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Automated Enhancement of Grayscale Images using a Fast and Scalable K-Means approach

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Abstract—**Image enhancement is a widely used technique in disciplines ranging from Medicine to Meteorology. A grayscale image can be regarded as a dataset in which each pixel has a spatial location and an intensity level. Enhancement of grayscale images is distinctly challenging, because of the inability of the human eye to distinguish between any two consecutive gray intensities, and due to the limited range of intensity levels among which the pixels of the image have to be redistributed, so as to make the whole image appear sharper than before. In this approach, initially, I alter some extreme intensities present in the image, and divide the residual ones into groups, known as clusters, based on their Eucledian distances from the clusters' mean intensities, using the K-Means clustering algorithm. Then, I change the final cluster means in proportion to their mutual distances, such that, the new means are spread over the entire range of possible intensity levels. Finally, I assign the pixels of the image to the intensity levels corresponding to the new means of the clusters to which the pixels' intensities before clustering were assigned. This technique was tested on satellite images of Kolkata and Mumbai, and on some other photographs. The clarity enhancement obtained was far better than what could be achieved by using conventional contrast enhancement tools like Contrast stretching and Histogram equalization. Moreover, this technique could process the 512 pixels X 512 pixels grayscale satellite images typically within 600 milliseconds, even on a slow computer running Java version 1.5 on a 568 MHz Intel Celeron processor. This fact clearly reflects its speed and scalability.**

Index Terms—**Satellite, Grayscale, Image Enhancement, Remote Sensing, Clustering, Fast Scalable K-Means.**

I. INTRODUCTION

Image enhancement is a technique that yields benefits as diverse as the areas of human endeavor in which it is applied. Helping physicians diagnose patients' ailments by looking at digital X-ray images or guiding meteorologists in tracking the progress of cyclones by analyzing satellite imagery, image enhancement has become one of our indispensable tools.

According to [1], "The aim of image enhancement is to improve the interpretability or perception of information in images for human viewers, or to provide `better' input for other automated image processing techniques." The author further goes on to classify image enhancement techniques broadly into two categories:

1. Spatial domain methods operating directly on pixels
2. Frequency domain methods operating on the Fourier transform of an image

He also makes the observation that, there is no general theory which can classify image enhancements as 'good' or 'bad' in the light of human perception, and implicitly designates the viewer of the enhanced images as the sole judge for giving the verdict on the quality of the applied enhancement technique.

While the appraisal of a single image enhancement technique based on a subjective evaluation of its outputs by human agents can help us decide whether or not to accept it as a tool for achieving a specific goal, selecting the best candidate for the job is possible only through a comparative evaluation of a number of such enhancement techniques. Thus, adopting this strategy, in this paper, the proposed *spatial domain* image enhancement method is compared against some existing and widely used image enhancement techniques to see how it fares against them in various aspects.

Among the handful of traditional methods for image enhancement, two of the most widely used are Contrast stretching [2] and Histogram equalization [3]. The former has been summarized in [2] as "Contrast stretching (often called normalization) is a simple image enhancement technique that attempts to improve the contrast in an image by `stretching' the range of intensity values it contains to span a desired range of values, *e.g.* the full range of pixel values that the image type concerned allows." The authors have also shown with an example of a 8-bit grayscale image that, when the input image contains even a single pair of pixels having their intensity levels as 0 and 255 (the lowest and highest possible intensity levels respectively for the image type concerned), simple normalization to the range 0 – 255 fails completely. They have also suggested a remedy to this problem by advising us to disregard those few pixels lying near the extreme ends of the intensity spectrum according to some acceptable, application-specific tolerance level, and to apply contrast stretching to the pixels lying in between, and later, to force the disregarded pixels (or "outliers") to either 0 or 255 depending on which side of the range they lie on. In the image enhancement method proposed in this paper, this 'outlier problem' has been tackled by implementing the remedy discussed above in a modified form to suit our purpose.

Histogram equalization, according to [3], is "a sophisticated method for modifying the dynamic range and

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contrast of an image by altering that image such that its intensity histogram has a desired shape." The authors also state that, this method "employs a monotonic, non-linear mapping which re-assigns the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities (*i.e.* a flat histogram)." They further go on to demonstrate the method on 8-bit grayscale images. The outputs show a drastic increase in the images' contrast when compared to the Contrast enhancement approach, but at the cost of "increasing visual graininess" or rendering the images "artificial". Some workarounds to overcome these deficiencies have been suggested which are either complex in nature or require human intervention, and so, are disregarded.

Some more recent works on grayscale image enhancement can be found in [4] and [5]. The task taken up in [4] involves rebuilding an image from properly stretched local extrema of wavelet coefficients across levels with a straightforward interpolation method to enhance the contrast of the image. This enhancement method is primarily based on the fact that "the Human Vision System (HVS) heavily depends on edges in the understanding and perception of scenes." Apart from the complexity in the workings of the method, it is arguable whether the human observers' comprehension of the information conveyed by a remotely sensed (satellite) image is primarily guided by the clarity in their perception of the edges present therein, thereby implying that, this method may not be suitable for certain types of grayscale images.

A comparatively more generalized approach to automatic grayscale image enhancement driven by evolutionary optimization has been taken up in [5]. Here, the authors propose a novel objective criterion for enhancement, and attempt to find the best image according to the respective criterion by employing an evolutionary algorithm (EA) as a global search strategy for the best enhancement. However, due to the very nature of EAs, this method is bound to be slow, and hence, would not be scalable.

The image enhancement method proposed in this paper is generic, easy to implement, and does not involve application of complicated mathematical concepts. It processes grayscale images fast enough for all practical purposes, and is extremely scalable, because its execution time depends very little on the size of the input image. It produces much better outputs than traditional grayscale image enhancement techniques. Lastly, it does away with any unnecessary human intervention.

The rest of this paper is organized as follows. Section II describes the K-Means clustering method used as part of the proposed image enhancement technique (which is sketched in Section III). Section IV presents the experimental results and discussions. Conclusion and future works are in Section V.

II. K-MEANS CLUSTERING

A. Introduction

Clustering, according to [6], is "the classification of objects into groups (called *clusters*) so that objects from the same cluster are more similar to each other than objects from different clusters." This similarity is often determined on the basis of the value of a distance metric which is found to be suitable for the concerned clustering application. Statistical data analysis commonly uses the clustering technique. It is used in many fields including image analysis. K-Means is a "partitional algorithm" [6] as it determines all clusters at once.

B. Algorithm

K-Means clustering, according to [7], is "a method of cluster analysis which aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean." It is an "attempt to find the centers of natural clusters in the data." A variety of heuristic algorithms are generally used for the K-Means clustering problem. The most common one uses an iterative refinement technique.

Starting off with an initial set of *k* means which may be obtained randomly or by some heuristic, the algorithm proceeds by alternating between the following two steps until it converges, when the means between its any two consecutive iterations do not change by more than a suitably chosen maximum numerical quantity denoted by Epsilon (E):

1. *Assignment step*: Assign each observation to the cluster with the closest mean.
2. *Update step*: Calculate the new means to be the centroid of the observations in the cluster.

C. Heuristic

I avoid initializing the starting means randomly, as it may designate some data occurring rarely in the dataset as initial centroids for some of the clusters. Rather, I select a set of *k* data having the highest frequencies as the starting means, via a common policy, that the selection criteria should only include centers where we believe there will be data.

III. PROPOSED IMAGE ENHANCEMENT TECHNIQUE

The image enhancement technique proposed in this paper takes the following three input parameters:

1. *P*: Percentile value for determining "outliers"
2. *K*: Number of clusters in K-Means clustering
3. *E*: Epsilon (for controlling clustering convergence)

In the beginning, the "outlier" intensities present in the input image are treated by the following procedure. From the histogram of the image, I determine a lowest intensity level *l*, such that, at least *P* percent of the total number of pixels present in the image have intensities lower than *l*. Then, I set the intensities of all those pixels to *l*. Similarly, I determine a highest intensity level *h*, such that, at least *P* percent of the total number of pixels present in the image have intensities higher than *h*, and set the intensities of all those pixels to *h*.

Next, I proceed to perform K-Means clustering on the intensities present in the altered image. The K most frequently occurring intensities in the image are selected as the starting means, as per the heuristic described in Section II, and I choose Eucledian distance as the distance metric. After the clustering converges (as per *E*), I get *K* final means (which are rounded off to the nearest integers representing intensity levels), and a mapping of every intensity level present in the image to the appropriate cluster (assigned through clustering).

Then, I alter the cluster means in proportion to their mutual distances, in a manner depicted in the following example, so that the altered means are spread over the entire range of possible 8-bit gray intensity levels (0 – 255). Let us suppose that, I chose to obtain *five* clusters using K-Means clustering, and ended up with *five* final means corresponding to those clusters, arranged in ascending order of magnitude, and denoted as m_1 to m_5. I calculate the quantities $D = (((m_1 - 0) + (255 - m_5)) / (5 - 1))$, $d_1 = ((m_2 - m_1) + D)$, $d_2 = ((m_3 - m_2) + D)$, and $d_3 = ((m_4 - m_3) + D)$. Now, I set m_1 to 0, m_5 to 255, m_2 to $(m_1 + d_1)$, m_3 to $(m_2 + d_2)$, and m_4 to $(m_3 + d_3)$. It must be noted here, that, the *m*'s are actually the final means rounded off to the nearest integers representing intensity levels. Also, while calculating the numerical quantity *D*, the denominator's magnitude should be (K - 1). Further, the total number of *d*'s to be calculated is (K - 2).

Finally, I assign the pixels of the image to the intensity levels represented by the altered means of the clusters to which the pixels' intensities before clustering were assigned.

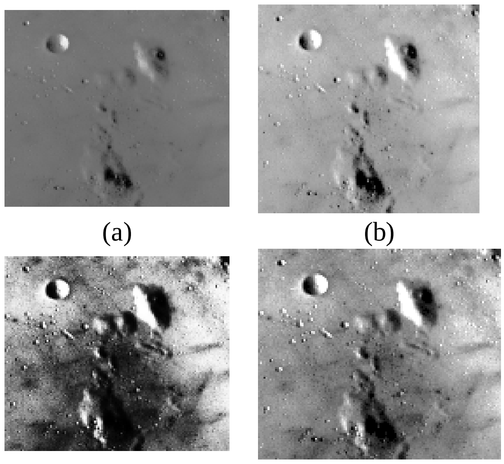
IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to test the proposed image enhancement technique, a graphical user interface with facilities for selecting the input image, entering the three input parameters, and displaying and storing the output image, along with the code implementing the image enhancement, and calculating and displaying the time taken for the same was developed using Java 2 Standard Edition version 1.5 from Sun Microsystems, Inc. Using it, the proposed image enhancement technique was tested on the set of eleven IRS-1A and SPOT satellite images of Kolkata and Mumbai obtained from [8], and on some small input images, three of which were used in [2] and [3], taking P=1, K=30 and $E=10^{-6}$. Contrast stretching and histogram equalization of most of the input images, and histogram analysis of all input and output images were performed using the popular graphics software Paint Shop Pro version 8.01 by Jasc Software, Inc.

However, here, due to space constraints, the findings are presented in a concise form, including one IRS-1A band-3 satellite image each of Kolkata and Mumbai from [8], and some of the small images, including those from [2] and [3].

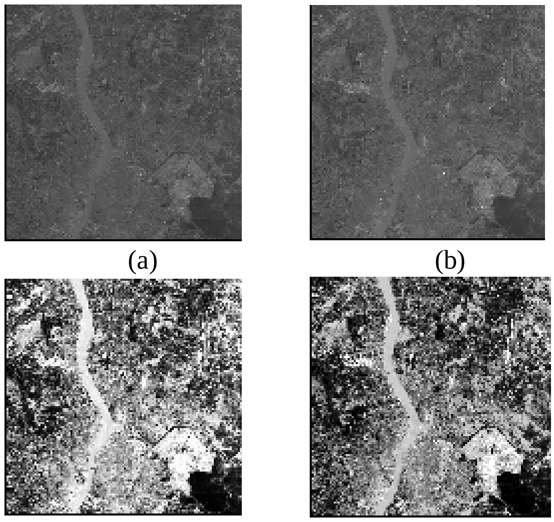
(a) (b) (c) (d)

Fig. 1. Photograph of the old lady a) original [2] b) result of contrast stretching [2] c) result of histogram equalization [2] d) result of the proposed image enhancement technique



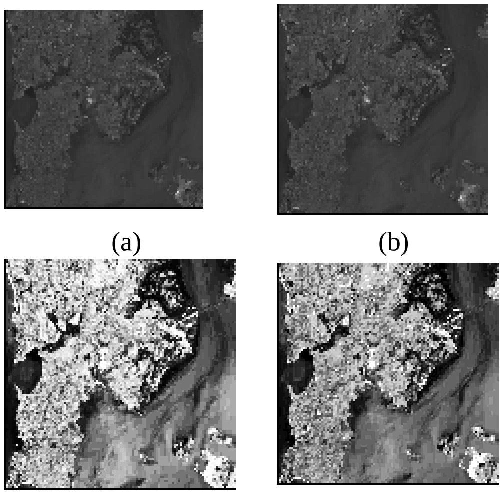
(a) (b) (c) (d)

Fig. 2. Image of the lunar surface a) original [2] b) result of contrast stretching [2] c) result of histogram equalization [3] d) result of the proposed image enhancement technique



(a) (b) (c) (d)

Fig. 3. IRS-1A band-3 satellite image of Kolkata a) original [8] b) result of contrast stretching with Paint Shop Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique

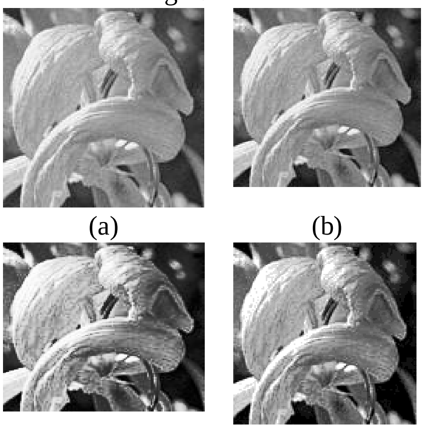


(a) (b) (c) (d)

Fig. 4. IRS-1A band-3 satellite image of Mumbai a) original [8] b) result of contrast stretching with Paint Shop

Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique

Examining the preceding four sets of images, we can easily observe that, in each set, the fourth image (representing the output obtained by applying the proposed image enhancement technique on the original, i.e., input image of that particular set) presents the most natural, yet effective enhancement among the three enhancement outputs contained in that set. The same trend appears in the following four sets of images:

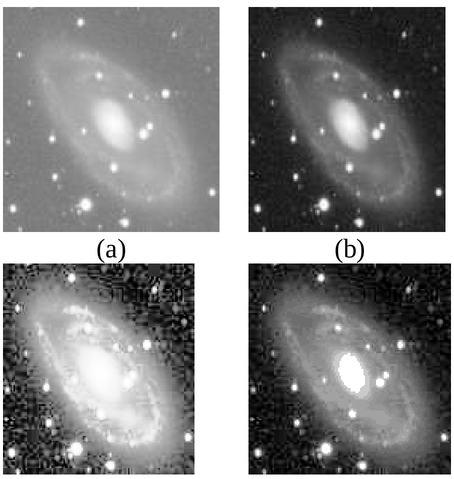


(a) (b) (c) (d)

Fig. 5. Image of a flower a) original b) result of contrast stretching with Paint Shop Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique

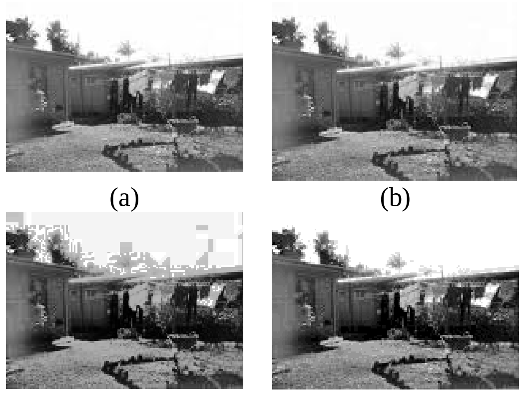
(a) (b) (c) (d)

Fig. 6. Image of a palace a) original b) result of contrast stretching with Paint Shop Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique



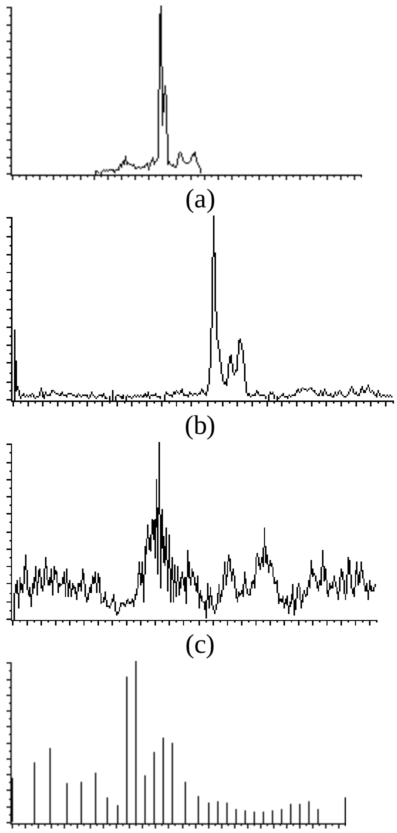
(a) (b) (c) (d)

Fig. 7. Image of a galaxy a) original b) result of contrast stretching with Paint Shop Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique



(a) (b) (c) (d)

Fig. 8. Image of a house a) original b) result of contrast stretching with Paint Shop Pro c) result of histogram equalization with Paint Shop Pro d) result of the proposed image enhancement technique



(a) (b) (c) (d)

Fig. 9. Histogram of the photograph of the old lady as obtained using Paint Shop Pro, with 8-bit grayscale intensity levels (0 to 255) plotted along the horizontal axis, and the number of pixels (0 to the maximum number of pixels having any particular intensity level present in the image) plotted along the vertical axis a) original [2] b) result of contrast stretching [2] c) result of histogram equalization [2] d) result of the proposed image enhancement technique

The above set of four histograms clearly brings out some of the differences in the modes of operation of the proposed image enhancement technique and the two traditional contrast enhancement tools. Since K-Means clustering is used as part of the former, the fourth histogram shows an entirely discrete graph, unlike the second and the third, which are mostly continuous. Further, in accordance with the cluster means redistribution strategy (described in Section III), the discrete vertical lines in the fourth histogram, representing the altered cluster means, are present all along the x-axis, including one each at the two extremities (0 and 255), but they do not appear at regular intervals, rather, at intervals determined by their mutual distances before the alteration, i.e., after completion of the clustering process. The contrast enhancement effected by the proposed image enhancement technique can be attributed to this discreteness and spread of the histogram of its output image, whereby we limit the number of intensities that can be present, and spread them as far apart as possible, so that the human eye, now, has to recognize and differentiate a much lesser number of distinct and widely differing gray intensities.

Lastly, the natural element in the outputs of the proposed technique is the result of K-Means clustering, which tries to find natural clusters in its input dataset, and due to the fact that I alter the cluster means according to their mutual distances after the completion of the clustering process, rather than deliberately trying to make them equidistant from each other.

The following tables list the run times (in milliseconds) of the proposed technique for enhancing each of the eleven 512 pixels X 512 pixels IRS-1A and SPOT satellite images of Kolkata and Mumbai obtained from [8] (Table I), and the small images of varying sizes (Table II) on a slow computer having a 568 MHz Intel Celeron processor. As stated before, the input parameter values used were: ***P***=1, ***K***=30 and ***E***=10^{-6}.

Table I: Run times of proposed technique for large images

No.	Time (ms)	No.	Time (ms)	No.	Time (ms)
1	801	5	571	9	621
2	571	6	571	10	571
3	581	7	581	11	581
4	571	8	581	Average	600

Table II: Run times of proposed technique for small images

No. of Pixels	Time (ms)	No. of Pixels	Time (ms)
4096	20	12060	40
4320	10	12150	50
7200	30	16050	61
8892	30	16384	60
9213	50	16640	81
10246	20	16764	60
10947	50	17161	60
11300	50	19404	70

It can be observed, that Table I quantitatively estimates the speed of the proposed image enhancement method for large images of fixed size (512 X 512 = 262144 pixels), while Table II does the same for small images of varying sizes. So, in the former case, I calculate the average execution time of the proposed image enhancement technique, and in the latter case, I try to demonstrate the variation in the time taken by the proposed technique to enhance images of varying sizes, as per the data supplied by Table II, in the following graph:

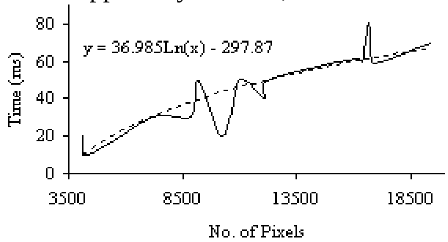


Fig. 10. Graph showing the variation in the time taken by the proposed technique to enhance small images of varying sizes, with the number of image pixels plotted along the horizontal (x) axis, and the time taken by the proposed technique to enhance the image plotted along the vertical (y) axis, and the logarithmic equation representing the dashed line (the best-fit curve reflecting the trend displayed by the graphical plot)

V. CONCLUSION AND FUTURE WORKS

In this paper, a simple, fast, scalable and efficient grayscale image enhancement technique has been proposed, which is easy to implement, and yet, produces better and more natural outputs than some traditional contrast enhancement tools. The set of input parameter values may be changed to obtain better results than those which we have observed till now. Lastly, the following are some ways to improve and extend this method:

1. automatically determining optimal values for ***P***, ***K*** and ***E***
2. discovering better ways of selecting the ***K*** starting means
3. extending the proposed method to enhance color images

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