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Histogram Equalization

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1 Introduction

This application note describes a method of imaging processing that allows medical images to have better contrast. This is attained via the histogram of the picture, using a method that allows the areas with low contrast to gain higher contrast by spreading out the most frequent intensity values. For example, in digital x-rays in which colors achieved are a palette of whites and blacks, different types of colors give the physician an idea of the type of density that he or she is observing. Therefore white structures are likely to indicate bone or water and black structures represent air. When pathologies are present in an image, trying to delimit the area of the lesion or object of interest may be a challenge, because different structures are usually layered one over the other. For example, in the case of the chest the heart, lungs, and blood vessels are so close together that contrast is critical for achieving an accurate diagnosis.

In this application note we will describe how to use the histogram equalization module from Freescale's imaging software library to equalize a histogram of a medical image, and thus achieve the contrast required in medical images.

2 Important definitions

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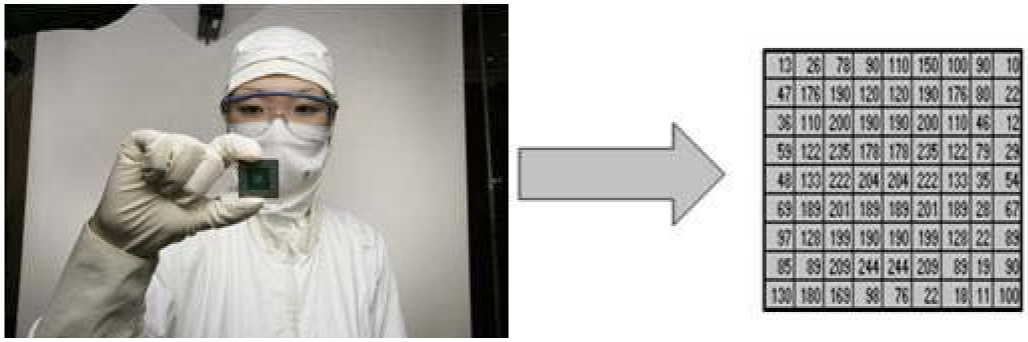
2.1 Digital image

A digital image is a binary representation of a two-dimensional image. The digital representation is an array of picture elements called pixels. Each of these pixels has a numerical value which in monochromatic images represents a grey level.



13	26	78	90	110	150	100	90	10
47	176	190	120	120	190	176	80	22
36	110	200	190	190	200	110	46	12
59	122	235	178	178	235	122	79	29
48	133	222	204	204	222	133	35	54
69	189	201	189	189	201	189	28	67
97	128	199	190	190	199	128	22	89
85	89	209	244	244	209	89	19	90
130	180	169	98	76	22	18	11	100

Figure 1. An image and its digital representation

2.2 Image histogram

In general, a histogram is the estimation of the probability distribution of a particular type of data. An image histogram is a type of histogram which offers a graphical representation of the tonal distribution of the gray values in a digital image. By viewing the image's histogram, we can analyze the frequency of appearance of the different gray levels contained in the image. In Figure 2 we can see an image and its histogram. The histogram shows us that the image contains only a fraction of the total range of gray levels. In this case there are 256 gray levels and the image only has values between approximately 50–100. Therefore this image has low contrast.

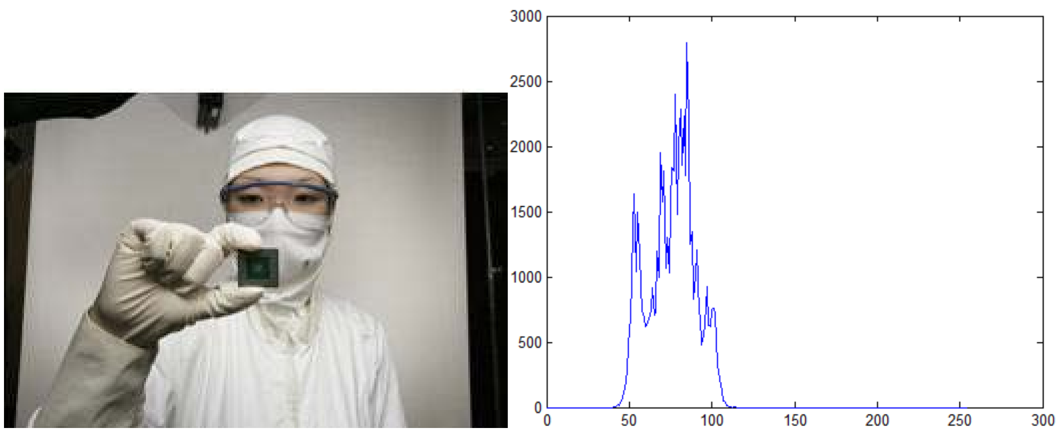


Figure 2. An image and its histogram

3 Histogram

3.1 What is a good histogram?

A good histogram is that which covers all the possible values in the gray scale used. This type of histogram suggests that the image has good contrast and that details in the image may be observed more easily.

3.2 Improving the contrast of an image through histogram equalization

As stated earlier, basically the histogram equalization spreads out intensity values along the total range of values in order to achieve higher contrast. This method is especially useful when an image is represented by close contrast values, such as images in which both the background and foreground are bright at the same time, or else both are dark at the same time. For example, the result of applying histogram equalization to the image in figure 2 is presented in Figure 3.

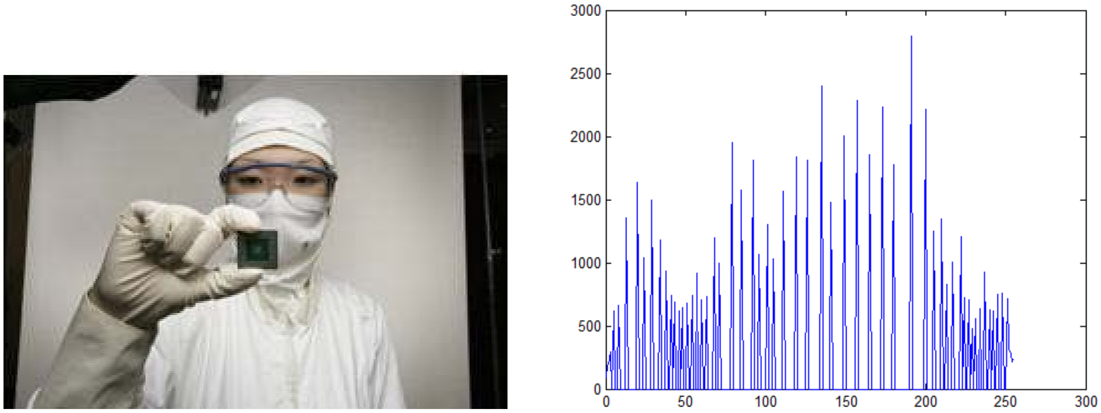


Figure 3. New image and its equalized histogram

We can see that the image's contrast has been improved. The original histogram has been stretched along the full range of gray values, as we can see in the equalized histogram in Figure 3.

3.3 Methods for histogram equalization

There are a number of different types of histogram equalization algorithms, such as cumulative histogram equalization, normalized cumulative histogram equalization, and localized equalization. Here is a list of different histogram equalization methods:

- Histogram expansion
- Local area histogram equalization (LAHE)
- Cumulative histogram equalization
- Par sectioning
- Odd sectioning

These methods were studied and compared in order to determine which one offers the best equalization and is also best suited to DSP implementation. Table 1 shows the advantages and disadvantages of each method.

Table 1. Methods for histogram equalization

Method	Advantage	Disadvantage
Histogram expansion	Simple and enhance contrasts of an image.	If there are gray values that are physically far apart from each other in the image, then this method fails.
LAHE	Offers an excellent enhancement of image contrast.	Computationally very slow, requires a high number of operations per pixel.
Cumulative histogram equalization	Has good performance in histogram equalization.	Requires a few more operations because it is necessary to create the cumulative histogram.
Par sectioning	Easy to implement.	Better suited to hardware implementation.
Odd sectioning	Offers good image contrast.	Has problems with histograms which cover almost the full gray scale.

In this document, cumulative histogram equalization is proposed for implementation in the DSP. This algorithm was selected due to its good performance and easy implementation in the C language.

3.4 Description of cumulative histogram equalization

In this section the general approach for cumulative histogram equalization is described. Here are the steps for implementing this algorithm.

1. Create the histogram for the image.
2. Calculate the cumulative distribution function histogram.
3. Calculate the new values through the general histogram equalization formula.
4. Assign new values for each gray value in the image.

This method is implemented as shown in Figure 4, outlining the steps enumerated above.

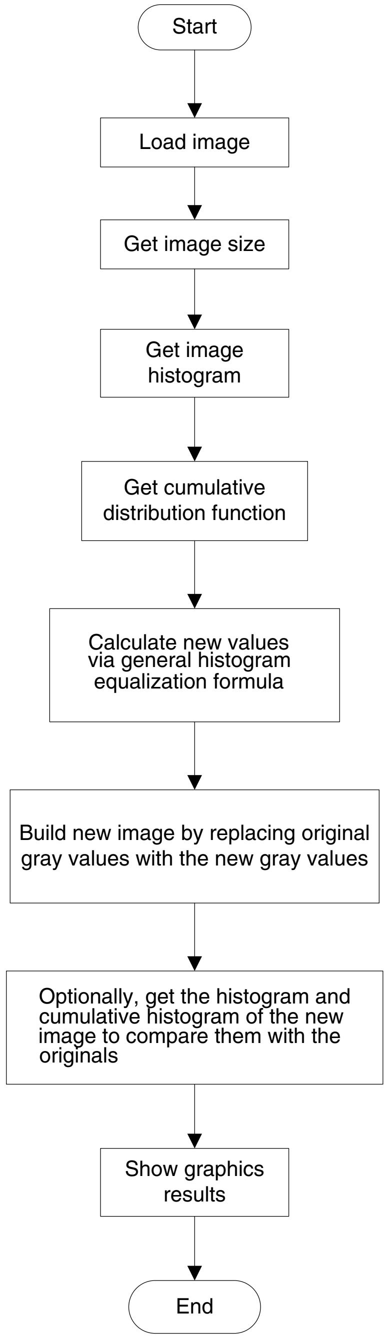


Figure 4. Block diagram of algorithm implementation

4 Matlab implementation

The cumulative histogram equalization was implemented and tested using MATLAB version 7.6. For an image with 256 gray levels like the one in Figure 5, the first step is to generate the image's histogram. This is done with the code shown.

Figure 5. Example image

```
% Getting histogram
for grey_level = 0:1:255
    images_histogram(grey_level + 1) = 0;
    for i = 1:1:size_c
        for j = 1:1:size_r
            if array_1(j,i) == grey_level
                images_histogram(grey_level + 1) = images_histogram(grey_level + 1) + 1;
            end
        end
    end
end
```

where size_c and size_r are the number of columns and number of rows respectively, array_1 is the matrix that contains the image data. The plot of this histogram is shown in Figure 6.

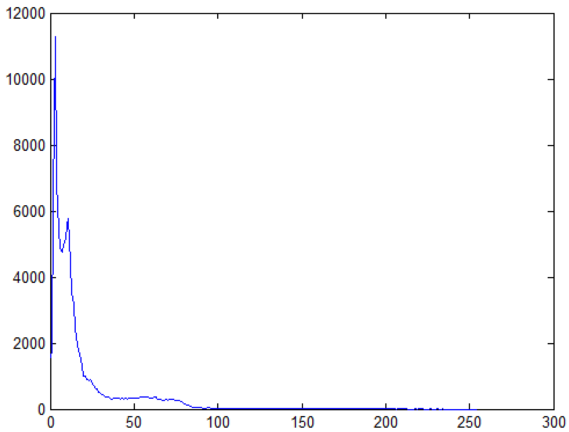


Figure 6. Histogram of example image

After this, we need to calculate the cumulative distribution function which is defined as

$$\mathrm{cdf}(x) = \sum_{j=1}^{x} h(j)$$

where x is a gray value and h is the image's histogram. The cumulative distribution function for each gray tone is calculated by the code shown here.

```
%Cumulative distribution function (cdf)
for grey_level = 1:1:256
    cdf(grey_level) = 0;
    for i = 1:1:grey_level
        cdf(grey_level) = cdf(grey_level) + images_histogram(i);
    end
end
```

And here is the plot of the cumulative histogram.

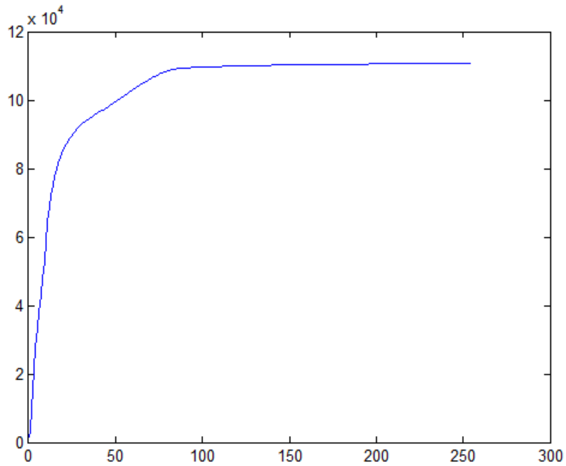


Figure 7. Cumulative histogram of example image

Now, the general histogram equalization formula is

$$\mathrm{eh}(i) = \mathrm{round}\left(\frac{\mathrm{cdf}(1) - \mathrm{cdf}_{\min}}{\mathrm{MxN} - \mathrm{cdf}_{\min}} * (L-1)\right)$$

where cdfmin is the minimum value of the cumulative distribution function, M x N are the image's number of columns and rows, and L is the number of gray levels used (in most cases 256). This formula is implemented in this code:

```
for i = 1:1:256
    h(i) = ((cdf(i)-1)/((size_r * size_c)-1)) * 255;
end
```

Applying this to the image in Figure 5, we obtain the next new image and its corresponding histogram and cumulative histograms.

Figure 8. Example image after applying algorithm

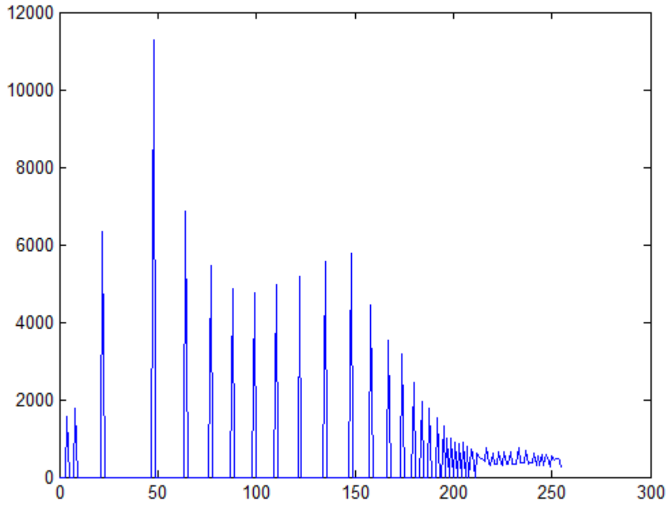


Figure 9. New equalized histogram

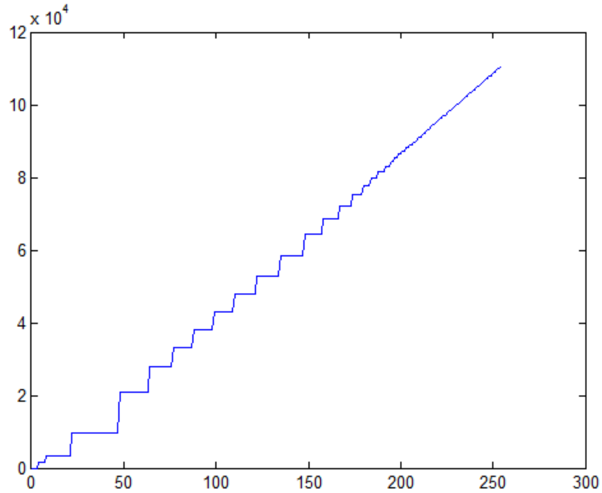


Figure 10. Equalized cumulative histogram

5 Conclusion

Histogram equalization is a straightforward image-processing technique often used to achieve better quality images in black and white color scales in medical applications such as digital X-rays, MRIs, and CT scans. All these images require high definition and contrast of colors to determine the pathology that is being observed and reach a diagnosis. However, in some type of images histogram equalization can show noise hidden in the image after the processing is done. This is why it is often used with other imaging processing techniques.

Freescale offers a complimentary imaging software library in which you will find histogram equalization, among other type of algorithms that can be used for your specific application. Please refer to the Medical Imaging Software Library User Manual to learn more about these algorithms.

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