Histogram Normalization of Medical Images in Real Time

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Abstract: Our work involves applying real-time histogram normalization to medical images using an FPGA. This technique enhances the visualization of anatomical structures for early and accurate diagnosis. FPGAs, due to their rapid processing capabilities, are ideal for medical imaging due to the substantial amount of data involved. The decision to use an FPGA is based on its ability to process data quickly and in parallel. Given the voluminous nature of medical data, processing speed is crucial to ensure real-time results. FPGAs enable specific hardware customization for the application, providing optimal performance for histogram normalization in the context of medical imaging. Our application highlights the significance of histogram normalization in the medical field by demonstrating how this technique can significantly improve image visualization. Furthermore, it underscores the efficiency of the FPGA in meeting the performance requirements necessary for rapidly and effectively processing medical data. In summary, our work contributes to the advancement of medical imaging technologies by combining a crucial image processing technique with an optimal hardware platform for real-time results.

Keywords : real-time, histogram normalization, medical images, VHDL, FPGA.

1 Introduction

In an image, the clarity of pixel information can make comprehensive perception challenging, especially when each pixel synthesizes multiple distinct data (Pierrefeu et al., 2005). To address this challenge, real-time histogram normalization of medical images with an FPGA (Krifa et al., 2008) proves to be a crucial technique for enhancing the quality of medical images (Bonagiri, Kande, & Reddy, 2023). This method operates by adjusting the distribution of gray levels in the image (Baba Hamed, Bechar, & Bendouma, 2023), providing a relevant solution in the medical context.

The use of FPGAs presents a promising solution for accelerated processing due to their well-suited parallel architecture (Barkovska et al., 2023). Our work sits at the intersection of the imperatives of histogram normalization, the challenges of real-time implementation, and the exploitation of FPGA potential (Babu & Parthasarathy, 2021) to effectively address these challenges (Bailey, Donald G, 2023). By exploring the underlying motivations for histogram normalization, our study aims to provide a comprehensive understanding of the issues encountered in the medical field while highlighting the ability of FPGAs to constitute a promising solution for the rapid and precise improvement of medical image quality.

2 Method

Histogram normalization, as an advanced image processing technique, plays a crucial role in adjusting the distribution of gray levels within an image. The main objective of this work is to improve image visualization by correcting inherent exposure defects. This approach relies on the fundamental principle of ensuring a balanced representation of all gray levels present in the image, thus providing a more accurate visual perspective.

Indeed, histogram normalization ensures that the new value assigned to each pixel is adjusted proportionally based on the complete range of gray levels defined by the minimum pixel (representing the minimum value of pixel gray levels) and the maximum pixel (representing the maximum value). This scale is typically normalized to a range of values from 0 to 255, thereby enabling a standardized and optimal representation of gray level variations in the image.

59	65	159	90	200	88
76	87	76	101	96	90
67	98	225	255	71	67
167	91	74	98	120	234
86	200	235	155	87	200

By adopting this approach, histogram normalization helps alleviate disparities in pixel exposure, thereby enhancing the overall quality of the image and facilitating a more accurate visual interpretation of medical or diagnostic information.

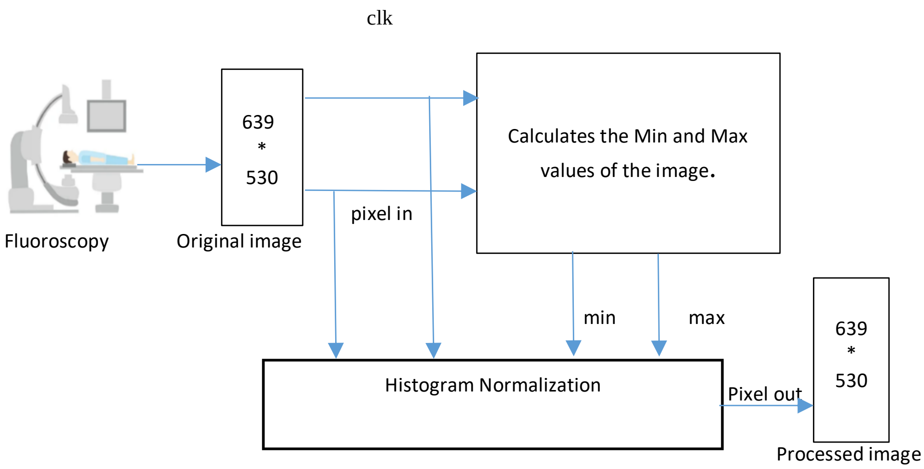

Figure 1 : Hardware architecture

Detailed explanation of the equation:

$$f(x,y) = 255 \times \frac{(I(x,y) - min)}{max - min}$$

- $f(x,y)$ Represents the pixel value at position (x, y) in the original image.
- • min represents the minimum value of pixels across the entire image.
- • max represents the maximum value of pixels across the entire image.

- The expression $(f(x, y) - \min)$ Calculates the difference between the current pixel value and the minimum value.
- The expression (max - min) calculates the dynamic range of the image.
- $(I(x, y) - min)$ / (max $-min$) Normalizes the difference by the dynamic range.
- By multiplying the result by 255, the equation extends the normalized value to the full range of gray levels (from 0 to 255).

  So the equation normalizes each pixel of the image so that it falls within the range of 0 to 255, based on the dynamic range of the original image.

  Using the histogram normalization algorithm, the hardware description of the circuit implemented on the FPGA component adjusts brightness levels, stretches the value range, and applies these adjustments to the pixels of the image. This transformation optimizes the distribution of intensities, enhancing contrast and visibility of details. The generation of the processed image is followed by the FPGA output. Thanks to its parallel architecture, the FPGA enables remarkably short processing times, providing significant improvements in the visual quality of medical images.

3 Result :

After the implementation of this hardware architecture, we were able to process the medical image in Figure 2, with a size of 639*530 pixels, in a remarkably short time of 338,670 ns (0.34 ms). This outstanding performance demonstrates the efficiency of our approach in accelerating the histogram normalization process. Examining Figure 3, which represents the image after processing, we clearly observed improvements such as brightness and contrast level corrections. For a better understanding of the changes made, we presented the histograms of both the original and processed images. These graphical representations visually illustrate the significant changes induced by the histogram normalization process, confirming the effectiveness of our method in enhancing the quality of medical images. Figures 2 and 3 play a crucial role in respectively illustrating the initial state of the medical image and the significant impact after the application of our technique. These results conclusively testify to the ability of our approach to optimize brightness and contrast levels in the specific context of medical images. This promising advancement could have major implications in the medical field, providing higher quality images that are essential for accurate diagnoses and in-depth analyses. In summary, our results demonstrate the relevance and effectiveness of our approach for significantly improving the visualization of medical images.

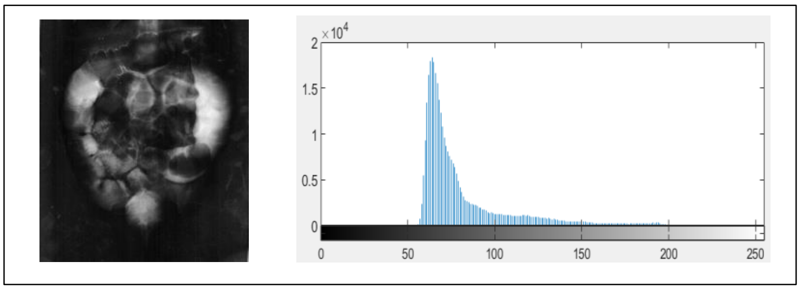

Figure 2 : Original Image and Histogram of the Original Image

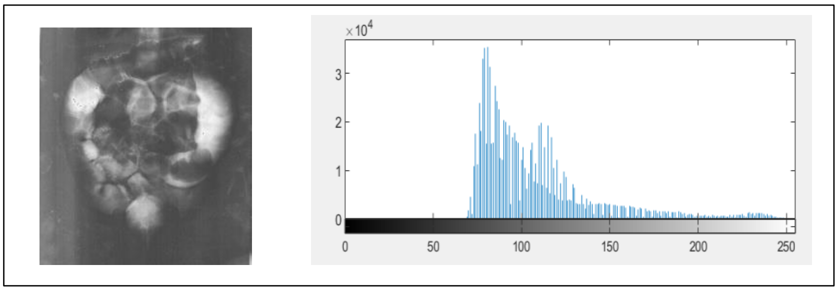

Figure 3 : Processed Image and Histogram of the Processed Image

4 Conclusion :

The obtained results confirm that applying histogram normalization through an FPGA has generated prompt and efficient processing of medical images, a crucial characteristic in real-time medical applications.
The decision to opt for an FPGA for the implementation of this technique has proven to be a particularly effective solution. The device's ability to rapidly process medical images is of paramount importance in the medical field, where real-time analyses are often necessary to enable physicians to make quick and informed decisions. The speed of image processing thus becomes a determining factor in enhancing the overall performance of medical systems.
The effectiveness of the FPGA in histogram normalization has significant implications. It ensures rapid correction of brightness and contrast levels, enabling improved visualization of anatomical and pathological structures in medical images. This increased visual precision can be crucial for early diagnoses, image-guided surgical interventions, and other critical medical applications.
The conclusions of this study highlight that using an FPGA for histogram normalization represents not only an efficient but also an essential approach for the rapid processing of medical images. These technological advancements have the potential to transform medical practices, paving the way for quicker and more accurate diagnoses and an overall improvement in healthcare.

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