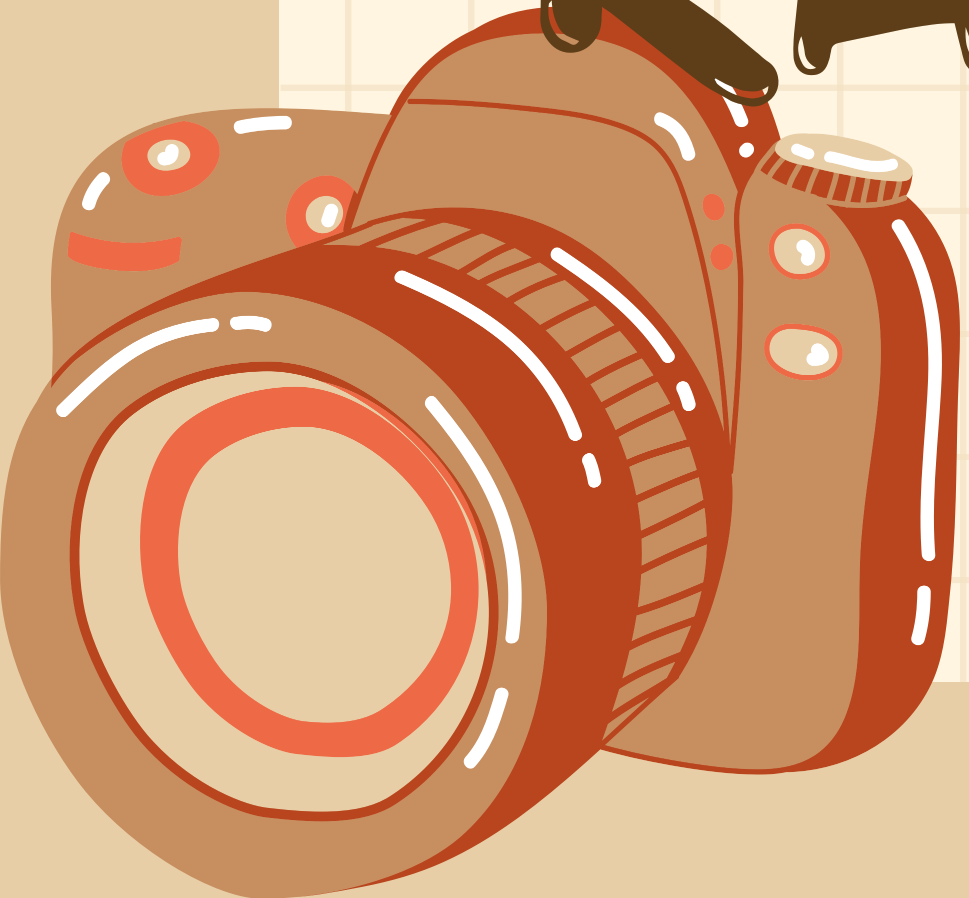
ACTIVITY 3

HIGH DYNAMIC RANGE IMAGING



Baldres, Jonabel Eleanor B.
Chai, Nicholas William L.
Manalang, Johnenn R.
Maypa, Julian Christopher L.

CONTENTS

OBJECTIVES

1. Capture a series of photographs with different exposure times.
2. Utilize the Debevec-Malik algorithm to recover the film response function and construct a high dynamic range (HDR) radiance map from the acquired images.

METHODOLOGY

Multiple images of a scene characterized by significant variations in both high brightness and deep shadows were captured. These images used varying exposure times, while maintaining a consistent f-number. This process involved ensuring the camera's stability and deactivating automatic settings such as gain, white balance, and exposure compensation.

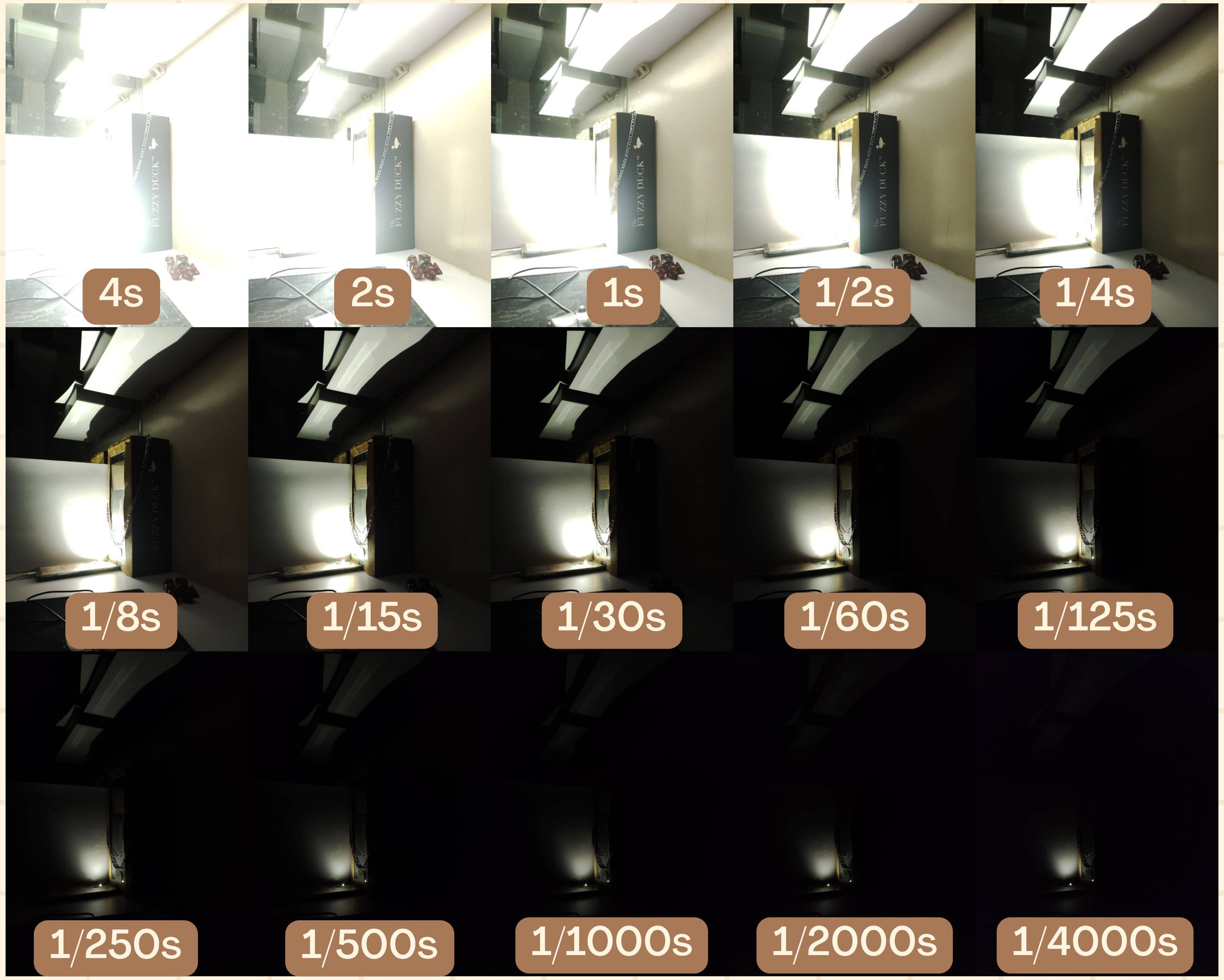


Figure 1. Series of images with constant focus and different exposure times.

1

METHODOLOGY

As instructed, we selected 5 random points, maintaining consistency across all the images. These points were subsequently employed to construct a plot depicting the logarithm of the shutter speed against the corresponding gray level values of these points [1]. Shown in Figure 2 are the 5 randomly selected points.

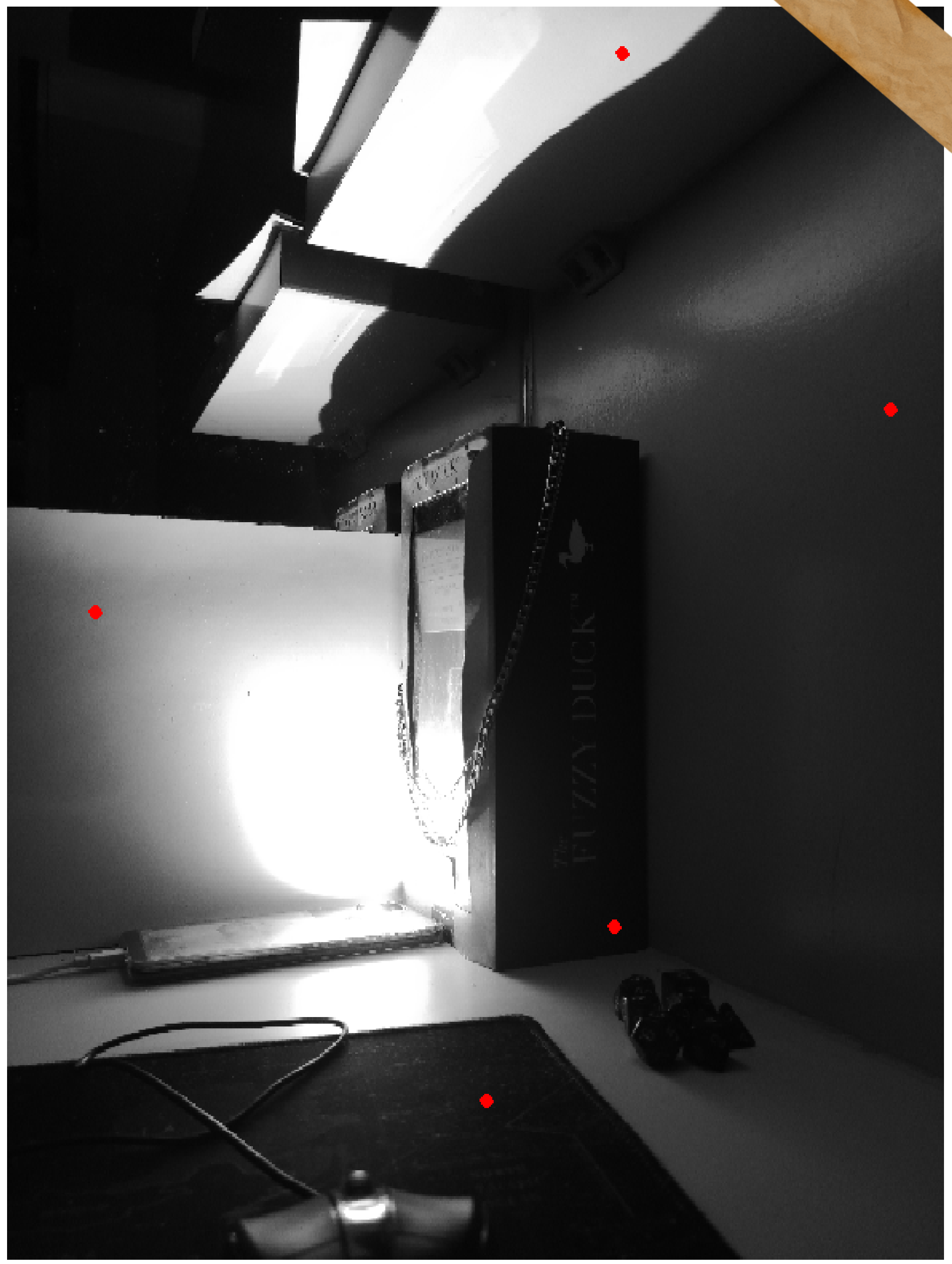


Figure 2. Five randomly selected points to be used for all the images.

2

METHODOLOGY

2.1

However, it is noteworthy that in the work of Debevec and Malik [2], a crucial emphasis is placed on ensuring the robustness of the algorithm. To achieve this, a sufficient overdetermination of the system is required. Specifically, for N points distributed across P photographs, the condition $N(P-1) > 255$ must be satisfied, with 255 representing the difference between the maximum and minimum gray level values. Consequently, in our case, we opted to employ 19 points for the analysis of our 15 images to adhere to this criterion.

Figure 3. Nineteen randomly selected for a sufficient overdetermination of the Debevec-Malik algorithm.

METHODOLOGY

After obtaining the gray values Zij of the points, we employed the methodologies outlined in the paper of Debevec and Malik to solve for the response function g [2]. Within our MATLAB code, this function has been designated as gMinimize. This function assumes that the minimum and maximum gray level values are 0 and 255, respectively. The smoothness constant that we used is $\lambda = 50$.

Inputs

- *pixel values of pixel location number i in image j Z(i,j)*
- *log shutter speed B(j)*
- *smoothness constant λ*
- *weighting function w(z)*

→ gMinimize →

Outputs

- *log exposure g(z)*
- *log film irradiance lE(i)*

3

METHODOLOGY

Once the response function g has been successfully recovered, the next step in our process is the recovery of high dynamic range radiance values. To achieve this, we utilize all available exposures for a given pixel to compute its radiance. For this purpose, we have implemented Equation 6, as described in Debevec and Malik's paper. This equation effectively combines the information from multiple exposures, thereby resulting in reduced noise levels in the recovered radiance values. Furthermore, it serves to mitigate the adverse effects of imaging and 'blooming' artifacts, contributing to the enhanced quality of the reconstructed image [2].

$$\ln E_i = \frac{\sum_{j=1}^{P} w(Z_{ij})(g(Z_{ij}) - \ln \Delta t_j)}{\sum_{j=1}^{P} w(Z_{ij})} \qquad (6)$$

Figure 4. A screen shot of Equation 6 from Debevec and Malik's paper.

4

RESULTS & ANALYSIS

As per the provided instructions, we initiated our process by randomly selecting five points. Additionally, in adherance to the Debevec-Malik algorithm, we further opted to choose an additional set of 19 random points for comparison. Figure 5 illustrates the graph of ln shutter speed vs the corresponding gray values of these selected points.

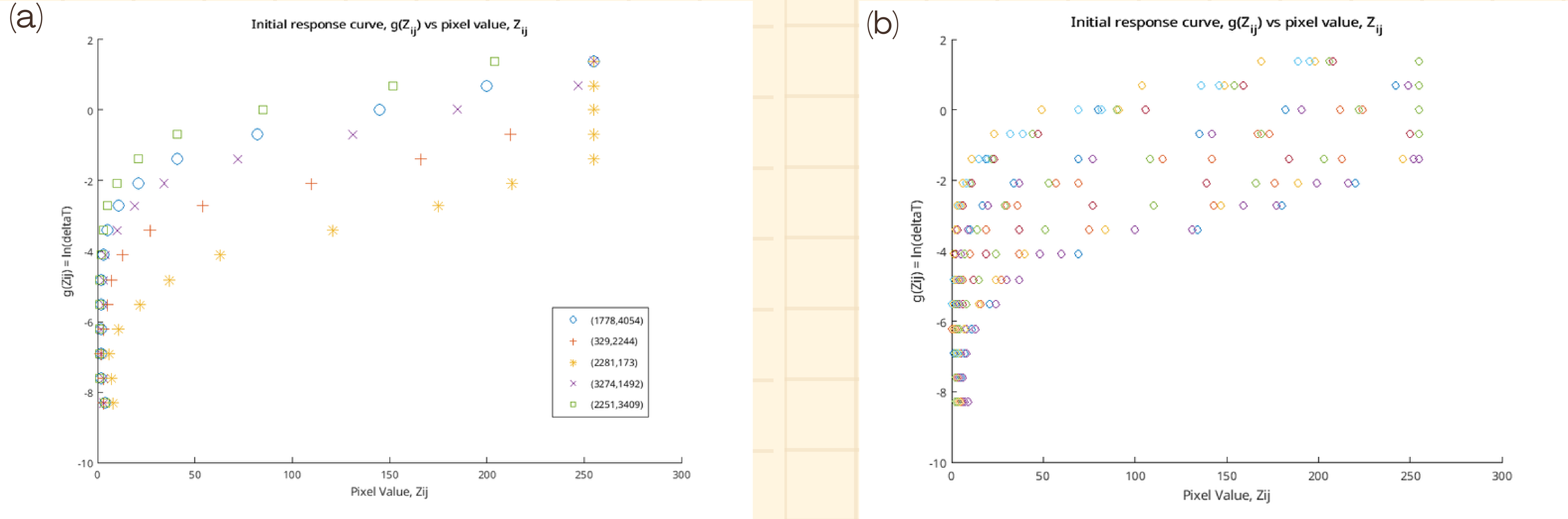


Figure 5. The graph for ln of shutter speed vs. gray level values of randomly selected (a) five points and (b) nineteen points.

RESULTS & ANALYSIS

Utilizing the gMinimize function, we successfully obtained the response function g. As shown in Figure 6, this response curve serves as a fundamental representation of the relationship between the incident light reaching the camera's sensor, and the resulting pixel values in the image. It is important to observe the non-linear nature of this curve, which directly influences the dynamic range of the camera system. This dynamic range determines the system's capacity to capture intricate details in scenes encompassing both shadowed and well-illuminated areas [2].

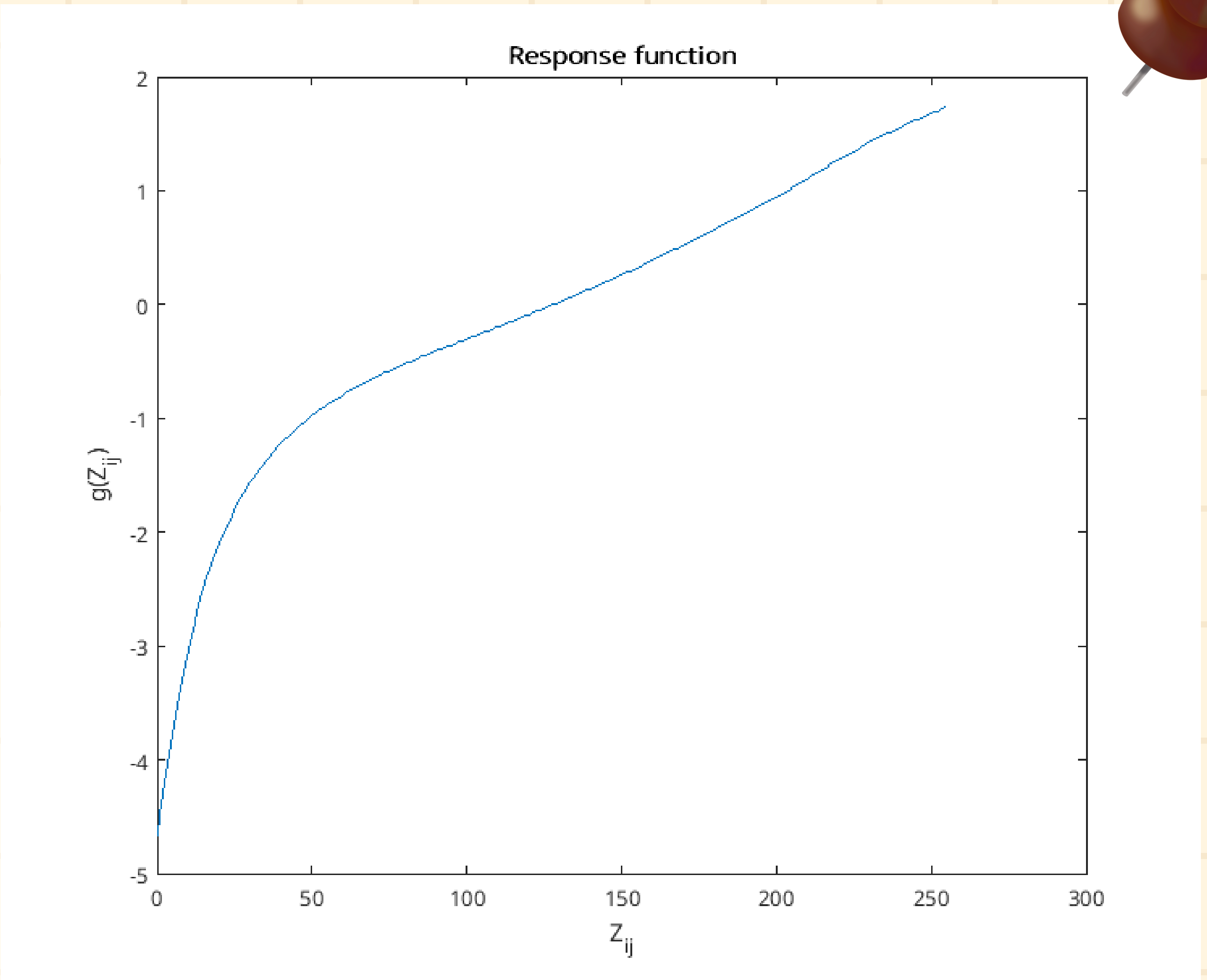
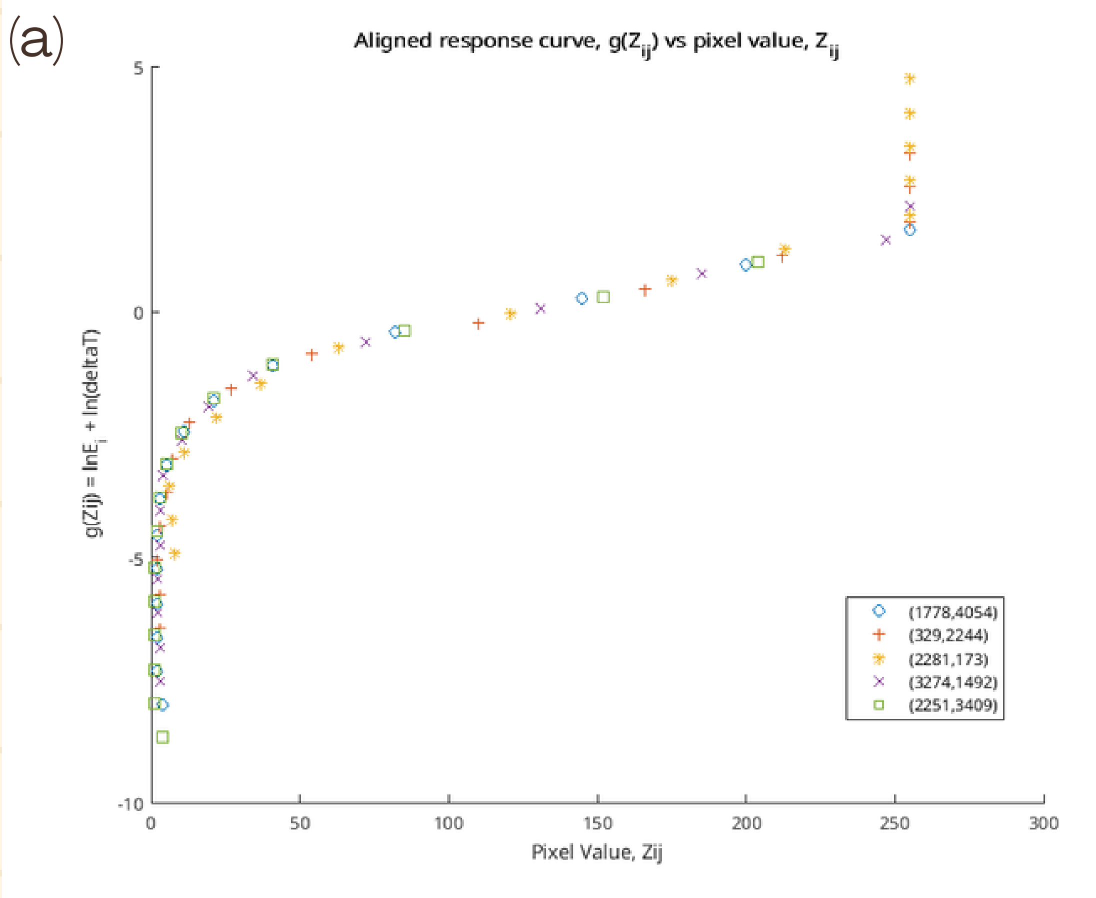


Figure 6. Response curve g obtained using the gMinimize function following the Debevec-Malik algorithm.

This curve can be effectively employed to ascertain radiance values within any image acquired through the imaging process associated with 'g'. Consequently, we have adopted this specific response curve for the analysis of both the 5 points and subsequent set of 19 points we selected for this activity.

RESULTS & ANALYSIS

Figure 7 illustrates the aligned pixel values achieved subsequent to the recovery of the response function g in the preceding step. Comparing this to Figure 5, it is noticeable that the pixel values aligned with the obtained response curve of the system. This alignment signifies that the pixel values now faithfully mirror the camera's response to light, regardless of the variations in exposure levels.



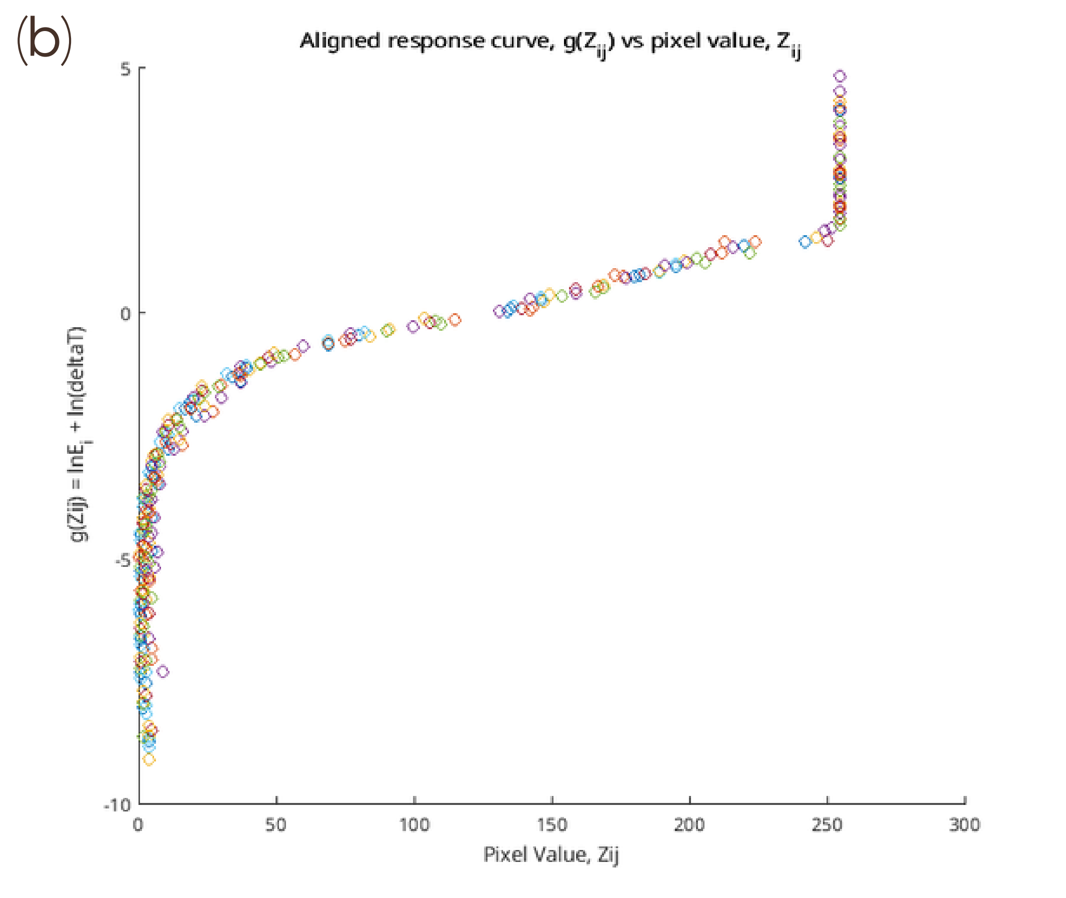
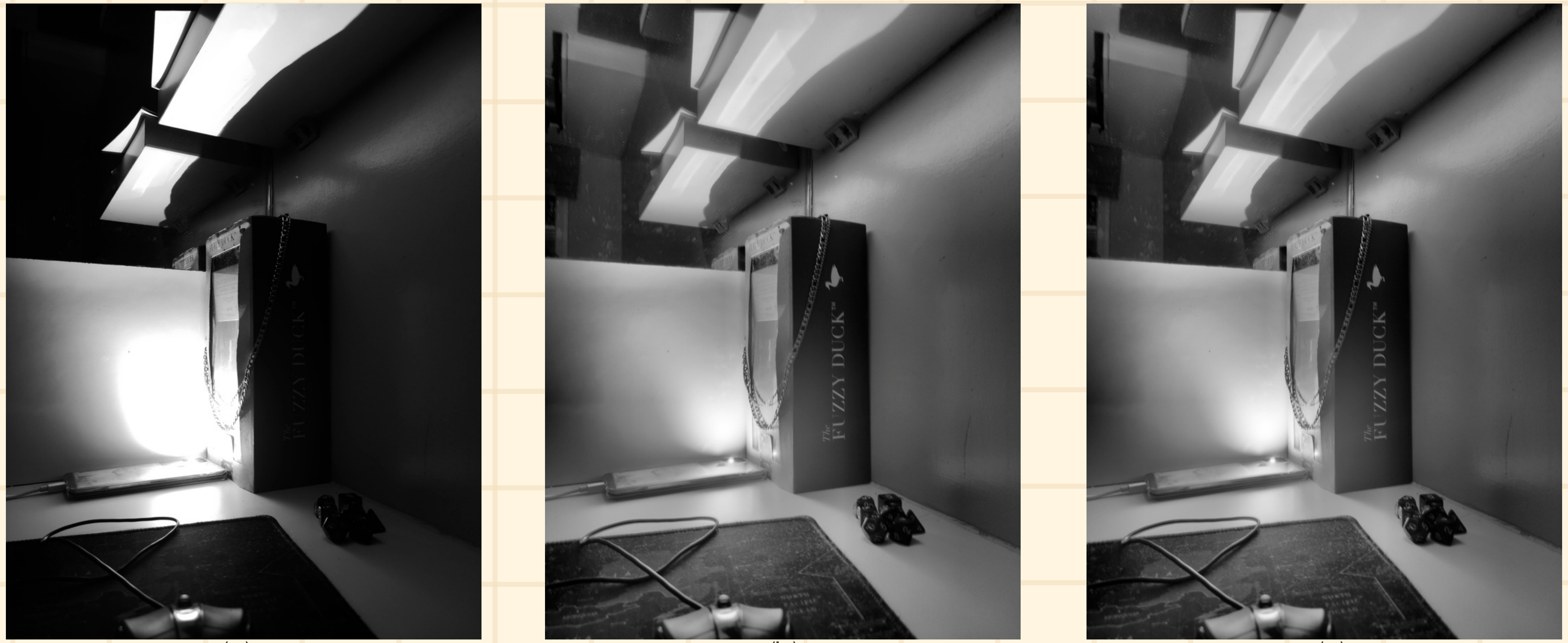


Figure 7. Aligned response curve for (a) 5 points and (b) 19 points randomly selected following the response curve recovered using Debevec-Malik's algorithm

RESULTS & ANALYSIS

QUALITATIVE

Figure 8 shows the HDR images recovered through the application of the Debevec-Malik algorithm. The tonemap( ) function in MATLAB was used to show In comparison to display the images. Figure 8a, both Figure 8b and 8c exhibit a greater level of detail in both shadowed and well-lit areas. For instance, in Figure 8a, the label on the box, the numbers on the dice, and the text on the mousepad are not distinctly discernible. Conversely, in Figures 8b and 8c, these elements as clearly visible. Upon qualitative examination of Figure 8b and 8c, it becomes evident that no discernable differences exist between the two images.



(a) (b) (c)

Figure 8. The (a) grayscale raw image and the recovered HDR images utilizing Debevec-Malik algorithm using (b) 5 points and (c) 19 points selected randomly.

RESULTS & ANALYSIS

QUANTITATIVE

To conduct a more rigorous comparison between these images, we proceed to employ a quantitative analysis methodology, incorporating **SSIM** (Structural Similarity Index).

For SSIM, we used the `ssim()` function in MATLAB for the two images. The result is 1.00 as shown in Figure 9. A SSIM index of 1.00 means that the images are identical in terms of structural information, luminance, contrast, and texture. Hence, there is no perceptible difference between the two images when it comes to human visual perception. To further compare the two images, we also employed **histogram comparison.**

```
The SSIM index between image1 and image2 is: 1.00
```

Figure 9. The SSIM index of the two HDR images recovered using 5 and 19 points.

RESULTS & ANALYSIS

QUALITATIVE

For the histogram comparison, the histograms of the three images featured in Figure 8 were generated utilizing the imhist( ) function within MATLAB. As illustrated in Figure 10, the histogram of the grayscale image denoted by the black line, exhibits prominent peaks in proximity to values close to 0 and 255. This characteristic signifies that the image possesses high contrast, primarily comprising dark and bright regions, with a limited presence of midtone values.

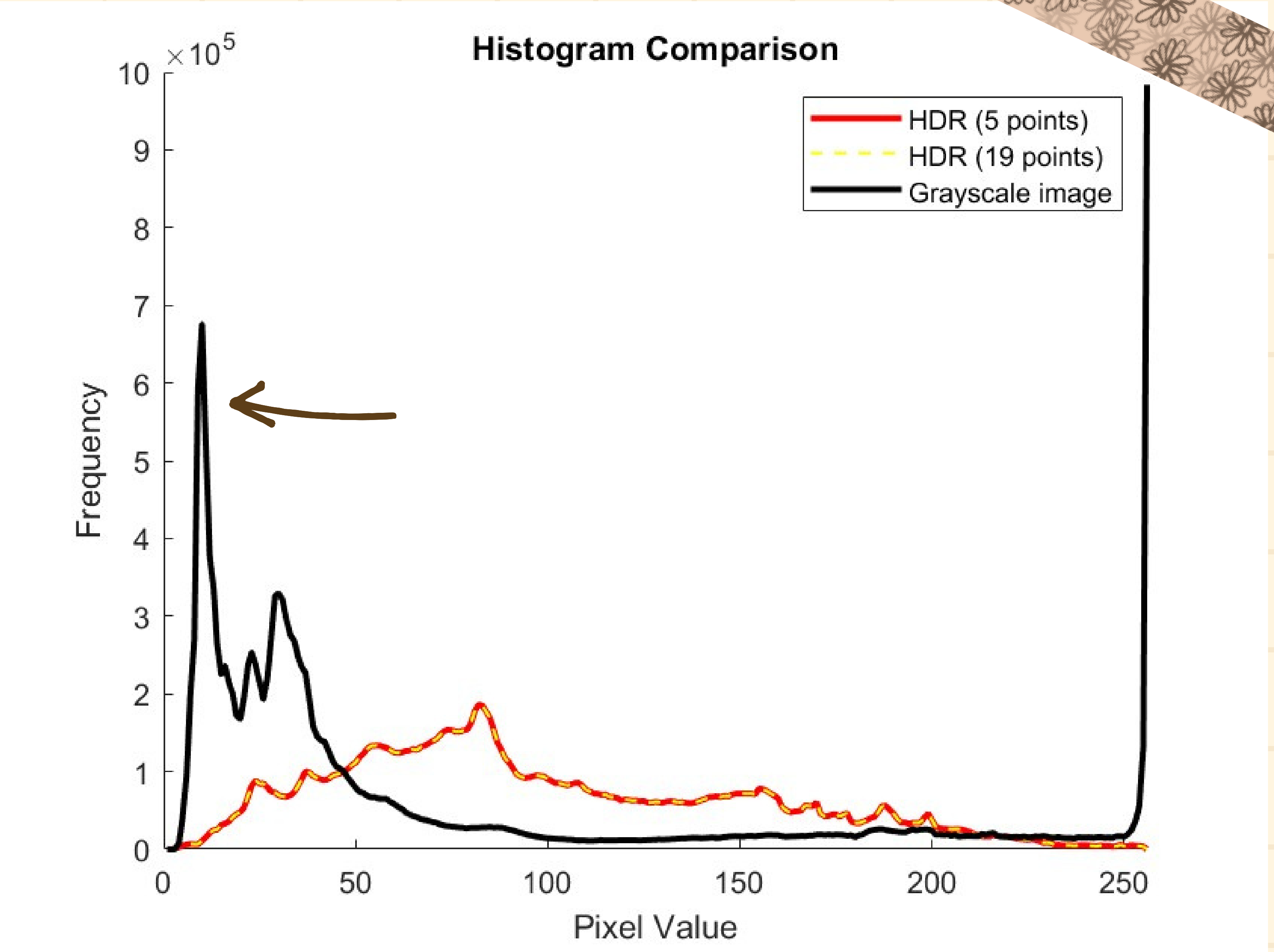


Figure 10. The Histogram comparison of the grayscale image of the scene and the recovered HDR images using 5 and 19 points.

RESULTS & ANALYSIS

QUALITATIVE

The histograms of the recovered HDR images, irrespective of the number of points employed in the process, demonstrate uniformity. This uniform distribution indicates that the images are well-exposed, encompassing both shadowed and bright areas with discernible details. Furthermore, this balanced contrast contributes to a natural and pleasing visual presentation. It's noteworthy that they have the same histogram which means that the images share the same distribution of pixel values. Consequently, this suggests a high degree of similarity between the images, underscoring their resemblance to one another.

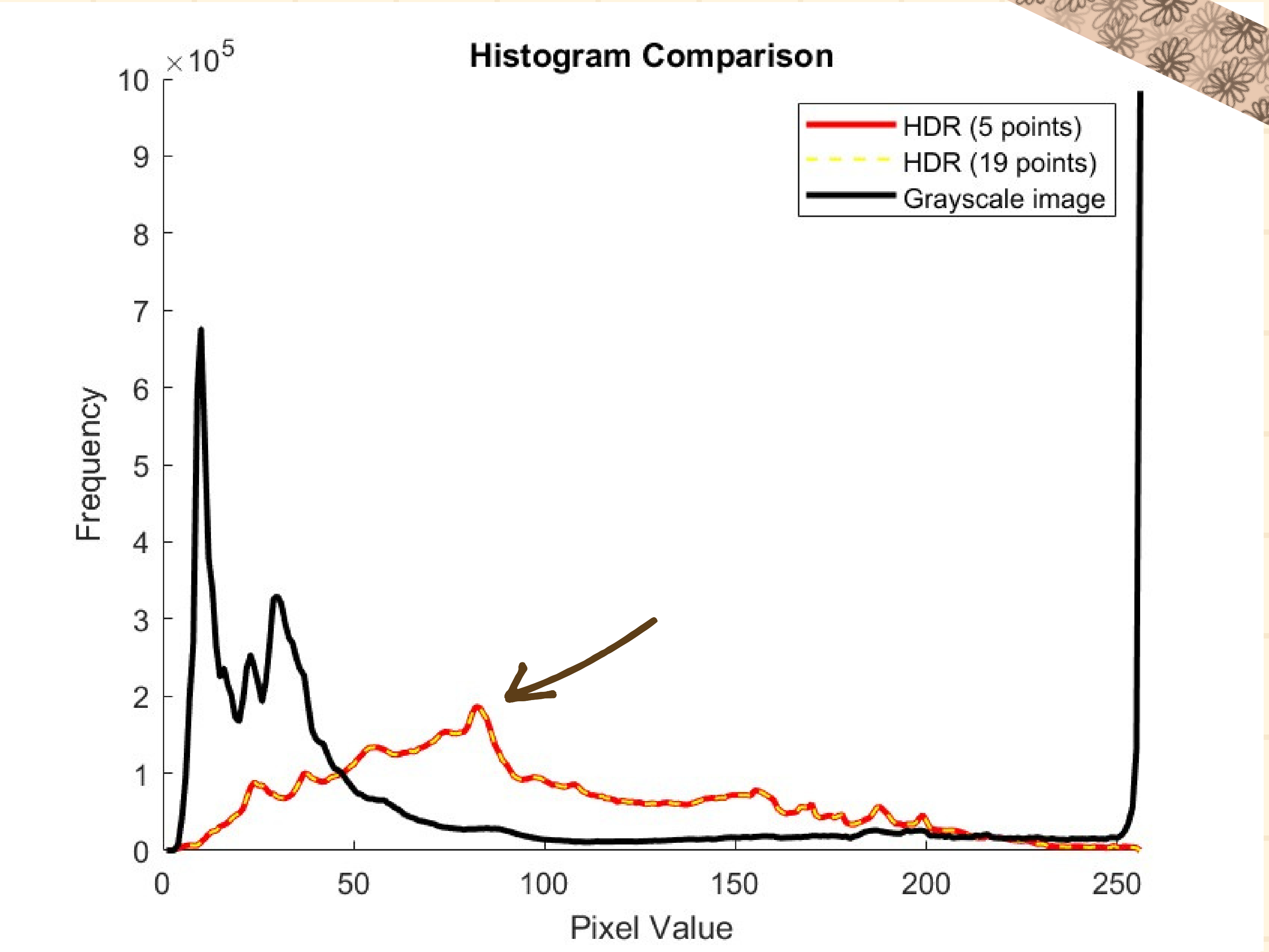


Figure 10. The Histogram comparison of the grayscale image of the scene and the recovered HDR images using 5 and 19 points.

ADDITIONAL

As we were looking for online references about HDR implementations, we found that OpenCV has functions dedicated for this. The OpenCV implementations served as a convenient way to produce HDR images using Debevec-Malik and Robertson algorithms. Comparing the Debevec-Malik and Robertson algorithm, their main difference is that the Robertson algorithm uses gaussian weighted functions instead of a triangular one [3].

By applying both algorithms with a Reinhard tonemap, we get the HDR images shown in Figure 11. Comparing the two images, it can be seen that both algorithms were able to show the details in both very bright and very dark regions of the image. But the Debevec-Malik algorithim produced a higher quality image as the Robertson algorithm's output appears to have a very low contrast.

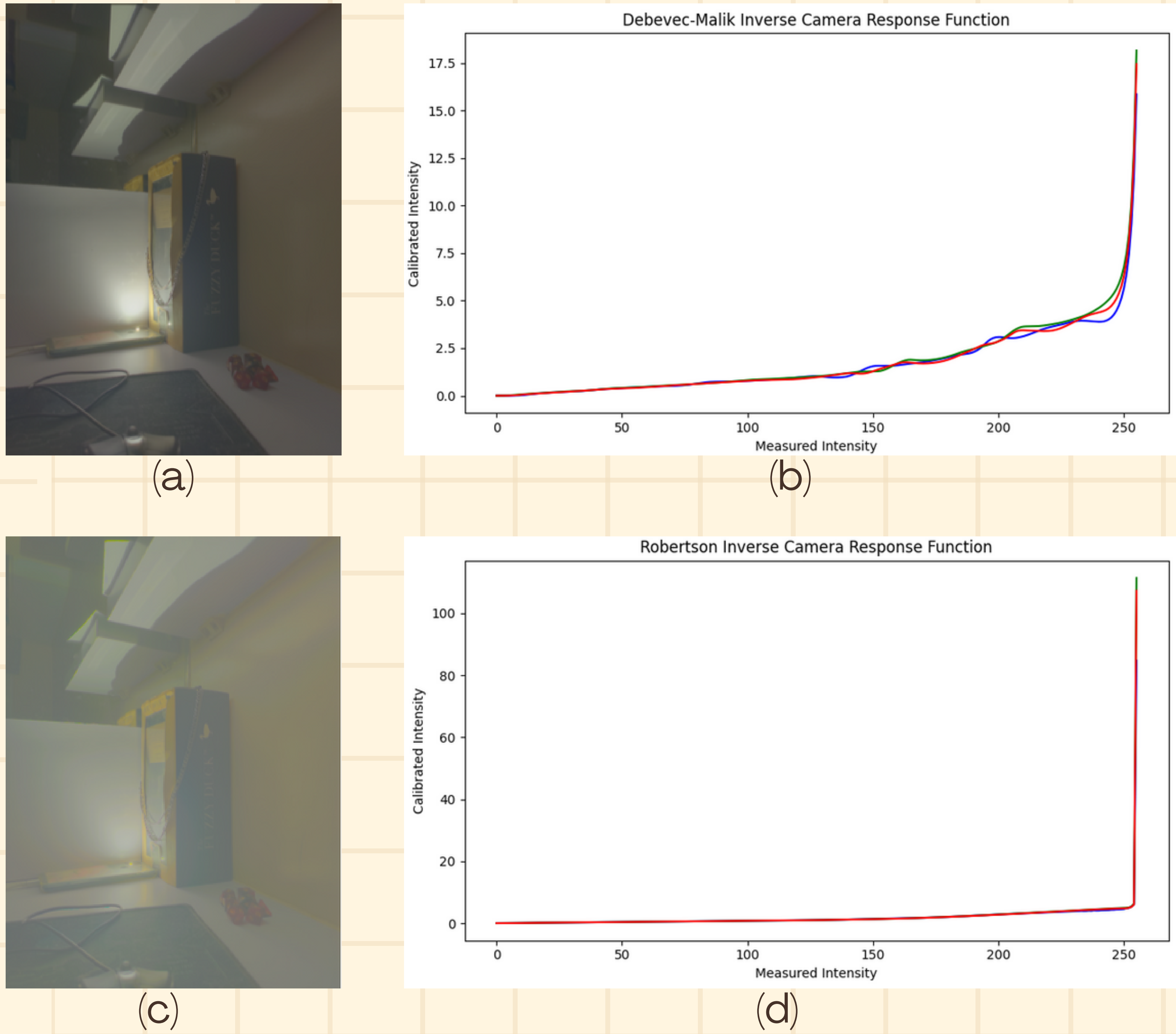


Figure 11. Recovered HDR image using (a) Debevec-Malik and (c) Robertson algorithm with Reinhard tonemapping and the corresponding inverse camera response function for (b) Debevec-Malik and (d) Robertson algorithm.

ADDITIONAL

We also tried using a different tonemap. In Figure 12, we used the Drago tonemap for both the Debevec-Malik and Robertson algorithms. Visually, the Drago tonemap yielded darker images. The Debevec-Malik HDR image with Drago tonemap in Figure 12a produced the best quality image among the different combinations of HDR and tonemap algorithms.

Also, Robertson algorithm with Drago tonemapping showed the worst HDR image as shown in Figure 12c. This is because a lot of detail was omitted such as the dice and the markings on the mousepad.

Lastly, we also obtained the Inverse Camera Response function of each HDR algorithm. The function takes in the intensity of a pixel, and then outputs its corresponding calibrated intensity.

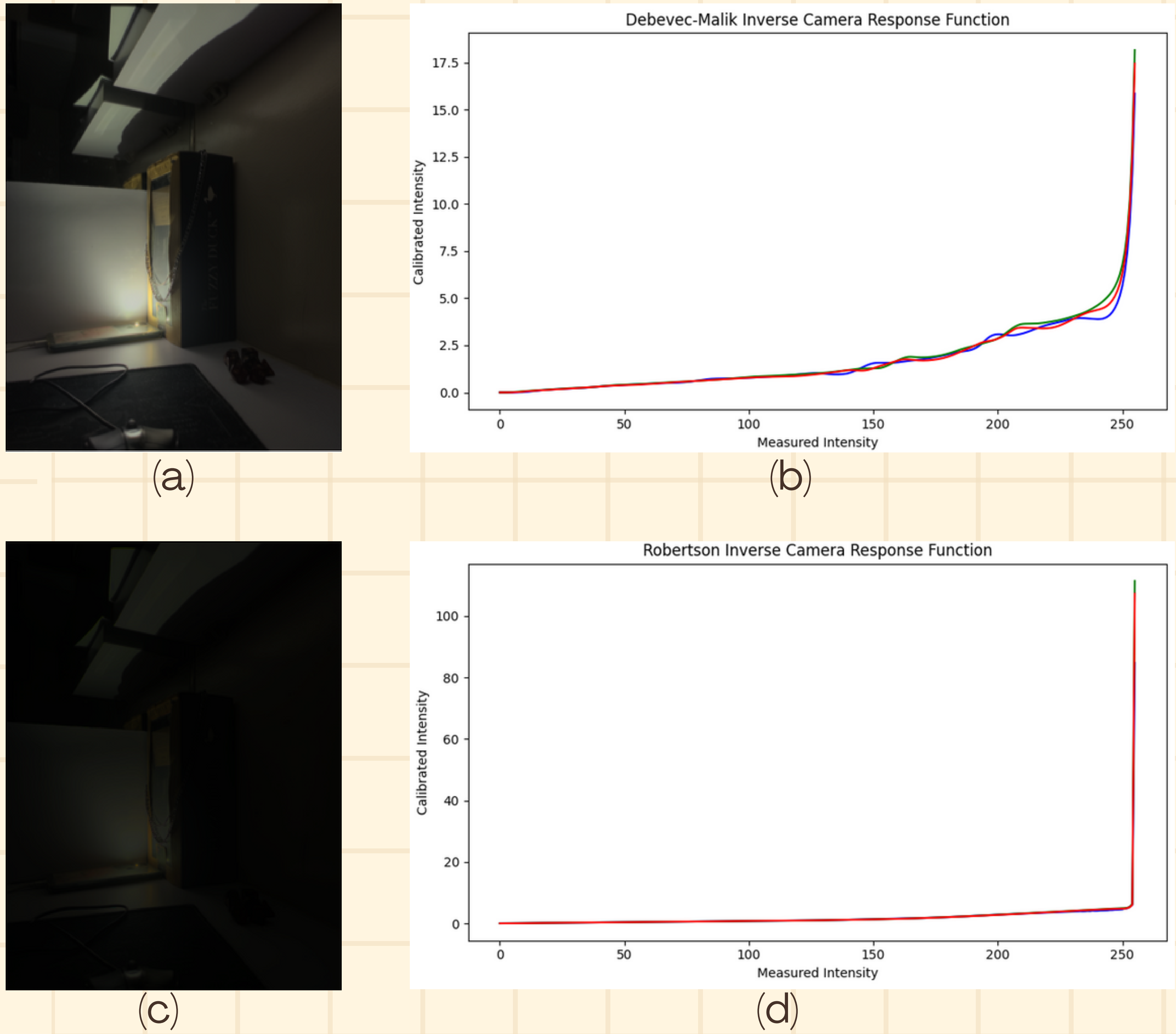


Figure 12. Recovered HDR image using (a) Debevec-Malik and (c) Robertson algorithm with Drago tonemapping and the corresponding inverse camera response function for (b) Debevec-Malik and (d) Robertson algorithm.

ADDITIONAL

We also found another implementation of fusing images with varying saturations, and it is called Mertenes Fusion. It is more computationally efficient than the other two HDR algorithms in this activity because it skips the camera response curve calibration. The Fusion algorithm utilizes the Laplacian decomposition of the images and it uses Gaussian pyramid of the weight maps [3].

Visually inspecting the images, the Mertenes fusion algorithm yielded a very high quality output as shown in Figure 13. Details such as the numbers on the dice, the text of the mousepad (it says 'North Pacific Ocean'), and the dust on the mirror can be clearly seen.

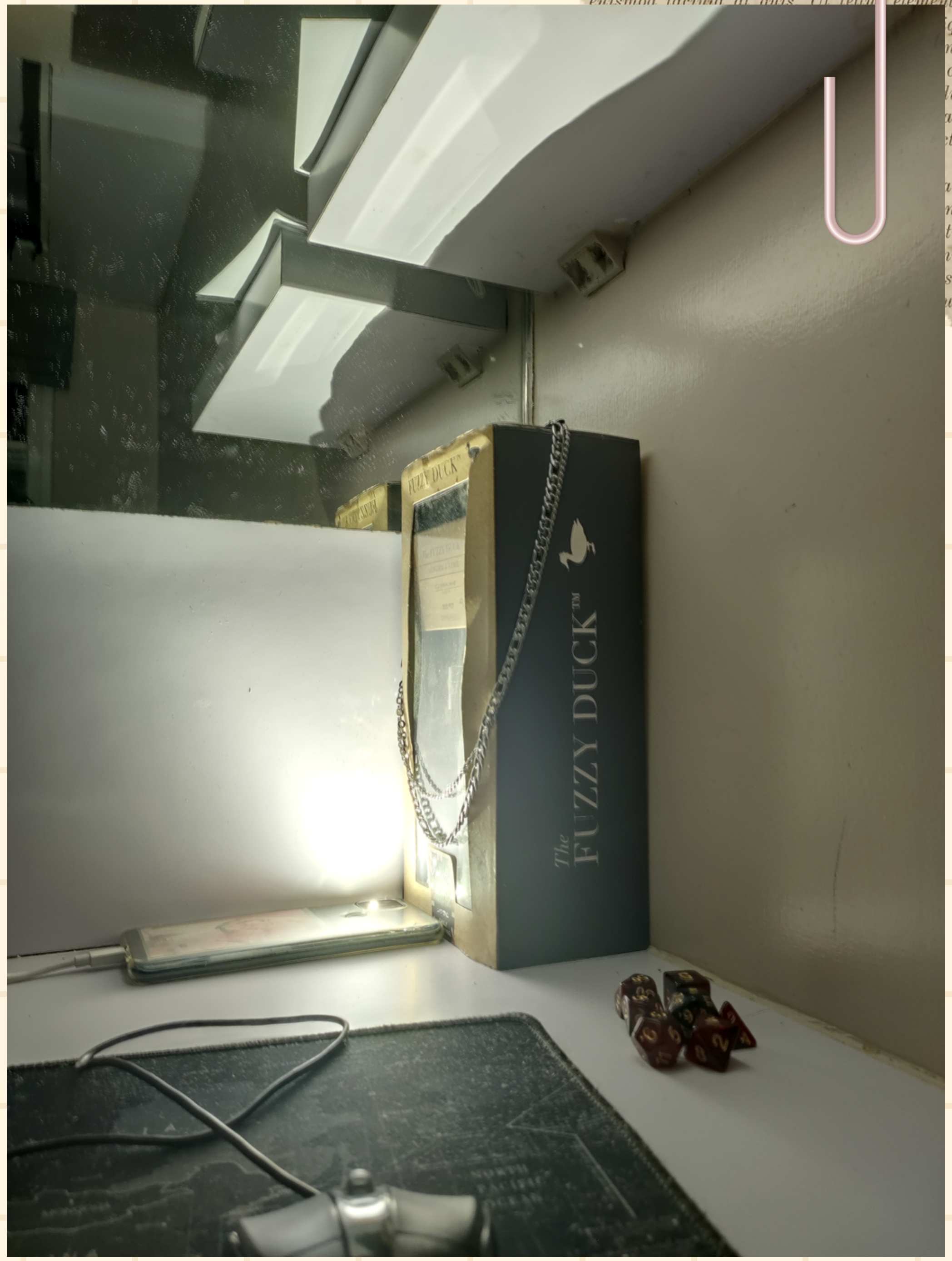


Figure 13. Recovered HDR image using the Mertenes Fusion algorithm.

CONCLUSIONS

The activity highlights the remarkable capacity of High Dynamic Range (HDR) imaging to faithfully capture and depict intricate details in both the brighest and darkest parts of a scene, akin to human visual perception. A widely-used method for creating HDR images is Debevec-Malik algorithm. Utilizing this algorithm, we've successfully produced HDR images that exhibit enhanced detail in both shadowed and well-lit areas.

It's important to note the significance of choosing an appropriate number of N points for recovering the film response function. The optimal quantity of points depends on factors such as dynamic range of the scene and the number of exposure times utilized during the process. Additionally, the choice of tonemapping methods can impact the visual representation of the resulting HDR images.

REFLECTION

We successfully achieved the objectives of this activity through effective teamwork. We distributed tasks evenly, ensuring that each member had a significant role to play. Specifically, one team member was responsible for capturing the images, while two others were assigned the task of developing the MATLAB code. Additionally, one team member was in charge of creating the slide report. Throughout the process, we actively collaborated and encouraged the exchange of opinions and ideas, making this activity a true collective effort.

One challenge we encountered revolved around the generation of the code. To fully grasp the algorithm, we had to meticulously study Debevec and Malik’s paper, requiring us to read it multiple times. Subsequently, we worked diligently to implement the algorithm on our own images. Despite the initial hurdles, our team persevered through consultations and group meetings, ultimately accomplishing the task. Overall, this activity proved to be an enjoyable and rewarding experience.

REFERENCES

1. High Dynamic Range Imaging| Applied Physics Lecture. UVLê. (n.d.). https://uvle.upd.edu.ph/pluginfile.php/1020539/mod_resource/content/1/HDR%20Lecture.pdf

2. Debevec, P. E., & Malik, J. (1997). Recovering high dynamic range radiance maps from photographs. Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '97. doi:10.1145/258734.258884

3. Robertson, Mark & Borman, Sean & Stevenson, Robert. (2000). Estimation-Theoretic Approach to Dynamic Range Enhancement Using Multiple Exposures. Journal of Electronic Imaging. 12.

4. T. Mertens, J. Kautz and F. Van Reeth, "Exposure Fusion," 15th Pacific Conference on Computer Graphics and Applications (PG'07), Maui, HI, USA, 2007, pp. 382-390, doi: 10.1109/PG.2007.17.

GROUP GRADE

CRITERIA	perfect score	our score
Technical correctness	30	30
Quality of presentation	30	30
Reflection	30	30
Ownership	10	10
TOTAL	100	100

WHY???

We were able to achieve all the objectives of this activity. We also made additional results by utilizing other HDR algorithms and tonemappings. Each of the members had a role to play in accomplishing the task. Overall, we give credit to ourselves for obtaining good results and being able to finish the activity on time.

CLICK TO SEE MATLAB CODE