

ENHANCING DIGITAL CAMERA IMAGE QUALITY AND THERMAL EFFICIENCY ANALYSIS

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Abstract

Digital camera technology has made significant advances in recent years, enabling the capture of high-resolution images. However, along with the pursuit of image quality, the thermal performance of digital cameras remains a critical consideration, especially in long-term use scenarios or adverse environmental conditions. This is essential in various fields like surveillance, smart cities, etc. This paper explores the application of image overlay algorithms, specifically high dynamic range (HDR) imaging techniques, and examines the impact of thermal efficiency on image quality in digital cameras. Through controlled experiments and analysis, this study aims to improve digital imaging capabilities.

Key words: image quality, HDR, thermal efficiency

Introduction. In today's urban landscape, the evolution of smart cities is intricately tied to the advancement of imaging technologies. Specifically, optimizing both digital camera image quality and thermal efficiency analysis emerges as a critical challenge in this trajectory [1]. As cities evolve into complex networks of connectivity and data exchange, the imperative to achieve exceptionally high-quality imagery becomes paramount. Digital cameras serve as the cornerstone of visual data acquisition in urban environments [2]. Their capability to capture high-fidelity images renders them indispensable tools for a myriad of urban stakeholders, including law enforcement agencies and environmental observers.

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However, the pursuit of enhanced image quality persists relentlessly, mirroring the multifaceted demands of modern urban landscapes [3].

As technology continues to progress, challenges arise, particularly concerning the miniaturization of imaging devices. Maintaining optimal image quality becomes increasingly challenging, prompting digital camera companies to explore innovative solutions [4]. One such method under scrutiny is image overlay, notably High Dynamic Range (HDR), aimed at improving the final output's quality [5]. Nonetheless, the implementation of such algorithms necessitates heightened processing power, thereby raising concerns about the thermal efficiency of device components.

Material and methods. The experimental setup is in controlled conditions with the aim of minimizing the influence of external factors such as temperature, non-uniform distribution of light as well as having full control over the intensity and colour temperature of the light using a Kino Flo lighting system. To capture the database, a device placed on a tripod is required to eliminate the effects of movement on the quality of captured frames, and the device must be placed at a distance consistent with the complete alignment of the chart (diagram) on the frame of the device. The light from the lamps should fall uniformly on the chart (diagram) at an angle of 45° .

Database creation. A Samsung Galaxy S23 Ultra device at initial conditions of 21°C was used to collect dataset 1. The footage is captured in two different conditions – real-world weather-influenced and controlled lab conditions with the Imatest 36-Patch dynamic range test chart, specially adapted for dynamic range testing and device evaluation range. For each condition, three frames are captured with different exposure -1EV , 0EV , $+1\text{EV}$ and with the image resolution of 4000×3000 pixels. A device is mounted on a tripod to prevent any form of movement when shooting.

Consecutive images will be captured over a period of 30 min under controlled conditions without changing the position of the device, the subject being photographed and the level of illumination of the scene. This process is automated and every 10 min a photo is downloaded along with the starting frame. Every 10 min, reports are taken directly from the processor of the device in use. Two types of scenes are captured to more clearly show the degradation of images over time.

We continued to collect images for the dataset 2, this time using a Samsung Galaxy S20 FE at initial conditions of 21°C . The process is again automated and images are captured under controlled laboratory conditions with an ISO 12233 Edge SFR (eSFR) Inkjet Chart and Imatest LED Light Source Scattered Coin Chart specifically tailored for noise testing and evaluation and the details of the devices. The frames are captured sequentially for 30 min, downloading respectively the first frame, the tenth minute frame of the capture (frame No. 36001), the twentieth minute frame of the capture (frame No. 72001), the thirtieth minute frame

of the capture (frame No. 98001) and the device CPU temperature reports corresponding to the same intervals. The resolution of the images is 4032×3024 pixels. A device is placed on a tripod to prevent any form of movement when shooting.

After capturing the images, it checks that all the images needed to run the rest of the algorithm are available. Images must have the same name and only differ in how they end – `name_-1EV`, `name_0EV`, `name_+1EV`. If the condition is not met, the program continues with the next images from the database. The program implementation of the algorithm is implemented in the Python programming language.

Proposed methodology. First, we proceed to the calculation of the pixel weights. It calculates the weight of each pixel in the image using the pixel's brightness. Pixels with brightness close to average values receive a higher weight, while very dark or light pixels receive a lower weight. It moves to the function that applies a simple tone mapping algorithm to the HDR image to enhance colour and contrast. The function compares the halftone values from the histogram of each image $[0, 255]$ and equalizes these values in order to suppress the overly bright or dark parts of the image. This helps create a more realistic and pleasing appearance of the final image.

After that, we performed image overlay. We use the three images with different exposure. Initially, each object is converted to an array. These arrays are used for easier mathematical processing of the images. Division by 255.0 converts the pixels from integers in the range $[0, 255]$ to real numbers in the range $[0.0, 1.0]$, which is more suitable for subsequent calculations.

$$(1) \quad \text{weights} = \exp \left[-\frac{1}{2} \left(\frac{\text{luminance} - 0.5}{\epsilon} \right)^2 \right].$$

We calculate the weights for each pixel based on its brightness (luminance). It uses the Gaussian function to assign higher weights to pixels with luminance values closer to the average (0.5) and lower weights to pixels with extreme luminance values. The parameter ϵ controls the spread of the weights and can be adjusted for different effects. These weights determine how much influence each pixel from each image will have on the final HDR result.

$$(2) \quad \text{total weight} = \text{weights_minus_ev} + \text{weights_zero_ev} + \text{weights_plus_ev} + 10^{-6}.$$

We merge three images with different exposures (minus, zero, and plus EV) to create a single HDR image. It calculates the weights for each pixel in each image. Then, we combine the images based on these weights to produce the HDR image. Additionally, a small constant (10^{-6}) is added to the total weight to avoid division by zero errors. Finally, tone mapping is applied to the HDR image to enhance its visual quality. The pixels from each image are multiplied by their respective weights and summed. The sum is then normalized by the total weight to ensure

that the final result is in the correct range. Once the HDR image is created, a tone-mapping is applied to help improve contrast and colour while maintaining the realistic appearance of the image.

We used a tone-mapping technique called the Reinhard tone mapping operator. This technique is commonly used to convert HDR images to low dynamic range (LDR) images. We also limit the values of the resulting tone-mapped image between 0 and 1. This is necessary because pixel values in images are typically in the range $[0, 1]$.

$$(3) \quad \text{tone mapping} = \frac{3 * \text{hdr_image}}{1 + \text{hdr_image}}.$$

This equation applies the Reinhard tone mapping operator to each pixel in the HDR image. The formula compresses the dynamic range of the HDR image to fit within the range $[0, 1]$. It does so by dividing each pixel's HDR value by the sum of that value and 1, and then multiplying the result by 3. Finally, the HDR image is converted back to an object by first scaling back to the full range of $[0, 255]$ and clipping values outside that range. The result of the image overlay is presented in Fig. 1.

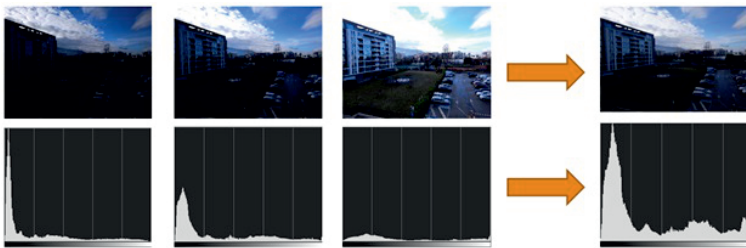


Fig. 1. Results for tone mapping

Results and discussion. We evaluated the digital camera image overlay and quality correction algorithm using Signal-to-Noise Ratio (SNR), dB:

$$(4) \quad \text{SNR}_{\text{dB}} = 20 \times \log_{10} \left(\frac{\text{max_signal_power}}{\text{variance}} \right).$$

It measures the ratio of the maximum signal power to the variance of the image. The max_signal_power is calculated as 255.255, representing the maximum possible pixel value for an 8-bit grayscale image. The variance is the variance of pixel values in the image.

The obtained results (Table 1) show a higher SNR for the HDR picture, compared to the base frame (0EV). The reason the -1EV shots have the highest SNR is because the photos are darker and accordingly the noise is suppressed and hidden and less gain (ISO) is applied. $+1\text{EV}$ shots have the lowest SNR, precisely because of the opposite reason, the use of high gain (ISO). Comparing the SNR

T a b l e 1

SNR calculation results for all images in our dataset 1

	SNR (dB)	
	Real conditions	Controlled conditions
−1 EV	24.08	21.71
0 EV	19.78	17.65
+1 EV	17.77	14.46
Our result	20.76	17.89
Samsung HDR	23.46	17.87

between the output image with the developed program and with Samsung’s official HDR algorithm under real conditions the official algorithm shows understandably better results, but under controlled conditions they are close. Looking at the pictures (Fig. 2), we see the clear combination between the three frames for the HDR picture in both scenes. HDR images have much more information in the light and dark parts of the photo, as well as better emphasized, realistic and natural colours. The so-called burnt pixels seen in the +1EV shots are almost eliminated.

Analysis of Fig. 2 clearly shows the simultaneous gradual appearance of noise over time, but also the overall blurring of the images in both scenes. This most likely comes from the device’s image noise reduction strategy, and since these are rather extreme conditions for it, it completely blurs the image in an attempt to reduce noise. The SNR metric shows just that, the blurrier a photo is, the more SNR it has.

We also perform a study of the influence of the processor temperature on the quality of the frames. The obtained results (Table 2) show several trends – the

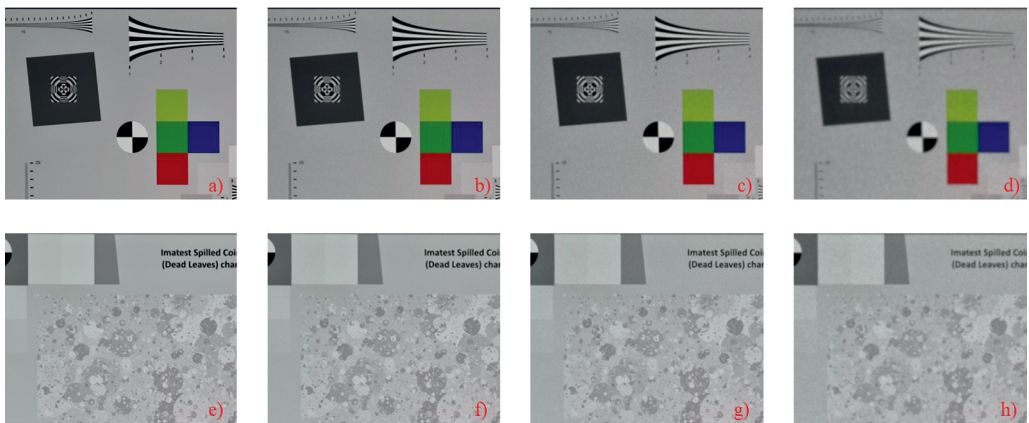


Fig. 2. Magnified comparison between: a) – d) captured eSFR map images and e) – h) the Spilled Coins chart, where a) and e) are captured at Frame No. 1, b) and f) at Frame No. 36001, c) and g) at Frame No. 72001, d) and h) at Frame No. 98001

T a b l e 2

SNR calculation results for all images in dataset 2

	eSFR		Spilled coins	
	SNR (dB)	Temperature (°C)	SNR (dB)	Temperature (°C)
Frame No. 1	27.12	38	32.03	38
Frame No. 36001	27.85	41	32.35	43
Frame No. 72001	28.43	46	32.72	47
Frame No. 98001	29.42	52	33.54	53

temperature of the processor rises exponentially with the increase of time, the SNR increases gradually with the increase of time.

The results shown in Table 2 present the Signal-to-Noise Ratio and corresponding temperatures recorded during the imaging process, specifically for the eSFR and Spilled Coins charts. SNR serves as a crucial metric for assessing image quality, with higher values indicating better signal strength relative to noise. In the case of the eSFR chart, we observe a gradual increase in SNR values over time, corresponding to an escalation in processor temperatures. From the initial frame (Frame No. 1) to the final frame (Frame No. 98001), SNR values consistently rise, indicating improved image quality as the temperature of the processor increases. This trend suggests that the image noise reduction strategy employed by the device becomes more effective with elevated temperatures, resulting in clearer and more detailed images.

Similarly, for the Spilled Coins chart, we observe a similar pattern of increasing SNR values with rising temperatures. As the experiment progresses from the first frame to the last, SNR values consistently climb, reflecting enhanced image quality under higher processor temperatures. This phenomenon aligns with the findings observed with the eSFR chart and underscores the positive impact of thermal management on image clarity and detail.

Overall, the results suggest a positive correlation between processor temperature and image quality, as indicated by the SNR values. However, it is essential to note that while higher temperatures may lead to improved SNR values, excessive heat can potentially pose long-term risks to the device's performance and reliability. Thus, maintaining optimal thermal management strategies is crucial for balancing image quality enhancements with device longevity and reliability in smart city imaging applications.

Conclusion. The focus of the article is the development of an algorithm for digital camera image overlay and quality correction and the study of the influence of the processor temperature on the quality of the frames. Using the HDR High Dynamic Range algorithm, most of the problems of recording an image with only one frame are solved. The dynamic range is increased dramatically and the amount of information in the light and dark parts of a photo is noticeably more.

Burned-out pixels in an image are reduced, and more pronounced, realistic and natural colours are observed. The thermal efficiency of the processors is of great importance and as the temperature increases too much, a visible degradation in image quality is observed. Technologies must continue to develop in this area, as devices on the market become more compact in terms of internal components, and it is important to control the problem of overheating processors.

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