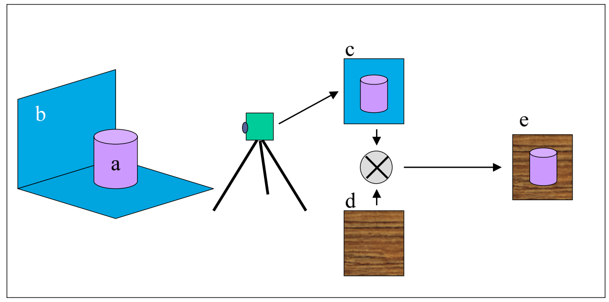

Figure 1. Chroma keying propcess. The forground object (a) is photographed in front of a blue background (b) to form an image (c). The background of the image (c) is replaced by a new background (d) to form a composite image (e).

A video camera captures the image of the foreground object and the blue background. The blue background is then replaced by a new background.

Chroma keying has several drawbacks that are discussed below.

Foreground color problem

Obviously, no foreground object can be close in color to the color used for the keying.

The cause of this problem is the usage of keying signal which is located within the visible spectrum. The keying signal competes with the foreground objects over spectral bandwidth.

Background lighting problem

Chroma keying also uses intensity information to incorporate semi-transparency and shadows into the matte. The background color and intensity are compared to a preselected reference color. Uneven background lighting conditions can cause wrong classifications of scene objects.

Background lighting problem is demonstrated in Fig. 2. We can see that a selection of different points as the reference blue leads to different mattes and hence different compositions. For still images, the operator can simply select different points until the desired result is obtained. However for a sequence of images, slight differences in the resulting matte can cause fluctuation - a very undesirable result in movies.

The Blue/Green spill problem

Spill is the contamination the foreground object by the background (keying) color. The blue screen is reflected from some foreground objects. Spill can cause problems in matte formation and in obtain a foreground image suitable for compositing. Moreover the large blue/green screen violates the color calibration assumption of many cameras which is usually set to gray 18% as a reference surface. This affects both brightness and color balance. Although the camera can be preset correctly, adjusting this setting during photography, while the scene is changing is problematic.

Solving The spill is difficult.

Fig. 3.a shows an image as it was taken in front of a green screen. We can see that the skin color is shifted towards magenta - the complementary color of green due to the effect of the green background on the automatic color calibration. Cutting and pasting the foreground onto a gray background as shown in Fig. 3.b intensify this effect simply because the human vision does not have the green background to compensate for. We can also see green spill mainly at the hair.

Fig. 3.c shows a manual color balance corrected image. The skin color looks more natural, but the green spill is still there.

Fig. 3.d shows a composite image of the previous example over a dense gray background. The result looks very good, no green spill is visible. However when the image is composite over a red background instead of the neutral gray as seen in Fig. 3.e we can see a considerable red contamination. This is caused by interpreting the green spill as transparency as seen in the matte shown in Fig. 3.f.

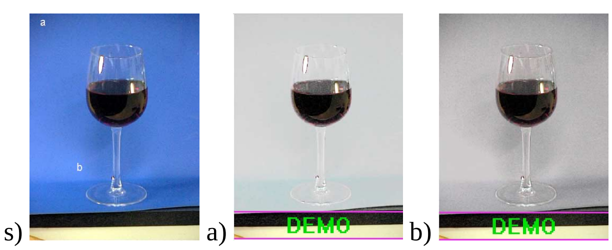

Figure 2. Background lighting problem problem. s) Selection of reference sites. a) Composite result for selection (a), we can see blue spill. b) Composite result for selection (b). We can see the brightness difference due to the different background reference points.

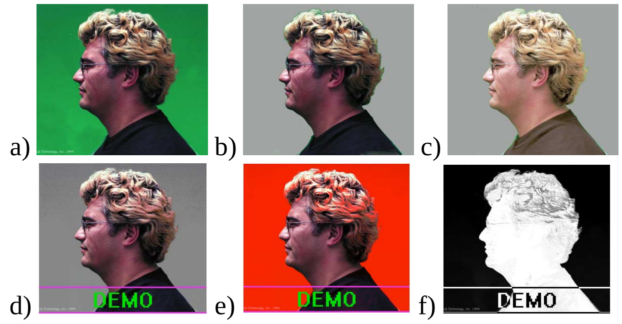

Figure 3. Green Spill problem - opaque object. a) The original image as it was taken in front of a green screen. b) The foreground cut and pasted over a gray background, we can see that the color of the skin is shifted towards magenta, which is the complementary color of green. We can also see some green spill mainly at the hair. c) Manual color balance correction. The green spill is still there but the skin look much more natural. d) Composition of the previous image with green spill correction over a neutral gray background. The result looks very good - no green spill left (Commercial product demo). e) Composition of the same image over a red background - Considerable red contamination appear. f) The produced matte shows that the green spill was interpreted as transparency - which was the cause for the red contamination.

A second example of blue spill is shown in Fig. 4 In this example the foreground is transparent and therefore the interpretation of the blue spill as transparency is the correct interpretation. However this cause color degradation over a considerable range of the spectrum even for neutral gray compositing. We can see the color degradation by the attached color bar that was copied from the original image before that keying took place.

The cause of these problems is the dominant background which (i) Violates the camera's gray 18% assumptions. (ii) Being a visible keying signal the keying signal cannot be simply filtered out without affecting the image. (iii) Reflection of the keying signal from the foreground objects.

A gray background and an invisible signal can solve the first two problems. In order to solve the reflectance spill problem a signal that is destroyed when it reflected from a foreground object is needed.

2 Keying with invisible signal

The invisible signal used in this article is light polarization, (infra-red and ultra-violet light can also be used).

An important property of polarized light is that once reflected from most objects (including human skin and clothes) it looses some or all of its former polarization. Only special materials such as silver-screen used for polarization based stereo presentation preserve the polarization. Polarized lights have some drawbacks that will be described later

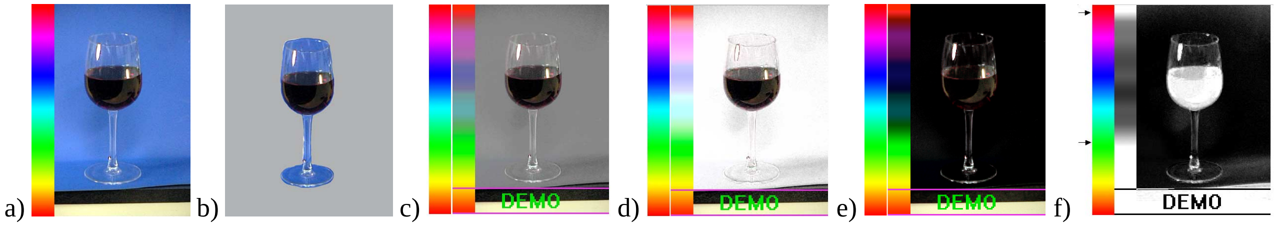

Figure 4. Blue Spill problem - transparent object. a) Original image - a glass over a blue screen with color spectrum bar attached to it, note that the human vision perceives it as it really is - a transparent glass over a blue background. b) Manually Cutting the glass and pasting it over a neutral gray background disables the human vision correction mechanism and reveals the real situation - the glass looks as a very blue glass, and this is what the blue spill algorithm should cope with. c) Compositing the image over a neutral gray background shows that the algorithm was able to eliminate almost every trace of the blue spill. The original color bar was attached to the image on the left, and as we can see that the blue spill correction algorithm caused a considerable degradation of colors. d,e) The color degradation is more apparent when the image is composite over a white or black background. f) The extent of the spectrum range affected by the blue spill correction algorithm is shown at the produced matte (marked with arrows).

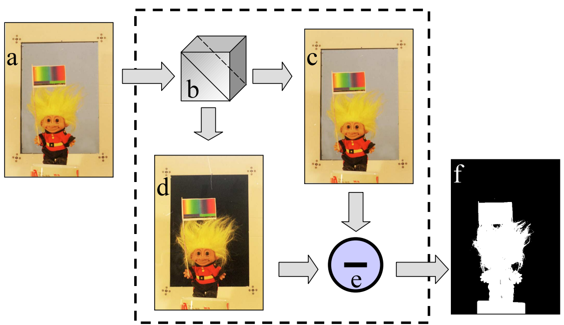

Figure 5. Principle of operation. a) Polarized background light and non-polarized foreground light enters the camera. b) A cube beam splitter splits the light by polarization to create an "in-phase" image **c** and an "out of phase" image **d** which has a dark background. e) The two images are aligned and the absolute brightness difference between them is used to create the matte **f**. The foreground for the composition is usually taken from the "in-phase" image **c** where the gray background is ideal for photography. All the icons in this diagram are real images obtained by the proposed method.

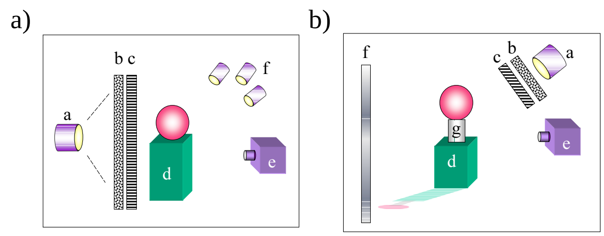

Figure 6. Studio setup. a) Back-lit setup: light from light source **a** passes through a diffuser **b** and through a linear polarizer **c** into the camera **e**. The foreground object **d** is illuminated by the non polarized ambient light **f**. b) Silver-screen setup: light from light source **a** passes through a diffuser **b** and through a linear polarizer **c**. The polarized light is reflected form the silver-screen **f** and it also casts shadows. The foreground objects **d** de-polarizes the light that illuminates it. The pole **g** is covered with silver-screen cloth and appear as background objects and thus allowing the ball to float above the box. (However, the shadow of the pole is still visible).

on.

At least two images are required for matting as the keying cue is brightness differences. The different images are obtained by using a polarization cube beam-splitter or a combination of regular beam splitter and two linear polarization filters.

The basic outline of a process is presented in Fig. 5. Polarized light from the background and unpolarized light from the foreground enter the camera. The light is split by cube and two images are formed. One image will look the same as the incoming image as only the intensity will be halved by the beam splitter. The second image will also have half the intensity of the foreground - however, the background, and only the background will turn black since it is "out of phase".

Both images must be aligned for matte formation. Since the two images have the same center of projection due to the use of the beam splitter, a homography transformation will fully aligned the images.

The matte was computed using the non-linear Sigmoid function $\frac{1}{1+e^{-\alpha(x-\beta)}}$ where x is the absolute difference, α is a slope parameter and β is the center point. For x in the range $[0 \ldots 1]$ good results were obtained for $\alpha = 15$, $beta = 0.5$.

Studio setup is described in Fig. 6. The background shown in Fig. 6.a is composed of a back-lit linear polarizer. This simple setup was used in the testing. The background shown in Fig. 6.b is composed of a silver-screen background and it is illuminated by a polarized light source. This setup can be used to hide objects and can capture shadows.

Keying problems in new light

Since the key in invisible, and the background color is neutral gray, the foreground colors problem and the color calibration problems are completely eliminated.

Since the keying is based on *relative* measure of brightness, it is adaptive to the illumination changes and no reference point is needed. For best results the camera should have a good dynamic range and the dark image does not be *completely* black.

The spill problems caused by transparency are completely eliminated by the invisible signal. Some spill may affect the matte due to reflectance of surfaces that preserve polarization (mainly in Studio setup (b)) - see limitations below.

Limitations

Polarized light usage is limited by: (i) Some surfaces, such as silver-screen and mirrors as well as specular points preserve some or all of the polarization and hence may cause spill problems especially in studio setup (b). Changing the orientation of the polarized light may reduce this problem. Setup (a) is almost free of polarized light reflection and did not showed any problems during experiments. (ii) Certain type of plastics, including CR-39 used for lenses of glasses, tend to show stress patterns when exposed to polarized light and viewed though a polarized filter. (iii) Very special minerals may rotate the angle of a polarized light going through them. (iv) Exact 45^o orientation of the camera will not detect brightness differences.

Infra-red and Ultra-violet may overcome some of these limitation, however they may present other limitations such as different transparency for visible light and IR/UV.

3 A Catadioptric camera design

Although it is possible to use two synchronized video camera at both sides of the beam splitter cube, this design is cumbersome and is not suited for film camera. We would like to use either a single high resolution camera to capture both images, or a convention stereo camera. A Catadioptric design have been used to build stereo camera using a single camera [2], here we use a stereo camera and mirrors to create two different images, but from a single view point.

A Catadioptric camera design is shown in Fig. 7, both images having the save view point. Fig. 7.a shows a very simple design suitable for a single camera with a disadvantage of a very slight scale difference between the left and right images due to the 1-2cm difference in light path length after the beam splitter. Fig. 7.b shows a more complex design which is symmetric and suitable for a stereo camera (film or video). A precise construction of the **b** camera design will eliminate the need for image registration. (The

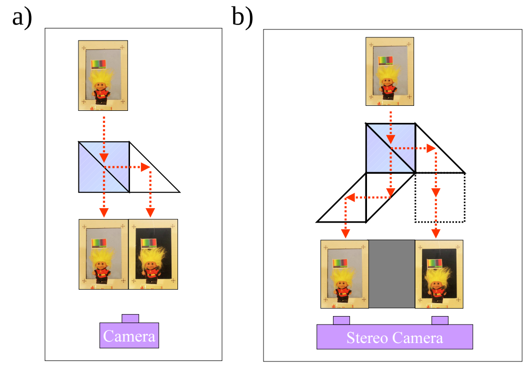

Figure 7. Catadioptric camera design. a) Beam splitter cube and a single prism design - suitable for single camera, but have a slight scale difference due to different length of the light path. b) Beam splitter and three prism design. suitable for stereo camera and fully symmetric.

Optic design used in the tests was of type **a**, and was not very precise, therefore image registration process was used to align the images).

4 Tests

Two tests were made: A transparent object test to check the color fidelity and a fine detail test to check the behavior of the polarized light and image registration at fine details like hair. The results of the transparent object tests results are shown in Fig. 8 and we can see that the transparency was captured well. Unlike the chroma keying, no false transparency was formed and both colors fidelity and composites showed good results.

The fine detailed test results are shown at Fig 9 we can see that fine detail like hair were detected and well integrated into the background. We believe that a precise optic system will produce even better result.

5 Proposed Single chip sensor layout

Modern color sensors such as CCD and CMOS sensor use micro filters to create RGB cells directly on the sensor. The filters are arranged as shown in Fig. 10.a. This design can be used to create a new type of sensor with a keying channel build in. All that is required is to place a complement pair of filters over the green sub-pixels. The color image formation remains un-changed. The keying channel is computed as the absolute different of the two green subpixels. This design is orientation invariant for polarizing filter pair and rotation invariant for IR/UV pair.

The keying channel can also be used to add markers into the scene that are visible only in the keying channel.

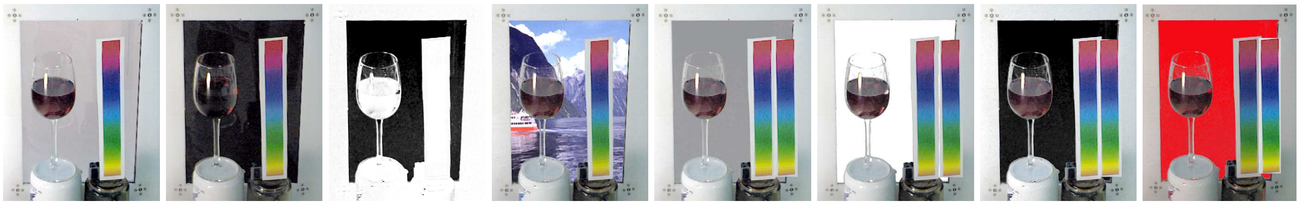

Figure 8. Transparent object test. The color bar is used to check color fidelity. The original color bar from the gray image was attached to the left of each image. a) "In-phase image" the background appear as light gray. b) "Out-of-phase image" the background appear as black. c) Produced matte. We can see that the matte expresses transparency and that it is not affected by color. d) Composite over a Fjord image. e) Composite over a synthetic gray background. f) Composite over a synthetic black background. g) Composite over a synthetic white background. h) Composite over a synthetic red background. We can see that in all composite images the colors of the foreground objects were not affected.

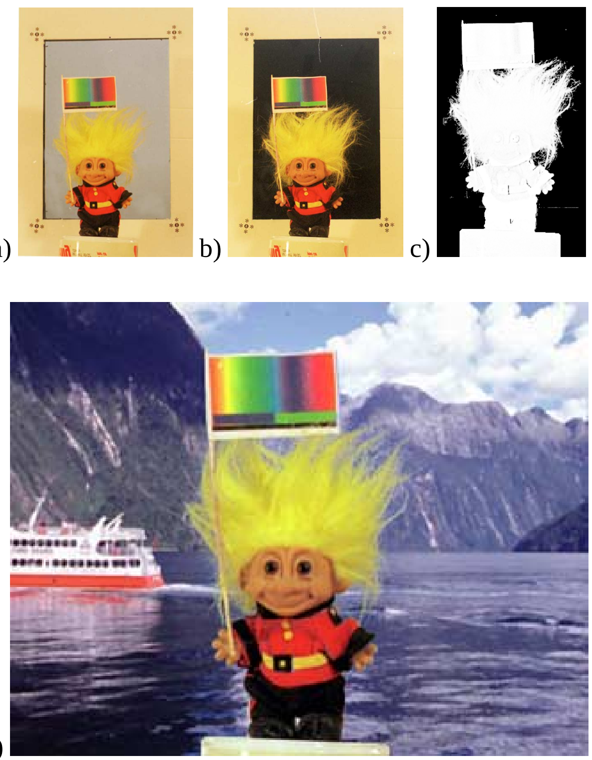

Figure 9. Object with fine details test. (The markers at the corners of the frame were used for alignment). a) "In-phase image" the background appear as light gray. a) "Out-of-phase image" the background appear as black. c) Produced matte. d) Compositing the doll image over a scenic image - fine details like hairs are visible and integrate well into the background.

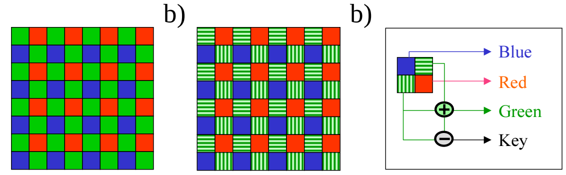

Figure 10. Proposed single chip sensor layout a) Conventional CCD/CMOS sensor layout. Pixels are covered with micro-filters. The Green channel which is the most visible to the human eye has twice as much sub-pixels as the blue and red channels. b) Proposed layout - The green pixels have complement pair of filters. c) Channel setup - The foreground image is generated as usual, for example average of the two green sub-pixels. The keying channel is produces by taking the absolute difference between the two green sub-pixels. This design is symmetric and it is orientation (landscape / portrait) invariant for polarized filters and rotation invariant for IR/UV filters.

6 Proposed Environment matting for dynamic objects

Environmental matting is the process of capturing not only the shape of the object but also its reflection and refraction pattern [5].

Environmental matting process uses a sequence of eighteen or more computer generated background images that forms a basis. The number of background images is a function of the desired resolution.

In order to capture the environment of a dynamic object, for example, a glass with water, all basis images should be captures at the same instance - which is not possible with chroma keying.

Getting several different background images at the same instance is possible if the background is composed of all the different background images and the input image that was captures at a single instance is decomposed into its original components. If color information is not important (trans-

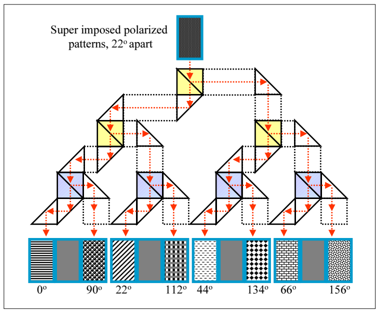

Figure 11. Environment matting outline. A recursive design for eight images. The input image that is a composition of eight different pattern that are projected onto a silver screen, is instantaneously decomposed into different background images required for environmental matting. Yellow cubes are regular beam-splitters. Blue cubes are polarized beam-splitters.

parent glass containing water) This can be done by using spectral information by a multi-spectral camera (as a regular RGB camera does not have enough channels). Fig. 11 shows a camera design that is based on polarization. It is based on the fact that polarized light is completely blocked only in a narrow angle of a polarization filter/beam-splitter, and therefore different pattern will appear at different angles. The design is a recursive implementation of the symmetric design shown at Fig. 7.b.

Replacing the polarization beam-splitter with regular beam splitter and adding band pass filters and monochromatic camera will forms a multi-spectral camera.

The foreground image for the composite should have a neutral texture. This image can be obtained - at the same instance - from a non-polarized, non-filtered branch of the tree.

7 Concluding Remarks

A new method of segmentation by keying was presented based on invisible keying signal. The method can segment objects with any color and any texture. It preserve original colors. It is completely spill free for foreground objects by filtering and almost spill free for matte generation due to the de-polarization of reflective light by most surfaces. The method is adaptive to background illumination changes. It does not require a-priori information, and it can work in real-time. No user attention is required. The method may be extended to environment keying of dynamic objects.

Acknowledgments

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