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Adaptive histogram equalization in GIS

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Abstract. In order to analyze, the aerospatial images must pass through a series of transformations. Interpretation can be done by a human or by a computer. Image enhancement is made for interpretation and the interpretation can be done by a human or by a computer. The color interpolation or color demosaicing technique is used to recover missing color components in a RGB color system. These techniques are classified in *nonadaptive* and *adaptive* histogram equalization algorithms. We will analyze and compare some of the nonadaptive and adaptive algorithms that are successfully used in processing of large image files, such as aerospatial images.

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1. Histogram equalization

Is known that the digital images held in a pixel three color components if we use RGB color model. There are several methods of image enhancement and each of them is needed for a different type of analysis. We can't classify these algorithms because a certain processing can serve as date input in a certain process. A processing that highlights the outline of an object is appropriate for an application that is designed to detect objects in an image, but not so good for an application that aims to extracting information derived from the color variations. When we talk about imaging techniques, histograms prominently. Since color images are composed of several components, the techniques applied in grayscale images will be adjusted. It is not indicated to use histogram equalization independent, for each color component. Instead of this, it is better to use a uniform distribution of color intensity and leaving the hue unchanged. Some color models are more adequate for aerospatial images processing. For example, HSV (or HSI) model is one of the preferred models. The color system used for capturing digital images is RGB, but we can make the transition from one color space to another by using conversion formulas [1].

The most used formula for HSV transformation is:

$$V = max(r, g, b) \tag{1}$$

$$S = \begin{cases} 0 & \text{, if } V = 0 \\ V - \frac{min(r,g,b)}{V} & \text{, if } V > 0 \end{cases} \tag{2}$$

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$$H = \begin{cases} 0 & ,\text{ if } S = 0 \\ \frac{60*(g-b)}{S*V} & ,\text{ if } V = r \\ 60*\left[2+\frac{b-r}{S*V}\right] & ,\text{ if } V = g \\ 60*\left[4+\frac{r-g}{S*V}\right] & ,\text{ if } V = b \end{cases} \quad (3)$$

$$H = H + 360, if\ H < 0 \quad (4)$$

where the r, g, b values are calculate by normalizing each pixels:

$$r = \frac{R}{R+G+B},\ g = \frac{G}{R+G+B},\ b = \frac{B}{R+G+B}$$

Histograms show how distributed brightness levels/gray levels in a color/grayscale image. If we analyze a histogram we can notice that not all levels of color (gray) are used. The histogram can be modified to cover as many color levels as is possible and with this technique we can increase the picture quality. If the image contains a large number of dark colors the histogram is irregular; after histogram equalization the histogram has smoothing tends.

We assume that the image is in grayscale with gray levels in the range [0, L-1] and the histogram of the image is a discrete function:

$$h(r_k) = n_k$$

where r_k is the k*th* gray level and n_k is the number of pixels having gray level r_k [2].

Usually a normalized histogram is:

$$p(r_k) = \frac{n_k}{n}$$

where n is the total number of pixels and k = 0,1,. . . ,L-1.

Image enhancement process by which the original image is transform based on its histogram is called histogram modification. When histogram is forced to be uniform the transformation process is called histogram equalization. We assume that transformation:

$$S = T(r),\ 0 \leq r \leq 1$$

is applied to each pixel r in the original image. The ends of the range in which r takes values represent the limits of colors value, 0 is for white and 1 is for black. The transformation function T(r) must be [2]:

1. single-value
2. monotonically increasing in [0,1]
3. $0 \leq T(r) \leq 1$ for $0 \leq r \leq 1$

If the transformation function is not monotonically increasing it is possible to invert gray levels in the result image. The inverse transformation from s to r is:

$$r = T^{-1}(s),\ 0 \leq s \leq 1$$

Let $p_r(r)$ and $p_s(s)$ be the probability density functions (PDF) for r and s. If $p_r(r)$ and $p_s(s)$ are known and $T^{-1}(s)$ is single-value and monotonically increasing in [0,1] then $p_s(s)$ is:

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right| \quad (5)$$

The transformation function in image processing is:

$$s = T(r) = \int_0^r p_r(w)dw \tag{6}$$

The cumulative distribution function (CDF) of variable r is in the right side of the equation (6). Transformation function is single-valued, monotonically increasing and $T \in [0,1]$ for $r \in [0,1]$.

$$\frac{ds}{dr} = \frac{dT(r)}{dr} = \frac{d}{dr}\left[\int_0^r p_r(w)dw\right] = p_r(r) \tag{7}$$

Substitute (7) in (5) and obtain:

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right| = p_r(r)\left|\frac{1}{p_r(r)}\right| = 1,\ \forall s\ \in [0,1] \tag{8}$$

Equation (8) give an *uniform probability density function.* T(r) depends on $p_r(r)$, but $p_s(s)$ is always uniform, independent of the form of $p_r(r)$ [2].

If n is the total number of pixels, n_k is the number of pixels having gray level r_k and L is the total number of gray levels, the discrete form of equation (6) is:

$$s_k = T(r_k) = \sum_{j=0}^{k} p_r(r_j) = \sum_{j=0}^{k} \frac{n_j}{n},\ k = 0, 1, 2, \ldots, L-1 \tag{9}$$

where $p_r(r_k) = \frac{n_k}{n}, k = 0, 1, 2, \ldots, L-1$ is the aproximation of the probability of the occurence of gray level r_k.

The transformation given in equation (9) is called *histogram equalization* [2].

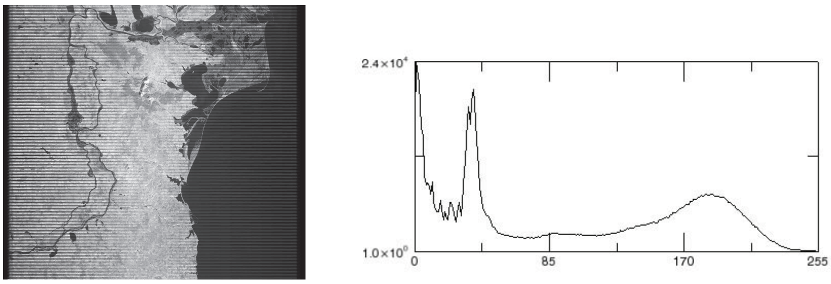

FIGURE 1. Black Sea, Romanian seaside; grayscale image and its histogram; image source [6]

In the Fig 1 we have a gray scale image and its histogram and in the Fig 2 we have the same image but we have applied the histogram equalization. We can see the difference between the histograms. Also, because the original image is darker the histogram is concentrated on the low side of the gray scale. Lighter images has histograms concentrated on the high side of the gray scale and high-contrast image cover almost the entire range of the gray scale. An image that have pixels that tend to occupy the entire range of gray scale and tend to be uniform have better quality.

2. Adaptive histogram equalization algorithms

Histogram equalization algorithms are classified into two categories: nonadaptive and adaptive. In the nonadaptive algorithms each pixel is modified by applying the

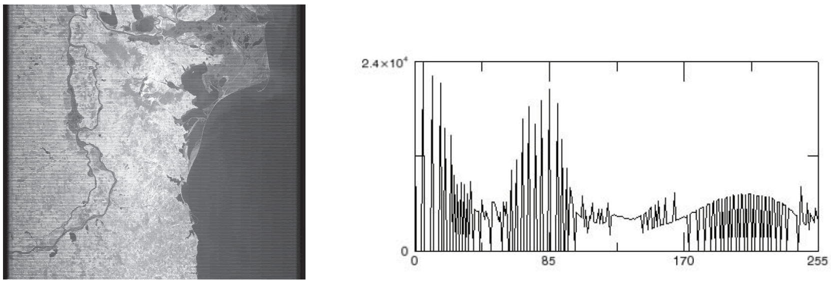

Figure 2. Black Sea, Romanian seaside - after histogram equalization and its histogram

same pattern of computation that use the histogram of entire original image. In beneral good quality images are degraded in a nonadaptive histogram equalization process. In works with better result for images that has details hiden in dark regions.

In the adaptive algorithms each pixel is modified based on the pixels that is in a region surrounding that pixel. This region is called *contextual region.* The adaptive histogram equalizations is computationaly intense and for this reason was developed some methods to increase the speed of the original method. If we have an image of n x n pixels, with k intensity levels and the size of contextual region is m x m, then the time required for calculations is $O(n^2(m+k))$. Better results are obtained if we use instead of the histogram of neighborhood pixels from a moving window only four nearest grid points. The transformation of each pixel is made by interpolating mappings of the four nearest points [3].

If (x,y) is a pixel of intensity i from the image, then we note with $m_{+,-}$ the mapping of right upper $x_{+,-}$, $m_{+,+}$ the mapping of right lower $x_{+,+}$, $m_{-,+}$ the mapping of left lower $x_{-,+}$ and $m_{-,-}$ the mapping of left lower $x_{-,-}$, then the interpolated adaptive histogram equalization is compute with:

$$m(i) = a\,[bm_{-,-}(i) + (1-b)m_{+,-}(i)] + [1-a]\,[bm_{-,+}(i) + (1-b)m_{+,+}(i)] \quad (10)$$

where

$$a = \frac{y - y_-}{y_+ - y_-},\ b = \frac{x - x_-}{x_+ - x_-}$$

Adaptive histogram equalization has the disadvantage to enhance not only the image, but also it enhace the noise in the image. For improvement it was proposed a contrast limited adaptive histogram equalization (CLAHE). This method enhance the image and suppress the noise. In the Fig 3 we have the result of the CLAHE.

3. Conclusion

Adaptive histrogram equalization has the advantages of being automatic, reproducible, locally adaptive, and usually produces superior images when compared with interactive contrast enhancement. It was prove that we can obtain better results if the original image has more dark regions. For that image that has not too much variations in the levels of gray was observed that adaptive histogram equalization has not good results. The noise is suppress by contrast limited enahancement and the result images are better.

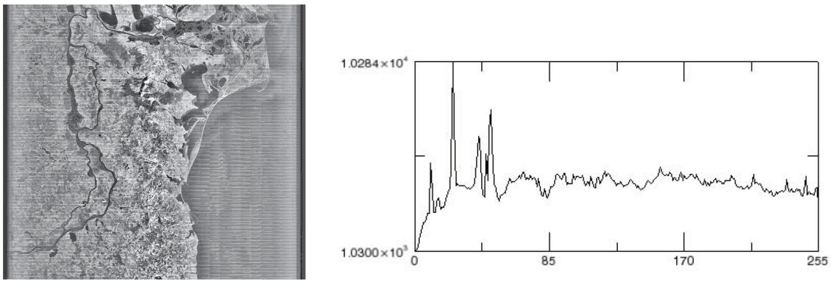

Figure 3. Black Sea, Romanian seaside - after adaptive histogram equalization and its histogram

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[6] `http://eros.usgs.gov/#/Home` Earth Resources Observation and Science (EROS)

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