Flicker and Black-streak Artifact Removal from Images of Display Monitors taken by Video Cameras

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***Abstract*—In this paper, we focus on removing black streak artifacts from video images of LED and VFD display monitors taken by video cameras. These streak artifacts affect the image recognition of characters displayed on the monitor, and also affect the quality of video compression. To interpolate correct pixel intensities, we apply an image composition method using light blending of images selected at an appropriate frame interval. The frame interval is decided based on the spectrum of the luminance oscillations at each pixel. Our experimental results show some improvements in the appearance of images and in video encoding.**

Keywords: artifact removal, flicker, refresh rate, image fusion

I. Introduction

When taking a video of display monitors such as electric billboards, artifacts such as moving black streaks are caused by the difference in drive frequencies between the camera and the monitor. Generally, this artifact poses no problem for humans since our eyes cannot perceive it; additionally monitor devices are designed taking this fact into account. In contrast, for machines, the artifact might become a cause for incorrect pattern recognition. For instance, some LED traffic signs are not captured by car-mounted cameras correctly. Therefore the post processing fails to recognize them [1], [2]. Also, the streak interferes with video encoding, because motion vectors calculated from luminances flickering at high frequencies often have the wrong orientation.

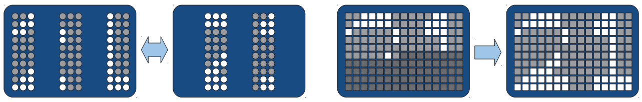
One way to solve the above problems is to adjust the camera shutter speed so it is synchronized with the refresh rate, i.e., the blinking speed of the monitor device. However, the refresh rates of traffic signs and electric billboards are different from each other. Therefore it is difficult to adjust the shutter speed for each device respectively. As a monitor device side solution, a novel monitor not producing the artifacts was developed [3]. However, it will take some time to come into widespread use, and there still remains a mountain of traditional monitors around the world. Additionally, the solution for this problem is mainly an improvement in the monitors. Thereby there seem to be few solutions on the camera device side.

In this paper, we present a simple but effective method to recover areas deteriorated by black streak artifacts. Our method is based on a photo composition method called ”light blending” that is used in star trail photography [4].

The contributions of our method are as follows:

(a) (b)

Fig. 1. Streaks arising on an LED monitor (a) and a VFD monitor (b). The arrows point to manually selected sampling pixels to detect the blinking interval.



(a) (b)

Fig. 2. Driving mode of LED monitors (a) and VFD monitors (b).

- **Frame interval estimation of flickering images**: To decide which image frames to use for blending, we analyze the luminance oscillation spectrum of a manually selected pixel.
- **Image composition method for selected frames**: Luminances of each pixel are compared among selected frames, and the maximum one is selected. We also present a multi-resolution method using the image fusion frame work.

The current limitations of our method is that the pixel used to analyze the spectrum has to be selected manually, and only supports movies of motionless objects.

II. Our Composition Method

In this section, we first explain black streak artifacts, then describe how to estimate the frame interval used in composition, and describe the luminance composition method based on light blending.

A. Flicker and black streak artifacts on monitors

There are several kinds of driving modes for monitor devices, and artifacts arise associated with these modes. Fig. 1 shows streak artifacts arising on an LED monitor (a) and a VFD monitor (b), while the driving mode of each monitor is illustrated in Fig. 2. LED monitors employ dynamic drives (a). VFD monitors employ raster scanning such as used in CRT monitors (b). These modes are used for power saving and mechanical simplification, and the blinking speeds are designed so as not to be detected by the human eye. However, when images of the monitors are taken by video cameras with shutter speeds higher than the monitor refresh rate, there are times when characters are not fully displayed, and this undrawn area causes streaks.

B. Detection of the streak frame interval

To decide which image frames to use for light blending, it is necessary to know the blinking interval of the streaks. First, we convert the image from RGB to YUV color, then select one pixel from among the blinking pixels manually, and observe the sequence of luminance intensities in the time direction $\{y_t\}_{t=1}^{N}$. In Fig. 1, the arrows point to the sampled pixels. Fig. 3 shows the luminance oscillations of the sampled pixels. The upper bounds are ideal luminances, and the lower bounds are luminances when streaks are present.

We analyze the spectrum of the oscillations by using the discrete fourier transform: $\{s^f\}_{f=1}^{N} = |\text{fft}(\{y_t\}_{t=1}^{N})|$, where the frequency f is normalized by dividing by the total number of frames and multiplying by the video frame rate r fps:

$$\bar{f} = f\frac{r}{N}. \tag{1}$$

Fig. 4 shows the spectra of the oscillations in Fig. 3, and the detected peaks.

For light blending, more than two image frames are required. Therefore, the frequency of the peak should be less than $r/2$ fps. For $r = 30$ fps video, the required peaks are lower than $r/2 = 15$ Hz. Additionally the afterimage effect that humans can detect is known to be at frame rates lower than 10 Hz. Therefore, we pay attention to peaks $\bar{f}_{\text{peak}}$ appearing in the range:

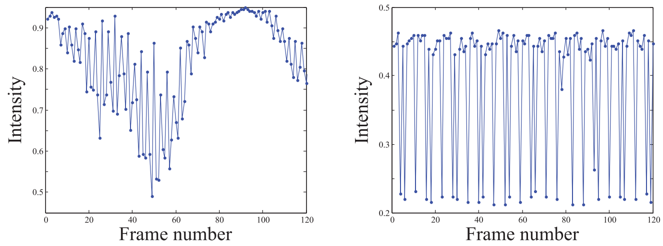
$$10\text{Hz} \leq \bar{f} \leq 15\text{Hz}. \tag{2}$$

Since the observed peaks $\{s^f\}_{f=\text{peaks}}$ generally have a sharp shape, the desired peak can be detected by using simple thresholding with an arbitrary threshold. In Fig. 4, the peaks of for the LED and VFD monitors are detected at 10.08 Hz and 12.40 Hz, respectively. The frame interval of the streak can be obtained by multiplying by the frame rate:

$$d_{\text{streak}} = \frac{r}{\bar{f}_{\text{peak}}}. \tag{3}$$

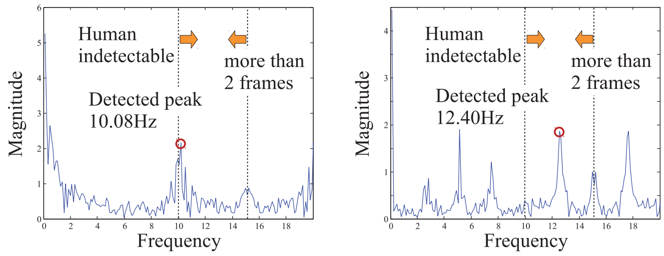
The streak intervals of the LED and VFD monitors are found to be 2.978 and 2.417 frames, respectively. This means that by selecting pixels from 1 of every 3 frames, at least 1 frame contains the actual pixel color. Thus the frame interval to remove the streak is the ceiling of d_{streak}:

$$\hat{d} = \lceil d_{\text{streak}} \rceil. \tag{4}$$



(a) (b)

Fig. 3. Luminance oscillation of an LED monitor (a) and a VFD monitor (b) at the pixels selected in Fig. 1. The oscillation of the LED intensity includes a different low frequency flicker associated with the afterglow of the LED.



(a) (b)

Fig. 4. Spectrum of the LED monitor (a) and the VFD monitor (b) at the pixels selected in Fig. 1. Note that the vertical axis uses a log scale to display the details, and the frequency of the horizontal axis is normalized by dividing by the total number of frames and multiplying by the frame rate.

C. Image composition using light blending

In image composition, we adopt two blending methods, simple light blending and multi-resolution blending.

Simple light blending

This method composes the selected image frames by taking the maximum RGB color intensity $c \in \{r, g, b\}$ at each pixel independently:

$$\hat{c} = \max(\{c_t\}_{t=\text{selected}}), \tag{5}$$

where t is the selected image frame. This method is very simple but effectively reduces the streak artifacts.

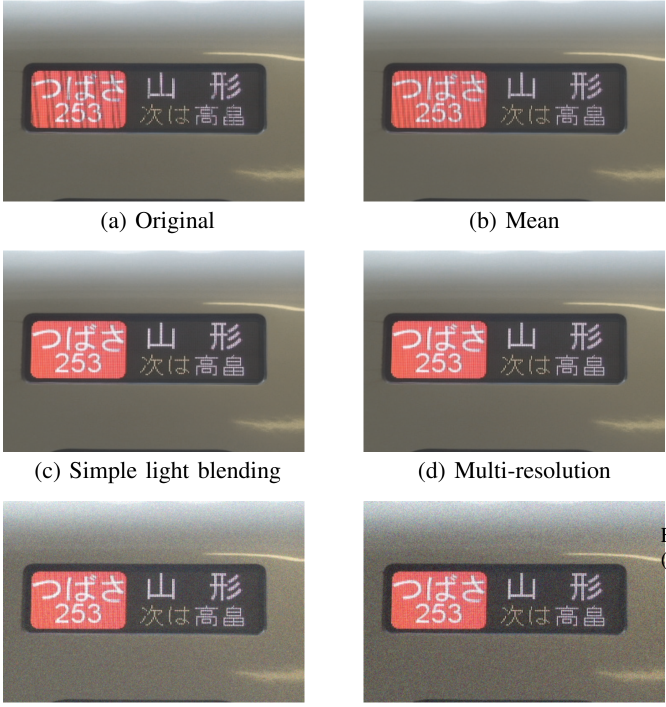
Multi-resolution light blending

Depending on the width and the gradation of the streaks, artifacts cannot be removed completely. Therefore we also apply a multi-resolution method based on image fusion such as exposure fusion [5]. This kind of image fusion method uses a weighted Laplacian pyramid. We set the weight (fusion rule) of each sub-band ℓ as follows:

$$\hat{c}^{\ell} = \frac{1}{\kappa} \sum_{t=\text{selected}} w_t^{\ell} c_t^{\ell}, \tag{6}$$

where $\kappa = \sum_t w_t^{\ell}$ is the normalization term. The initial weights at the finest resolution sub-band $\ell = 0$ are defined as:

$$w_t^0 = \begin{cases} 1 & \text{if } \max_t(\{c_t\}_t) = t \\ 0 & \text{otherwise} \end{cases}. \tag{7}$$

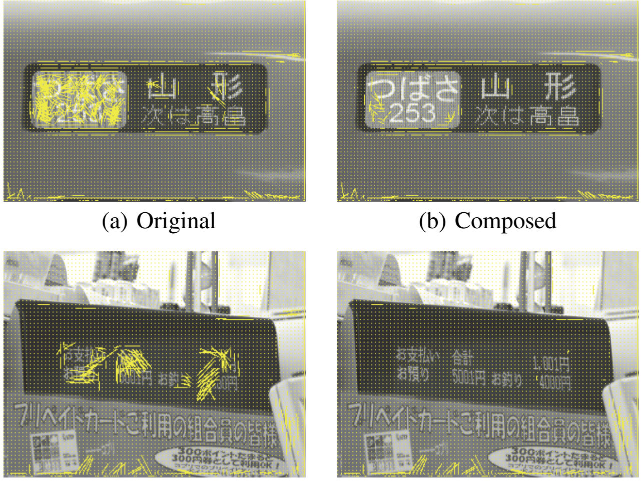


(a) Original (b) Mean

(c) Simple light blending (d) Multi-resolution

(e) Simple light blending with noise (f) Multi-resolution with noise

Fig. 5. Comparison of the composition methods. (a) Original, (b) simple mean, (c) simple light blending, (d) multi-resolution method. (e) and (f) are results under noisy conditions to emphasize the difference between (c) and (d).



(a) Original (b) Composed

(c) Original (d) Composed

Fig. 7. Detected motion vectors for video coding in the LED monitor images (a) and (b), and the VFD monitor images (c) and (d).

TABLE I

MPEG2 COMPRESSION RESULTS

	Source	Result	Difference	Improvement
LED	2.39 MB	2.07MB	0.32MB	13.9%
VFD	1.93MB	1.75MB	0.18MB	9.3%

The weights for other resolutions w_t^ℓ are generated by the Gaussian pyramid, and the Laplacian coefficients c_t^ℓ are decomposed by the Laplacian pyramid, in the same manner as [5]. Finally the new coefficients $\hat{c}^\ell$ are composed, and the fused result is obtained. When only the finest level $\ell = 0$ is used, this method corresponds to Eq. 5.

Fig. 5 shows a comparison of the composition methods. From this result, by using simple light blending (c) and multi-resolution light blending (d), better results are obtained. Actually the difference between (c) and (d) is small, and the multi-resolution method tends to emphasize the high frequency components including noise as shown in (e) and (f). Thus we think simple light blending (c) is appropriate for real time composition processing.

III. Experimental Results

We show some experimental results of our streak artifact removal method. The frame rate of the video camera is 59.94 fps in interlaced mode, and the de-interlaced frame rate is 29.97 fps. The resolution of the images is $360W \times 240H$.

Improvements in appearance

Fig. 6 shows the resulting images of an LED monitor (a) and a VFD monitor (b). The images in the upper row are the original images and those in the bottom row are the composition results. The sampled pixels to detect the blinking interval are the same as in Fig. 1. The frame intervals required to remove the streaks were determined to be $\hat{d} = 3$ in both cases using the same technique as for Fig. 3 and Fig. 4. From the results, we can see the streak artifacts have been successfully removed. When viewed as a movie, the images appear almost the same as they would when viewed with the naked eye.

In this experiment, only the adjacent three frames $\{c^{t-\hat{d}}, c^t, c^{t+\hat{d}}\}$ are used for the composition, and the processing delay $\hat{d}/r$ is only 0.1 sec. Therefore the motion blur caused by the composition is small.

Application to video encoding

Streak removal also affects video encoding, mainly during the process of motion vector estimation. Fig. 7 shows the motion vectors estimated by block matching (SSD), where (a) and (c) are the results in the presence of streak artifacts. We can see that a lot of vectors are incorrectly estimated. Looking at the images obtained after streak removal, (b) and (d), we can see that the number of incorrectly estimated motion vectors has been reduced.

We practically compressed the sequence of resulting images by using MPEG2. The compression results are shown in Table I. The improvement in the compression rate of the LED and the VFD monitor images are 13.4% and 9.3% respectively.

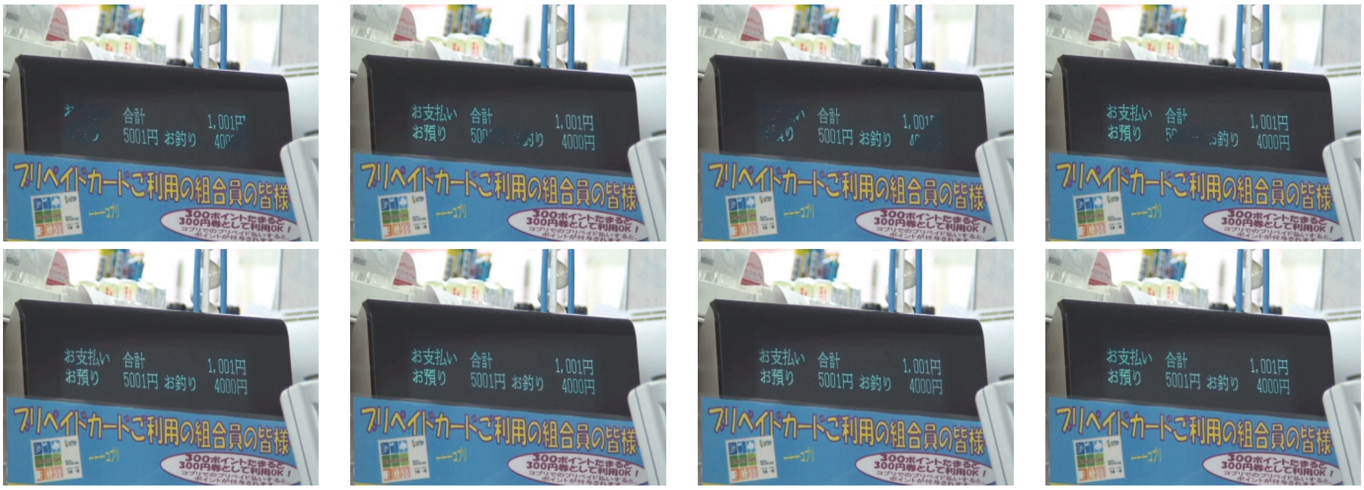
IV. Conclusions

In this paper, we showed a new approach to remove black streak artifacts from video images. Our method works on monitor devices such as LED and VFD, and improves the accuracy of post processing.

Currently, we assume the motion of the video cameras and photographic subjects are small. Therefore, to be able to

10^{th} frame 40^{th} frame 70^{th} frame 100^{th} frame

(a) LED monitor images deteriorated by streak artifacts (Top), and the interpolated images (Bottom)



10^{th} frame 40^{th} frame 70^{th} frame 100^{th} frame

(b) VFD monitor images deteriorated by streak artifacts (Top), and the interpolated images (Bottom)

Fig. 6. Resulting images of the LED monitor (a) and the VFD monitor (b).

use our method in practical situations such as vehicle video systems, additional modifications are required. For example, to detect the area with the luminance oscillation, the particle filter [6] based tracking method with oscillation likelihood is thought to be effective. Moreover, there is a possibility that important information such as text strings is displayed in these areas.

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