DESIGN OF HARDWARE ARCHITECTURE FOR IMPLEMENTATION OF REAL TIME DEHAZING ALGORITHMS OF WEATHER DEGRADED IMAGES

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Synopsis

Dehazing is a crucial technique for addressing visibility issues caused by adverse weather conditions such as fog, rain, and snow. It plays a significant role in enhancing the clarity of images and videos affected by these conditions, thereby improving the accuracy of object tracking systems. By restoring image sharpness and removing weather-induced distortions, dehazing ensures that surveillance systems can maintain reliable performance and security in critical infrastructures like ports and airports. Moreover, in autonomous applications like self-driving vehicles and drones, dehazing techniques enable real-time tracking of objects even in low-visibility scenarios, which is vital for safe and efficient operation. The development of sophisticated dehazing algorithms, optimized for computational efficiency, is essential to meet the challenges of real-time processing while maintaining high accuracy. These advancements contribute significantly to the broader field of computer vision, ensuring functionality in environments affected by inclement weather.

This research work has made the following significant contributions:

- **Image Parameter Analysis**: The main contributions of this work include a comprehensive analysis of ten widely used image quality assessment (IQA) metrics—MSE, PSNR, SSIM, MSSIM, Correlation, MDSI, LPIPS, GMSD, BRISQUE, and NIQE—specifically evaluated for their effectiveness in haze removal scenarios. A novel perceptual benchmark, the Human-Level Haze Quality Assessment (HLHQA) dataset, is introduced, containing 36 hazy and corresponding haze-free images rated on a 0–10 scale based on human perception. Each metric is thoroughly analyzed for its alignment with human-level perception (HLP) across varying haze intensities, including no haze, low haze, dense haze, and night haze conditions. Additionally, a user-friendly graphical interface has been developed to streamline the comparison of haze removal models, enabling both qualitative and quantitative evaluations in an accessible and efficient manner.

- **Parallel Processing in Real-Time**: This work presents a parallel hardware architecture for efficient computation of airlight estimation and transmission coefficients, with an optimized airlight estimation process to reduce execution time. It introduces a contrast enhancement technique that bypasses time-consuming operations like soft matting, thereby improving image quality efficiently. Additionally, an automatic gamma correction logic is proposed to enhance images without relying on prior-based or computationally expensive methods, making the overall dehazing process faster and more suitable for real-time hardware implementation.

- **Night Time Image Dehazing**: The study introduces a luminance-aware enhancement strategy tailored for nighttime hazy images, where excessive brightness often leads to loss of detail and poor visibility. It employs a gamma mapping technique to suppress high luminance while preserving image features, improving both contrast and perceptual quality. A weighted combination of RGB channels is used to estimate luminance, which is then adaptively modified using gamma correction. The enhanced image is further refined through a haze removal function that integrates luminance estimation, atmospheric light compensation, and transmission map adjustments. This approach ensures a well-balanced luminance distribution across all color channels, resulting in visually clearer and more detailed dehazed images, especially under challenging low-light conditions.

- **Light Invariant Dehazing Network (LIDN)**: The introduction of the Light Invariant Dehazing Network (LIDN), a system is designed specifically to satisfy the growing demand for effective image dehazing in computer vision. The Deep Global Atmospheric Light Estimator, the Medium Transmission

Extractor, the Encoder-Decoder, and the Feature Extractor are the four sub-modules that make up this novel network. It turns out that LIDN, equipped with Quadruplet loss training, is a powerful tool for minimizing artifacts and creating clearer, dehazed images. Extensive testing under various lighting circumstances reveals LIDN to be a superior performer compared to standard daytime and nighttime dehazing techniques, completing this feat with impressive effectiveness.

- **Real-Time Video Dehazing**: In this research, a novel 'SATVAL' haze parameter is introduced and applied to an image scattering model across video frames processed within a second. The study addresses the challenging problem of real-time video dehazing on edge devices. While the proposed method performs effectively, it relies on a prior-based approach, leading to occasional limitations. In contrast, the developed GAN-based method consistently outperforms the prior-based approach. However, it comes with the drawback of being computationally expensive and necessitating GPU resources. To address this challenge, research is conducted to compress the model from float32 to int8. This adjustment takes advantage of the computational efficiency of the int8 format over float32. Subsequently, the optimized model is deployed on the "Raspberry Pi 4B" platform, achieving a remarkable frame rate of 11FPS, all without the need for a GPU.

- **An Empirical Comparison of Dehazing Algorithm in Different Hardware**: The key contributions of this study include the investigation and development of a novel hardware-efficient parallel architecture that incorporates an optimized guided filter for precise transmission coefficient estimation and an improved atmospheric light estimation module. These advancements significantly enhance both the accuracy and speed of the dehazing process. Furthermore, the study provides a comprehensive hardware performance analysis across platforms such as the Raspberry Pi Model 4B, Pynq Z2, and NVIDIA Jetson Nano, delivering detailed quantitative metrics and valuable insights to identify the most suitable options for real-time image dehazing applications.

- **ASIC Model for Image Dehazing**: This study presents a hardware-efficient image dehazing algorithm tailored for ASIC implementation to enable real-time performance in resource-constrained environments. The method introduces a pipelined architecture where preprocessing is handled using shift registers and parallel FIFO buffers, facilitating smooth image data flow. Edge detection is performed via parallel MAC units using Sobel or Prewitt filters, followed by an efficient dark channel prior (DCP) estimation using comparator circuits. Atmospheric light is estimated through a max-pooling strategy aided by priority encoders, while the transmission map is computed using fixed-point arithmetic for hardware compatibility. Guided filtering with FIR filters is employed to refine the transmission map by preserving edges and removing noise. Finally, the dehazed image is reconstructed using fixed-point division and accumulation circuits, maintaining visual fidelity. The ASIC-based design significantly reduces power consumption and chip area compared to general-purpose processors, making it ideal for embedded vision systems such as autonomous navigation, aerial surveillance, and low-power IoT devices where real-time, high-quality image enhancement is essential.

The field of dehazing, encompassing image and video processing, has significantly progressed through my research. This study introduces a unified model designed to eliminate diverse weather-induced degradation effects from visual data, enhancing clarity and reliability. These advanced dehazing techniques have practical applications in computer vision and surveillance, ensuring optimal performance even in adverse weather conditions.