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Video Image Enhancement of CCTV Footage Using a Combination of Contrast Limited Adaptive Histogram Equalization (CLAHE) and Filtering Methods

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Abstract

The quality of CCTV video footage often deteriorates due to poor lighting conditions, unfavorable environmental factors, and limited hardware specifications. These issues can result in the loss of critical visual details, such as faces or monitored objects. This study aims to enhance the visual quality of CCTV video by combining the Contrast Limited Adaptive Histogram Equalization (CLAHE) method with several filtering techniques, including median, mean, and Gaussian filters. The video format used in this research is .mp4, and the image enhancement process is implemented through a desktop application developed using Visual Studio Code. The results demonstrate that the combination of CLAHE and filtering techniques significantly improves contrast and reduces noise, making previously obscured details more visible. This approach enables the developed application to effectively enhance video surveillance footage captured under suboptimal lighting conditions.

Keywords: *CLAHE, Filtering, Video Quality Enhancement, CCTV, Visual Studio Code.*

1. Introduction

CCTV is a digital video camera designed to continuously observe an object at all times and transmit video signals to a room, which are then forwarded to a monitor screen [3]. The quality of video recordings from a CCTV camera depends on the hardware specifications; some can capture images in dark environments while others cannot. When the room has ample lighting, the CCTV footage appears clear, but in low-light conditions, the footage only shows the illuminated parts of the object, leaving some areas dark and resulting in suboptimal image quality [4].

Image enhancement is a process aimed at improving the visual quality of an image by minimizing disturbances, enhancing details, or overall appearance. This can be achieved through various techniques such as spatial filtering, contrast adjustment, and noise removal, making the image easier to interpret by both humans and computer systems.

A common issue is that many shops use low-quality CCTV cameras, leading to unclear footage, especially in poor lighting conditions [5]. In criminal investigations such as theft, CCTV footage can serve as crucial evidence. Another problem is that images captured by low-specification CCTV cameras often have excessively high contrast and brightness, which causes the captured images to appear unclear and less sharp [1].

Contrast Limited Adaptive Histogram Equalization (CLAHE) is a method used to improve image contrast [8]. It addresses the problem of over-enhancement found in the Adaptive Histogram Equalization (AHE) method by applying a limit to the histogram, known as the clip limit, which defines the maximum height of the histogram [2].

Noise in images is caused by physical disturbances during the acquisition process or intentionally due to improper processing. To overcome this, filtering methods are applied to reduce noise in images enhanced by CLAHE [10]. Filtering serves to reduce noise and smooth the image. It is called nonlinear because its operation is not based on convolution processes [6]. Nonlinear operations involve sorting the intensity values of a group of pixels and replacing the processed pixel with a certain value [7].

Based on these issues, the proposed solution combines CLAHE and filtering methods [9]. CLAHE aims to enhance local contrast in video images without causing noise over-amplification, making hidden details in dark or bright areas more visible. Meanwhile, filtering reduces noise such as small speckles commonly found in CCTV footage while preserving the sharpness of object edges. This study employs several filtering techniques, including median filter, mean filter, and Gaussian filter.

2. Research Method

This research consists of several processes as illustrated in Figure 1.

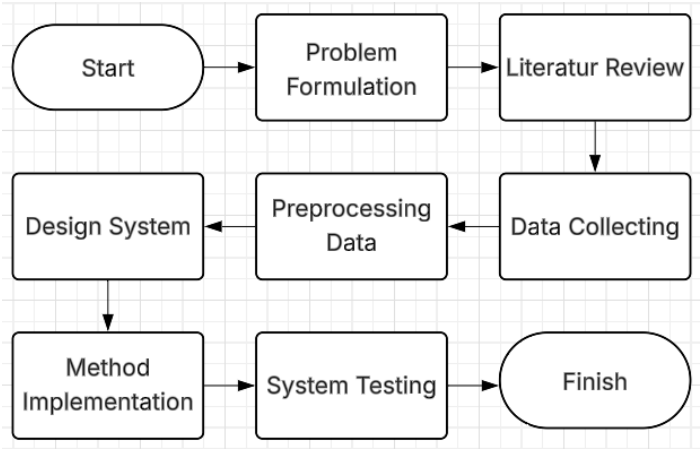


Fig. 1: Research Workflow

2.1. Problem Formulation

This stage identifies the main issues found in CCTV video recordings, such as noise, low contrast, and blurry details caused by poor lighting conditions or hardware damage. The aim of this study is to find a solution to improve video quality using Contrast Limited Adaptive Histogram Equalization (CLAHE) and median filter methods.

2.2. Literatur Review

The researcher collects and analyzes various literature related to image processing, particularly techniques for enhancing video quality. The focus is on CLAHE and median filter methods, including their application for improving CCTV video quality, to gain a comprehensive understanding of their working principles, advantages, disadvantages, and relevant case studies.

2.3. Data Collecting

Data is obtained directly from CCTV video recordings owned by the researcher under various lighting conditions. The videos are recorded in different situations to acquire representative data and to test the effectiveness of CLAHE and median filter methods in handling various noise types and common image quality issues..

2.4. Preprocessing Data

At this stage, the CCTV videos are converted into .mp4 format due to its wide compatibility with image processing software and efficient storage. The videos are then divided into image frames at an interval of one frame per second to obtain sufficient visual representation without generating excessively large data..

2.5. Design System

The researcher develops an image processing system based on programming using Visual Studio Code. The system uses appropriate image processing toolboxes to implement the CLAHE and median filter algorithms. The design includes detailed workflows starting from video reading, frame extraction, to the application of image processing methods.

2.6. Method Implementation

CLAHE is applied to each frame to enhance local contrast, making previously unclear details more visible. Subsequently, the median filter is sequentially applied to reduce noise resulting from the CLAHE process or previously existing noise in the video. Parameters such as the clip limit in CLAHE and kernel size in the median filter are adjusted to achieve optimal results.

2.7. System Testing

The developed system is tested using CCTV videos of varying qualities. The testing involves comparing the original videos with the processed ones to observe significant improvements. A thorough analysis is conducted to identify system strengths and weaknesses as well as to determine the best parameters for producing optimal video quality..

3. Method

These are some of the methods used in this research. Contrast Limited Adaptive Histogram (CLAHE), Median Fiter, Gaussian Filter, Mean Filter, Mean Squarred

3.1. Contrast limited adaptive histogram equalization

CLAHE is only applied to the L (Lightness) channel of the LAB color space to improve the contrast or brightness of the image. An example of calculating the clip limit with an 8x8 block size using the equation.

$$\beta = \frac{M}{N}\left(1 + \frac{\alpha}{100}(S_{max} - 1)\right)$$

Where represents the clip limit, represents the block area, represents the number of unique grayscale levels (256), represents the clip factor limit of the histogram valued between 0–100, and represents the maximum histogram value.

$$\beta = \frac{75}{10}\left(1 + \frac{75}{100}(14 - 1)\right)$$

$$= \lceil 2{,}6875 \rceil$$

$$= 3$$

Calculate the Cumulative Distribution Function (CDF) using the equation:

$$f_{i,j}\,(n) = \frac{N-1}{M}\sum_{k=0}^{n} h_{i,j}(k)$$

Where represents the cumulative distribution, represents the grayscale value (256), represents the block area, and represents the frequency of pixel value occurrences.

3.2. Median Filter

In median filtering, an N x N dimensional matrix is used. The data within this matrix is then sorted and placed into a 1 x (N x N) matrix. This process helps to simplify finding the median value from the sorted data set.

3.3. Gaussian Filter

The Gaussian filter method is a linear filter that works by using the Gaussian function to calculate the weights of surrounding pixels. This filter is very effective in reducing Gaussian noise while preserving image details. In the Gaussian filter, the kernel used contains values that follow a Gaussian distribution, with the central pixel having the highest weight and the surrounding pixels having progressively smaller weights as their distance from the central pixel increases.

3.4. Mean Filter

In mean filtering, an N x N dimensional matrix is used as the kernel. From this matrix, the pixel values within the kernel are summed, and the result is divided by the total number of pixels in the kernel (N x N) to obtain the average value.

3.5. Mean Squarred Error (MSE)

Mean Squared Error (MSE) is a statistical metric used to measure the average squared error between two images: the original image and the reconstructed or compressed image. MSE is calculated by summing the squares of the differences in pixel intensity values of the two images at corresponding positions, then dividing by the total number of pixels.

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}}\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - K(i,j)]^2$$

3.6. Peak Signal to Noise Ratio (PSNR)

PSNR is a widely used metric to measure the quality of images that have undergone reconstruction or compression processes. PSNR measures the ratio between the maximum signal power (in this case, the maximum pixel intensity value) and the noise power (error) present in the resulting image.

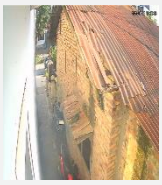
$$\text{PSNR} = 10 \cdot log_{10}\left(\frac{MAX_1^2}{MSE}\right)$$

4. Result and Discusion

At this stage, testing is conducted on 4 CCTV video images with a resolution of 980 x 1080 pixels in mp4 format. The testing is performed by applying the CLAHE method combined with several filters such as median filter, Gaussian filter, and mean filter. This stage aims to clarify objects in the CCTV images as well as to improve noise in the images. The testing is carried out through the application of CLAHE followed by filtering.

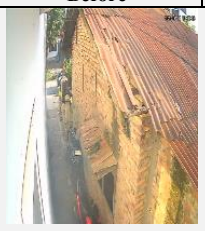
4.1. Data

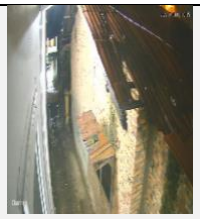
Table. 1: Example Data

Data No.	Data	
	Image	**Size Of Pixel**
1		960x1080
2		960x1080
3		960x1080
4		960x1080

4.2. Result Data With Filter Clahe

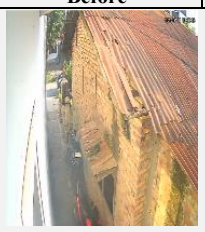
Table. 2: Result Data with Filter Clahe

Data No.	Data		Value MSE and PSNR	
	Before	**After**	**MSE**	**PSNR**
1			95.77	28.32

2			90.03	28.59
3			101.58	28.06
4			91.03	28.54

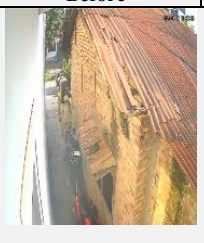
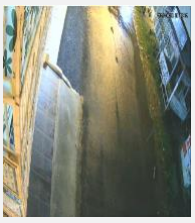
4.3. Result Data With Filter Clahe and Median Filter

Table. 3: Result Data with Filter Clahe and Median Filter

Data No.	Data		Value MSE and PSNR	
	Before	After	MSE	PSNR
1			29.81	33.39
2			15.92	36.11
3			33.14	32.93
4			24.36	34.26

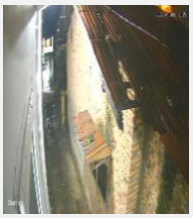
4.4. Result Data With Filter Clahe And Gaussian Filter

Table. 4: Result Data with Filter Clahe and Gaussian Filter

Data No.	Data		Value MSE and PSNR	
	Before	After	MSE	PSNR
1			43.01	31.80
2			21.36	34.84
3			45.84	31.52
4			32.53	33.00

4.5. Result Data With Filter Clahe And Mean Filter

Table. 5: Result Data with Filter Clahe and Mean Filter

Data No.	Data		Value MSE and PSNR	
	Before	After	MSE	PSNR
1			48.68	31.26
2			26.37	33.91

3			51.11	31.05
4			38.70	32.25

4.6. Value Comparison of MSE

Table. 5: Value Comparison MSE

Data No.	Value MSE			
	CLAHE	CLAHE & Median Filter	CLAHE & Gausssian Filter	CLAHE & Mean Filter
1	95.77	29.81	43.01	48.68
2	90.03	15.92	21.36	26.37
3	101.58	33.14	45.84	51.11
4	91.03	24.36	32.53	38.70

4.7. Value Comparison of PSNR

Table. 5: Value Comparison PSNR

Data No.	Value PSNR			
	CLAHE	CLAHE & Median Filter	CLAHE & Gausssian Filter	CLAHE & Mean Filter
1	28.32	33.39	31.80	31.26
2	28.59	36.11	34.84	33.91
3	28.06	32.93	31.52	31.05
4	28.54	34.26	33.00	32.25

5. Conclusion

The application of the CLAHE method showed good results in enhancing the contrast or brightness of CCTV images. Among the 4 tested images using CLAHE, an average MSE value of 94.6 and an average PSNR value of 28.38 were obtained. These values indicate that the CLAHE method can significantly improve image quality. Visually, the contrast or brightness of the CCTV video images increased. The application of filters to reduce noise in the CLAHE-processed images yielded very good results. Of the three filters applied to the CCTV images in the tests, the median filter achieved the best results with the lowest MSE and highest PSNR values. The median filter effectively reduced noise significantly on CLAHE images without altering the improved contrast or brightness. The combination of CLAHE and median filter methods proved to be effective in enhancing CCTV image quality, both in terms of contrast and noise reduction..

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