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A Low Complexity Change Detection Algorithm Operating in the Compressed Domain

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Abstract

This paper introduces a simple, fast, and efficient algorithm for image change detection in the compressed domain. The proposed technique operates directly on Discrete Cosine Transformed (DCT-ed) data which makes it suitable for processing compressed bitstreams produced with DCT-based encoders such as Motion JPEG, MPEG-x, and H.26x. Its limited hardware requirements render this method compatible with low-cost, low-complexity, and low-power systems. The results given in the frame of a videosurveillance application demonstrate the excellent performance of this technique to detect the significant change in a scene while filtering out the noise. This method exploits the fact that the phase of the DCT coefficients of a transformed image contains a significant amount of information. By processing only the phase part of the DCT coefficients a simple, fast, efficient, and yet robust change detection method is achieved.

Categories and Subject Descriptors (according to ACM CCS): I.4.8 [Image Processing and Computer Vision]: Scene Analysis

1. Introduction

Most digital images and video sequences today are stored and transmitted in compressed form. This generalized compressed status of visual information in current multimedia system promotes a large interest in the design and implementation of image and video processing algorithms that operate directly in the compressed domain. These algorithms present the advantage of avoiding the allocation of computational and electric power to the heavy decompression modules before executing the specific image or video processing application in the spatial domain. Several compressed-domain techniques for image and video applications have been reported in [1][2][3][4].

In this paper we address the issue of image change detection in the compressed domain. The effectiveness of the proposed technique is illustrated in the frame of a videosurveillance application.

1.1. Change detection

Change detection is an important low-level image processing operation that identifies the changing pixels associated with moving/changing objects in a given monitored scene. The output of a change detection module is a binary-valued change mask that has its pixels classified as changed or unchanged based of a given criterion.

The number of applications that use a change detection stage is very large and includes videosurveillance [5][6], traffic monitoring [7][8], remote sensing [9][10], and medical diagnosis [11][12], to mention a few. The approach, the structure, and the parameters setting of a change detection algorithm might largely differ depending on the application.

Multiple techniques have been proposed for executing image change detection [9][13][14]. Most popular methods include: image differencing, image regression, image ratioing, principal components analysis and statistical change detection. In the videosurveillance arena, the differencing and threshold techniques are very common. They have been applied with success in applications such as intruder detection, object detection, vehicle surveillance, and monitoring. One key advantage of the differencing techniques lies in their simplicity of implementation. On the other hand, they present the inconvenience of a high sensitivity to noise and to illuminations changes. Background differencing is a particular implementation of the differencing techniques in which the changes in a video sequence are evaluated with respect to a stationary background frame.

This paper introduces a background differencing technique in the compressed domain that retains the simplicity feature of its spatial domain counterparts while circumventing the drawback of noise and illumination sensitivity.

1.2. Organization of the paper

The remainder of this paper is organized as follows. Section 2 recalls the underlying principle that motivated the study of the proposed change detection technique. Section 3 describes the change detection algorithm itself along with a low complexity implementation scheme. In Section 4 are discussed the mechanisms by which the proposed method deals with the noise and illumination changes issues. Section 5 presents the results obtained in the frame of a video-surveillance application including a comparison with the results achieved with previously reported techniques. Finally, Section 6 states the conclusions.

2. The DCT-phase of images

A study on the significance of the DCT-phase in images was reported in [15] where it is showed that the DCT-phase in spite of its reduced binary value $\{0,\pi\}$ conveys a significant amount of information of its associated image. An example given in [15] is reproduced in Figure 1 and is briefly described below.

Figures 1(a) and 1(b) show the test images Lena and Baboon, both monochrome and with a spatial resolution of (512×512) pixels. By applying a 512-point 2-D DCT over these images, two sets of transformed coefficients are obtained. Figures 1(c) and 1(d) show the reconstruction back into the spatial domain after an inverse DCT (IDCT) has been applied over the magnitude array of the two sets of transform coefficients and when the corresponding phase values were all forced to zero. Figures 1(e) and 1(f) show the reconstruction when the IDCT is applied over the original binary-valued phase arrays and when the value of the magnitudes was set to one. These last two figures put in evidence the high amount of information conveyed by the DCT-phase, which is further emphasized in Figures 1(g) and 1(h). The reconstructed image in Figure 1(g) is the result of the IDCT when applied on the magnitude of the DCT coefficients of Baboon combined with the DCT-phase of Lena; the result of the alternative magnitude-phase combination is shown in Figure 1(h). It is clear from these images that the DCT-phase prevails over the magnitude in this reconstruction process.

3. Change detection algorithm

Considering the results in the previous section, a change detection algorithm for a videosurveillance application was studied and implemented. The underlying rationale of the algorithm is that given the significant amount of information conveyed by the DCT-phase, a phase-only-processing scheme can provide a simple and yet reliable robust measure to detect the significant changes between two frames.

Since this phase-only-processing takes place directly in the DCT domain, this method is inherently suitable for dealing with bitstreams that have been generated by using any of the widely popular standardized DCT-based compression algorithms such as JPEG, MPEG-x, and H.26x.

In this section we address the change detection issue in the frame of a common videosurveillance application which presents the following features. First, the image change is

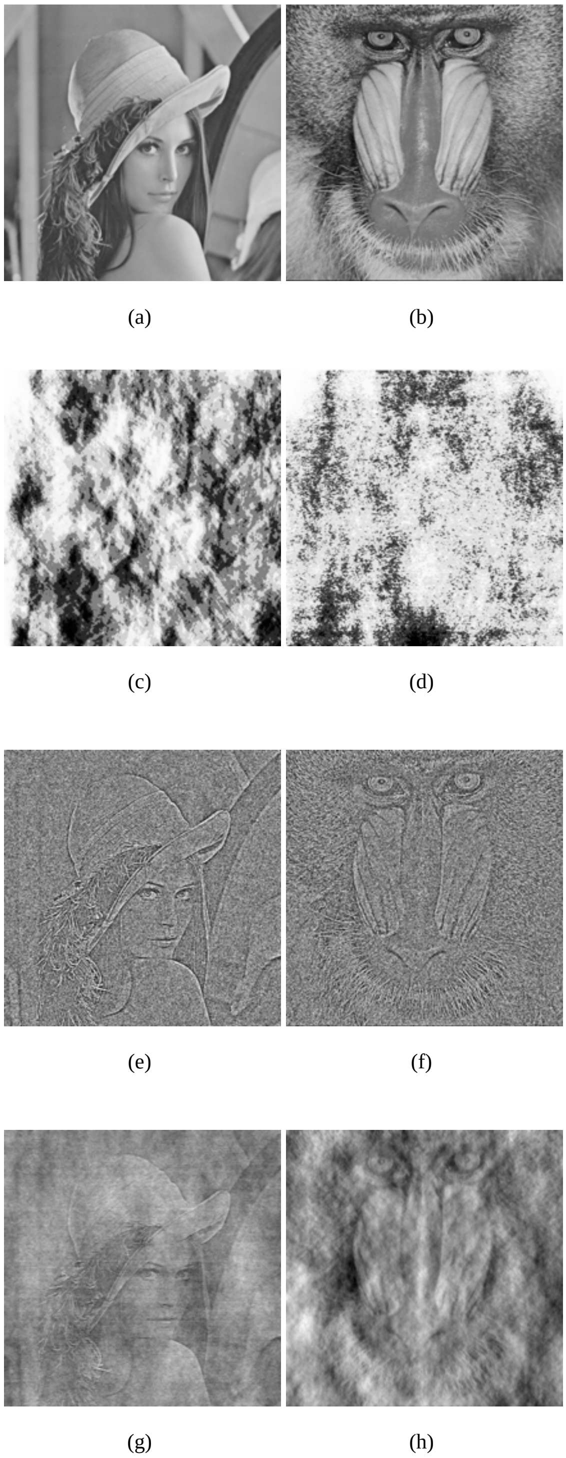


Figure 1: *Examples of the relevance of the DCT-phase in images [15]. Original images: (a) Lena; (b) Baboon. IDCT reconstructed images from: (c) DCT-magnitude of Lena with DCT-phase $\equiv 0$; (d) DCT-magnitude of Baboon with DCT-phase $\equiv 0$; (e) DCT-phase of Lena with DCT-Magnitude $\equiv 1$; (f) DCT-phase of Baboon with DCT-magnitude $\equiv 1$; (g) DCT-phase of Lena with DCT-magnitude of Baboon; (h) DCT-phase of Baboon with DCT-magnitude of Lena.*

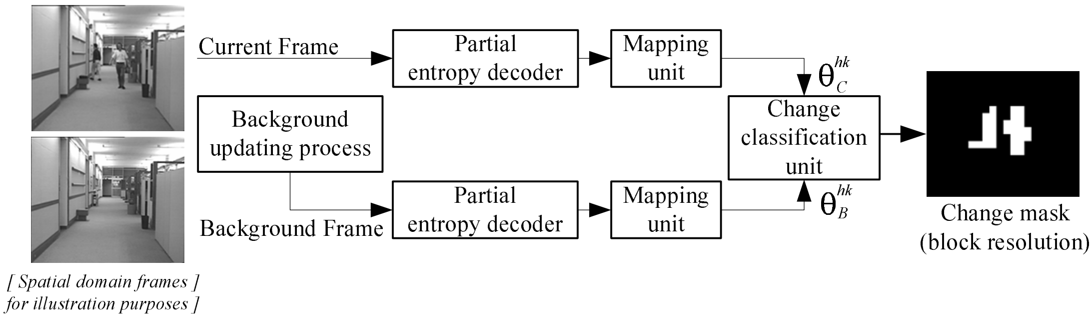


Figure 2: *DCT-phase-based change detection algorithm.*

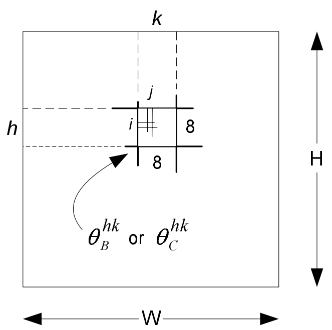


Figure 3: *Indexing scheme for the DCT-phase arrays.*

evaluated with respect to a background reference image. Second, the video frames are captured with a stationary camera which assures their correct registration with respect to the reference image, the latter can be replaced by using a selected background updating technique. Finally, the video frames are encoded by using the Motion JPEG algorithm. Motion JPEG compression is commonly used in current commercial videosurveillance systems. It has also been reported in some studies as the compression method of choice in both cabled or wireless videosurveillance systems [16][17][18].

The general scheme of the change detection algorithm is given in Figure 2. A partial entropy decoding is all what is required to extract the phase information from the current JPEG-compressed frame. The same operation is used to extract the phase from the background image, all the same, at a significantly lower frame rate depending on the background updating algorithm, if there is any.

An elementary mapping unit is used to convert the output values of the partial entropy decoder to an alternative application-dependent and/or implementation-friendly phase set. In this scheme the output of the mapping unit is the ternary set $\{-1,0,1\}$ corresponding respectively to negative, zero valued, and positive DCT coefficients.

3.1. Change classification metric

Once the ternary phase symbols are available, multiple metrics can be implemented to classify the pixels of the current frame as *changed* or *unchanged*. Among those multiple evaluated, the metric reported below produced effective results to detect significant change while demanding a minimum of computational resources.

Referring to Figure 2 and Figure 3, for a background frame B with a spatial resolution of $(W \times H)$ pixels, the output of the mapping unit is a ternary-valued DCT-phase-symbol matrix of $(W \times H)$ elements. In accordance with the (8×8)-element block-based processing of JPEG, this matrix can also be expressed as θ_B^{hk}, where the indexes h and k identify the corresponding (8×8)-element sub-blocks the complete $(W \times H)$-element array is composed of, and where $h = 0,1,2,\ldots,(H/8)-1$, and $k = 0,1,2,\ldots,(W/8)-1$. By following the same notation, the DCT-phase-symbol array of the current frame C can be expressed as θ_C^{hk}.

In this study, the change mask M that identifies the changes in the current frame C is obtained by first executing an absolute difference of the corresponding phase-symbol-values of the current and the background frame and then summing up the results within each block hk. If the final sum is higher than or equal to a given threshold Th, then the block hk is classified as *changed* (part of a foreground object), otherwise, it is considered *unchanged* with respect to the background.

Mathematically, the sum of absolute differences and the binary change mask generation are given respectively by Equations (1) and (2) below:

$$SAD_{hk} = \sum_{ij} \left| \theta_C^{hk}(i,j) - \theta_B^{hk}(i,j) \right| \qquad (1)$$

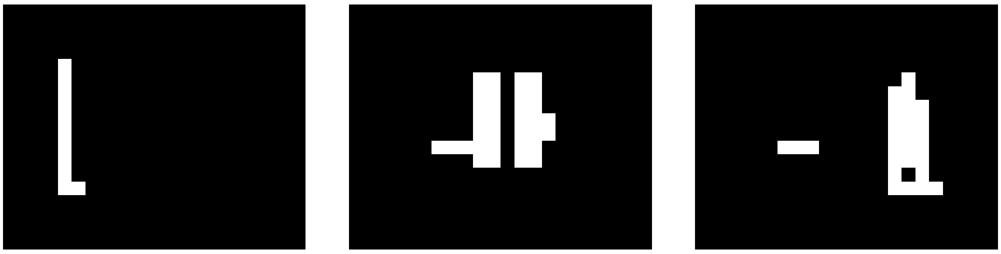
where, $i,j = 0,1,2,\ldots,7$, represent the row and column index within an (8×8)-element block. The binary change mask M_{hk} is then produced by thresholding :

$$M_{hk} = \begin{cases} 1 & \text{if } SAD_{hk} \geq Th \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

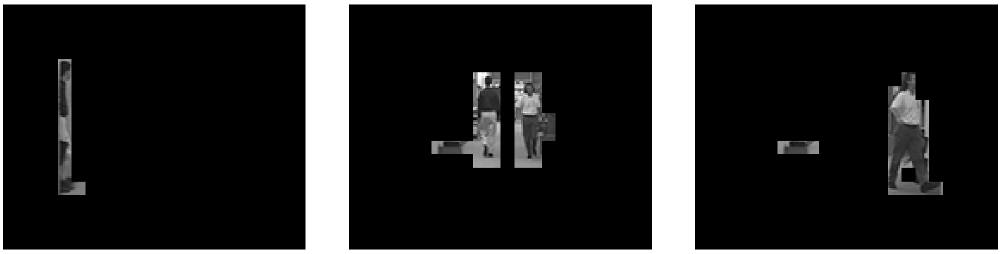
4. Noise and illumination changes issues

As stated before one of the drawbacks of the differencing and threshold methods is their high sensitivity to noise and

(a) Original frames No. 18, 188, and 296.



(b) Block-resolution change masks.



(c) Illustration of the detected scene changing elements.

Figure 4: *Results of the DCT-phase-based method.*

to illumination changes. We discuss below the mechanisms by which the proposed technique deals with these two issues.

4.1. Robustness to noise

In order to improve the rejection of non-significant change or noise, some spatial domain change detection algorithms execute the classification of change of the frame pixels by processing each pixel not independently, but by also considering the information regarding the status of the pixels in the neighborhood. This efficient approach makes part of the so-called geo-pixel or region-based techniques [13]. For this family of algorithms the improved efficiency in terms of robustness to noise comes at the expense of an increase of control and computational complexity.

Processing Motion JPEG frames directly in the compressed domain makes it all natural to obtain a geo-pixel-oriented change detection algorithm, and this, without a major penalty in terms of computational or control complexity. This is because, as it is known, the basic JPEG processing units are not individual pixels but non-overlapping blocks of (8×8) pixels.

As reported in Section 3.1, and explicitly shown in Equations (1) and (2), the proposed algorithm performs the change classification at the (8×8)-element level. It presents thus the advantage of the robustness to noise of region-based change detection algorithms without incurring in a major increase of complexity. Consequently, the change mask M at the output of the change classification unit is at block-resolution.

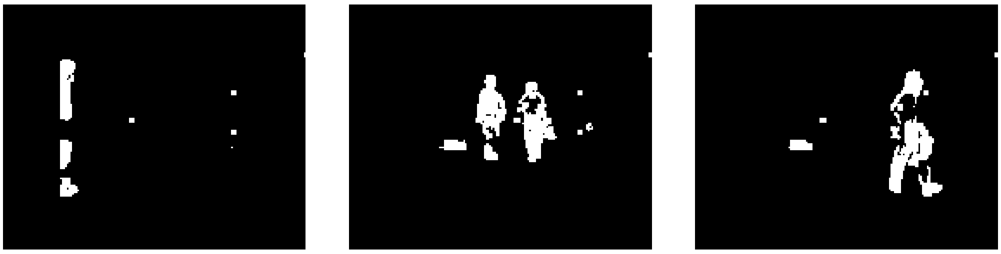
4.2. Robustness to illumination changes

While the inherent region-based feature of the proposed algorithm contributes to its robustness to noise, a particular characteristic of the Discrete Cosine Transform makes it possible to address the issue of illumination changes.

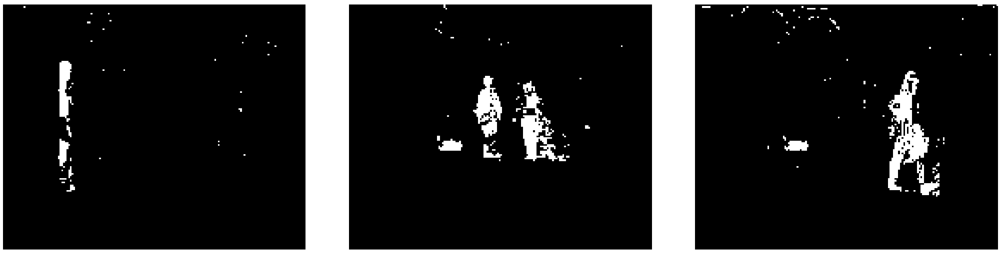
In effect, it is known that in an N-point 2-D DCT coefficient array, the DC coefficient conveys all by itself the information regarding the average luminance of the original block of $(N \times N)$-pixels. Illumination changes will thus mainly have an effect on the magnitude of the DC coefficient.

Since neither Equation (1) nor (2) is a function of the magnitude of the DC coefficients, the proposed change detection

(a) DCT-phase-based method.



(b) Method reported in [19].



(c) Method reported in [20].

Figure 5: *Comparison with other techniques.*

algorithm presents an attractive robustness to illumination changes.

5. Results

Some samples of the performance of the proposed method to detect changes with respect to a background frame in the sequence Hall Monitor are shown in Figures 4 and 5. Only the luminance band of the image data was used in this study; using color will add robustness in exchange of computational complexity. The very first frame of the sequence, which is shown in the left-bottom part of Figure 2, was selected as the background model for all the remaining 299 frames. Furthermore, a threshold of $Th = 10$ in Equation (2) turned out to be a good compromise between removing non-significant change and still detecting all the pertinent changing foreground objects.

Figure 4a) displays the frames number 18, 188, and 296 of the original sequence. The resulting block-resolution change masks produced after the execution of the change classification function are shown in Figure 4b). Finally, for illustration purposes, Figures 4c) displays the pixel of the blocks that were detected as belonging to changing objects.

The results of the DCT-phase-based method in comparison with two previously reported spatial domain techniques [19] [20] are shown in Figure 5. Since these two methods produce change masks at pixel resolution, then for comparison purposes an additional threshold operation was carried out on those blocks of pixels that had been classified as changed in the DCT-phase method. These blocks (on the current frame) were decompressed and their pixels subtracted from the corresponding pixels of the decompressed background frame. When the absolute value of these differences was higher than or equal to a threshold then the current pixel was classified as changed (binary value 1), otherwise the change mask was assigned a zero value, indicating an unchanged status. For this comparison the value of the threshold was set to 25.

Figure 5a) depicts the resulting change masks produced with the DCT-phase method, while Figures 5b) and 5c) show respectively the resulting change masks obtained with the methods reported in [19] and [20]. The chosen frames are a good indicator of the global results of the comparison study, which demonstrates the efficiency of the proposed technique to detect significant change while featuring an excellent robustness to noise.

6. Conclusions

This paper introduced a simple and efficient algorithm for detecting image change with respect to a background reference image. The presented method operates directly in the compressed domain and features a low computational complexity which makes it suitable for low-power, low-cost videosurveillance applications. The presented results showed the efficiency and robustness of the algorithm as well as its excellent performance with respect to previously reported techniques. The underlying method is based on the processing of the rich in information phase-component of the DCT coefficients, which makes this technique exploitable for videosurveillance bitstream generated by using ubiquitous industry standard methods such as JPEG, MPEG-x or H.26x.

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