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RESEARCH ARTICLE

A Modified Singular Value Decomposition (MSVD) Approach for the Enhancement of CCTV Low-Quality Images

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ABSTRACT Image enhancement and reconstruction is an important field of research in digital image analysis. To increase the quality of low-contrast images, a variety of image-enhancing technologies are available. Among these image enhancement techniques, singular value decomposition and discrete wavelet transform are the popular approaches for enhancing low-quality images. In this study, we have developed a modified singular value decomposition approach to enhance low-contrast and low-resolution close-circuit television images. Low-quality and low-resolution images with singular values near zero are used as input in the proposed approach. On the selected data, a threshold value was determined in the singular values of the diagonal matrix. Finally, the proposed modified singular value decomposition technique was applied to enhance the value of images with low quality and resolution. The datasets include 90 facial images of different individuals with low quality and resolution from a university database. The performance of the proposed approach is assessed using image entropy, peak signal to noise ratio, mean square error, contrast measurement, time computation, structure similarity index measurement and image enhancement factor. During the experiments performed on the obtained dataset, it was found that the proposed modified singular value decomposition approach outperformed the existing singular value decomposition, discrete wavelet transform-singular value decomposition and stationary wavelet transform methods.

INDEX TERMS Low quality images, entropy, human face, image enhancement, security, technological development.

I. INTRODUCTION

Today, high-quality images are deeply integrated into many people's daily lives through image and computer vision applications. Enhancing images and computer vision applications, which process and analyze visual data, is constantly evolving, providing users with better capabilities and ease [1], [2]. Image enhancement performs a crucial part in many imaging and computer vision applications. The primary purpose of enhancing low-quality images is to prepare them more suitable and tangible for a particular purpose by processing them. In digital images, brightness and contrast are often used to illustrate their visual appearance and perception. One of the most difficult issues in image processing and computer vision is maintaining brightness and improving contrast [3], [4].

The closed-circuit television (abbreviated as CCTV) camera is indispensable in daily life in the public and the private sector due to its ability to monitor and record events in buildings, markets, shopping centers, airports, and residential and commercial settings. It is now possible to monitor and record video in various public places using computer-based CCTV cameras. CCTV cameras are used for a wide range of

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purposes such as monitoring of class and examination, security, and tracking criminal activities [5], [6].Another example would be video surveillance in bad weather, such as heavy rain, fog, or snow and low illumination using CCTV cameras. Due to the hindrance produced by weather elements, the CCTV camera may collect images with diminished contrast and quality in such scenarios [7]. The low-contrast images may make it difficult to distinguish essential information, such as a vehicle's license plate in road accident [8] or the facial features of a suspect in a crime. The limitations offered by low-contrast and low-resolution CCTV images in these weather-affected circumstances can have serious consequences for law enforcement and emergency response teams. In such scenarios, accurate identification and prompt action are crucial, and the limitations of these images may impair the effectiveness of video surveillance systems, thereby altering the outcome of investigations or emergency situations [9].

Spatial domain and frequency domain processing are the common methods used for image enhancement. Spatial image enhancement includes directly enhancing each pixel inside an image; this may be done using a variety of approaches, including enhanced unsharp mask methods and modified histogram methods [10], [11]. As an alternative, the image is converted into a mathematical function using frequency domain methods, such as the Fourier transform (FT), discrete wavelet transform (DWT), or discrete cosine transform (DCT) [12], [13].The image is then enhanced using the frequency domain's unique features. Digital images are frequently suffered from noise, poor contrast, and sharpness during acquisition and transmission [14], [15], [16].

Spatial domain image enhancement has various advantages, including its simplicity, ease of implementation, and real-time applicability. However, it is coupled with poor robustness and may not reach optimal perceptual quality [12]. It is also worth mentioning that the quality of CCTV camera is low due to various external and internal factors such as low resolution, distance from the camera, haze, fog, darkness, glare, and noise. Sometimes the quality of the image is so weak that the necessary detail is either missing or not enough to get the required information from it. The above approaches get substantial results appropriately under certain circumstances. However, due to some limitations, these approaches have been found under extreme low-light conditions [16].

The issue of low-quality images can be enhanced using SVD techniques [17]. The visual system of human is more susceptible to contrast as compared to absolute luminance. This problem necessitates applying image enhancement techniques for turning the low-quality image into a good-quality image through the use of SVD. SVD has very important applications in image processing, signal processing, radar system, etc. We have used SVD updating techniques which are very stable and even works for rank-deficient problems effectively.

The existing SVD approach enhances low resolution and low-quality CCTV images by replacing the lower singular values with higher singular values due to which the image is difficult to recognize.

A novel approach is proposed in this study for enhancing the low-quality and low-resolution CCTV images by using MSVD. In the proposed approach, the facial features are enhanced by estimating the singular values of low-quality and low-resolution CCTV images. The enhanced values of the original images are exchanged with the low-quality and low-resolution images based on a threshold value. The sigma values (Σ) of the resultant image are enhanced by having high contrast and high resolution of the low-quality CCTV image. The existing SVD approach is modified by setting a threshold value at the diagonal matrix of low-quality and low-resolution CCTV images. The threshold point replaces the values near to zero in the diagonal matrix of the low-quality image with the enhanced values of a good-quality image. A threshold value must be set to eliminate the zero values in the diagonal matrix. This is because these values are lacking information, so higher values from the original CCTV image will replace them. The modification to SVD is expected to increase the contrast and resolution of CCTV images, thereby providing more information about images with lower contrast and lower resolution.

The following are the contributions of the study.

- Enhanced the facial features of CCTV images having low quality and low resolution using MSVD.
- An adjustable threshold value was added to the diagonal values of the SVD to improve the diagonal matrix's singular values, resulting in a modified singular value decomposition (MSVD).
- Finally, low-quality image enhancement, natural facial features, and specific information are considerably improved and preserved, facilitating image recognition and computer vision applications.

The different sections of the paper are organized in the following way. Section II deals with the related work, and the Methodology section forms part of Section III. Results are displayed in section IV while the last part i.e. section V is about discussion and conclusion.

II. RELATED WORK

Technology has advanced to bring us a wide range of CCTV cameras. It is, however still difficult to discern the events in the footage we are watching due to the poor quality of the image. Numerous studies have been conducted to enhance low-quality images with various image enhancement techniques. For instance, SVD is employed for feature extraction, face recognition, and compression. Besides, it is also used for enhancing images having low-contrast and illumination problems [18]. Many methods have been developed for improving images, including histogram equalization (HE), which is one of the most classical [19]. In HE, brightness distribution on the histogram enhances local contrast without affecting overall contrast. The Global Histogram Equalization (GHE) approach increases contrast by spreading and lengthening an image's dynamic range, which modifies the narrow histogram. can also improve image contrast more effectively, but due to fully overlapping subblocks, it is much more complex computationally. Gamma correction is another popular method that enhances the brightness of dark regions. It compresses the bright pixels to achieve the intended purpose. Dark channel prior method, illumination map estimation method, and retinex-based methods have also been considered to address image enhancement issues besides gamma correction and HE. The retinex-based method [9], [20] is considered as the most popular among the above methods.

Furthermore, studies on using SVD-based approaches for improving low-contrast images have been done. By adding SVD, these approaches try to alleviate the constraints of histogram equalization (HE) methods [17], [21]. The SVD technique is used to decompose image matrix A∈R m x n with m ≥ n into three matrices as shown in equation 1.

$$A = U.\Sigma \cdot V^T \quad (1)$$

where U and V are right and left orthogonal matrices and U∈R m x n, D ∈R m x n,V∈R m x n. The diagonal component of Σ is shown as singular values of matrix A in the matrix. While the columns of V are designated as right singular vectors of matrix A, the columns of U are displayed as left singulars of that matrix. The singular value matrix contains the image's intensity information. The intensity of the input image varies when the singular values of the SVD vary. When the singular value is higher, information in the image will also be greater [22], [23]. SVD shows an accurate representation of any matrix and it is possible to edit the less important data of the matrix to bring forth a low-dimensional approximation [24], [25].

Image enhancement is an active research area, and several types of image processing and computer vision-based techniques are available. Four frequency sub-bands were created from a low-contrast input image using the method developed by Demirel et al. [26]. The low sub-band image's singular value matrix and DWT are both employed for this. This method (DWT-SVD) uses the IDWT (Inverse Discrete Wavelet Transform) to reproduce the improved image. GHE, LHE, BPDHE, and SVE image enhancement approaches have been compared to the changes (performance) of DWT-SVD. The study reported in the article demonstrates that DWT-SVD outperforms the other contenders in terms of visual quality. It is necessary to mention that the SVD technique enhances the images having low-contrast issues. it is achieved through scaling its singular value matrix.

Atta and Abdel-Kader [18] conducted an important study on enhancing various types of images such as buildings, nature, flowers, and an airplane. The weighted sum of the GHE and singular matrices of the image being studied is used in this investigation. The mean brightness of the low-quality image is preserved using the SVD technique. The SVD-based techniques enhanced the results of the input images by scaling the singular values. On the other hand, the images lose the natural look when enhanced with the proposed technique.

Satapathy and Das [27] developed an approach that enhances the image by dealing with the problems associated with the low quality and brightness of the human brain. They utilized VMD (variational mode decomposition) along with SVD as an image enhancement technique. The enhancement techniques presented significant results by enhancing low-quality images and brightness into high-contrast and good-quality images of the human brain. Khallel and Hamida [28] proposed an algorithm that has features of simplicity and adaptability. They employed DWT-SVD as an image enhancement approach for dark CT scan images.The study's results demonstrate that the suggested strategy outperformed other cutting-edge methods of medical image enhancement.

In a work by Bhandari et al. [29], they used the SVD and DWT to improve satellite images. Their investigations employed knee function and gamma correction methods and focused on dark and low-quality images. They significantly improved the image quality by modifying the gamma parameters, resulting in better satellite images with enhanced clarity and contrast. The suggested technique efficiently improved dark satellite images with very low quality () [26]. Sahnouna et al. [3] presented a new T1-W MRI contrast enhancement. It is based on a modified DWT-SVD approach for brain exploration and tissue differentiation. The study's contribution is to attach an adjustable parameter(μ) to compute the enhanced singular value matrix. The enhanced image was constructed by employing IDWT and ISVD. The main advantage of this approach is that it optimizes contrast enhancement performance without introducing undesirable artifacts, erasing information, or altering the unique properties of brain tissues.

Blind Image Quality Assessment (BIQA) is a proposed technique in [30] determines the assessment of image quality. It does not rely on a reference image. The proposed technique extracts feature from Spatial and transform domains using morphological gradient, discrete Laplacian and stationary wavelet transform (SWT) coefficients. SWT enhancement is utilized to enhance the quality of digital images by the application of wavelet basis functions. SWT categorizes the image into a set of wavelet basis functions. This fixed basis set of image explains the efficient and artifact free image processing. BIQA technique showed better performance. It is ranked among the top methods across image databases and distortion types. It is also known for its lack of database and distortion type independence. Besides, it is also known for its potential of the quality of real-time image in diverse environment. It is also noted that this technique took a little longer time when compared to state-of-the-art techniques.

Kaplan [31] put forwarded an approach that shows the global air light and the transmission map Standard deviation and the mean value of the original image were utilized as statistical metrics. With this procedure, the input image is improved more than with the other techniques. On top of that, it preserves the image's original values. It performs more effectively in comparison to conventional techniques for remote sensing enhancement. Loss of detail, particularly in brighter areas, was one of the drawbacks of this method [32], [33].

The research mentioned above demonstrates a variety of image enhancement methods that have been applied to improve images, however, they need to provide superior contrast and resolution enhancement [33], [34]. Additionally, most of the studies were carried out on architectural, natural, satellite, and medical images [35], [36]. The work is driven by the requirement to improve low-quality and low resolution CCTV images to overcome their intrinsic shortcomings, such as reduced clarity, diminished details, poor contrast, and lower resolution, which may prevent accurate image recognition and analysis [37], [38]. So, we suggest an automatic way to enhance and remove these obstacles to get an enhanced and good-quality image. It is also worth mentioning and to the best of our knowledge, little work is being done to improve CCTV images. The focus of the paper is on the enhancement of low quality and low contrast of CCTV image of the facial features of human beings. Generally, the image of CCTV camera has low quality and having low contrast. This challenge creates problems in the identification of human beings. Thus, to overcome this challenge, it is necessary to design such an algorithm that is beneficial in overcoming the low quality and low resolution of CCTV images. The potential impact of computer imaging (CI) has several applications in the field of facial features enhancement, editing software both in smartphones and computer, forensic purposes, cosmetic, dermatology, and security purposes. The potential impact relevant to the present study can be limited to forensic and security purposes.

In this research, we suggest a modification to the SVD-based strategy that addresses the limitation of the SVD methods by placing a threshold at the diagonal values of the sigma matrix of the CCTV low quality and low-resolution images. The proposed method successfully improves CCTV images without introducing undesired artifacts that reduce image visual quality [39], [40]. The main contribution is to propose a modified SVD algorithm, in which a new singular value matrix image is computed by adjusting the singular value of the diagonal matrix. As a result, the low-quality CCTV images are enhanced with high accuracy.

III. METHODOLOGY

An overview of the proposed MSVD CCTV image enhancement method is shown in Figure 1. The proposed method is composed of the following steps. These include the acquisition of CCTV (3 megapixel) video recordings from the University database, converting the videos into frames (123*123, two-dimension images) using Matlab2020a, feature extraction of good and low-quality images, use of SVD technique on bad and good quality images, the transformation of the good and bad images into three matrices (left orthogonal, sigma and right orthogonal) using SVD, placement of threshold at the diagonal value of sigma matrix, use of MSVD/replacement of good quality image values with the diagonal values of low-quality images, and finally production of an enhanced image.

The proposed study's main objective is to improve the facial features of individuals in poor-quality CCTV images. The human facial images are obtained from low-quality CCTV video streams. The proposed modified SVD will highlight various factors that cause noise and produce low-quality CCTV images. The modified SVD techniques will be used to remove those adverse factors which help in its enhancement.

In the proposed approach, the SVD of good quality images is mathematically computed using (2).

$$G = U_g \Sigma_g V_g^T \tag{2}$$

where $U_g \in R^{m \times n}$ is the left orthogonal matrix transposing this into, the Equation (3) as shown below.

$$U_g U_g^T = U_g^T U_g = I, \tag{3}$$

where $\Sigma_g \in R^{m \times n}$ is the diagonal matrix with entries along the diagonal order in a non-increasing order by (4)

$$\sigma_{E1} \geq \sigma_{E2} \geq \sigma_{E3} \ldots\ldots\ldots\ldots\ldots\ldots \geq \sigma_{En} \tag{4}$$

where $V_g^T \in R^{m \times n}$ is the right orthogonal matrix. The SVD of low-quality and low-resolution image is computed in (5).

$$B = U_b \Sigma_b V_b^T \tag{5}$$

where $U_b \in R^{m \times n}$ is the left orthogonal matrix transposing this into (6)

$$U_b U_b^T = U_b^T U_b = I, \tag{6}$$

where $\Sigma_b \in R^{m \times n}$ is the diagonal matrix with entries along the diagonal order in a non-increasing order by (7).

$$\sigma_{s1} \geq \sigma_{s2} \geq \sigma_{s3} \ldots\ldots\ldots\ldots\ldots \geq \sigma_{sn} \tag{7}$$

where $V_b^T \in R^{m \times n}$ is the right orthogonal matrix. The diagonal matrix is represented using (8)

$$\Sigma = \begin{bmatrix} \sigma_1 & 0 & 0 & 0 \\ 0 & \sigma_2 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \sigma_n \end{bmatrix} = diag\,\{\sigma_1, \sigma_2, \sigma_3, \ldots\ldots, \sigma_n\} \tag{8}$$

Let $\sigma_{E1}, \sigma_{E2}, \sigma_{E3} \ldots\ldots\ldots\ldots\ldots \sigma_{En}$ are the singular values of the diagonal matrix (Σ_b) which caused the low quality and low resolution in the given image B. Now the singular value of image B (bad quality image) will be replaced by the singular value of image G (Good quality image) $\sigma_{s1}, \sigma_{s2}, \sigma_{s3} \ldots\ldots\ldots\ldots\ldots \sigma_{sn}$. The threshold technique will extract the singular value of image G and will replace it with a value other than 1.

The process of the threshold value is laid such that when the diagonal values of the sigma matrix of SVD comes near to zero (0). The quality of the image becomes bad when the diagonal values have more zero's in the diagonal matrix.

Thus, it is necessary to place a technique namely, threshold to zero. The function of this type of threshold is to replace the diagonal values (near to zero) of the sigma matrix. Replacement of such low values will take place between the low-quality values of the input image i.e. diagonal values and good-quality image. This replacement of low values (near to zero) with high values of the diagonal matrix is performed by the threshold.

For the matrix B (low-quality and low-resolution image), the condition number K(B) is very high using (9)

$$K(B) = \frac{\sigma_{s1}}{\sigma_{sn}} \tag{9}$$

because the singular values after the threshold value tend to zero, which indicates the instability (blurriness) in the image.

Now to bring stability (brightness) in the system, all the singular values below the threshold value will be replaced with the good quality image singular values 'σ_{sp}' and the system will be updated accordingly, using equation (10)

$$K(M) = \frac{\sigma_{s1}}{\sigma_{sn-p} + \sigma_{sp}} \tag{10}$$

Which is stable as the value '$\sigma_{sn-p} + \sigma_{sp}$' is not too small or not tends to zero.

This replacement of the values turns the low-contrast and low-resolution image into a bright image.

The above replacement of values brings image enhancement in the singular values matrix as well as left and right orthogonal matrixes. It is substituted into the enhancement matrix of (9)

$$M = U_m \Sigma_m V_m^T \tag{11}$$

The proposed Modified SVD approach for low-quality CCTV images is conducted with the following algorithm implementation.

Input: Given the low-quality and low-resolution image (image B) and High-Quality image (image G)

Step 1: x = imread(image G)// read the high quality image

Step2: m = imresize(x) //resize the high-quality image

Step3: a = rgb2gray(m) //convert the image to gray scale

Step 4: y = imread(image B) //read the bad quality image

Step 5: n = imresize(y) // resize the bad quality image

St0ep 6: d = rgb2gray(n) //convert the image to gray scale

Step 7: SVD(a) && SVD(d)

// Apply SVD to both images to perform matrix factorization for generation of three matrices(U, V and $\sum$)

Step 8: Swap the diagonal singular value of image B with image G under the specific threshold.

//obtain new diagonal singular value for MSVD by adjusting the diagonal value of good quality and bad quality image

Output: Obtain the enhanced quality image by multiplying all the three matrices of MSVD using (9).

A. DATASETS

During the development of the proposed MSVD technique, 90 images of human faces were used. The selected images (facial features) were obtained from the university database (different dataset). These images were deformed, and their singular values were lowered to nearly zero. This resulted in images with low quality and low resolution. The training set consisted of 75% of these images, the validation set comprised 10%, and the test set consisted of 15%.

B. EVALUATION METRICS

Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Entropy, contrast, time computation, structure similarity index measurement and image enhancement factor have been used as evaluation metrics in this approach.

1) MEAN SQUARE ERROR VALUES

MSE refers to the sum of the squared error between the base and enhanced image. It is a risk function related to the expected value of squared error. It is also the 2nd moment of error and includes both the variance of the estimate and its bias.

$$MSE = \frac{sum\left((original\ image - enhanced\ image)^2\right)}{MXN} \tag{12}$$

In the above equation, M signifies the number of rows in the image matrix while N shows the number of columns in the image matrix. The value of MSE will be zero when the 2 images have been found same.

2) PEAK SIGNAL TO NOISE RATIO

PSNR is a statistic used to calculate the maximum error between the input and improved image. It computes the ratio of the highest attainable power of a signal to the power of the noise that affects its true appearance. PSNR is used as an evaluation criterion to quantify image enhancement fidelity, with higher values indicating better image quality retention and lower noise interference.

$$PSNR = 10 \log_{10}\left(\frac{r^2}{MSE}\right) \tag{13}$$

where r represents the maximum fluctuation.

3) ENTROPY

It is the computation of the richness of the image details as well as the average information content.

$$Entropy(p) = -\sum\nolimits_{k=0}^{L-1} p(k) \log pk \tag{14}$$

where p(k) is the probability density function (PDF) at the intensity level k and L is the total number of grey levels of the image.

4) MEASUREMENT OF CONTRAST

Contrast measurement gives idea about contrast measure and image quality together. Thus, one can measure contrast levels of input (original) and processed (output) images separately to quantitatively asses the level of contrast change. Thus, contrast measurement does not only measure the relative change of contrast but also takes the distortion introduced on the enhanced image relative to the considered original image. The most common formula to measure the contrast is to employ the standard deviation of pixel intensities. The contrast of an image using standard deviation method is expressed in the following equation.

$$\sigma = \sqrt{\left(\sum (I(x,y)-\mu)^2/N\right)} \tag{15}$$

In equation (15), σ (sigma) refers to the image contrast and I (x, y) shows the pixel intensity value of the image. The mean (average) intensity of all pixels of the image is represented by μ (mu). The total number of pixels is shown by N. The above equation measures the standard deviation (σ) of pixel intensities in an image. It gives the measurement of the image contrast. The contrast in the image is greater when the value of standard deviation is greater. The higher the contrast value, the better the image information [41], [42].

5) TIME COMPARSION

The computation time for the enhancement of low quality and low resolution using other state of the art techniques i.e. SVD, DWT-SVD, SWT and the proposed MSVD techniques. The computation time of the above techniques are presented in Figure 2. The experiments are performed on Intel(R) Core ™i5-5300U CPU @ 2.30 GHz with HD Graphics 5500 and 8GB RAM. The images have been evaluated using MATLAB 2020a. TIC-TOC commands of the Matlab 2020a have been applied [30], [42].

6) STRUCTURE SIMILARITY INDEX MEASUREMENT

Structure Similarity Index Measurement (SSIM) measures the similarities between two images. It takes the values in the range of [−1, 1]. Higher values of the image show the best preservation of the structure of the image. The results shown in figure showed that the proposed method gave the highest SSIM values when compared with the other methods [3].

SSIM estimates the visual impact of shifts in the luminance of the image, contrast changes, errors if any. All these are together identified as structural changes. SSIM can be represented in the mathematical form as follow in equation (16)

$$\boldsymbol{SSIM}(\boldsymbol{x},\boldsymbol{y}) = \frac{\left(2\mu_x\mu_y + C_1\right)\left(2\sigma_{xy} + C_2\right)}{\left(\mu_x^2 + \mu_y^2 + C_1\right)\left(\sigma_x^2 + \sigma_y^2 + C_2\right)} \tag{16}$$

7) IMAGE ENHANCEMENT FACTOR

IEF (Image Enhancement Factor) is a metric utilized to quantify the enhancement in image quality. It is obtained through enhancement of image or restoration [42]. It is estimated as the ratio of Mean square Error (between the original image and a low-quality image) to the Mean Square Error (between the original image and enhanced image). The IEF can be represented in the following mathematical form in equation (17).

$$\boldsymbol{IEF} = \frac{\boldsymbol{MSE}(\boldsymbol{OriginalImage}, \boldsymbol{Lowqualityimage})}{\boldsymbol{MSE}(\boldsymbol{OriginalImage}, \boldsymbol{EnhancedImage})} \tag{17}$$

The image quality having higher IEF values shows a significant improvement. The higher values of the numerator in the above equation (17) shows more degradation. At the same time the lower value in the denominator shows better enhancement or restoration. Higher values of IEF suggest the effectiveness of the enhancement process while the lower value of the IEF suggests that the enhancement process has not been effective.

IV. RESULTS AND ANALYSIS

We used 90 CCTV images having low quality and low resolution. The experiments were performed using Matlab 2020a environment. We considered two-dimensional images having 123∗123 size. The following qualitative and quantitative results were produced during our experiment. PSNR, MSE, entropy, contrast measurement, time computation, structure similarity index measurement and image enhancement factor are used to evaluate the modified algorithm's performance along with histogram analysis for each image.

A. QUALITATIVE ANALYSIS

The existing SVD, DWT-SVD, SWT and proposed MSVD approaches were applied to the selected data set. Original and enhanced image visual quality utilizing various enhancing techniques is shown in Figure 2. In the figure 2, the SVD algorithm is applied to low-quality and low-resolution images (b1 to b9), and the modified images are put in the images (c1 to c9). The efficiency of MSVD is compared with SVD, DWT-SVD and SWT. The comparison shows a better performance of our proposed MSVD technique. The qualitative analysis exhibited the following results. A histogram graph is included for each original and enhanced image. The input images are considered low-quality images because their histogram graphs show a limited range (shown in figure.2 H-b1 to H-b9). In the histogram graph of the figure.2 H-f1 to H-f9, the MSVD has shown better results than the SVD, DWT-SVD and SWT. MSVD has equalized appearance of the grayscale intensity values while the SVD histogram graph (figure. 2 H-c1 to H-c9), DWT-SVD (figure.2, H-d1 to H-9) and SWT (figure.2, H-e1 to H-e9) have an irregular and unbalanced grayscale intensity values. Accordingly, the proposed MSVD has shown better result among the SVD, DWT-SVD and SWT. Because it has not only preserved the facial features of the image but also enhanced them as clearly shown in figure 2. The better performance of the proposed MSVD was due to the use of a threshold to zero parameter with a diagonal value of the sigma matrix in modified singular value decomposition method.

B. QUANTITATIVE ANALYSIS

A quantitative analysis is necessary in order to support the qualitative analysis. To achieve this purpose, we used five different evaluative matrices i.e. PSNR, entropy, MSE, contrast, time computation, structure similarity index measurement and image enhancement factor. The entire data of the study is processed with the already discussed methods. The values of these SVD, DWT-SVD, SWT and proposed algorithm MSVD are computed, and the results are presented in Figure 3.

The obtained average value for PSNR of images (c1 to c9) is 56.8799. The higher the PSNR value, the more desirable will be its result. After the implementation of SVD algorithm on images (c1 to c9) we get 0.02074 average value of Entropy for images (c1 to c9), average value 31.93 for MSE, average value 61.99 for contrast, average value 0.30142 for processing time, SSIM average value 0.5515 and IEF average value 0.7055. The same images (b1 to b9) are tested on the DWT-SVD method and the resultant image are labelled as (d1 to d9) as depicted in Figure 2. The obtained average values in DWT-SVD for PSNR, Entropy, MSE, contrast, time computation, SSIM and IEF metrices are 61.2989, 0.02022, 29.22, 62.93, 0.333789, 0.7666 and 0.9444 respectively. The images (b1 to b9) are tested on SWT method, and the resultant images are labelled as (e1 to e9) as shown in figure 2. The obtained average values in SWT for PSNR, entropy, MSE, contrast, time computation, SSIM and IEF metrices are 61.5748, 0.02014, 32.93, 67.13, 0.315697, 0.7552 and 0.8033.

In the proposed MSVD approach the obtained average values for PSNR, Entropy, MSE, contrast, time computation, SSIM and IEF were 64.0027, 0.0158, 24.29, 74.58, 0.20006, 0.8751 and 1.3288 respectively by setting a threshold value at the diagonal matrix. The low-quality and low-resolution images (b1 to b9) are tested on the MSVD approach which shows the resultant image in (f1 to f9). It is obvious from the above analysis that MSVD with threshold value gave better results than SVD, DWT-SVD and SWT algorithms. In terms of PSNR, Entropy, MSE, contrast, time computation, SSIM and IEF the proposed MSVD method surpasses others. The higher the PSNR, MSE, contrast values, SSIM and IEF, the better the image quality. On the other side, a lower entropy number indicates a higher-quality image and also take less time of image processing.

The proposed and existing approaches were also applied to the dataset of CCTV low-quality and low-resolution images (a1 to a9, b1 to b9, c1 to c9, d1 to d9, e1 to e9, f1 to f9) in terms of PSNR, Entropy, MSE, contrast, time computation, SSIM and IEF. The MSVD with its threshold value outperform the existing algorithms. The acquired PSNR, Entropy, MSE, contrast, time computation, SSIM and IEF values were graphically shown in Figures 3, 4, 5, 6, 7, 8 and 9 which demonstrate the comparative analysis of all tested images.

The results obtained using PSNR are displayed in Figure 3. The graphical representation makes it clear that the suggested method outperforms other methods in terms of low-resolution and low-quality artifacts. The proposed method achieves an average PSNR of 16.54%,7.2% and 5.7% over SVD, DWT-SVD and SWT by enhancing the texture structure while removing low resolution and low quality. The high-impact research paper's experimental results prove the effectiveness of the proposed technique and algorithm. The achieved PSNR metrics show that the method works better than the most recent state-of-the-art enhancement strategies. Notably, the findings imply that non-adaptive smoothing approaches are

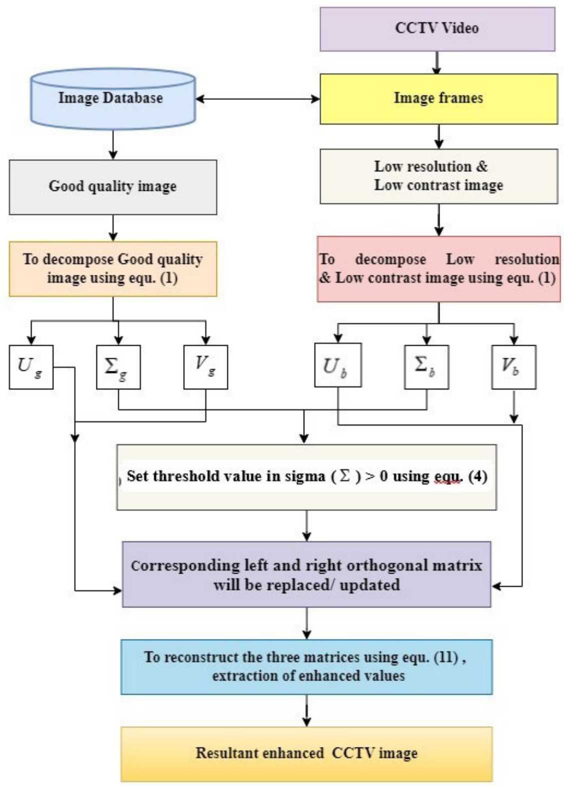

FIGURE 1. An overview of the proposed MSVD CCTV image enhancement method.

less effective at minimizing artifacts than non-linear diffusion. Non-linear diffusion also produces enhancing results that are aesthetically pleasant and natural since it better preserves the image's texture regions. By increasing the PSNR, the resulting image becomes smooth and gives better eye perception. In case of an increase in structural similarity index, the image tends to its original image. High mean square error, low PSNR, and poor structural similarity index values are all indicators of highly distorted images. If the value of PSNR is ∞, the associated mean square error value is zero, and the consequent structural similarity value is at its greatest.

Figure 3 shows the different values of CCTV low-quality and low-resolution images. In the low-quality and low-resolution images, the singular value for the low-quality images is low and PSNR average value for SVD is 56.8799. The higher the values of the PSNR the higher will be the resultant quality of the images. After the application of the DWT-SVD on the low-quality images of CCTV camera. The quality is enhanced by enhancing the singular values and the average PSNR value is 64.0027 and SWT average value of PSNR is 61.5748. Our proposed technique showed better results by enhancing the singular values of low-quality images to 64.34675. Thus, the proposed technique could enhance the low-quality and low-resolution images.

The proposed method enhances CCTV images as compared to SVD by preserving brightness and average

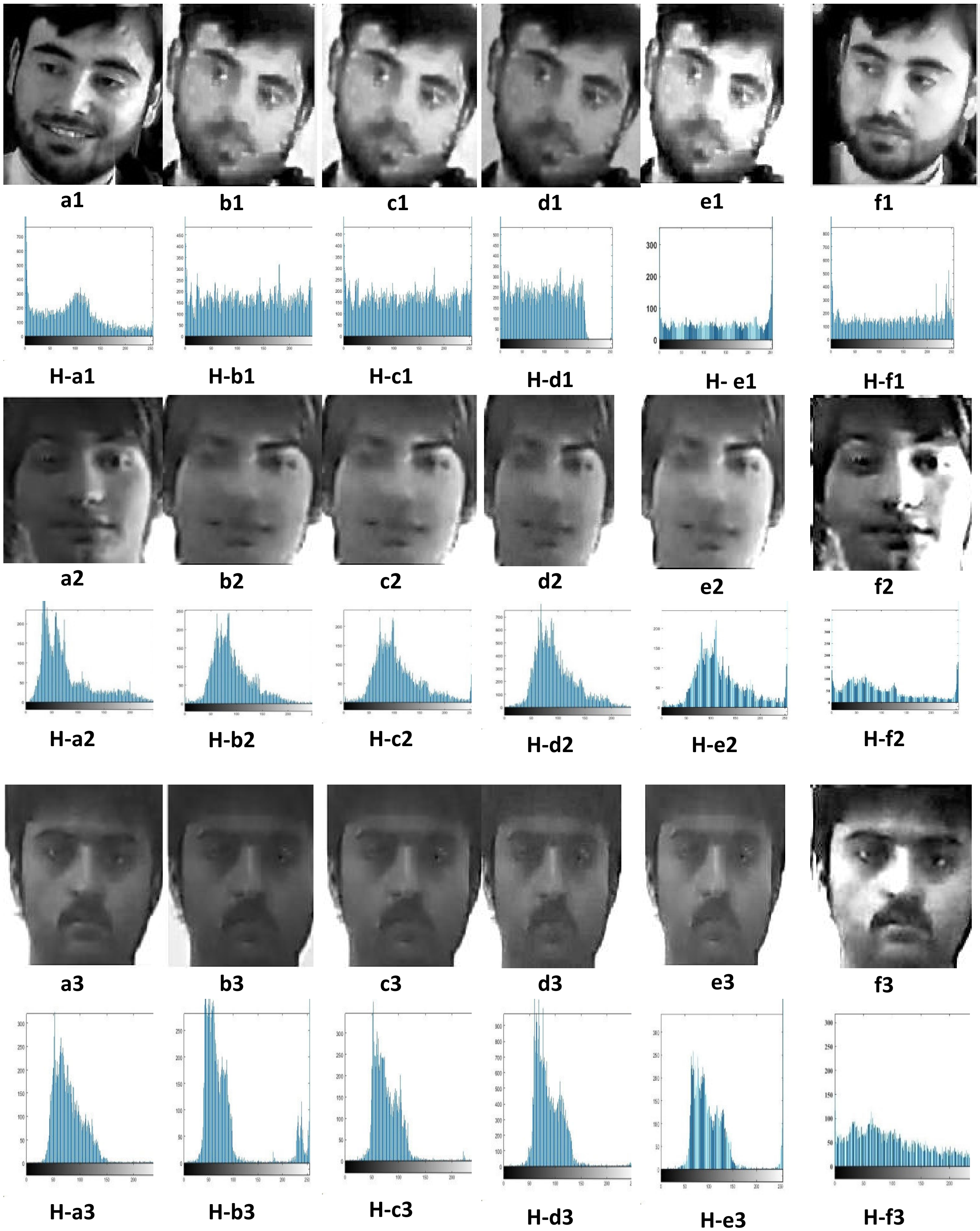

FIGURE 2. Visual qualities of the original and equalized images using various enhancement methods (a1 to a9 and H-a1 to H-a9) Original good quality image and their respective histograms,(b1 to b9 and H-b1 to H-b9) low quality & low-resolution image and their histograms,(c1 to c9 and H-c1 to H-c9) Image enhanced with SVD (d1 to d9 and H-d1 to H-d9) Image enhanced with DWT-SVD and their histograms,(e1 to e9 and H-e1 to H-e9) Image enhanced with SWT and their histogram, (f1 to f9 and H-f1 to H-f9) Image enhanced with proposed method (MSVD) and their related histograms.

FIGURE 2. *(Continued.)* **Visual qualities of the original and equalized images using various enhancement methods (a1 to a9 and H-a1 to H-a9) Original good quality image and their respective histograms,(b1 to b9 and H-b1 to H-b9) low quality & low-resolution image and their histograms,(c1 to c9 and H-c1 to H-c9) Image enhanced with SVD (d1 to d9 and H-d1 to H-d9) Image enhanced with DWT-SVD and their histograms,(e1 to e9 and H-e1 to H-e9) Image enhanced with SWT and their histogram, (f1 to f9 and H-f1 to H-f9) Image enhanced with proposed method (MSVD) and their related histograms.**

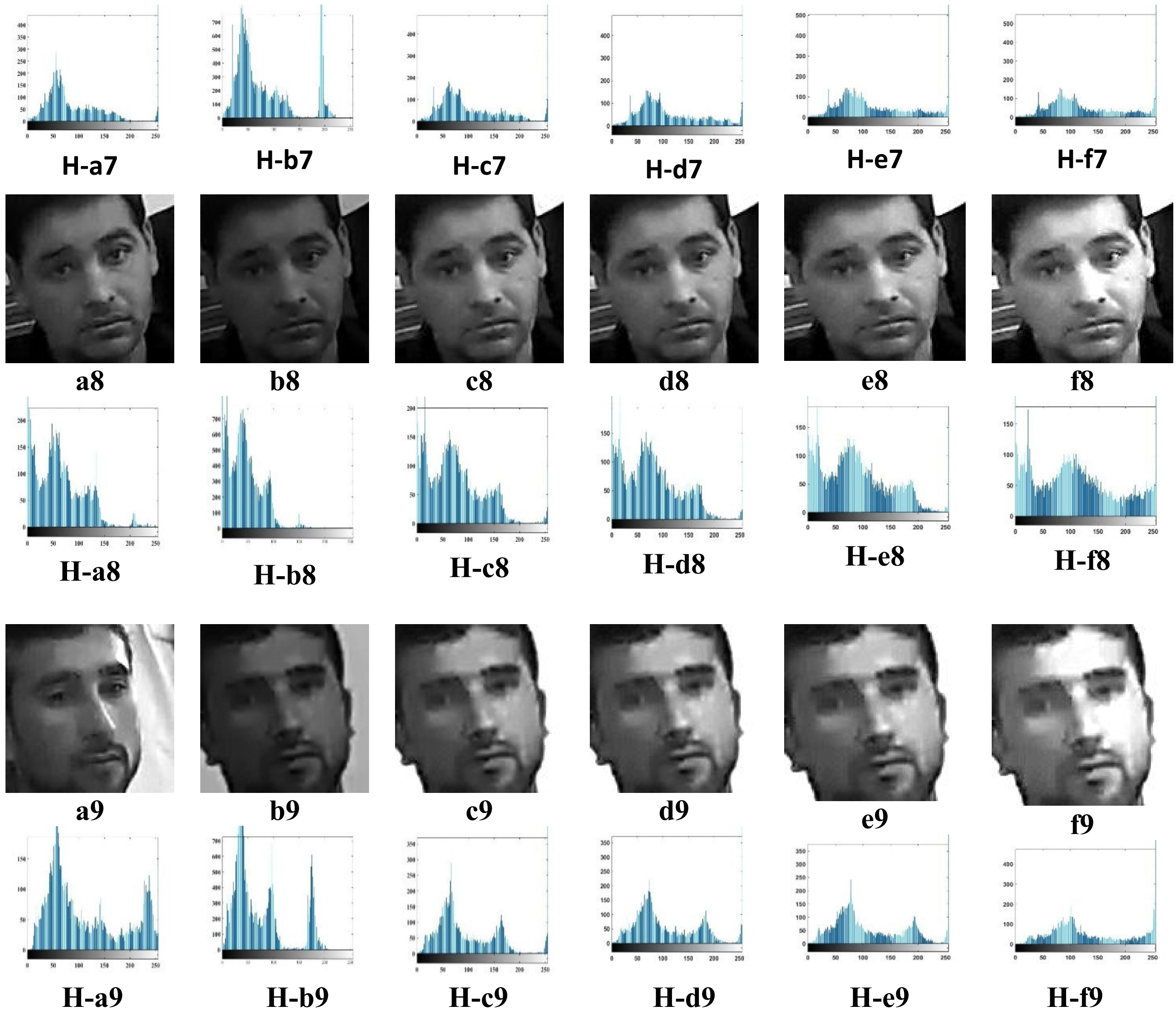

FIGURE 2. *(Continued.)* **Visual qualities of the original and equalized images using various enhancement methods (a1 to a9 and H-a1 to H-a9) Original good quality image and their respective histograms,(b1 to b9 and H-b1 to H-b9) low quality & low-resolution image and their histograms,(c1 to c9 and H-c1 to H-c9) Image enhanced with SVD (d1 to d9 and H-d1 to H-d9) Image enhanced with DWT-SVD and their histograms,(e1 to e9 and H-e1 to H-e9) Image enhanced with SWT and their histogram, (f1 to f9 and H-f1 to H-f9) Image enhanced with proposed method (MSVD) and their related histograms.**

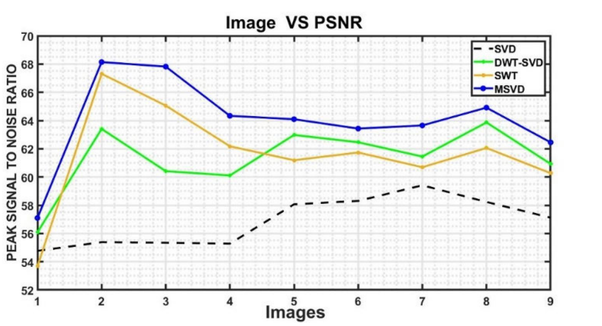

FIGURE 3. **Representation of PSNR values for the SVD, DWT-SVD, SWT and MSVD method.**

information content by enhancing low resolution and low quality as shown in Figure 4. The graphical representation shows that the proposed MSVD provides fewer values of MSE as compared to SVD, DWT-SVD and SWT. The MSE of SVD, DWT-SVD and SWT have been observed higher than the proposed algorithm. The lesser the values of the MSE the higher will be its accuracy. Thus, the proposed algorithm proved successful over the SVD, DWT-SVD and SWT. Despite the poor lighting and extremely low mean values of the input CCTV images, the proposed approach yields better results.

Figure 4 show the values of MSE. The MSVD has again exhibited enhanced values for the low-quality and low-resolution images.

Compared to other techniques indicated in Figure 5, the entropy value is typically very near to that of the original image, guaranteeing the highest information content. Higher

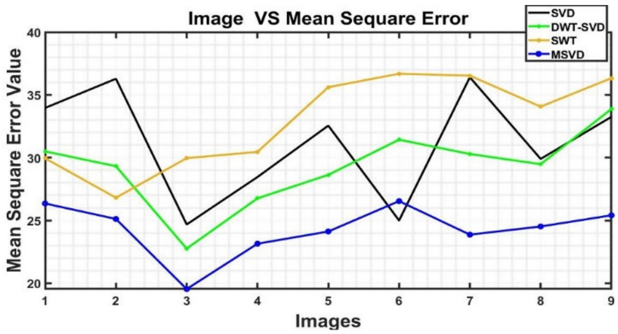

FIGURE 4. Representation of MSE values for SVD, DWT-SVD, SWT and MSVD.

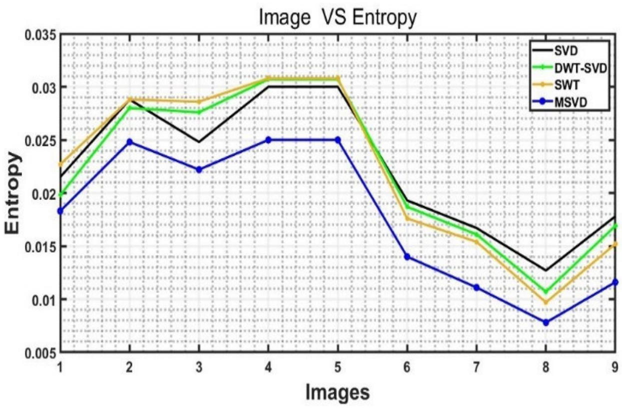

FIGURE 5. Representation of Entropy values for SVD, DWT-SVD, SWT and MSVD.

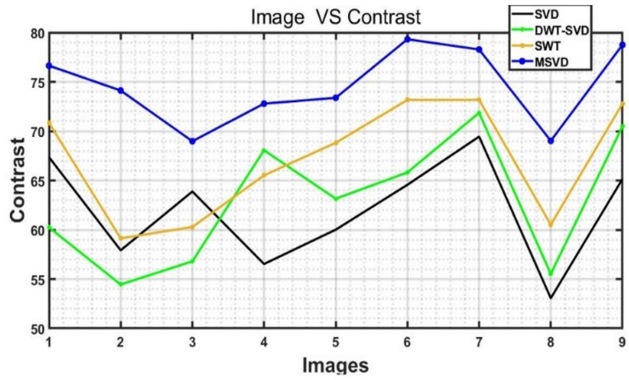

FIGURE 6. Representation of measurement of contrast for SVD, DWT-SVD, SWT and MSVD.

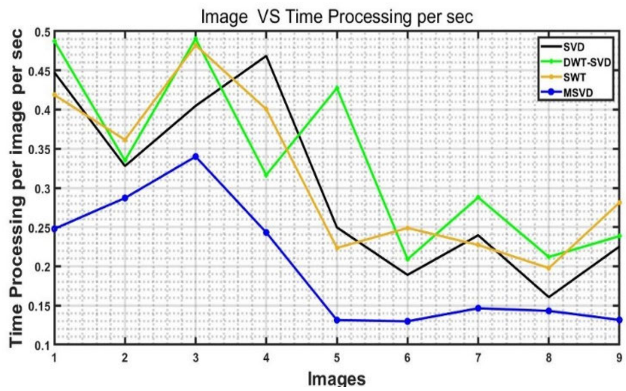

FIGURE 7. Comparison of the MSVD technique in terms of execution time with SVD, DWT-SVD and SWT.

values of entropy indicate a greater quantity of details captured in the image. The proposed algorithm achieves average Entropy of 13.98%, 14.28% and 16.87% over SVD, DWT-SVD and SWT.

The improved PSNR values demonstrate an enhanced image devoid of poor contrast and low-resolution components that generate an unnatural appearance, while the entropy value measures the overall preservation of average information inside an image. We determined from the preceding investigation that MSVD outperforms SVD, DWT-SVD and SWT.

Figure 5 show the obtained values of Entropy. It is the opposite of the PSNR metrics. The lower the values of the resultant or output image the better will be the resultant value. The Entropy values in the figure 5 also show the better performance of MSVD against the SVD, DWT-SVD and SWT.

In Figure 6, this study has considered the gray scale images by focusing on the enhancement of low quality and low-resolution images. The range of the gray scale images is from 0 to 255 level. Comparing the measurement of contrast of state-of-the-art techniques with the proposed MSVD. The proposed MSVD has shown high contrast value than the rest of the techniques. Thus, the higher the values of the contrast the better the performance of the image. Figure 6 show the comparative measurements of the proposed MSVD and state of the art techniques.

In Figure 7, computation of time is an important variable in the enhancement of low quality and low-resolution images. Experts are interested both in the speed of image enhancement as well as the quality of the image. The proposed algorithm has taken less average time than the other state of the art techniques.

Figure 7 show the time comparison of various algorithms utilized in the present study. Comparing the time taken by the other state of the art techniques with the proposed algorithm have taken less time.

Figure 8 show graphical representation of SSIM values of different algorithms. The graphical representation of the above figure 8, shows that the proposed algorithm MSVD has shown better results than the other methods.

Figure 9 shows graphical representation of image enhancement factor of different algorithms. The graphical representation of the above figure shows the higher values of measure of enhancement factor for the proposed algorithm (MSVD) than the other comparative methods.

The proposed method enhances low-quality and low-resolution CCTV images using four image enhancement techniques i.e. SVD, DWT-SVD, SWT and MSVD.

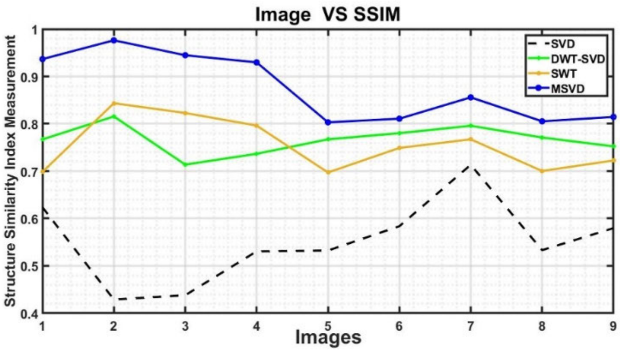

FIGURE 8. Representation of SSIM value for SVD, DWT-SVD, SWT and MSVD.

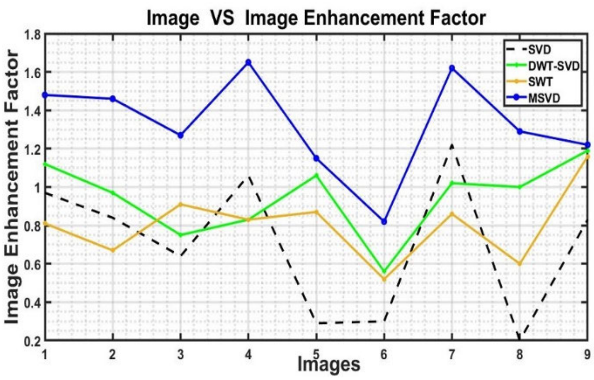

FIGURE 9. Representation of Measure of enhancement factor value for SVD, DWT-SVD, SWT and MSVD.

The qualitative analysis and comparison are shown in Figure 2 and other graphical comparison in figure 3 to figure 9. The results of these algorithms are measured by the seven performance parameters PSNR, Entropy, MSE, measurement of contrast, time computation, SSIM and IEF. The obtained outcomes show that the proposed MSVD surpassed the existing SVD, DWT-SVD and SWT in terms of PSNR, Entropy, MSE, contrast, time computation, structure similarity index measurement and image enhancement factor. After comparing the MSVD techniques with the three state-of-the-techniques i.e. SVD, DWT-SVD and SWT in the study, the proposed MSVD has shown better results in terms of the evaluative techniques of PSNR, entropy, MSE, contrast, time computation, SSIM and IEF.

V. CONCLUSION

In this study, we describe a novel method for the enhancement of low-quality CCTV images. The aim is to achieve high-quality images with high accuracy and faster processing speed. In the proposed method, we have added an adjustable threshold value to enhance the values of the singular value diagonal matrix. The PSNR, entropy, MSE, contrast, time computation, SSIM and IEF were used as performance parameters in the experiments which shows that the proposed MSVD approach outperforms existing SVD, DWT-SVD and SWT algorithms. The MSVD approach significantly enhanced and replaced the low singular values with high singular values of the CCTV images. The replaced and enhanced singular values displayed a better-quality image when the MSVD approach exchanged the low singular values of the poor-quality image with the high singular values of a good-quality image. The obtained enhanced images show a natural look with preserved and detailed information like the original. The scope of the present work is limited only to the gray-scale CCTV images. In future work, the existing approach will be extended to CCTV colour images. Further, the limitation of the paper is that we selected only the front side of the human face in the daytime. However, if the direction is from the different orientation (left or right side of the human face). It is supposed to produce fruitful results and information in the field of image enhancement. Most of the images were collected during the day with relatively little attention paid to potential variations in lighting during the night.

DECLARATION

Authors declare no conflict for this research.

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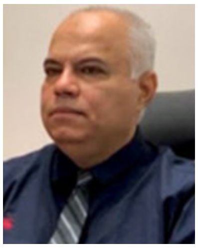

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