学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（情報科学）　　氏名　Dabwitso Kasauka

学　位　論　文　題　名

A Study on Acceleration of Image Smoothing and FPGA Implementation of Image Enhancement and Haze Removal as an Application of Image Smoothing

（画像平滑化の高速化ならびにその応用としての画像輝度補正およびヘイズ除去の FPGA 実装に関する研究）

In recent years, much research interest in digital image and video processing has developed focusing on various aspects. Some of these include image smoothing, enhancement and haze removal. With continued advancement in development and deployment of mobile consumer electronics capable of capturing images and streaming video, the need for image processing technique optimization geared to support real-time processing is increasing. Based on this, we investigate image smoothing techniques, Retinex-based image enhancement and haze removal optimization for real-time processing. We further propose an FPGA architecture to support efficient real-time processing. Our research work has been done in two segments; 1) Image smoothing, 2) Retinex-based enhancement and haze removal with FPGA implementation. Our research in the first segment compliments the second segment.

Image smoothing techniques basically separate a digital image into its structure and texture layers, hence the term smoothing as the structure can exist apart from details. Such techniques have found relevance in various image processing applications such as edge detection, detail enhancement, image tonal mapping, image compression artifact removal, image noise removal, and in computer vision object imaging/ robotics. It has also found application in the field of optical measurement as a calibration method in image sensing. In this thesis, implementation of image smoothing using spatial iterative methods is investigated. We formulate a smoothing algorithm suitable for spatial implementation and compare our proposed multigrid preconditioned conjugate gradient implementation with existing smoothing algorithms. Furthermore, we take into account the image boundaries and eliminate wrap around errors which are inherent in some existing smoothing algorithms including those implemented using Fast Fourier Transform solvers. According to experimental results obtained using various image datasets, our approach computes smoothed output in competitively low processing time. Some existing methods such as based on bilateral filtering, tree filtering and weighted least squares, converge to a solution faster than our proposed approach. However, according to qualitative results obtained, our approach produces better smoothing results. A full HD image is processed in 0.85 secs. In further optimization, we incorporated image downsampling in one case, and in another case implemented flow optimization by pre-calculating and loading the computationally costly Laplacian operator matrix from memory. In the case of downsampling, processing time was reduced by approximately 21.6 %. However, a trade-off between processing time and smoothing quality was encountered in this case. In the case of flow optimization, processing time was reduced by approximately 46.1 %. This optimization approach is useful and applicable to constant resolution input stream, extending application to video

processing.

Image enhancement and haze removal optimization are key research topic in intelligible information gathering and classification. Environmental illumination conditions play a major role in influencing visual perception and scene classification. The quality of images and video taken from outdoor scenes is influenced by scattering of light which occurs before reaching the camera sensor. The amount of scattering depends on the distance between the scene points and the sensor, making degradation spatial-variant. In haze (fog) weather, an elevated presence of atmospheric particles such as water-droplets results in more scattering, resulting in low contrast and colour fidelity images. Scattering is caused by two basic phenomena, which are attenuation and airlight. Haze removal depends upon the unknown depth information. This particularly makes haze removal a challenging task. Haze removal is highly desired in computer vision applications. It not only serves to significantly increase the visibility of the scene and correct the colour shift, it can also benefit many vision algorithms and advanced image editing. Both Retinex-based image enhancement and haze removal are computation costly. Considering real-time processing in applications such as monitoring systems, autonomous cars, and live streaming systems, there still remains much room for the development of efficient hardware implementation of image enhancement and haze removal. Motivate by this, we propose an architecture supporting both real-time Retinex-based image enhancement and haze removal, at low memory and process overhead utilizing a single module. The implementation results reveal that just 1 % logic circuits overhead is required to support Retinex-based image enhancement in single mode and haze removal based on Retinex model. This reduction in computation complexity by using a single module reduces the processing and memory implications especially in mobile consumer electronics, as opposed to implementing them individually using different modules. Furthermore, we utilize image enhancement for transmission map estimation instead of soft matting, thereby avoiding further computation complexity which would affect our goal of realizing high frame-rate real time processing. Our FPGA implementation, operating at an optimum frequency of 125 MHz with 5.67 M total block memory bit size, supports WUXGA (1,920 $\times$ 1,200) 60 fps as well as 1080p60 color input. The maximum logic utilization and number of registers used are 3212 and 3648, respectively. At high frequency of 240 MHz, our approach has the capability of processing 4K video at 30 fps. We compare our approach to existing state-of-the-art algorithms, both quantitative and qualitatively. Performing PSNR and SSIM tests on multiple inputs, it is observed in average that our approach provides better results. In hardware architecture comparison with existing architectures, our approach provides the highest throughput of 125 Mpixels/s, utilizing 9 line buffers of 240 width size.