# FLICKER COMPENSATION FOR ARCHIVED FILM USING A SPATIALLY-ADAPTIVE NONLINEAR MODEL

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## ABSTRACT

We present a novel approach for the compensation of temporal brightness variations (commonly referred to as flicker) in archived film sequences. The proposed method[1] is motivated by fundamental principles of photographic image registration and provides a substantial level of adaptation to temporal but also spatial variations of picture brightness. Additionally our scheme provides an efficient mechanism for the appointment and dynamic update of reference frames which makes it suitable for the compensation of long duration film sequences while it addresses problems arising from scene motion using a novel motion-compensated greylevel tracing approach. We present experimental evidence which suggests that our method offers high levels of performance and compares favourably with competing state-of-the-art techniques for flicker compensation.

## 1. INTRODUCTION

Flicker refers to random fluctuations of image brightness which is a signature impairment in archived films. While film ageing, multiple copying, mould and dust may also be contributing factors, the main underlying cause is inconsistent film exposure at the acquisition stage. Flicker is easily noticeable and recognisable - especially in low-motion content scenes - and can be quite unsettling for the viewer leading to vision fatigue after prolonged viewing. Flicker has often been categorised as a global artefact in the sense that it affects frames in their entirety (as opposed to dirt, for instance, which is often a localised effect). However flicker may also contain an element of slow spatial variation within the boundaries of a single frame. While there are instances where the profile of this spatial variation can remain virtually unchanged from one frame to the next, it is also not uncommon for it to change in an unpredictable manner. This renders any attempt at modelling ineffective. Contributing causes can be traced to incorrect light synchronisation, fogging, vignetting, mould static marks caused by mechanical friction of the film strip and so on.

Initial efforts on flicker modelling reported in the literature assumed that the entire degraded frame was affected in a similar fashion. In [1], flicker was modelled as a global intensity shift between a degraded frame and the mean level of the shot to which this frame belongs. In [2] flicker was expressed as a multiplicative constant relating the mean level of a degraded frame to that of a reference frame. Spatial variation was considered in [3, 4] where additive or multiplicative constants were replaced by 2nd order polynomial approximations. In [3] a robust hierarchical framework was proposed to estimate the polynomial functions, going from zero-order to 2nd order polynomial. In [5] estimation of semi-global parameters was performed based on a block-partitioning of the degraded frame. Each block was assumed to have undergone a linear transformation and a linear minimum mean-square estimator was used. Bilinear interpolation was used to obtain a dense parameter field. Work in [6] approached the problem using histogram equalisation. A degraded frame was first histogram equalised and then inverse histogram equalised with respect to a reference frame. Our own non-linear model described in [7] is also histogram-based and is detailed in Section 2.

While the above efforts addressed the fundamental problem with varying degrees of success far fewer attempts were made to formulate a complete and integrated compensation framework suitable for the challenges posed by processing longer sequences. In [6] references frames were appointed within a sequence of frames and a linear combination of the inverse histogram equalisation functions of the two closest reference frames (forward / backward) was used for compensation purposes. In [5] compensation was performed recursively. Error propagation is likely in this framework as previously generated corrections are used to estimate future flicker parameters. A bias is introduced as the restored frame is a mixture of the actual compensated frame and the original degraded one. In [4] an approach motivated from video stabilisation described in [2] is proposed. Several flicker parameter estimations are computed for a degraded frame within a temporal window and

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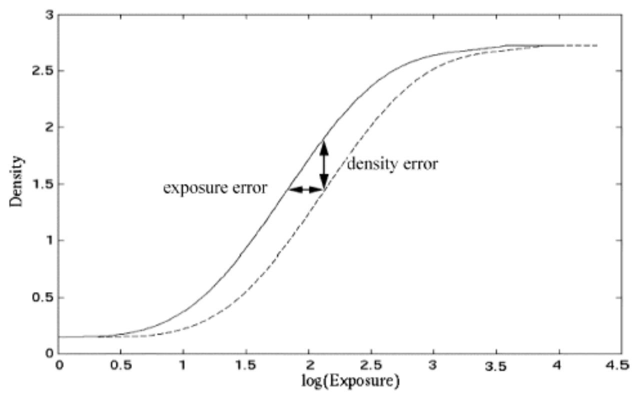


**Fig. 1**. Effect of exposure and corresponding density errors shown on the Hurter-Driffield $D(\log E)$ characteristic.

a filter is employed to provide a degree of smoothing of those parameters.
This paper is organised as follows. Section 2 provides a brief review of nonlinear modelling of flicker. Section 3 details the proposed method while experimental results are presented in Section 4 and conclusions are drawn in Section 5.

## 2. NONLINEAR MODELLING

As described in [7], the Density versus log Exposure characteristic $D(\log E)$ attributed to Hurter and Driffield [8] (solid line in Figure 1) can be used to characterise exposure inconsistencies and their corresponding density errors (dashed line). The relationship between $\log(\text{Exposure})$ and $\text{Density}$ is nonlinear and as a consequence density errors may vary for a constant amount of exposure error. The amount of correction $\Delta I_{t,\text{ref}}$ required for an observed greylevel $I_t$ in frame $F_t$ is calculated relative to a corresponding observed greylevel $I_{\text{ref}}$ in reference frame $F_{\text{ref}}$ (assumed to be flicker-free) as $I_t = I_{\text{ref}} - \Delta I_{t,\text{ref}}(I_t)$. A greyscale correction profile $P_{t,\text{ref}}$ (dashed curve in Figure 2) between a degraded frame and a reference frame (typically the first one of the sequence) was then estimated as a least-squares quadratic polynomial fit to raw correction measurements $\Delta I_{t,\text{ref}}$ (solid line). In this example, the shape of the profile suggests that the correction to be applied is unimodal, peaking towards the middle of the greyscale as well as concave which is in agreement with the theoretical profile derived in [7]. To further take into account greyscale non-linearity associated with telecine grading ([7]), $P_{t,\text{ref}}$ can also be obtained using a cubic polynomial fit to the raw correction profile $\Delta I_{t,\text{ref}}$.

## 3. FLICKER COMPENSATION

### 3.1. Reliability weighting

The first improvement to the baseline scheme in [7] is motivated by the observation that greylevel frequency of occurrence was not taken into account. Indeed, greylevels which

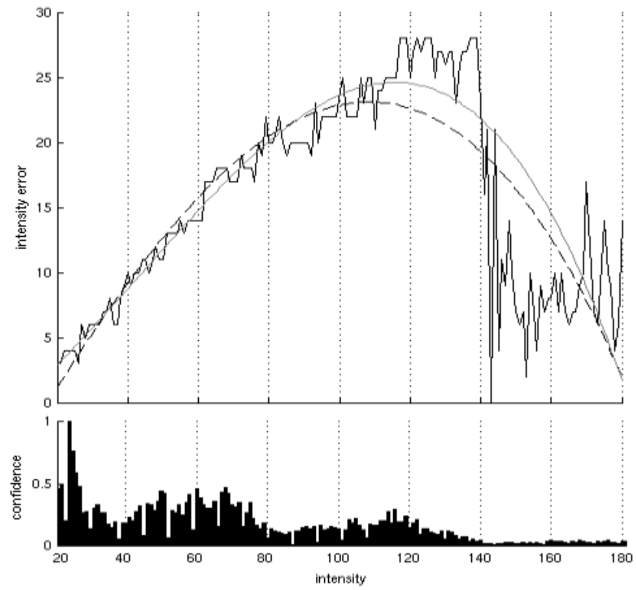


**Fig. 2**. Measured ($\Delta I_{1,0}$) and polynomial approximated (dashed:basic fitting ($P_{1,0}$) - solid:weighted fitting ($C_{1,0}$)) correction profiles between the first two frames of test sequence *caption*. The histogram below shows the normalised confidence values $r_{1,0}$ for each intensity.

occur more frequently in a frame are likely to provide, on average, more reliable estimates and vice versa. On the other hand, greylevels which are totally absent (a situation arising in quantised and/or compressed material) should not be allowed to have an influence at all. To address this problem we use weighted polynomial fitting based on a reliability measure $r_{t,\text{ref}}(I_t)$ which is obtained as the maximum of the histogram of those greylevel values in the current frame which correspond to a specific greylevel value in the reference frame ([7]). An example of such a reliability distribution is shown at the bottom of Figure 2 while the modified correction profile $C_{t,\text{ref}}$ due to weighting is shown as a solid, lighter-shade line. A comparison with the original unweighted profile $P_{t,\text{ref}}$ (dashed line) confirms that more densely populated greylevels have a stronger influence on the fidelity of the fitted profile with respect to the raw correction data.

### 3.2. Dynamic appointment of references

Another weak element of the baseline algorithm was that the correction was performed relative to a fixed reference frame $F_{\text{ref}}$. As a consequence performance deteriorates with progressively longer temporal distances between a compensated frame and the appointed reference especially when considerable levels of camera and scene motion are present.
To overcome this limitation we approximate reference greylevel

$I_R$ by a temporal average of observed greylevels $I_t$ :

$$\frac{1}{N}\sum_{t=-N/2}^{N/2} I_t = \frac{1}{N}\sum_{t=-N/2}^{N/2}(I_R - \Delta I_{t,R}(I_t))$$
$$= I_R - \frac{1}{N}\sum_{t=-N/2}^{N/2}\Delta I_{t,R}(I_t)$$

$N$ being, in general, a number of frames specifying a temporal sliding window centred at the current frame so that a degree of dynamic adaptation to localised content is achieved. Considering the weak and intuitively plausible assumption that exposure errors $\Delta I_{t,R}(I_t)$ are zero-mean distributed we obtain:

$$\lim_{N\to\infty}\frac{1}{N}\sum_{t=-N/2}^{N/2}\Delta I_{t,R}(I_t) = 0 \Rightarrow \lim_{N\to\infty}\frac{1}{N}\sum_{t=-N/2}^{N/2} I_t = I_R$$

### 3.3. Estimation of the correction profile

The correction profile $C_{t,R}$ between $I_t$ and $I_R$ is estimated by first considering the raw correction profile :

$$\Delta I_{t,R}(I_t) = I_R - I_t$$
$$\approx \frac{1}{N}\sum_{i=t-N/2}^{t+N/2} I_i - I_t = \frac{1}{N}\sum_{i=t-N/2}^{t+N/2}\Delta I_{t,i}(I_t)$$

The last equality is a consequence of $I_i = \Delta I_{t,i}(I_t)+I_t, \forall i = [0 : N]$ as explained above. Subsequently we use the polynomial approximation $C_{t,i}(I_t) \approx \Delta I_{t,i}(I_t)$ (Section 3.1) to obtain:

$$C_{t,R}(I_t) = \frac{1}{N}\sum_{i=t-N/2}^{t+N/2} C_{t,i}(I_t)$$

In other words a correction value $C_{t,R}(I_t)$ on the profile is obtained by averaging correction values $C_{t,i}(I_t)$ where $i \in [t - N/2; t + N/2]$ i.e. a sliding window of width $N$ centred at the current frame. We incorporate reliability weighting (as obtained from Section 3.1) by taking into account individual reliability contributions for each frame within the sliding window and normalising for unity:

$$C_{t,R}(I_t) = \sum_{i=t-N/2}^{t+N/2} r'_{t,i}(I_t)\cdot C_{t,i}(I_t) \quad \text{with} \sum_{i=t-N/2}^{t+N/2} r'_{t,i}(I_t) = 1$$

### 3.4. Correction profile estimation between distant frames using greylevel tracing

As Frames $F_t$ and $F_i$ can be distant in the video stream, motion may interfere in the estimation process. A dense motion field is estimated with the Black and Anandan method ([9]) and then consecutive frames are compensated. Afterwards raw correction profiles and associated reliabilities are computed in both directions yielding $\Delta I_{t,t+1}, \Delta I_{t+1,t}$ and $r_{t,t+1}, r_{t+1,t}$ for $t = [0; L]$, $L$ being the number of frames of the sequence. Then correction values are combined as follows:

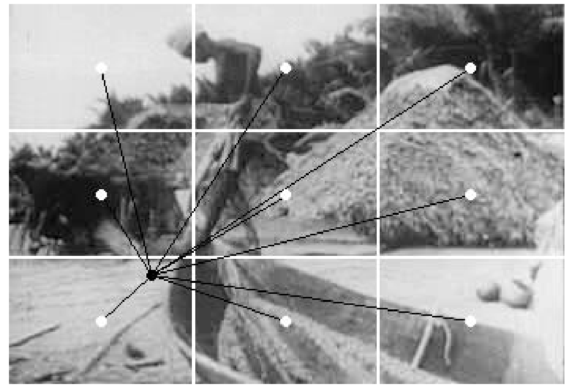

**Fig. 3**. Block partitioning of the first frame of *boat* using a 3×3 grid. The processed pixel and the centre of each blocks are represented by black and whites dots respectively. The black lines represent the distances i.e. inverse of $d_b(\vec{p})$.

$$\Delta I_{t,t+2}(I_t) = \Delta I_{t,t+1}(I_t) + \Delta I_{t+1,t+2}(I_t + \Delta I_{t,t+1}(I_t))$$

which can be generalised for $\Delta I_{t,t\pm i}, i > 2$. This amounts to tracing correction values from one frame to the next under the influence of motion. The associated reliability is computed as:

$$r_{t,t+2}(I_t) = \min(r_{t,t+1}(I_t), r_{t+1,t+2}(I_t + \Delta I_{t,t+1}(I_t)))$$

The above also generalises for any frame-pair. If a specific correction $\Delta I_{t,t+1}$ is unreliable then the $\min$ operator above ensures that this also renders the compound reliability $r_{t,t+i}(I_t)$ unreliable.

### 3.5. Spatial adaptation

Spatial adaptation is achieved by means of block-based frame partitioning and is illustrated in Figure 3. Correction profiles $C_{t,R,b}$ are computed independently for each block $b$ of frame $F_t$ using the previous approach. As brute force correction of each block would lead to blocking artefacts at block boundaries, a bilinear interpolation is performed using $d_b(\vec{p})$ as a weight. This weight is calculated as the inverse of the distance between a pixel located in $\vec{p}$ (black dot) and the centre of its own block as well as centres of neighbouring blocks (white dots). The final correction $F'_t(\vec{p})$ for pixel $F_t(\vec{p})$ is given by :

$$F'_t(\vec{p}) = F_t(\vec{p}) - \sum_{b=1}^{N}[d_b(\vec{p})\cdot r_{t,R,b}(F_t(\vec{p}))]\cdot C_{t,R,b}(F_t(\vec{p}))$$
$$\text{with} \sum_{b=1}^{N}[d_b(\vec{p})\cdot r_{t,R,b}(F_t(\vec{p}))] = 1$$

It is worth noting that definition of the reliability measure had to be modified for the above block-based scheme so that aggregation is carried out over the sliding window ie. $r_{t,R,b}(I_t) = \sum_{i=t-N/2}^{t+N/2} r_{t,i,b}(I_t)$. This was necessary because greylevel representation within a block might be limited (as opposed to an entire frame) thereby not providing a sufficient amount of support for the calculation of the reliability measure.

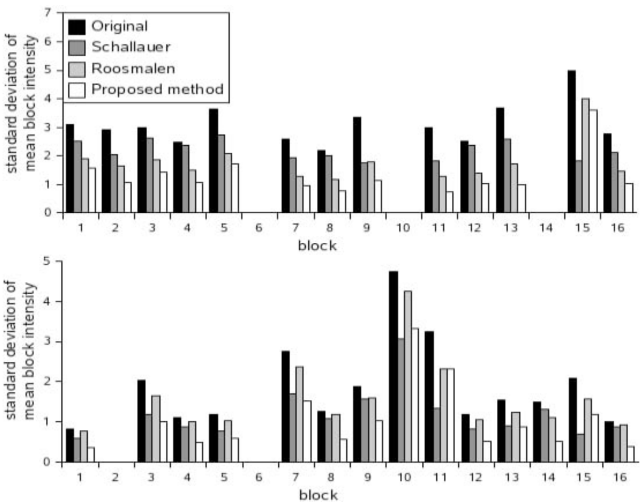


**Fig. 4**. Standard deviation of mean static-block intensity of for frames 0-49 and 0-100 of test sequences *Tunnel* and *Lostworld* respectively.

## 4. EXPERIMENTAL RESULTS

The proposed flicker compensation method is compared with two state-of-the-art techniques, detailed in [6] (global compensation) and [5] respectively (spatial adaptive compensation). CIF resolution (360x288) monochromes test sequences *Tunnel*, *Lostworld*, and *Greatwall* composed of 50, 101 and 140 frames respectively are used for evaluation purposes. The first two sequences contain object but not camera motion while the last one contains a panoramic scan of the Chinese Great Wall. While a degree of reduction of flicker impairment is achieved by all algorithms under consideration, the method described in [5] results in noticeable residual flicker as corrected frames are a mixture of raw corrected and degraded frames (Section 1).

Standard deviation of mean block intensity computed for manually selected static blocks is employed for performance assessement purposes using a $4 \times 4$ grid partitioning (similar to Figure 3) with block indices increasing from top-left to bottom-right of a frame. Standard deviation is plotted in Figure 4 where it can be seen that the proposed method offers the best performance followed by [6]. These results were confirmed by visual inspection of compensated sequences. Test sequence *Greatwall* cannot be assessed in this way as all blocks contain a considerable amount of motion.

MPEG-4[2] compression ratios between original and restored sequences are shown in Table 1 to reflect the fact that flicker compensation has a beneficial impact on the efficiency of video compression algorithms. In that respect too our method outperforms the two competing schemes. In addition method [6] fails for test sequence *Greatwall* as references frames are uneasy to select in a complete moving shot.

[2]FF-MPEG software is used : http://ffmpeg.sourceforge.net

| **Sequences** | *method [5]* | *method [6]* | *new method* |
|---|---|---|---|
| *Tunnel* | 1.16 | 1.07 | 1.31 |
| *Lostworld* | 1.12 | 1.05 | 1.18 |
| *Greatwall* | 1.03 | 0.89 | 1.06 |

**Table 1**. Flicker compensation effect on MPEG-2 compression ratio for state-of-art and proposed methods on several sequences.

## 5. CONCLUSION

In this paper, a new scheme for flicker compensation was introduced. The approach was based on nonlinear modelling introduced in previous work but contains important new components that allow it to address successfully the challenges posed by spatial variability of flicker impairment, varying reliability of correction parameters, appointment of reference frames and scene motion. Our results demonstrate that the algorithm is very effective towards flicker compensation both in subjective and objective terms and compares favourably to state-of-art methods that feature in the literature.

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