Ancient Degraded Document/Image Restoration using Hybrid Intelligent Water Droplets Algorithm and Sauvola Thresholding Technique

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***Abstract:** A historical document that have been affected by degradation and that are of poor image quality is difficult and continues to be a focus of research in the field of image processing. So, there is the need of image restoration techniques that can improve the visibility for the human eye to directly read these documents. Document image restoration aims to improve the document image quality by reducing the noise level, which not only enhance human perception, but also facilitate the subsequent automated image processing. In this research work, we are using hybrid approach of swarm intelligence based Intelligent Water Drops Algorithm (IWD) and Sauvola Binarisation method. IWD is a nature inspired optimization algorithm that work as per the moving water droplets with soil particle obstacles in their path. Sauvola's algorithm is an improvement of Niblack's method which is based on the local mean and standard deviation of the image. Sauvola's approach computes the threshold value by using the dynamic range of gray-value standard deviation. The obtained results are compared with the Sauvola, Niblack, Wolf, M1-S, M2-N, M3-W algorithms. The results are also evaluated in parametric form with PSNR and F-Measure values.*

***Index Terms:** Intelligent Water Drops Algorithm, Niblack Method, Sauvola Method, Image Enhancement, Ancient Documents*

I. INTRODUCTION

An image is worth a thousand words. In this contemporary world, images are the most familiar and convenient means of communicating information. Visual information in the form of digital images allows humans to perceive and understand the world surrounding them in a better manner. Consequently, image processing plays a really vital character and has been making a significant consciousness of the researchers over the last few decades. Digital imaging is very essential in many applications such as object recognition, biomedical instrumentation, satellite imaging, entertainment media, internet etc [1].

In this research work, we are considering the image restoration technique for the restoring the degraded ancient documents and images. The whole procedure is depends upon the processing of digital images. The area of image restoration deals with recovering image information that has been degraded. In other words *image restoration* means the elimination or declination of degradations that were incurred when the image was obtained. The whole procedure is depends upon the processing of digital images. The performance of proposed algorithm is also compared with other techniques with the performance parameters of PSNR and F-Measure.

The rest sections of the paper are structured as: Section II describe the basic concept involved in the hybridization concept. Section III explains the proposed concept. Section IV gives the result values and comparison with other concepts. Section V concludes the paper.

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II. BASIC CONCEPTS

This section covers the concept of basics of IWD, Niblack and Sauvola Method. These two concepts are explained as below:

A. Niblack Thresholding Method

Niblack method [2] is based on variable threshold value of image which depends upon the local standard deviation and mean of the image. The threshold at pixel (x, y) is calculated by equation (1) as:

$$T(x,y) = k \, . \, s(x, y) + \mu(x, y) \qquad (1)$$

where s(x, y) and μ(x, y) are the standard deviation and mean values respectively in a local neighbourhood of (x, y) and k is the value to adjust object boundary.

Essentially, the Niblack Method uses the local mean and deviation that provides an approximation of the mean level by the amount of local deviation. However, increment or decrement of this mean value depends on a constant k, where if $k > 0$, mean value will be approximated to upper boundary, if $k < 0$, mean value will be approximated to lower boundary and if $k = 0$, mean value will become the threshold point [3].

B. Sauvola Thresholding Method

The Sauvola et al. method [4] is an improvement of Niblack thresholding method aimed at producing better results with degraded documents. It can be described by equation (2) as:

$$T(i,j) = \mu(i,j) + \left(1 + k.\left[1 - \frac{\sigma(i,j)}{R}\right]\right) \qquad (2)$$

where μ(i, j) and σ(i, j) is the mean and variance value respectively in a local neighborhood of (i,j) with k and R. R is the maximum value of Standard Deviation and generally

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considered as 128 for grayscale images.

Sauvola et al. improved Niblack method to add more adaptive local deviation to the mean value. However, the effect of local deviation is mostly eliminated by R.

C. Intelligent Water Drops Algorithm

Intelligent Water Drops algorithm was proposed by Shah-Hosseini in 2007 by giving his optimized solution for the Travelling Salesman Problem (TSP) [5]. It is one of the newly introduced population based Swarm Intelligence technique. Similar to the other algorithms of Swarm Intelligence like Particle Swarm Intelligence (having social insects/birds/fishes for optimization), Ant Colony Optimization (having ants as a social agent), Bee Colony optimization (having honey bees for optimization) etc. , Intelligent Water Drops algorithm have natural water drops as an optimization agent. The work behaviour of IWD algorithm can be noticed by flowing water drops from one place to another in a river [6]. During its flow, it carries soil particles that are increased or decreased as per the velocity and path of the river. The imitation of the IWD concept can be used for the solution of various optimization problems.
This velocity and soil values vary from one point to another i.e. (i to j) can be calculated by the formulas as presented by Equation (3).

$$vel^{IWD}(t+1) = vel^{IWD}(t) + \frac{a_v}{b_v + c_v.soil(i,j)} \quad (3)$$

where,

$vel^{IWD}(t+1)$ is the change in velocity at the destination point.

$vel^{IWD}(t)$ is the velocity at source point.

a_v, b_v, c_v are the velocity parameters.

The soil that the IWD removes from i to j locations can be calculated by formula as given by Equation (4):

$$\Delta Soil(i,j) = \frac{a_s}{b_s + c_s.time(i,j,vel^{IWD})} \quad (4)$$

where,

$\Delta Soil(i,j)$ is the change in soil value

a_s, b_s and c_s are the soil parameters

and the soil of the river between two locations reduced can be calculated by formula as given by Equation (5):

$$soil(i,j) = 1 - \rho_n.soil(i,j) - \rho_n.\Delta soil(i,j) \quad (5)$$

Where,

ρ_n is the local soil updation parameter

Intelligent Water Drops algorithm explode its application area by giving solution to various problems like Multidimensional Knapsack Problem (MKP) [10], Travelling Salesman Problem (TSP) [5], Robotic Path Planning [7], Vehicle Routing Problem [8], Data Clustering [9] etc.

All the above binarisation methods can be used for the enhancement of old documents and images. But no method is able to restore the ancient document upto the optimum level. So, here we are considering the hybrid concept of IWD & Sauvola methods as a proposed technique for ancient documents restoration.

III. PROPOSED CONCEPT

In this section, the proposed algorithm of Hybrid IWD and Sauvola Thresholding technique is presented. IWD is based on the moving water droplets model that provides optimized solutions in various real time problems. Sauvola method improved Niblack method to add more adaptive local deviation to the mean value. Niblack Method uses the local mean and deviation that provides an approximation of the mean level by the amount of local deviation. The effect of degradation of images can be reduced more effectively by considering the hybridisation of these IWD & Sauvola concepts. This proposed algorithm is structured as below:

Input: Degraded Document/Image.

Output: Restored Document/Image.

Assumptions:

- Intelligent water drops are considered as the pixels of the image and soil particles as the noise/degraded image pixels that interrupt the water velocity.
- The focus of the IWDs is to restore the degraded particles by considering the soil pixels into their account.
- More the concentration of the water drops shows the originality of image pixels. As the soil particles keep on adding more & more, shows the image pixels are more degraded. We have to reduce the soil concentration and increase the water velocity by reducing the noise particles from the image.

ALGORITHM

Step 1: Consider the old degraded document/image as the input image for experimentation.

Step 2: Convert the image into gray scale image of the degraded document image and change the window size of the image to extract the edge values of the image.

Step 3: Apply neighborhood interpolation to get rough estimation of foreground details and background degradation/noise particles.

Step 4: Convert the image into HSV plane to extract the foreground text and to convert the image degradation in the form of different contrast value. Here HSV plane is used because color image enhancement using RGB color space is found to be inappropriate as it destroys the color composition in the original image.

Step 5: Initialise both the dynamic and static parameters of the IWD algorithm.

5.1. In the beginning of IWD algorithm, numbers of water drops are represented by N_{IWD}, number of soil particles as N_{SOIL} and number of iterations represented by $Iter_{count}$,

5.2. Here, numbers of Intelligent Water Drops considered are lesser from the number of enhanced pixels of the considered image. And soil particles are considered as higher at the initial stage. The image degradation process continues till the maximum iteration values reach and total number of pixel of water droplets increases.

5.3. Soil updating parameters are initialized by a_s, b_s & c_s and Velocity updating parameters are initialized by a_v, b_v & c_v.

5.4. The local and global soil updating parameter are initialized as ρ_n and ρ_{IWD} respectively.

5.5. The initial velocity of water drops is represented by *InitVel* and initial soil is between the two pixels soil is represented as *InitSoil.*

Step 6: Consider the image pixels and begin the process of restoration by starting the flow of IWD algorithm. Restore the image pixels by using Sauvola Approach.

Step 7: For Sauvola Approach, firstly apply the Niblack Thresholding technique to the previous input image pixels from IWD. This method adapts the threshold according to the local mean and standard deviation over a window size of x*y. The Niblack threshold at pixel (i,j) is calculated by equation (6) as below:

$$T(x,y) = k \,.\, s(x, y) + \mu(x, y) \qquad (6)$$

where μ(x, y) and s(x, y) are the standard deviation and mean values respectively in a local neighbourhood of (x, y) and k is the value to adjust object boundary.

Step 8: Apply Sauvola binarisation method to the previous input received from the image. This can be calculated by equation (7) as below:

$$T(i,j) = \mu(i,j) + \left(1 + k.\left[1 - \frac{\sigma(i,j)}{R}\right]\right) \qquad (7)$$

where μ(i, j) and σ(i, j) is the mean and variance value respectively in a local neighborhood of (i,j) with k and R.

Step 9: The probability for selecting the next neighbour pixels can be calculated by the equation (8) as given below:

$$p_i^{IWD}(j) = \frac{f(soil(i,j))}{\sum_{k\epsilon vc(IWD)} f(soil(i,k))} \qquad (8)$$

Where,

$$f\big(soil(i,j)\big) = \frac{1}{\varepsilon_s + g(soil(i,j))} \qquad (9)$$

And

$$g\big(soil(i,j)\big) = \begin{cases} soil(i,j) & if\ min_{l\epsilon vc(IWD)} soil(i,l) \geq 0 \\ soil(i,j) - min_{l\epsilon vc(IWD)} soil(i,l) & Else \end{cases} \qquad (10)$$

Then, select the next neighbour pixel to calculate the distance and mean value between the two pixels as per experimentation procedure.

Step 10: Update the velocity and soil parameters.

This velocity and soil values vary from pixel *i* to *j* by the equation (11) and equation (12) (13) respectively.

$$vel^{IWD}(t+1) = vel^{IWD}(t) + \frac{a_v}{b_v + c_v.soil(i,j)} \qquad (11)$$

The soil that the IWD removes from *i* to *j* pixels can be calculated by equation (4.7):

$$\Delta Soil(i,j) = \frac{a_s}{b_s + c_s.time(i,j,vel^{IWD})} \qquad (12)$$

And the soil of the river between two points added can be calculated by equation (4.8):

$$soil(i,j) = 1 - \rho_n.soil(i,j) - \rho_n.\Delta soil(i,j) \qquad (13)$$

Step 11: During the Image degradation, the soil particles decreases and water pixels increases with the increase in velocity of water droplets.

Step 12: Repeat the step 5 to 11 for each pixel value of the image and do this till the maximum iteration value reach by $Iter_{max}$.

Step 13: Apply swell and shrink filter for the post-processing of image by removing noise and fill broken stroke's connectivity.

Step 14: Obtain the output image with enhanced quality of restored image.

IV. RESULTS & DISCUSSION

In this section, we have discussed the experimental setup and evaluated results. The proposed concept is implemented in MATLAB 8.3.052. The performance of the proposed concept and comparative analysis is discussed with parameters with PSNY and F-measure values.

A. Results

The proposed algorithm is implemented for the DIBCO dataset images. We have used randomly selected 10 images for the experimentation. The original degraded Images and restored images are shown in figure 1 below.

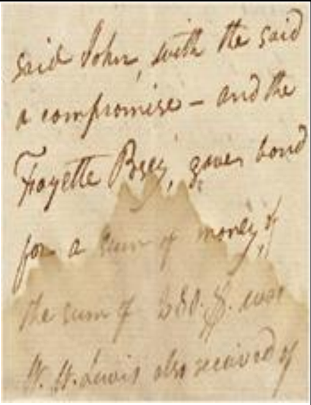
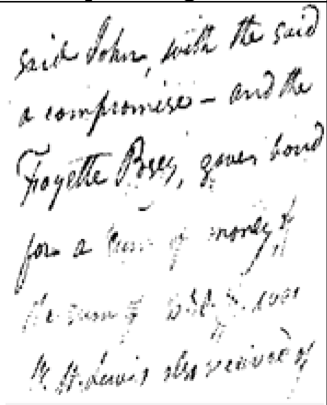
Degraded Documents/Images	Restored Documents/Images using Proposed Algorithm
	

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Figure 1: Restored Documents/Images using proposed hybrid concept

From the above figure 1, it can be say that the proposed algorithm performs well for the restoration of Ancient documents/images. But these visual enhancements images are not able to evaluate the parametric accuracy of our proposed algorithm. So, we have considered the following parameters for the enhancement of ancient degraded images.

B. Evaluation Parameters

For the evaluation of proposed concept, we have considered the PSNR and F-Measure parameters. Based on PSNR and F-measure values, results are compared for the different images considered.

1. F-Measure

F-measure is the combination between recall and precision. To calculate the F-Measure, we have to understand the following terms as below:

- **TP (True Positive)**: is the number of restored pixels, which are classified as restored.
- **FN (False Negative)**: is the number of restored pixels, which are classified as degraded.
- **TN (True Negative)**: is the number of degraded pixels, which are classified as degraded.
- **FP (False Positive):** is the number of degraded pixels, which are classified as restored.

We keep a record of some important measures which are TP, FN, TN, FP. From these we compute the measures Precision (*p*), and Recall (*r*), which are defined as follows:

- **Precision (*p*)**
  Precision denotes the probability that restored pixels from the degraded images are truly restored. It is denoted by symbol ***p***. It can be calculated as shown by equation 14 below:
  $$p = \frac{TP}{TP+FP} \tag{14}$$
- **Recall (*r*)**

Recall shows the probability that the restored pixels are detected. It is denoted by symbol ***r.*** It can be calculated as shown by equation 15 below:

$$r = \frac{TP}{TP+FN} \tag{15}$$

These Precision and Recall are further used to calculate the value of F-measure. F-measure can be calculated as in equation (16) shown below:

$$F = \frac{2pr}{p+r} \tag{16}$$

2. PSNR (Peak Signal to Noise Ratio)

The Peak Signal to Noise Ratio (PSNR) can be defines as the proportion of maximum possible power and corrupting noise that affect image representation. PSNR is commonly described as image reconstruction quality measure and units are decibel. Here, original data is considered as signal and error is described by noise value. High quality of image is described in terms of higher PSNR value.

The calculated values of PSNR and F-Measure from our proposed dataset images are shown as below in table 1:

Table 1: Parametric Values of Considered Dataset Images

Image	F-Measure	PSNR
Image 1	93.7669	31.622
Image 2	93.7768	31.853
Image 3	93.9013	34.633
Image 4	93.7475	31.484
Image 5	93.4673	31.473
Image 6	93.8503	34.332
Image 7	93.6715	32.870
Image 8	93.5911	27.241
Image 9	93.7244	28.714
Image 10	93.6797	38.786

From the above evaluated parametric values, we can say that the value of F-Measure lie between 93.4673 to 93.9013 and PSNR value lie between 27.241 to 38.786. To compare the values of PSNR and F-measure, there should be single value. So, we are considering the mean of all the obtained values. So, we have 10 images considered.

The calculated mean of the F-Measure and PSNR value are 93.717 and 32.30 respectively.

C. Comparison with other Techniques

To check the accuracy of our proposed algorithm, we have considered the concepts of Sauvola, Niblack, Wolf, M1-S, M2-N, M3-W methods [11]. This is shown by evaluation parameters of PSNR and F-Measure are shown in table 2 below:

Table 2: Comparison based on F-measure and PSNR value

Technique	PSNR	F-Measure %
M3-W	08.24	52.97
M2-N	15.49	82.91
M1-S	16.67	87.82
Wolf	16.65	83.99
Niblack	06.32	42.89
Sauvola	14.29	65.93
Proposed Concept	32.30	93.717

From the above comparison table 2, we can say that proposed algorithm gives better results as compare to Sauvola, Niblack, Wolf, M1-S, M2-N, M3-W algorithm [11]. These are also shown in the respective graphs as shown in figure 2 and 3.

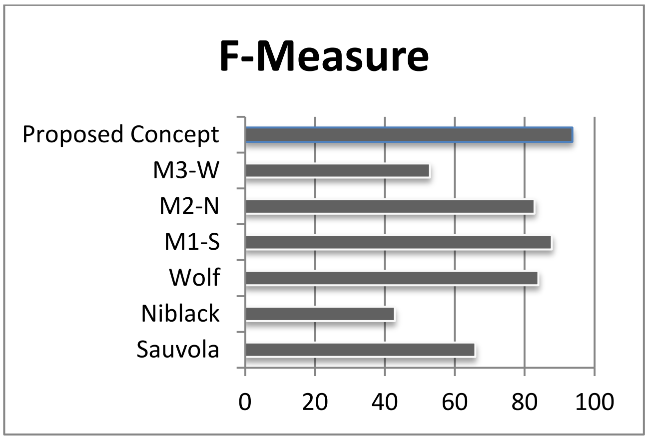

Figure 2: Comparison based on F-Measure value

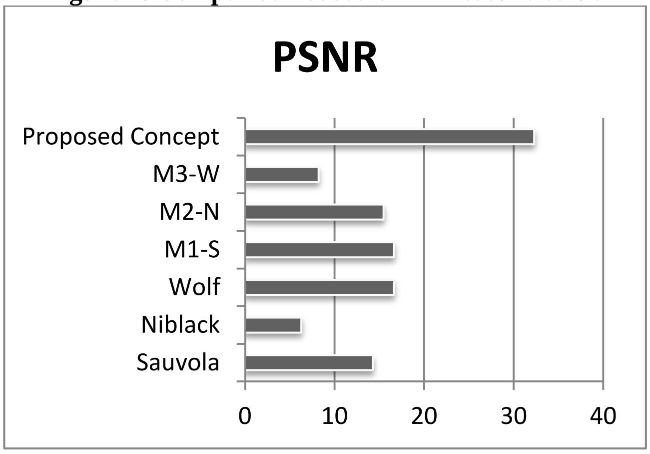

Figure 3: Comparison based on PSNR Value

V. CONCLUSIONS

In this research work, a hybrid concept of IWD and Sauvola threshold technique is proposed for the restoration of ancient degraded documents/images. In this concept, IWD is based on the moving water droplets model that provides optimized solutions in various real time problems. Sauvola method improved Niblack method to add more adaptive local deviation to the mean value. Niblack Method uses the local mean and deviation that provides an approximation of the mean level by the amount of local deviation. The effect of degradation of images can be reduced more effectively by considering the hybridisation of these two IWD and Sauvola concepts. The experimental results showed that the features of the proposed algorithm are outperforming as compare to other techniques like Sauvola, Niblack, Wolf, M1-S, M2-N, M3-W algorithm [11] by giving verification results in the form of parametric evaluation as shown in figure 2 and 3.

From the present work, it has been observed that the results obtained using proposed algorithm is highly satisfactory and found an edge on other techniques. Thus, it can be said that proposed algorithm is fit for the enhancement of old degraded documents

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