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REAL-TIME CONTRAST MANAGEMENT IN DIGITAL IMAGES USING LOCAL HISTOGRAM EQUALIZATION FILTER

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ABSTRACT

This thesis reports a new adaptive tone mapping algorithm, along with its real-time FPGA implementation. Several algorithms exist in literature that can combine global and local tone control. These tone control functions are known to be difficult to manage in a unified manner. The proposed smoothed LHE method can easily manage the global and local tone curves in the same tone mapping space. Lateral inhibition is an important early stage mechanism of visual processing that leads to many perceptual effects and needs to be considered in any image processing algorithm's design specification. From our detailed analysis we conclude that the proposed algorithm can generate naturally perceived tone mapped images when compared to other state of the art algorithms. We also demonstrate the algorithm's usefulness in medical image processing tool with a subjective study by a radiologist. Furthermore, the additional contributions presented in this thesis can be viewed as a setup for full HDR pipeline, and this is illustrated with a demo video published on YouTube.

Index Terms— High dynamic range imaging, tone mapping, FPGA, lateral inhibition, optical illusion, Mach band and digital X-ray

1. INTRODUCTION

Growing demand for displays with superior quality and higher resolutions have been continuously driving the high dynamic range market. High Dynamic Range (HDR) imaging has come to become a compelling aspect of the new 4K/8K Ultra-high-definition (UHD) format [1]. For enhanced viewing experience high dynamic range imaging techniques are being employed in various fields as a replacement for standard digital techniques. This thesis contributes to the field of real-time tone mapping algorithm based on a smoothed local histogram equalization (SLHE) method. There are discussions on algorithm design and implementation on a FPGA device. Multiple detailed subjective user studies have been conducted to assess the image quality and validate the algorithm. Following are the main contributions of this thesis:

- Design of a SLHE-based tonemap pipeline.
- FPGA implementation of the SLHE algorithm for real-time acceleration.
- Detailed study on characteristics of SLHE visualization.
- Application of SLHE algorithm for medical image enhancement.

2. PROPOSED SLHE ALGORITHM

LHE-based local tone mapping converts target pixels by using tone curves constructed from local cumulative histograms, and are widely used for image enhancement. However, the LHE processes often result in unacceptable modification of the original image appearance. Therefore, in this thesis we propose a smoothed LHE method, in which we use a bin reduced intensity stacked histogram and sum of sigmoid curves as basis functions as illustrated in Fig. 1. Smoothed local tone curves without ripples are directly calculated; all local medians are mapped to constant value of 127 by the generated tone curves, which are loci of the function's midpoints. This means that, the spatial low frequency components can be completely converged and removed by our functions. Arranging the loci then becomes reconstruction of the low frequency components which are related to global tone control; limiting of the tone mapping space is utilized as the gain control of the local functions. Also, in this thesis we present a real-time FPGA implementation for our proposed smoothed LHE tone mapping algorithm. In our FPGA implementation, we were able to minimize the system latency to $0.81\mu s$ @162 MHz system clock and reduce 98% frame memories by using down-sampled local statistics from a previous frame [2].

3. VISUALIZATION & APPLICATION OF SLHE ALGORITHM

Lateral inhibition (LI) is an important early stage mechanism of visual processing that helps the brain cope with the enormous redundant visual information it receives from the surroundings. This inhibitory mechanism leads to many perceptual effects and needs to be considered in the algorithm's specification. We have studied in detail the LI phenomena and its influence on visual perception by comparing multi-layer (ML) and SLHE filters response to images with optical illusion [3]. Our findings are as follows:

- ML algorithms use only a few subjectively selected filters with small kernel size and user set gain, generating images with unnaturalness.
- Unmanageable Mach effects are generated in processed images even with latest edge-preserving filters.

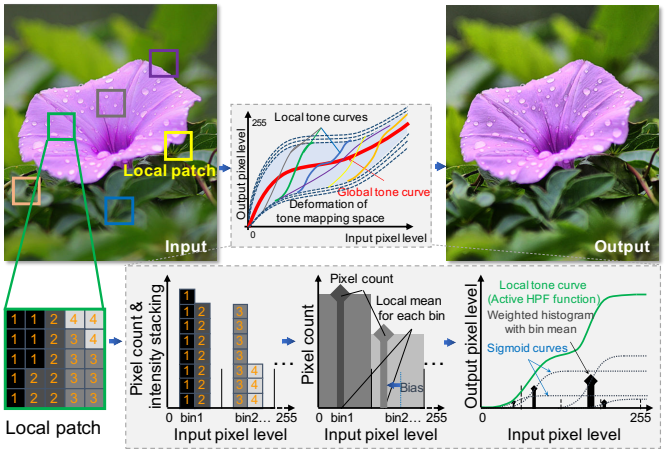

Fig. 1. Proposed algorithm's conceptual framework. We directly calculate smoothed local tone curve as sum of sigmoid functions, for each local patch which is computed from intensity stacked histogram.

- Saw-tooth like edge forms are practical for generating naturally perceived images with optical illusion.
- Large kernel size filters are useful for generating saw-tooth like edge forms and SLHE can support large kernels.

We carefully analyzed ML and SLHE filter response for varying kernel sizes. We observe that, with larger radius ML filters like Guided filter[1] tend to treat edges like textures, and user set gain causes output saturation. This effect is lower in domain transform filter[2], but it does exhibits similar characteristics. These ML filters are frequency selective, i.e., ML detail manipulation makes use of fewer layers thus limiting itself to certain frequencies. On the other hand, our SLHE filter with large kernel support can process the images without disturbing the edge forms.

Radiology is a visual specialty. We collaborated with a radiologist to subjectively assess our algorithm's usefulness for medical image enhancement [4]. Following is an example application, the chest X-ray of a normal person (image courtesy [3]) shown in Fig. 2 has Mach band effect adjacent to the left heart border (see markers). This condition must be differentiated from a pneumomediastinum. The different sets of SLHE manipulated X-rays are presented in Fig. 2. They are graded with the best image demonstrating preservation of normal pulmonary vasculature while decreasing the Mach band effect around the heart border. Evaluation scores (5: best, 1: worst) are given in table 1. It is very important to not exaggerate Mach effect as increased prominence of the pulmonary markings can simulate false positive diagnoses such as pulmonary edema. SLHE algorithm can enhance finer details in these low contrast X-rays with Mach bands.

[1] DOI: 10.1109/TPAMI.2012.213 [2] DOI:10.1145/1964921.1964964
[3] RADIOPEDIA

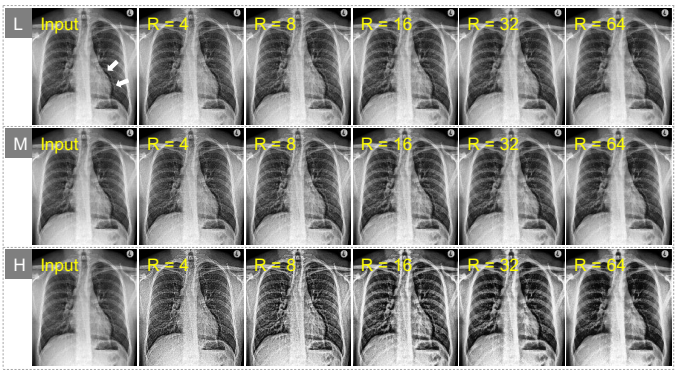

Fig. 2. Chest X-ray with Mach band illusion adjacent to heart marked by pointers, and effect of kernel size tuning (radius 4 → 64) on X-Ray contrast.

Table 1. Fig. 2 subjective evaluation by radiologist

Preset	R=4	R=8	R=16	R=32	R=64
L	1	2	3	4	5
M	5	1	2	3	4
H	5	4	3	2	1

4. CONCLUSION

This thesis reports a new adaptive tone mapping algorithm, along with its real-time FPGA implementation. Our smoothed LHE method can easily manage the global and local tone curves in the same tone mapping space. From our study we find that the proposed smoothed LHE algorithm which operates with large kernel size, can generate saw-tooth like edge forms thereby avoiding the stacked LI effect. We demonstrate the usefulness of SLHE algorithm by enhancing digital X-rays, and included a case with Mach bands in it. These processed X-rays were positively evaluated by a Radiologist.

5. REFERENCES

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