Estimation of ambient illumination variation between colour images in the presence of content changes for real-time illumination-invariant change detection

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Abstract-The task of detecting changes between two image frames is obstructed by the influence of noise and by the existence of ambient illumination variations between the image frames. The former is an inherent property of all electronic imaging devices. The latter appears when changes in camera exposure or white balance settings occur and tends to degrade the efficiency of change detection, if left untreated prior to frame differencing. An additional difficulty lies in the fact that a change detection process is required to accurately detect illumination changes in the presence of both luminance and content changes. In this paper, a luminance invariant change detection method is proposed. It consists of a three-channel brightness correction stage employed for the brightness normalization process and followed by a block-based clustering method, which aims to detect content changes from changes caused by the influence of noise.

I. Introduction

Change detection techniques are algorithms used in inspection applications such as intelligent indoor surveillance systems and intruder detection systems. They are expected to perform the change detection task, which is not feasible by the straightforward procedure of image differencing, due to the influence of noise and illumination changes.

Illumination changes pose difficulties in the change detection process since an underlying luminance offset tends to swamp content changes, if it is not accounted for prior to image differencing. Ambient illumination changes may be caused either by the change in the brightness of the surveyed scene or by a scene change which may trigger adjustment of the gain in the image acquisition device. Moreover, brightness changes may not be of equal weight to all colour channels. This is the case when white balance settings of the image acquisition device are reconfigured or when the scene is subjected to light of time-varying colour temperature. The change of daylight colour temperature is an example of the latter case. Therefore, in order to address these factors, one must take into account the application of illumination change detection methods in each colour channel separately.

With the illumination offset issue treated, the second obstacle in the change detection process lies in the discrimination of changes related to content alteration from changes related to the effect of noise. For this task, the application of a block-based statistic analysis combined with clustering techniques is proposed.

II. Ambient illumination correction

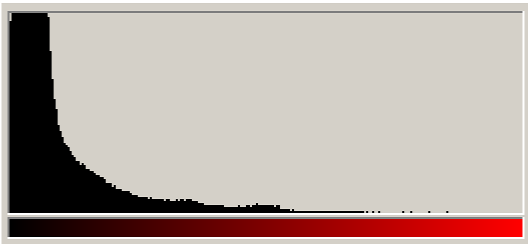
The first step applied to the proposed change detection process focuses on correcting the differences in ambient illumination. Variations in global luminance when no other changes occur, are accurately detected with the use of image histograms. A change in the global illumination of an image causes shifting of its histogram towards brighter or darker regions. Therefore, one may expect that, with no content changes present, all pixels of the histogram of the image difference would concentrate in one peak. In practice, the noise effect dictates that the largest percentage of pixels will spread in a region around the histogram peak. The extent of this region depends on noise variance.

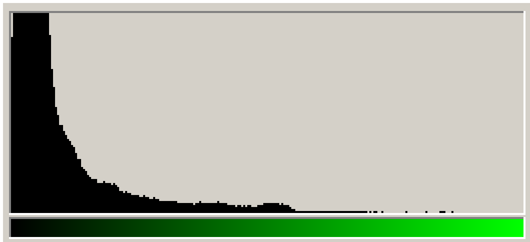
In real conditions, the difficulty that a change detection application encounters in luminance normalization is the fact that it needs to perform tracking of ambient luminance variations when both illumination and content changes exist. It is possible that content changes will introduce additional peaks to the histogram of the image difference. In such cases, plain peak detection does not suffice. An example of this case is illustrated in the histograms (Fig 2a,2b,2c) of the absolute difference of the sample frames displayed in Figures 1a and 1b.


a)


b)

Figure 1.a,b) Sample frames used for the application of change detection algorithms


a)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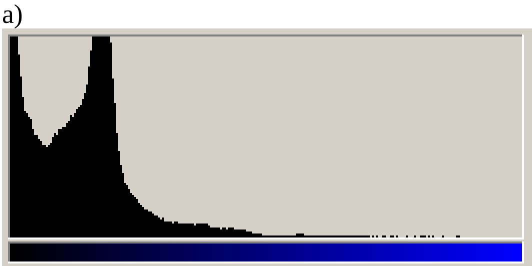

c)

Figure 2: Histograms of the absolute difference of frames 1a 1b corresponding to the (a)red , (b) green and (c) blue colour channel. Apart from a peak denoting the luminance offset in each colour channel, additional peaks are present due to content changes.

The brightness correction technique proposed in the present paper is based on the assumption that *there's no content change that occupies more than half of the image plane and causes homogeneous change of brightness to its entire extent at the same time*. This assumption is valid in most cases and fails in the exceptional case of large objects with homogeneous luminance covering regions of also homogeneous luminance. The noise influence dictates that *a large percentage of the image difference pixels will be strongly concentrated to a region around the peak of the histogram with index that lies close to the luminance offset*. Therefore, one may take advantage of the fact that the peak corresponding to the luminance offset will be characterized by larger pixel concentration compared to the peaks caused by content changes. Consequently, instead of the amplitude of a specific peak of the histogram, the amount of pixels concentrated to its neighbourhood is considered a reliable criterion for luminance difference detection.

The aforementioned process can also be used to address the issues of light temperature change and white balance readjustment. These scenarios represent a problem of unequal change of ambient luminance between the colour channels, therefore they constitute a problem of a similar nature. In order to cope with such changes, it is enough to apply the luminance correction technique on each colour channel of the image difference independently.

Let $D(x, y)$ denote the image difference of two frames $I_1(x, y), I_2(x, y)$ subjected to comparison:

$$D(x,y) = I_2(x,y) - I_1(x,y) \qquad (2.1)$$

Frames $I_1(x,y)$ and $I_2(x,y)$ are considered to present variations in both content and luminance. Let $h[n]$ denote the histogram function corresponding to the image difference $D(x,y)$. The histogram function definition which is adopted in the present paper differs from the classic definition of the image histogram, since it extends to the support [-255,255]. This variant of the image histogram is formulated in order to enable discrimination of positive from negative brightness changes.
The histogram function, in its initial form, contains numerous spurious peaks, which need to be suppressed prior to peak detection. This removal is accomplished by Gaussian smoothing, thus exporting the low-pass filtered histogram function $h_S[n]$:

$$h_S[n] = h[n] * g[n] \qquad (2.2)$$

In the experiments presented in this paper, a 9-sample Gauss sequence with standard deviation $\sigma = 3$ has been applied in the convolution process:

$$g[n] = e^{-\frac{(n-4)^2}{18}}, \quad n = 0,1,\ldots,8 \qquad (2.3)$$

Peaks of the filtered histogram function are located by tracking changes from negative to positive values in its first derivative. In order to distinguish the local maximum whose index corresponds to the appropriate brightness offset, the pixel amount concentrated to the neighbourhood of each peak P_i is calculated:

$$E_{P_i} = \sum_{n=x_{il}}^{x_{ih}} h_S[n] \qquad (2.4)$$

where x_{il}, x_{ih} correspond to the indices of the local minima of $h_S[n]$ which lie closest to peak P_i in its left and right side respectively.

The highest pixel count distinguishes the winner-peak. The corresponding peak index denotes the brightness offset for the respective colour channel. Therefore, when processing colour images, three offsets $\delta L_R, \delta L_G, \delta L_B$ are acquired. At this point, the normalized colour components $I_{1R}', I_{1G}', I_{1B}'$ of the corrected reference frame can be calculated as follows:

$$\begin{aligned} I_{1R}'(x,y) &= I_{1R}(x,y) + \delta L_R \\ I_{1G}'(x,y) &= I_{1G}(x,y) + \delta L_G \\ I_{1B}'(x,y) &= I_{1B}(x,y) + \delta L_B \end{aligned} \qquad (2.5)$$

Figure 2 shows the ambient brightness conditioning flowchart applied to each colour channel.

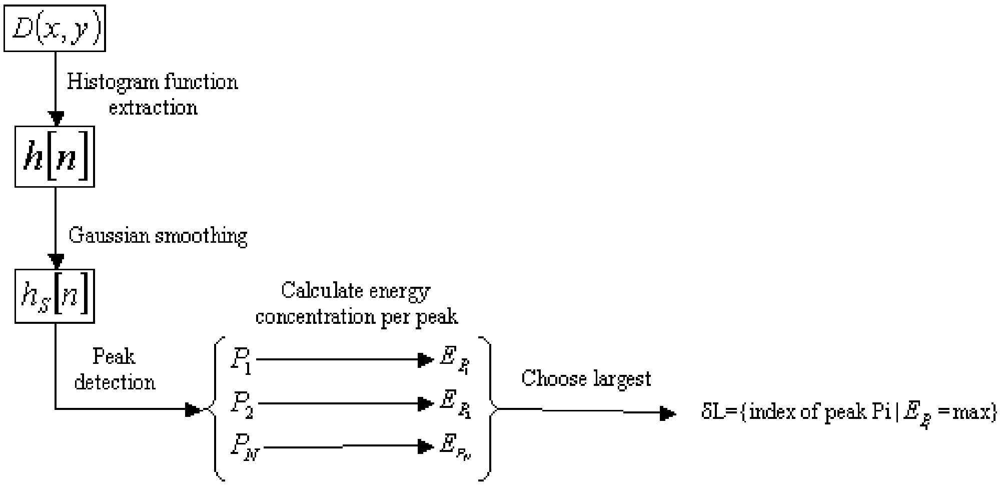


Figure 3: Flowchart of the ambient illumination conditioning algorithm applied to each colour channel of the image difference

III. Change mask extraction

The second stage in the change detection process aims to discriminate changes caused by noise from content changes. This task can be based on the calculations of localized statistic information. Such calculations are performed at block-level and are used to export a statistic map of the image absolute difference. A decision rule that discriminates the regions where significant changes have occurred focuses on the comparison of localized properties against noise properties. Areas with a mean value exceeding the noise mean value by a certain threshold are considered changed. Obviously this comparison requires knowledge of noise properties and the choice of a suitable threshold.

For small scale changes, one may assume that the overall mean value of the absolute difference represents the mean value of noise. However, for large scale changes, this is not the case.[1] In order to cope with this issue, a block-based change detection approach which is tolerant to large scale changes is proposed. This method aims to detect noise properties by grouping image blocks of the absolute difference, based on the similarity of their mean values. [2]

In the proposed approach, the centroid of each cluster is described by an average mean value and standard deviation m_{G_i}, σ_{G_i}, which are defined by the equation set:

$$\begin{aligned} m_{G_i} &= \frac{1}{N_{G_i}} \cdot \sum_{k=1}^{N_{G_i}} m_k \\ \sigma_{G_i} &= \frac{1}{N_{G_i}} \cdot \sum_{k=1}^{N_{G_i}} \sigma_k \end{aligned} \qquad (3.1)$$

The proposed clustering procedure forms clusters and then calculates their properties by the following iterative procedure:

a) The centroid of the first cluster is defined by the parameters of the first image block:

$$\begin{aligned} m_{G1} &= m_{11} \\ \sigma_{G1} &= \sigma_{11} \end{aligned} \qquad (3.2)$$

b) Successive image block values are compared against the mean value of cluster G_1. Let B_{ij} denote an image block characterized by mean value m_{ij} and standard deviation σ_{ij} the *mean value distance* between block B_{ij} and cluster G_1 is calculated:

$$d_{ij,G1} = \left| m_{ij} - m_{G1} \right| \tag{3.3}$$

i) If $d_{ij,G_1} < \sigma_{G_1}$, block B_{ij} is added to cluster G_1 and the cluster centroid coordinates are recalculated as dictated by Eq. 3.1 . N_{G_1} denotes the number of image blocks grouped in cluster G_1 up to the current point of the algorithm execution.

ii) If $d_{ij,G_1} > \sigma_{G_1}$, a new cluster G_2 is initialized, with centroid parameters:

$$\begin{aligned} m_{G2} &= m_{ij} \\ \sigma_{G2} &= \sigma_{ij} \end{aligned} \tag{3.4}$$

c) The procedure is repeated until all subsequent image blocks have been grouped to clusters. Their parameters are compared against the parameters of each cluster formerly created.

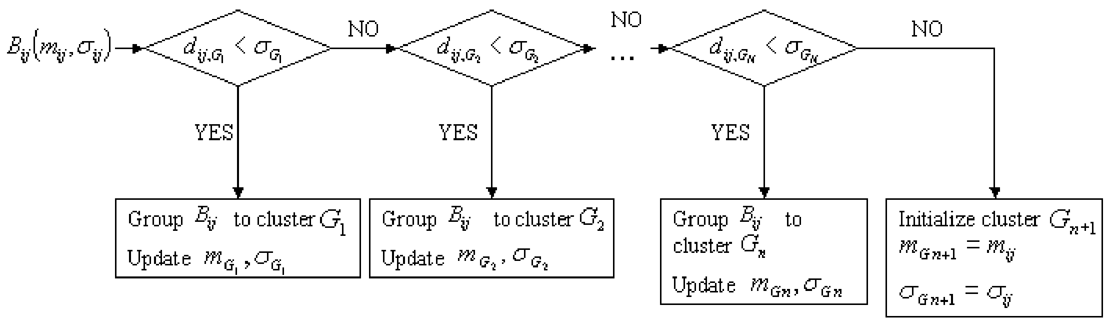


Fig 4. Flowchart of the image block clustering algorithm

After the clustering procedure the largest cluster is considered to represent noise parameters. Specifically:

$$\begin{aligned} m_n &= m_{G_{\max}} \\ \sigma_n &= \max(\sigma_i),\ i = 1,\dots,N_{G\max} \end{aligned} \tag{3.5}$$

The decision rule applied for the mask creation stage consists of a comparison of each block mean value against the noise mean value:

a) If $\left| m_{ij} - \sigma_n \right| > m_n$, image block B_{ij} is added to the change mask.

b) If $\left| m_{ij} - \sigma_n \right| < m_n$, image block B_{ij} is discarded.

In order to detect changed regions which preserve similar luminance level but differ in chrominance, the aforementioned clustering process is applied on each colour channel independently. The results are combined into a single change mask.

IV. Experimental results

The proposed change detection application has been developed in the LabView programming platform. The algorithms have been applied on colour images at a resolution of 640×480 pixels (illustrated in figures 1a and 1b). Block size has been preset to 16×16 pixels. Figure 1a presents the reference background frame and Figure 1b presents an altered frame of the surveyed scene. The frames have been shot with different exposure settings. Additionally, white balance adjustment has been changed, in order to introduce different amount of luminance alteration to each colour channel.

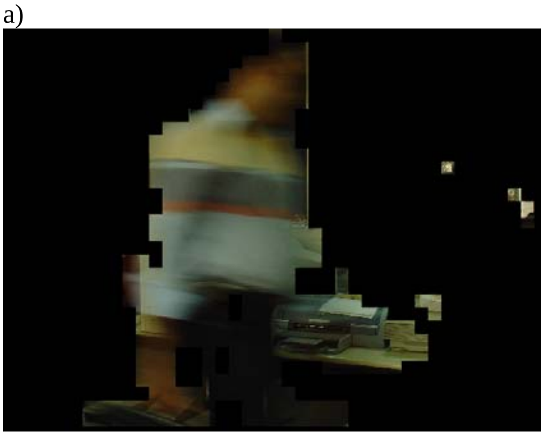
Direct application of the block clustering technique without ambient illumination correction provides the result illustrated in figure 5a. Application of the luminance conditioning algorithm on the background frame exports the adjusted frame displayed in figure 5b. Application of the block-blustering method on the frame pair 1b-5b detects the content changes shown in Figure 5c.

Apparently, suppression of illumination differences aids to the detection of a largest percentage of the content change, as it removes a constant brightness offset, which would otherwise be considered as noise of increased mean value by the block clustering procedure. It mainly contributes to the detection of content changes of a weaker effect.

An advantage in the presented implementation of the brightness correction technique lies in its execution speed. Since the algorithm is based on plain mathematic procedures (two image additions, limited summations in the histogram values and one low-pass filtering of a single dimension signal), its application introduces minimal computational cost.

a)

b)



c)

Figure 5: a) Changes detected between the image pair 1a. and 1b without illumination correction b) Adjusted reference frame after the application of the three-channel illumination correction technique on frame 1a c) Content changes detected after the comparison of frames 5b and 1b.

V. Conclusions - Open issues

A technique for the suppression of ambient illumination difference in the presence of content changes has been proposed, aiming to improve change detection efficiency. Experimental results confirm its necessity in change detection, as this stage increases the percentage of changes detected. Moreover, its computational cost is minimal, because of the plain mathematic operations involved. However, it should be noted that the proposed method compensates only for additive illumination changes. Multiplicative illumination is not accounted for. In order to cope with multiplicative illumination, an additional refinement stage of homomorphic filtering needs to be implemented.[3] Nevertheless, a reduced computational cost is predicted, since the refinement stage is expected to be performed over a limited search space.

References

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[3] Daniel Toth, Til Aach and Volker Metzler, “Illumination–Invariant Change Detection”, *4^{th} IEEE Southwest Symposium on Image Analysis and Interpretation*, p.p. 3-7, Austin, Texas, April 02-04, 2000, ISBN:0-7695-0595-3