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Additional Information

# **Chroma Key without Color Restrictions based on Asynchronous Amplitude Modulation of Background Illumination on Retroreflective Screens**

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**Abstract.** A simple technique to avoid color limitations in image capture systems based on chroma key video composition using retroreflective screens and light-emitting diodes (LED) rings is proposed and demonstrated. The combination of an asynchronous temporal modulation onto the background illumination and simple image processing removes the usual restrictions on foreground colors in the scene. The technique removes technical constraints in stage composition allowing its design purely based on artistic grounds. Since it only requires adding a very simple electronic circuit to widely used chroma keying hardware based on retroreflective screens, the technique is easily applicable to TV and filming studios.

**Keywords.** Chroma keying, Video segmentation, Image processing, Digitization and image capture

## **Introduction**

Chroma key video composition is a widespread technology in filming and video production used to combine a background image with video captures of real objects [1-6]. This technique offers good performance, cost savings by avoiding exterior filming and expensive scenery as well as versatility to integrate real and computer-generated shots while requiring no complex infrastructure. Due to these advantages chroma key is employed not only in the film industry but also in other areas such as press, education, gaming, and augmented reality ([4,7]).

Conventional chroma key is based on filming a real object in front of a monochromatic even surface known as cyclorama. This image provides an input into a chroma key processor which removes the cyclorama color and substitutes it by the desired background image (which can be a still image or moving video of real objects or a computer-generated image). Thus, the chroma key processor combines two images in such a way that they can be keyed to a different background by replacing the color key of the real image with the background image. After chroma processing, the composite image is broadcast or recorded.

At first, any color can be used for the cyclorama provided it is not present in the foreground. Initially, blue was the main choice since it is complementary to human skin and thus the replacing of the chroma key color with the background image can be eased. When digital cameras expanded in the studios, green became more popular since it requires less light in the background and is less common in costumes. Thus, blue and green are the most common colors employed although other options, as magenta for example, have been used.

Although a part of everyday filming and television studios, chroma key present the problem that the background color, or a similar one, cannot be present in the foreground since areas of this color will be removed. This result in restrictions in the design of costumes, props, makeup, etc which limit artistic creativity.

To ease this problem, modifications to the conventional chroma key system have been presented. Among others these include a nonparametric sampling-based technique [8], the use of a two-tone checker pattern background [9], synchronized flash keying [10-11], and synchronized video projections and illumination for luma keying [13]. In [13] it is shown for still images that if the image is shot with two background colors (triangular matting), it is possible to extract a foreground containing any color. A technique to extend this approach to process moving objects was proposed in [14]. By adding a flatpanel monitor, a backprojection screen or a softbox to the setup, it is shown that a synchronized color sequence can be displayed in the background and, by doubling the frame rate and averaging two subsequent frames, color spill can be neutralized while the system can operate with any foreground color.

Here, we report on a method to further simplify chroma keying systems without restrictions on foreground colors. Instead of a synchronized system [10-13], a technique to eliminate color restrictions based on an asynchronous background illumination alternating between two background intensities and a retroreflective screen is presented. An asynchronously electronic-controlled LED ring (chroma ring) is used to project a temporally alternating color pattern onto a retroreflective screen. In this approach, color spill is inherently reduced due to the properties of the retroreflective material. Unlike previous work, this technique only introduces a simple electronic controller plus extra processing while the rest of the components and infrastructure are those already present in a chroma key system. Thus, it simplifies the setup in comparison to previous proposals and reduces cost while allows chroma keying with any color in the scene.

### **Principle of Operation**

For chroma key segmentation a bright monochromatic surface is needed. During the last years it has become increasingly common to use a screen made of retroreflective fabrics which reflects the light of a chroma ring (typically a ring of LEDs mounted around the lens designed to illuminate retroreflective screens) to generate a good key signal with low noise. This approach offers a uniform surface color as well as quick deployment. Additionally, thanks to its highly directive retroreflexion, color spill from the background is reduced in comparison to diffuse screens.

Retroreflective materials are typically made of small glass beads with a reflective coating on half the surface or corner-cube prisms. For chroma key applications [4] a cloth coated with a large number of microscopic randomly-oriented half-silvered microsphere glass beads is usually employed. Random orientation of the glass beads offers a higher uniform reflectivity for any angle of incidence in comparison with corner-cube reflective materials.

Here, it is shown that besides its easy deployment, low cost and good performance, a retroreflective screen can also be used to avoid color restrictions in video segmentation based on chroma key by adding a simple electronic controller.

The technique is based on using a temporal pattern on the background in such a way that a processing algorithm can identify changing pixels with the expected pattern as background.

Figure 1 shows a diagram of the proposed setup which is basically a standard recording setup for chroma key filming based on retroreflective screens. A chroma ring is attached to the camera and the actors are shot against a retroreflective screen. To implement the temporal background pattern from this setup, it is only needed to add a simple control circuit to control the light intensity emitted by the chroma ring and include some additional processing in the Chroma Key unit.

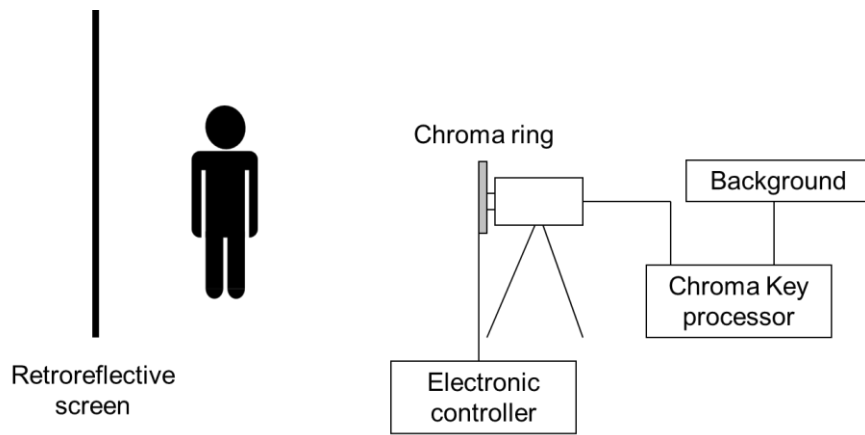


Figure 1. Schematic diagram of the proposed technique.

The composite color ( $C$ ) at each pixel for frame  $t$  is computed from a linear combination of foreground ( $C_f$ ) and background ( $C_b$ ) colors as given by,

$$C(t) = \alpha(t)C_f(t) + (1 - \alpha(t))C_b(t) \quad (1)$$

where  $\alpha(t)$  is the alpha key value or alpha matte which represents the transparency of each pixel. The color of each pixel can be represented as  $C_i = [R_i \ G_i \ B_i]$ .

Instead of the conventional alpha matte based on the level of a certain color from a single image, in the proposed technique this information is combined with a second alpha matte. In this new alpha matte, pixels where the color of the constant background changes from one image to the next are marked as background. Taking green as the background color (key color), the final alpha matte can be expressed as:

$$\alpha(t) = \alpha_{conventional}(t) \wedge [A_1(t) \vee A_2(t)] \quad (2)$$

where  $\alpha_{conventional}(t)$  is the traditional alpha matte algorithm, and

$$A_1(t) = \begin{cases} |G_f(t) - G_f(t-1)| \geq Th_G \wedge |R_f(t) - R_f(t-1)| \leq Th_R, \\ \forall t \mid \frac{dG(t)}{dt} > 0 \\ |G_f(t) - G_f(t-1)| \leq Th_G \wedge |R_f(t) - R_f(t-1)| \leq Th_R, \\ \forall t \mid \frac{dG(t)}{dt} < 0 \end{cases} \quad (3)$$

$$A_2(t) = \begin{cases} |G_f(t+1) - G_f(t)| \geq Th_G \wedge |R_f(t+1) - R_f(t)| \leq Th_R, \\ \forall t \mid \frac{dG(t)}{dt} > 0 \\ |G_f(t+1) - G_f(t)| \leq Th_G \wedge |R_f(t+1) - R_f(t)| \leq Th_R, \\ \forall t \mid \frac{dG(t)}{dt} < 0 \end{cases} \quad (4)$$

where the parameter  $Th_i$  with  $i = R, G, B$  is the color increase/decrease threshold for green, red and blue, respectively, and  $R_f$  and  $G_f$  correspond with the red and green components in the foreground image. An increase or decrease of the key color is used to identify background pixels since only the retroreflective screen will follow the evolution of the chroma ring. An additional condition, based on small changes in the red components, is included to ensure that only the key color is changing and avoid identification errors due to movements in the scene.

The rate of the temporal pattern is given by the electronic controller. This rate could be limited by the switching speed of the chroma key ring but since they are made of standard LEDs which show switching times of the order of ns there is not restriction from this side. Another restriction comes from the fact that the LEDs rate has to be fast enough to avoid discomfort to actors from the blinking illumination, especially in situations where actors look directly at the camera with the attached chroma ring, since it can be really unpleasant especially when light is switched on/off with a high modulation index. However, rates above the critical flicker frequency of human vision [15] strongly reduce the perception of the temporal pattern.

In the proposed technique, no synchronization is needed. Although a system where background illumination is synchronized to the camera is also possible, using no synchronization simplifies the setup and reduces cost, cable connections and deployment time.

### **Experimental Results**

To validate the feasibility of the proposed technique some experiments have been carried out in a TV studio using the setup of Fig. 1. A retroreflective screen by Reflectomedia is used jointly with a standard chroma key ring made of green LEDs [16]. For video recording, a HD camera (model Canon XL H1) and a NewTek Tricaster production unit have been employed to capture 1920x1080i video sequences. A very simple circuit (whose estimated cost is under 10 dollars) based on a 555 timer integrated circuit, shown in Figure 2, has been used to control light emission by the chroma ring. It provides a square signal to feed the chroma ring with a configurable frequency by means of a switch.

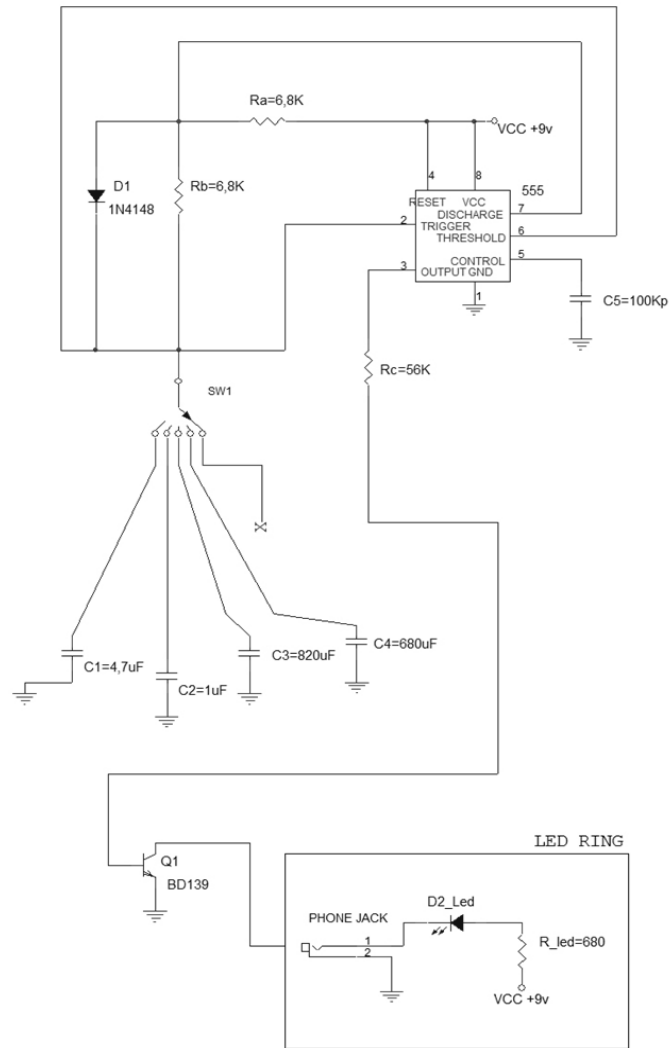


Figure 2. Asynchronous chroma ring illumination controller based on an astable-mode 555 circuit connected to the LED ring. A switch allows the selection of the square wave light: C<sub>1</sub>) T=44 ms (22 Hz); C<sub>2</sub>) T=9.5ms (106 Hz); C<sub>3</sub>) T=7.7 ms (130 Hz) and C<sub>4</sub>) T=6.4 ms (156 Hz) as well as combinations between them. Although only one LED is shown in the schematic for the sake of simplicity, the LED ring is made of 36 green LEDs.

Several tests were carried out showing that using frequencies beyond 50 Hz no flicker was observed. On the other hand, recording was not recommended with lower frequencies due to considerable discomfort generated by the flickering. The square illumination pattern generated with the setup of Fig. 2 is sampled by the camera at 25 frames per second as shown in Figure 3. Since the sampling frequency does not satisfy Nyquist theorem (what would require a very slow



chroma ring frequency which will be very disturbing to people on the stage), the shape of the light pattern is not conserved by the camera and a certain background intensity pattern is generated. For frequencies close but not equal to the sampling frequency a triangular pattern can be observed as it is schematically depicted in Fig. 3.

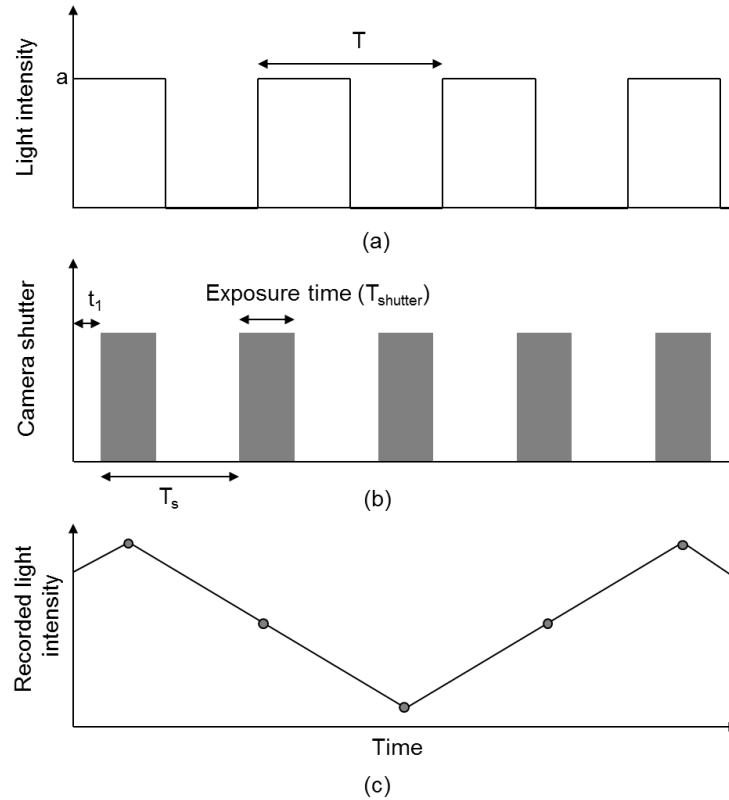


Figure 3. Background light subsampling by camera shutter: a) on-off lighting generated by the circuit of Fig. 2; b) sampling by the camera; c) light pattern captured by the camera.

The light intensity at frame  $n$  given by the gating and subsampling is,

$$y[n] = \int_{t_1+nT_s}^{t_1+nT_s+T_{shutter}} \sum_{n=-\infty}^{\infty} \alpha \Pi(t - kT) dt \quad (5)$$

where  $t_1$  is the time offset between the background light and camera sampling rate,  $T_s$  is the camera sampling period (inverse of the frame rate),  $T_{shutter}$  is the exposure time of the camera (inverse of the shutter speed),  $a$  is the light intensity,  $\Pi$  is the square waveform, and  $T$  is the period of the square wave background light.

Assuming that the circuit of Fig. 2 is generating a square wave light with a 50% duty cycle and  $T_{shutter} < T/4$ , equation (5) can be expressed as,

$$y[n] = \begin{cases} 0, & x < \frac{T}{4} - T_{shutter} \\ a \left( x - \frac{T}{4} + T_{shutter} \right), & \frac{T}{4} - T_{shutter} < x < \frac{T}{4} \\ aT_{shutter}, & \frac{T}{4} < x < \frac{3T}{4} - T_{shutter} \\ -ax + \frac{3T}{4}a, & \frac{3T}{4} - T_{shutter} < x < \frac{3T}{4} \\ 0, & x > \frac{3T}{4} \end{cases}$$

where  $x = t_1 + (n-1)T_s \bmod T$ .

Figure 4 shows color intensity (for red, green and blue) for two pixels corresponding to: (solid) the retroreflective screen (background); and (dashed) an object in the scene (foreground) when the frequency of the square illumination is 98 Hz.

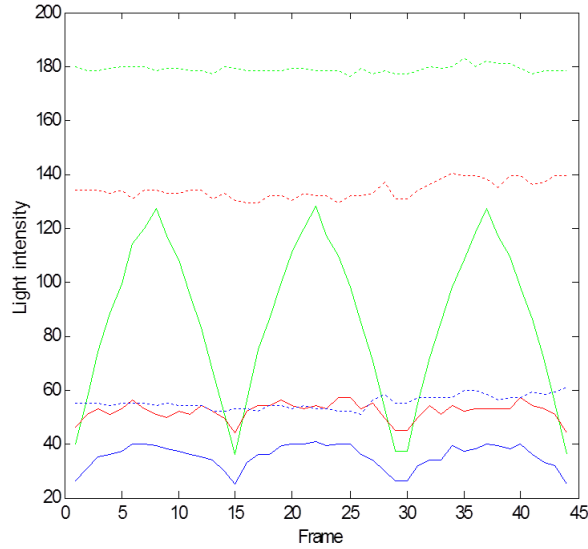


Figure 4. Color evolution for two pixels: background made by the retroreflective screen (solid) and an object in the foreground (dashed).

As can be seen from Figure 4, a temporal pattern (triangular signal) is present in the green component of background pixels due to subsampling of the square illumination by the camera (in this case with a shutter time of 1/120 of a second). A small change with time of the blue component can also be seen. Due to this change only the red component is checked in equations (3)-(4) to ensure that

color change is due to the temporal pattern given by the circuit of Fig. 2 and not due to movements in the scene.

Using the conditions given by equations (2)-(4), a processing code in MATLAB was developed to compute the alpha matte and implement the chroma key. The added computational cost due to the extra processing of the algorithm is around a 14% higher in computing time than a conventional chroma key system. For these experiments a frequency of 58 Hz and a shutter time of 1/120 seconds were chosen.

Figure 5b shows an unprocessed frame captured using the proposed setup as well as a previous (5a) and a posterior (5c) frame used for processing. A cloth, with a set of green tones as close as possible to the green tone of the background, has been included to test the capability of chroma keying without color restrictions.



(a)



(b)



(c)

Figure 5. Original moving image sequence for composition: a) Previous image; b) Image to be processed; c) Posterior image.

Figure 6 shows image composition using a conventional chroma key algorithm based on a single image. As it can be seen, foreground extraction fails

and regions of the same color of the background are wrongly interpreted as background and they are transparent in the composed image.



Figure 6. Image composition based on a conventional chroma key algorithm.



Figure 7. Alpha matte derived using equations (2)-(4).

Using the temporal background pattern, and taking advantage of the use of the retroreflective screen, the alpha matte can be derived independently of the foreground colors. The alpha matte can be obtained using equations (2)-(4) and it is shown in Figure 7.



Figure 8. Image composition based on the algorithm shown in equations (2)-(4).

The extracted foreground image using the alpha matte of Fig. 7 and a background image are combined using equation (1). The composed image is shown in Figure 8. In this figure is shown that foreground regions whose colors are the same as the background color are successfully extracted. The general lighting conditions of the studio were not altered when using the proposed technique.

As in conventional chroma keying, any darkened area in objects of the foreground may result in a poor result. Thus, proper lighting is still a key aspect when using the proposed technique.

### **Conclusion**

A simple technique to implement a chroma key which avoids restrictions on the colors used in the stage has been proposed. The technique is completely based on simple electronics and components of daily use in the television industry which result in straightforward compatibility with TV and filming studios with very low additional cost (less than \$10 in hardware) plus a reduced increase in computer time. It shows that color restrictions can be avoided without the need of complex electronics or setups.

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