Low Complexity Contrast Enhancement Algorithm for Nighttime Visual Surveillance

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***Abstract*—This paper presents a new algorithm for nighttime contrast enhancement. The proposed algorithm modifies the traditional histogram equalization algorithm to maintain the color information of the original nighttime images. The algorithm has a low computational cost that makes it suitable for real-time hardware implementation. In addition, its efficient hardware implementation is detailed on a Xilinx Spartan3A DSP XC3SD3400A device. The targeted resolution is 1920x1080@30fps. The hardware prototype utilizes 6.45% of the slices, 1.59% of the Block RAMs, and 7.14% of the DSP48As available in Spartan3A DSP XC3SD3400A device.**

I. INTRODUCTION

The need for smart visual surveillance systems is a worldwide phenomenon, attracting private companies, governmental and public institutions, with the aim of enhancing public safety [1] and asset protection. Over the last few years, the visual surveillance market has experienced a rapid growth due to price drop and improvement of surveillance cameras. Nowadays, the new challenge is to develop and implement robust automatic processing systems attached to the surveillance cameras that can detect and track moving objects, and interpret their activities and behaviors. Recently the need for better video resolution created an interest in using high definition (HD) rates for video surveillance. Along with its increasing processing bandwidth and its computational complexity, visual surveillance is a very active research area in computer vision and a key technology in the following areas [1]-[5]:

- The fight against terrorism and crime including threat assessment.
- Public safety, especially in transport networks, town centers and public facilities such as schools, hospitals and sports grounds.
- The efficient management of transport networks and public facilities

Video surveillance algorithms do not perform quite well in low illumination environment, which is typically the case in nighttime scenes. There are two main problems limiting the usage of the same daytime surveillance algorithms in the nighttime scenes. First, the low illumination makes it difficult for these algorithms to accurately estimate the background. Second, the lost color information may reduce the abilities of tracking algorithms to differentiate between the different moving objects.

This paper presents a low complexity contrast enhancement algorithm suitable for nighttime surveillance systems. Section II reviews a few contrast enhancement techniques for nighttime surveillance. Section III presents the proposed algorithm. Section IV demonstrates and discusses the simulation results. In section V, a hardware implementation of the proposed nighttime contrast enhancement algorithm is presented. Section VI concludes this paper.

II. NIGHTTIME SURVEILLANCE SYSTEM

Nighttime image sequences of a scene from a surveillance camera have lower contrast than their corresponding daytime images of the same scene due to low and uneven illumination [6]. A denighting method is proposed in [6] which uses the scene data captured during the daytime to enhance the nighttime images. In this method, the image is decomposed into an illumination layer *L*, and a reflectance layer *R* that is assumed to be the textures. Then the nighttime image is enhanced by improving its illumination so that it is closer to the illumination of daytime by using day and nighttime background illuminations that have already been computed.

While the denighting and image fusion techniques improve the nighttime images appearance, they do not help in objects detection and tracking. The moving objects are detected and tracked in the nighttime images since the daytime images carry information about the background only. As explained in [6], background estimation is carried out for the nighttime images before improving the nighttime images quality with the daytime background information. Hence, contrast enhancement of nighttime images is essential for background estimation and object detection processes.

A nighttime surveillance system is introduced in [7]. The enhancement of nighttime video is accomplished using a Low Dynamic Range (LDR) tone mapping algorithm proposed in [8]. The mapping function is shown in Equation 1.

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$$y = 255.\frac{\log\left(\frac{x}{255}(\Psi - 1) + 1\right)}{\log(\Psi)} \tag{1}$$

where x is the pixel value of the original nighttime image, y is the pixel value of the enhanced image, Ψ is a parameter which controls the shape of the correction curve. This mapping function is similar to the traditional Gamma Correction function except that it performs better in dark areas [7][8].

Another method which is commonly used for contrast enhancement is the histogram equalization (HE). HE remaps the gray levels of the image based on the probability distribution of the input gray levels [9]. For an input image with $Y(i,j)$ gray scale values, a total number of pixels N and K gray levels, the HE algorithm is described as follows:

1. Find the probability density function (PDF) of the input image,

$$P(k) = \frac{n_k}{N}, \qquad \text{for } k = 0,1,\ldots,K-1 \tag{2}$$

2. Compute the cumulative distribution function (CDF) of the input image,

$$C(k) = \sum_{m=0}^{k} P(m), \qquad \text{for } k = 0,1,\ldots,K-1 \tag{3}$$

3. Use the CDF values to remap the gray levels of the input image,

$$\begin{aligned} y(i,j) &= C(Y(i,j)) \\ Y'(i,j) &= y(i,j)\cdot(\max(Y(i,j)) - \min(Y(i,j))) + \min(Y(i,j)) \end{aligned} \tag{4}$$

There are mainly two problems in the application of the HE method in nighttime surveillance. The first problem is that the colors of the resultant frames are washed out as will be shown in the simulation results section. The second problem is the need to store the whole frame to build the probability density function before starting the equalization. This problem represents a serious difficulty in hardware implementation when dealing with high definition resolutions.

The performance of the above mentioned algorithms in comparison with the proposed algorithm is discussed in the simulation results section.

III. The Proposed Algorithm

In the proposed algorithm, the traditional HE algorithm described in the previous section is modified to maintain the color information of the original nighttime frames. All the HE steps described before are done until a gray scale image $Y'(i,j)$ is reached. Then the contrast enhancement is applied to the color frame by enhancing each of the three image components, red, green, and blue (RGB), separately instead of applying the contrast enhancement to the luminance (Y) component. This is done by multiplying each of the RGB values of each pixel by the ratio of its enhanced luminance $Y'(i,j)$ to the original luminance $Y(i,j)$ as shown in Equation 5.

$$\begin{aligned} R'(i,j) &= R(i,j)\frac{Y'(i,j)}{Y(i,j)} \\ G'(i,j) &= G(i,j)\frac{Y'(i,j)}{Y(i,j)} \\ B'(i,j) &= B(i,j)\frac{Y'(i,j)}{Y(i,j)} \end{aligned} \tag{5}$$

where $R(i,j)$, $G(i,j)$, and $B(i,j)$ are the original red, green, and blue components at pixel (i,j) and $R'(i,j)$, $G'(i,j)$, and $B'(i,j)$ are the enhanced red, green, and blue components.

In addition, the CDF from the previous frame is used to enhance the current frame in order to avoid storing any frames. Our simulation results show that, for surveillance sequences captured with fixed camera, the CDF of two consecutive frames are very similar. Using this observation, the nighttime frames are processed in real time without storing any frames. Hence, the first frame in the sequence is not enhanced but just used to build the CDF which will be used to enhance the next frame. The proposed algorithm is described in Figure 1.

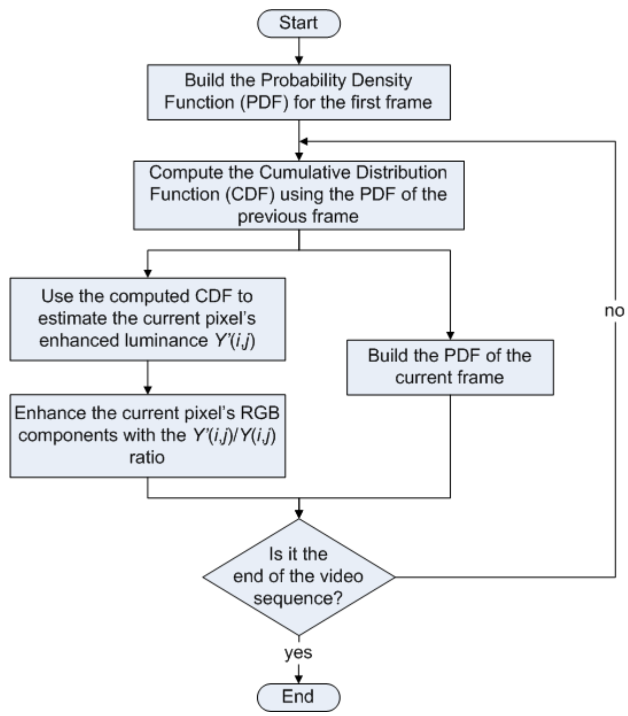
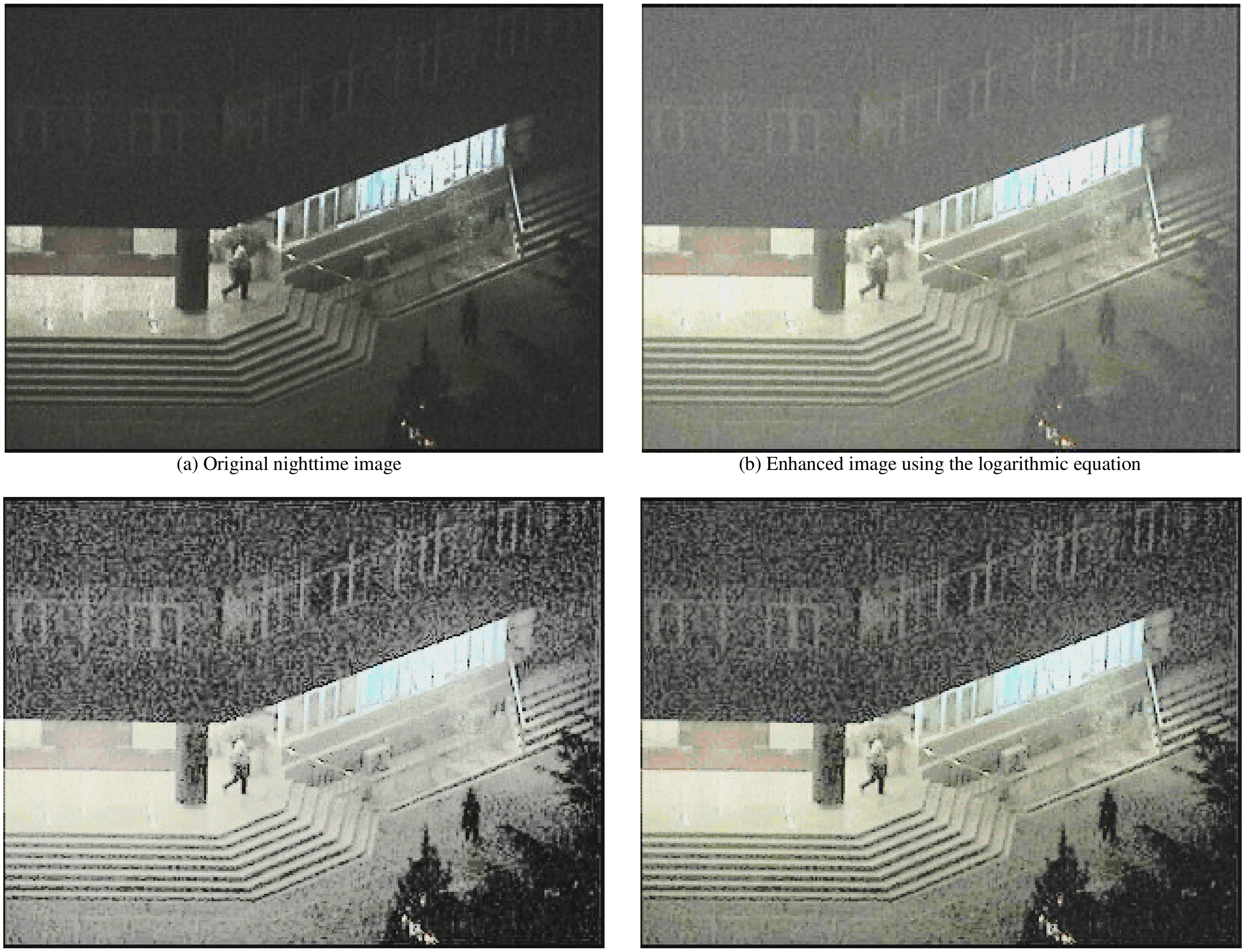


Figure 1. The proposed contrast enhancement algorithm

IV. Simulation Results

The output results of applying different contrast enhancement algorithms on a nighttime video sequence are shown in Figure 2. In Figure 2a an image (frame) of the original sequence is shown. The enhanced image with the logarithmic equation used in [7][8] is shown in Figure 2b while the image shown in Figure 2c is enhanced with the HE algorithm. Figure 2d shows the enhanced image with the proposed algorithm.



(a) Original nighttime image

(b) Enhanced image using the logarithmic equation

(c) Enhanced image using the HE

(d) Enhanced image using the proposed method

Figure 2. Contrast enhancement using different methods

When comparing the enhanced images with the algorithm in [7][8] (Figure 2b) and the proposed algorithm (Figure 2d), it can be seen that the proposed algorithm has better performance in dark areas. With the proposed algorithm, the dark moving objects, such as the man near the trees area, can be easily differentiated from the dark background. This is an important feature required in nighttime surveillance systems.

It can also be seen from Figure 2 that the proposed method enhanced the image as good as the HE algorithm but it has better color information than the image enhanced with the HE algorithm. This is seen clearly in the background colors at the building entrance and the running man above the stairs. The colors in the enhanced image with the HE algorithm are washed out as shown in Figure 2c.

V. NIGHTTIME CONTRAST ENHANCEMENT HARDWARE IMPLEMENTATION

This section presents a hardware implementation of the proposed contrast enhancement algorithm for nighttime surveillance with fixed camera. The architecture block diagram is shown in Figure 3. The input to the architecture is RGB images (frames) in raster scan order. The histogram equalization is accomplished for the luminance image and applied to the RGB image as explained in Section III. The architecture uses one line buffer to buffer 256 input pixels. These 256 cycles are required to evaluate the cumulative distribution function (CDF) from the probability density function (PDF) of the previous frame. The PDF of the previous frame is used instead of the current frame's PDF to avoid storing any frame. The simulation results do not show any notable difference between the enhanced frames using the previous frame's PDF and the enhanced ones using the current frame's PDF. The architecture has two local memories to store the 256 PDF values and 256 CDF values. No external memory storage is required for the architecture.

The architecture operation can be described as follows:

- Initialization:
  1. Build the histogram PDF for the 256 gray levels in the luminance image of the first frame.
  2. Compute the minimum and maximum values of the luminance image.

3. Store the histogram PDF in PDF memory 1 and another copy in PDF memory 2.

- For each new image do:
  1. Compute the CDF of the previous frame according to Equation 3 using the stored values in PDF memory 2.
  2. Use the CDF values to remap the gray levels of the current frame according to Equation 4 using the stored minimum and maximum luminance values of the previous frame.
  3. Use the remapped gray levels and the current gray levels to enhance the current frame's RGB values according to Equation 5.
  4. Meanwhile, build the histogram PDF for the current frame that will be used for the next frame and store it PDF memory 1.
  5. Compute the minimum and maximum values of the luminance image for the current frame that will be used for the next frame.
  6. Copy the histogram PDF values to PDF memory 2.

The proposed architecture was prototyped using Xilinx Spartan3A DSP XC3SD3400A. The architecture processes 30 frame/s with high definition resolution 1920x1080 pixels. The input line buffer uses 1 block RAM. The two PDF and CDF memories uses 1 block RAM. This adds up to 2 block RAMs. The prototyping results of the proposed architecture are summarized in Table I.

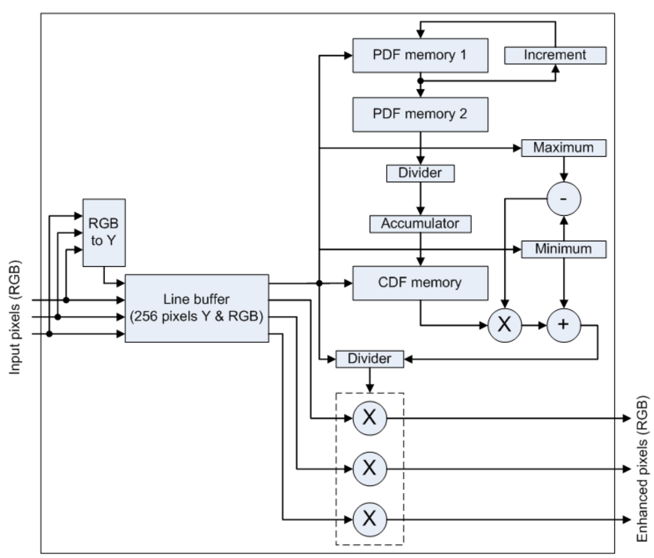


Figure 3. Block diagram of the proposed architecture

TABLE I. THE ESTIMATED RESOURCES OF THE ARCHITECTURE

# Block RAM	External Memory Size	External Memory BW	# Slices	# DSP48
2	0	0	1540	9

VI. CONCLUSION

This paper presents a low complexity contrast enhancement algorithm suitable for nighttime surveillance systems. The traditional HE algorithm is used to estimate an enhanced luminance image for the current image. The contrast enhancement is then applied to the color image by enhancing each of the three image components, red, green, and blue (RGB), separately. The RGB values of each pixel are multiplied by the ratio of its enhanced luminance to the original luminance. The proposed algorithm has a low computational cost that makes it a suitable choice for real-time hardware implementation.

The paper also presented a hardware implementation of the proposed algorithm using Xilinx Spartan3A DSP XC3SD3400A device. The targeted resolution is 1920x1080@30fps. The hardware prototype utilizes 6.45% of the slices, 1.59% of the Block RAMs, and 7.14% of the DSP48As available in Spartan3A DSP XC3SD3400A device.

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