

古いフィルム映像のデジタル修復のためのショットチェンジ検出と カメラワーク推定

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あらまし 本稿では、古いフィルム映像のデジタル修復のためのショットチェンジ検出法とカメラワーク推定法を提案する。多くの古いフィルム映像では、映像が上下左右に揺れる位置ずれを発生しており視覚的に大変見辛くなっている。この位置ずれを補正するためには、映像をショット毎に分割し、分割されたショット毎にカメラワークを推定する必要がある。提案法において、ショットチェンジ検出には位相限定相関を用いる。位相限定相関を解析しその結果得られた性質より、ショットチェンジ検出に必要な閾値を設定する。カメラワーク推定は、位置ずれ推定結果をローパスフィルタリングすることにより行う。実験結果より、ショットチェンジ検出において、提案法は従来法より優れた検出精度を示した。また、カメラワーク推定結果を用いて位置ずれ補正した映像より、視覚的に十分な精度で位置ずれ補正が行えることが確認された。

キーワード 映像修復, 位置ずれ補正, ショットチェンジ検出, カメラワーク推定

Shot Change Detection and Camerawork Estimation for Old Film Restoration

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Abstract This paper proposes a shot change detection method and a camerawork estimation method for frame displacement correction of old films. The phase-only correlation is used for the shot change detection. The threshold of the shot change detection is determined mathematically using the properties of the phase-only correlation in the proposed method. Camerawork is estimated by lowpass filtering the frame displacement value. Experimental results show that the proposed method can detect the shot changes accurately and estimate the cameraworks. Visual inspection shows that the frame displacement is significantly reduced by the proposed method.

Key words old film restoration, displacement correction, shot change detection, camerawork estimation

1. Introduction

The main object of this paper is to detect shot changes and estimate cameraworks for frame displacement correction of old films. Frames of old films may suffer from vertical and horizontal movements, which we call the frame displacement. The frame displacement results from the slight distortion caused by film perforations [1] and the inaccurate timing of film transporting system in a camera. The correction of such displacement makes old films comfortable to view. If the

films are degraded by the frame displacement and other defects, it is difficult to make the task of video compression such as MPEG [2], [3]. Thus, the correction of the frame displacement improves the performance of an MPEG coder significantly [4]. In addition, the existence of the frame displacement has a bad influence on the result of blotch removal and flicker reduction. Therefore, the correction of the frame displacement is important as a preprocess of old film restoration.

We proposed the frame displacement estimation method

with subpixel accuracy using the phase-only correlation [5]. The steady movie can be obtained by the method with high accuracy unless the movie has camerawork. Cameraworks should be considered in the process of the frame displacement correction because many movies contain cameraworks.

Displacement estimation results by the proposed method include frame displacement and cameraworks. The cameraworks should be separated from the displacement estimation results by some method. For camerawork estimation, shot change detection is necessary as a previous process of camerawork estimation, because camerawork should be estimated in each shot. A conventional shot change detection method in Ref. [6] is very susceptible to noises such as blotches and flickers. A method robust to such noises is needed for old film restoration.

This paper is organized as follows: Section 2 introduces important properties of the phase-only correlation and displacement estimation method using the phase-only correlation. Section 3 proposes a shot change detection method using the properties of the phase-only correlation. Section 4 proposes a camerawork estimation method. Section 5 gives some experimental results to show the efficiency of the proposed method.

2. Phase-Only Correlation

The phase-only correlation [7] is defined as the inverse Fourier transform of the normalized cross power spectrum between two images, and represented as follows:

$$g_{ab}(n_1, n_2) = \text{IDFT} \left[\frac{A(k_1, k_2) B^*(k_1, k_2)}{|A(k_1, k_2)| |B(k_1, k_2)|} \right] \quad (1)$$

where IDFT denotes the discrete inverse Fourier transform, and $A(k_1, k_2)$, $B(k_1, k_2)$ are the spectrum of the original images $a(n_1, n_2)$ and $b(n_1, n_2)$, respectively. The phase-only correlation is robust against intensity flicker, which is a visible global brightness variation from one frame to the next, since the amplitude spectrum is normalized. The phase-only correlation is suitable for frame displacement estimation of old films.

The phase-only correlation can measure the displacement between a pair of images subject to unknown translational differences. Two important properties of the phase-only correlation are used for displacement estimation. One is that the phase-only autocorrelation is the delta function. The other is that the phase-only correlation is shifted at the same amount as the displacement between the two images. That is, if the image is shifted by τ then its phase-only correlation is shifted by $-\tau$. The displacement between the two images can be estimated by finding the location of the highest peak of its phase-only correlation, since the phase-only correlation of two similar images has a sharp peak.

The accuracy of displacement estimation is extended to subpixel by the method in Ref. [5]. Now, we consider the phase-only correlation $g_{ab}(n_1, n_2)$ between $a(n_1, n_2)$ and $b(n_1, n_2) = a(n_1 - \delta_1, n_2 - \delta_2)$, where δ_1 and δ_2 are subpixel displacement, respectively. When the discrete Fourier transform is used, the general form of the phase-only correlation depends on image size [8]. In case that the image sizes N_1 and N_2 are odd number, $g_{ab}(n_1, n_2)$ becomes as follows:

$$\begin{aligned} g_{ab}(n_1, n_2) &= \text{IDFT} \left[e^{j \frac{2\pi}{N_1} k_1 (n_1 + \delta_1)} e^{j \frac{2\pi}{N_2} k_2 (n_2 + \delta_2)} \right] \\ &= \frac{1}{N_1 N_2} \frac{\sin(\pi(n_1 + \delta_1))}{\sin(\frac{\pi}{N_1}(n_1 + \delta_1))} \frac{\sin(\pi(n_2 + \delta_2))}{\sin(\frac{\pi}{N_2}(n_2 + \delta_2))}. \end{aligned} \quad (2)$$

Since N_1 and N_2 are much larger than $\pi(n_1 + \delta_1)$ and $\pi(n_2 + \delta_2)$ in case that n_1 and n_2 are close values to $-\delta_1$ and $-\delta_2$ respectively, Eq. (2) can be approximated as a sinc function given by

$$g_{ab}(n_1, n_2) \simeq \text{sinc}(n_1 + \delta_1) \text{sinc}(n_2 + \delta_2). \quad (3)$$

In case that the image sizes N_1 and N_2 are even number, $g_{ab}(n_1, n_2)$ can be obtained as

$$\begin{aligned} g_{ab}(n_1, n_2) &= \frac{1}{N_1 N_2} \left(\frac{\sin(\frac{N_1-1}{N_1} \pi(n_1 + \delta_1))}{\sin(\frac{\pi}{N_1}(n_1 + \delta_1))} \pm \cos(\pi n_1) \right) \\ &\quad \left(\frac{\sin(\frac{N_2-1}{N_2} \pi(n_2 + \delta_2))}{\sin(\frac{\pi}{N_2}(n_2 + \delta_2))} \pm \cos(\pi n_2) \right). \end{aligned} \quad (4)$$

The terms $\cos(\pi n_1)$ and $\cos(\pi n_2)$ are caused because there are phase discontinuity at $k_1 = \frac{N_1}{2}$ and $k_2 = \frac{N_2}{2}$. The sign of each cosine term depends on the displacement values δ_1 and δ_2 . Equation (4) also can be approximated to the sinc function but the difference between Eq. (4) and the sinc function is larger than that of the Eq. (2) because the effect of cosine terms. We can obtain the displacement with subpixel accuracy by fitting the continuous sinc function to the discrete phase-only correlation. The quadratic curve fitting is used for the reduction of computation cost in our method. Figure 1 shows the computation process of the proposed displacement estimation method.

Other important properties are that the energy and the summation of the phase-only correlation between images always become unity as

$$\begin{aligned} \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} |g_{ab}(n_1, n_2)|^2 &= 1, \\ \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} g_{ab}(n_1, n_2) &= 1. \end{aligned} \quad (5)$$

For example, in the case of the phase-only autocorrelation, the energy and the summation become unity. Even if the

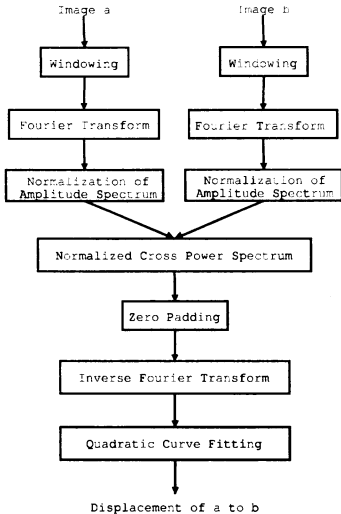


Fig. 1 Computation process of the proposed displacement estimation method

two images have no relationship (like white noise), the energy and the summation of the phase-only correlation also become unity.

3. Shot Change Detection

We must estimate cameraworks for frame displacement correction of old films, because the estimated displacement by the method described in the previous section includes both frame displacement and cameraworks as the estimated value. Separation of cameraworks and frame displacement is necessary for frame displacement correction preserving cameraworks. Moreover, shot change detection is necessary as a preprocess of camerawork estimation. This section introduces a conventional method of shot change detection and proposes a shot change detection method using the phase-only correlation.

3.1 Conventional method

We investigate a conventional method of shot change detection. This method uses color histograms to temporally segment video sequences [6], [9]. The difference between the histograms of consecutive frames is computed and large differences are marked as shot changes. The evaluation function of this method is shown as

$$f_{chi}(n) = \sum_{i=1}^M \frac{(h_{n-1}(i) - h_n(i))^2}{h_n(i)}, \quad (7)$$

where $h_n(i)$ indicates the histogram of frame n and M indicates the number of histogram bins. The histogram $h_n(i)$ is a color histogram in Ref. [6], but gray histogram is used in this paper because we only treat grayscale sequences.

This method is susceptible to noises. If the sequence is

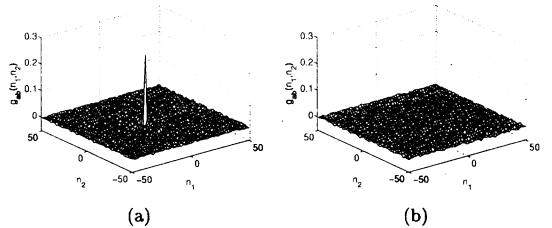


Fig. 2 Phase-only correlation near the origin

suffering from flickers, the value of Eq. (7) becomes large, because the difference between the histograms of the consecutive frames is larger. We have to develop a shot change detection method robust to noises such as flickers and blotches for old film restoration.

3.2 Proposed method

The proposed method estimates the frame displacement between consecutive frames in a sequence. This displacement estimation is performed from the first frame to the last frame. As described previously, the proposed method uses the phase-only correlation for displacement estimation. The phase-only correlation between two similar images has a sharp peak shown as Fig. 2(a), but the phase-only correlation between two different images has small random values shown as Fig. 2(b). The peak value of the phase-only correlation at shot boundaries becomes much smaller than the other points. The shot boundaries can be detected by measuring the peak values of the phase-only correlation and finding the small ones.

The threshold value for shot change detection should be considered. If the threshold is too high, the number of misdetections will increase. If the threshold is too small, we cannot detect any shot boundaries. It is significant to determine an appropriate threshold for accurate shot change detection.

The phase-only correlation between images on a shot boundary has no large peak but small random values. The sample values of the phase-only correlation between different images is distributed to the normal distribution. This is proved using the central limit theorem. Figure 3 shows the histogram of sample values of the phase-only correlation between different images. The histogram indicates that the normal distribution is a good model for this data set. The mean value and the variance of the normal distribution can be determined by the properties of the phase-only correlation. The mean value μ is determined as

$$\mu = \frac{1}{N_1 N_2} \quad (8)$$

by the property that the summation of the phase-only correlation always becomes unity as Eq. (6). The variance σ^2 is also determined as

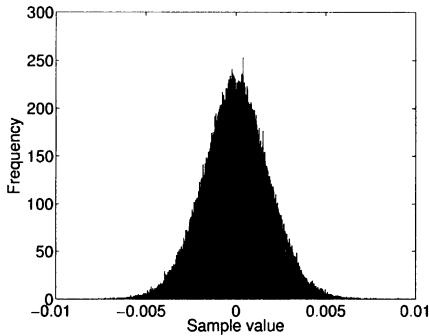


Fig. 3 Distribution of sample values of phase-only correlation between different images

$$\sigma^2 = \frac{1}{N_1 N_2} \quad (9)$$

by the property that the energy of the phase-only correlation always becomes unity as Eq. (5). Thus the sample values of the phase-only correlation between different images follows the normal distribution, and the mean value and the variance depend on the image sizes.

The threshold of shot change T_p is determined from these properties of the phase-only correlation. It is desirable to determine T_p slightly larger than the maximum of the phase-only correlation between different images. Figure 4 shows an example of the normal distribution. If the area of the hatched region covers 100% of all region, T_p may be a good threshold. However, we cannot detect the shot boundaries by the threshold, because T_p becomes ∞ when the percentage becomes 100%. In this paper, T_p is determined as $\mu + 4x_{3\sigma}$, where the percentage becomes 99.73% at the point $\mu + x_{3\sigma}$. The magnification 4 is experimentally set. Because $x_{3\sigma}$ can be obtained by the image size, T_p is mathematically written as:

$$T_p = \mu + 4x_{3\sigma} \quad (10)$$

$$= \frac{1}{N_1 N_2} + \frac{12}{\sqrt{N_1 N_2}}. \quad (11)$$

The threshold only depends on the image sizes. The efficiency of this shot change detection method will be shown in experiments.

4. Camerawork Estimation

Camerawork is estimated in each shot segmented by the shot change detection method mentioned above. We only deal with pan and tilt, which are horizontal and vertical camera movement, as camerawork since old film sequences hardly include zoom and rotation. Camerawork can be estimated by low-pass filtering the frame displacement estimation result, because the frame displacement has generally high temporal frequency and camerawork has low temporal frequency. We

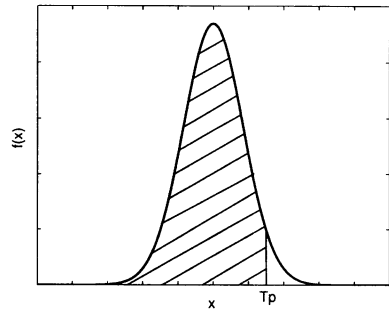


Fig. 4 Example of normal distribution



Fig. 5 Sequence “Asahikawa”



Fig. 6 Sequence “Hakodate”

use an order 30 FIR filter with a lowpass cutoff frequency 0.01π . The frame displacement corrected movie can be obtained by shifting the image at the difference between the frame displacement and the estimated camerawork.

5. Experiments

The proposed method is applied for the displacement correction of two actual old film sequences. We use sequences shown in Fig. 5 and 6. The sequence “Asahikawa” is 597 frames long and consists of 5 shots. The sequence “Hakodate” is 596 frames long and consists of 7shots. There are frame displacement and some other defects such as blotches and flickers in the sequences. The image size of each frame is 480×720 pixels.

5.1 Shot change detection

Figure 7 shows the log plot of evaluation value of the conventional method in Ref. [6] for “Asahikawa”. The arrows in the figure indicates shot boundaries and the dashed line indicates the threshold for shot change detection. The threshold in this method is determined experimentally. We interpret that a shot change occurs when the evaluation value exceeds

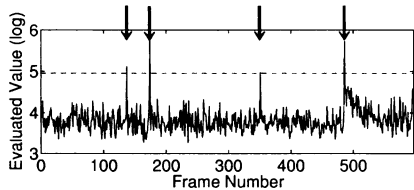


Fig. 7 Evaluation value of the conventional method for “Asahikawa”.

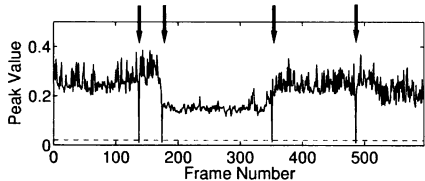


Fig. 8 Peak value of the phase-only correlation for “Asahikawa”.

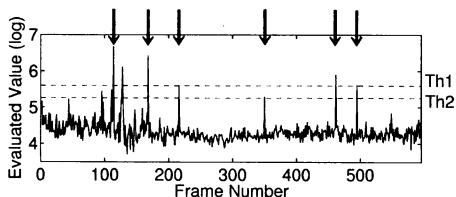


Fig. 9 Evaluation value of the conventional method for “Hakodate”.

the threshold. From the result of Fig. 7, we see that the conventional method can detect the shot changes if the threshold is determined adequately.

Figure 8 shows the peak value of the phase-only correlation for the sequence “Asahikawa”. We interpret extremely small values as shot boundaries. The threshold value 0.02 is mathematically determined using Eq. (11). It can be seen that the peak values of shot changes are below the threshold and the shot changes are detected by the proposed method. For “Asahikawa”, both the conventional and the proposed method can detect the shot changes accurately.

Figure 9 shows the log plot of evaluation value of the conventional method for “Hakodate”. It is difficult to determine a threshold in this case. If T_{h1} is set as the threshold, the shot change at frame 350 is not detected besides frame 128 is misdetected as a shot boundary. If T_{h2} is set, the shot change at frame 350 can be detected but some other frames are detected as misdetections. The conventional method cannot detect all the shot changes without misdetection.

Figure 10 shows the peak value of the phase-only correlation for the sequence “Hakodate”. The threshold value 0.02 is same value as the case of “Asahikawa”, because the threshold of the proposed method depends on the size of each frame. It can be seen that the peak values of the shot change

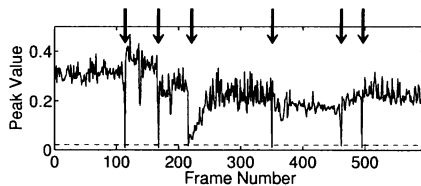
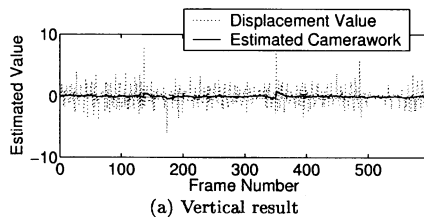
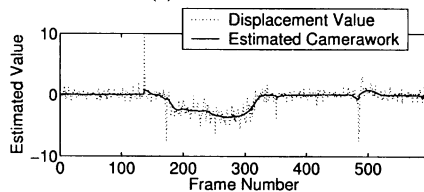


Fig. 10 Peak value of the phase-only correlation for “Hakodate”.



(a) Vertical result



(b) Horizontal result

Fig. 11 Estimated displacement and estimated camerawork for “Asahikawa”.

are below the threshold and the shot changes are detected by the proposed method. Although the conventional method cannot detect all the shot change boundaries for “Hakodate”, the proposed method can detect the shot changes accurately.

5.2 Camerawork estimation

Camerawork is estimated in each shot segmented by the shot detection method mentioned above. We only deal with pan and tilt, which are horizontal and vertical camera movement, as camerawork since old film sequences hardly include zoom and rotation. Camerawork can be estimated by low-pass filtering the displacement estimation result, because the frame displacement has generally high temporal frequency and camerawork has low temporal frequency. We use an order 30 FIR filter with a lowpass cutoff frequency 0.01π .

Figure 11 shows the displacement estimation results (dotted line) using the phase-only correlation of subpixel level and the estimated camerawork (solid line) for “Asahikawa”. In each figure, we can see that the camerawork follows the estimated frame displacement. Figure 12 shows the displacement estimation results for “Hakodate”. We can also see that the camerawork follows the estimated frame displacement.

5.3 Frame displacement correction

We can correct the frame displacement using the results in Fig. 11 and 12. When we correct the original movie, the accumulation result is used for the displacement correc-

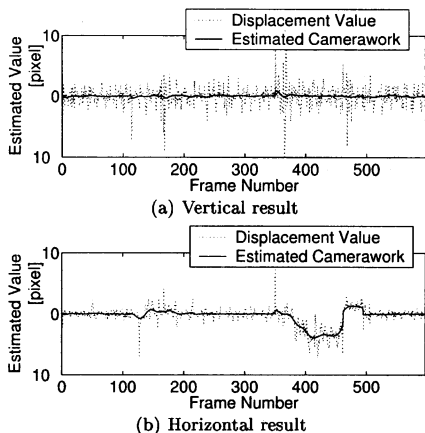


Fig. 12 Estimated displacement and estimated camerawork for “Hakodate”.

tion. Namely, we correct the original movie by using the first frame of each shot as a criterion. Frames are shifted at the difference between the frame displacement and the estimated camerawork. Subpixel displacement can be corrected by bilinear interpolation. Using our proposed method, we can perform the frame displacement correction preserving the camerawork. Visual inspection shows that the frame displacement is significantly reduced by the proposed method.

6. Conclusion

This paper has proposed a shot change detection method and a camerawork estimation method for old film restoration. The threshold for shot change detection is determined mathematically in the proposed method and the camerawork is estimated by lowpass filtering. Experimental results show that the proposed method is more robust to noises than the conventional method. Visual inspection shows that the proposed method can estimate the frame displacement and then correct frame displacement preserving the camerawork.

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