Activity 4

MODULATION TRANSFER FUNCTION

Applied Physics 167

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Objectives

1. Capture images of the resolution test chart using the burst feature of a phone camera.

2. Obtain the modulation transfer function of the phone camera.

Methodology

Multiple images of the I3A/ISO 12233 Resolution Test Chart (#56-074) were acquired by utilizing the burst feature of my mobile phone's camera, with careful attention to maintaining parallel alignment between the camera sensor and the test chart. Figure 1 shows one of the images that I captured.

1

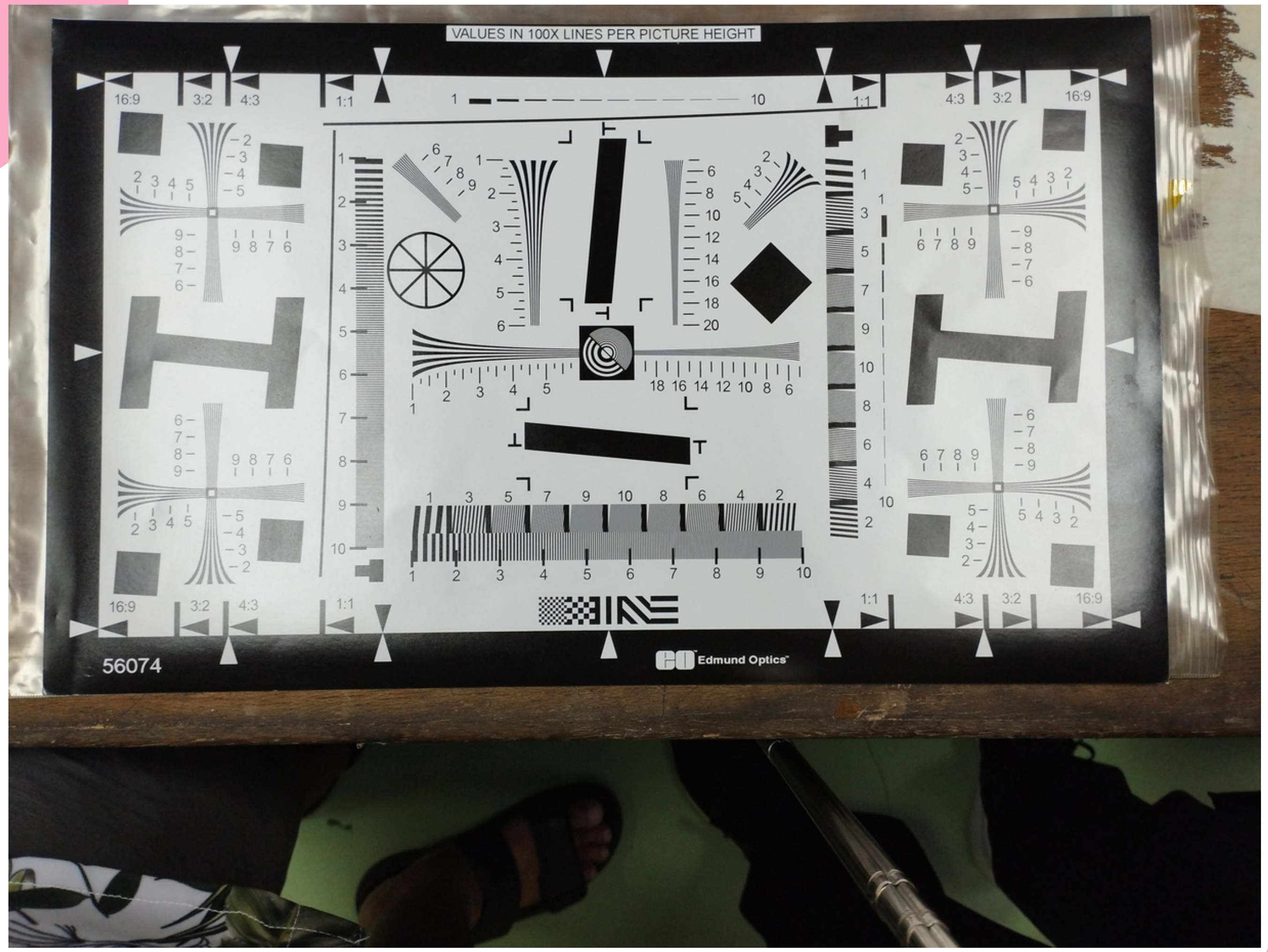


Figure 1. Sample image of the resolution test chart captured using the burst feature.

Methodology

To ensure precise alignment of twenty images that I captured, I employed an automated image stacking algorithm sourced from Github, and implemented it using OpenCV. This algorithm leverages two perspective transformation techniques, namely, ORB keypoint matching and ECC maximization [1]. I used both the images obtained.

2

(a) (b)

Figure 2. Stacked images using (a) ORB keypoint matching and (b) ECC maximization.

CLICK FOR THE GITHUB LINK

Methodology

Figure 3 shows the chosen region of interest (ROI) for this activity, which is a segment of the slanted edge situated at the center of the chart. To compute the Modulation Transfer Function (MTF) of the camera, I developed a MATLAB code. The ensuing steps for accomplishing this will be elaborated upon in the subsequent slide.

3

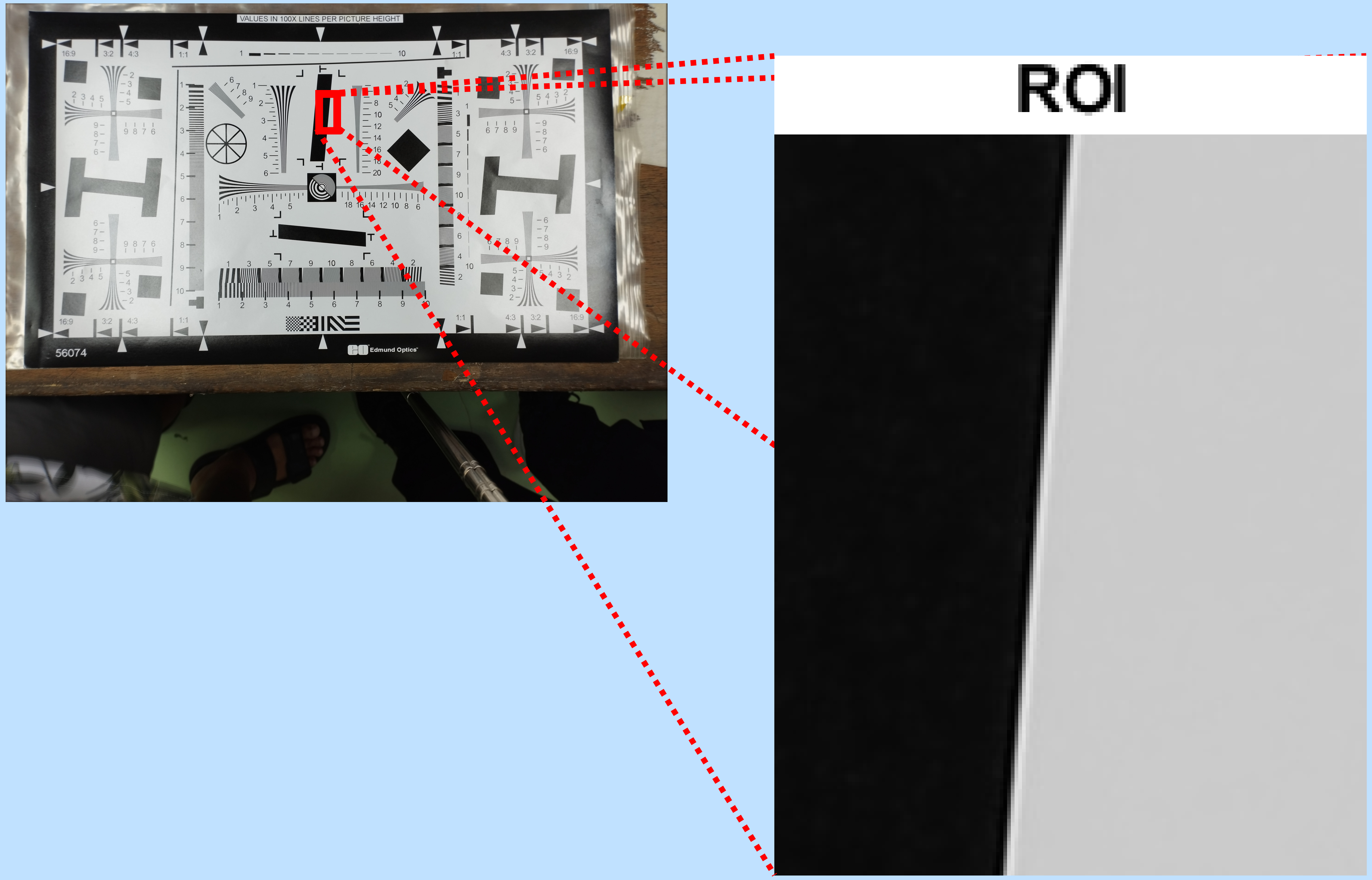


Figure 3. The region of interest taken from the slanted edge at the center of the chart.

Methodology

MATLAB CODE WENT LIKE THIS...

4. Get the intensity profiles of several lines crossing the edge using improfile( ) function.

5. Get the derivative of the intensity profiles using the gradient( ) function.

6. Get the Fourier Transform (FT) of the derivative using the fft( ) function.

7. Get the modulus of the FT by obtaining its absolute value using the abs( ) function.

CLICK FOR THE FULL CODE

Methodology

Calibration was performed to ensure that the FT plot would display frequency units in line pairs per millimeter. This was achieved by measuring the pixel values corresponding various line pairs on the chart, as exemplified in the sample image presented in Figure 3. Subsequently, I calculated the average of these measurements and determined that the conversion ratio equates to 1mm:36 pixels. Following this, I computed the average of the absolute FT values for all the lines and normalized the average MTF to a value of 1.0.

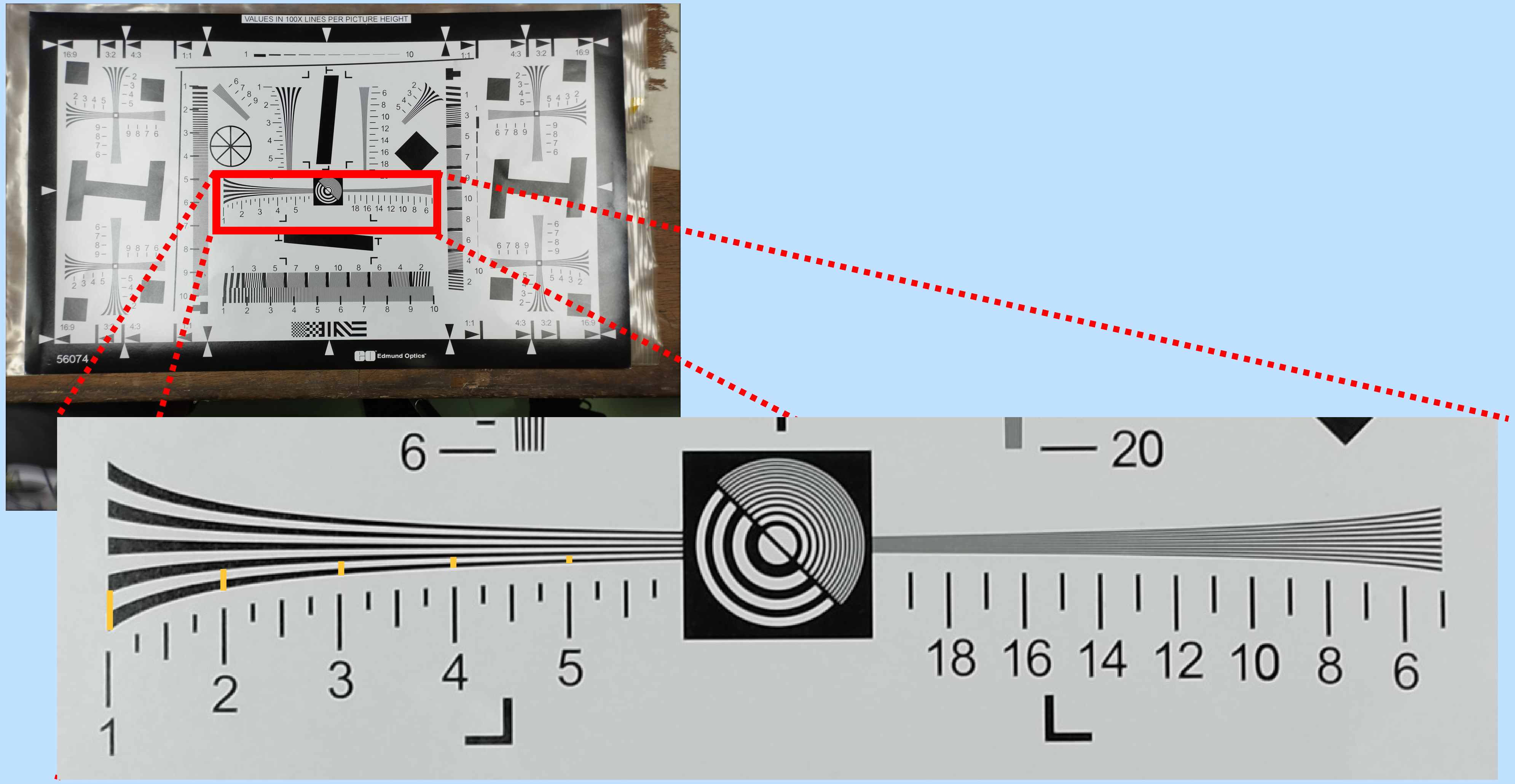


Figure 3. The region of interest taken from the slanted edge at the center of the chart.

Results & Analysis

Figure 4 shows the intensity profile and the line spread function (LSF) of line 70 within the ROI for both images. As the ROI consists of a slanted edge, the resulting intensity profile exhibits a sharp, linear transition between the black and white regions. However, it is worth noting that this transition is not perfect, which could be attributed to potential noise or the manner in which the image was captured.

The application of a derivative to the intensity profile yields a triangular-shaped LSF, where the peak of the LSF is centered at the point where the intensity shifts from the black to the white region. Upon comparing the intensity profile and LSF from both the images, no discernible differences are apparent.

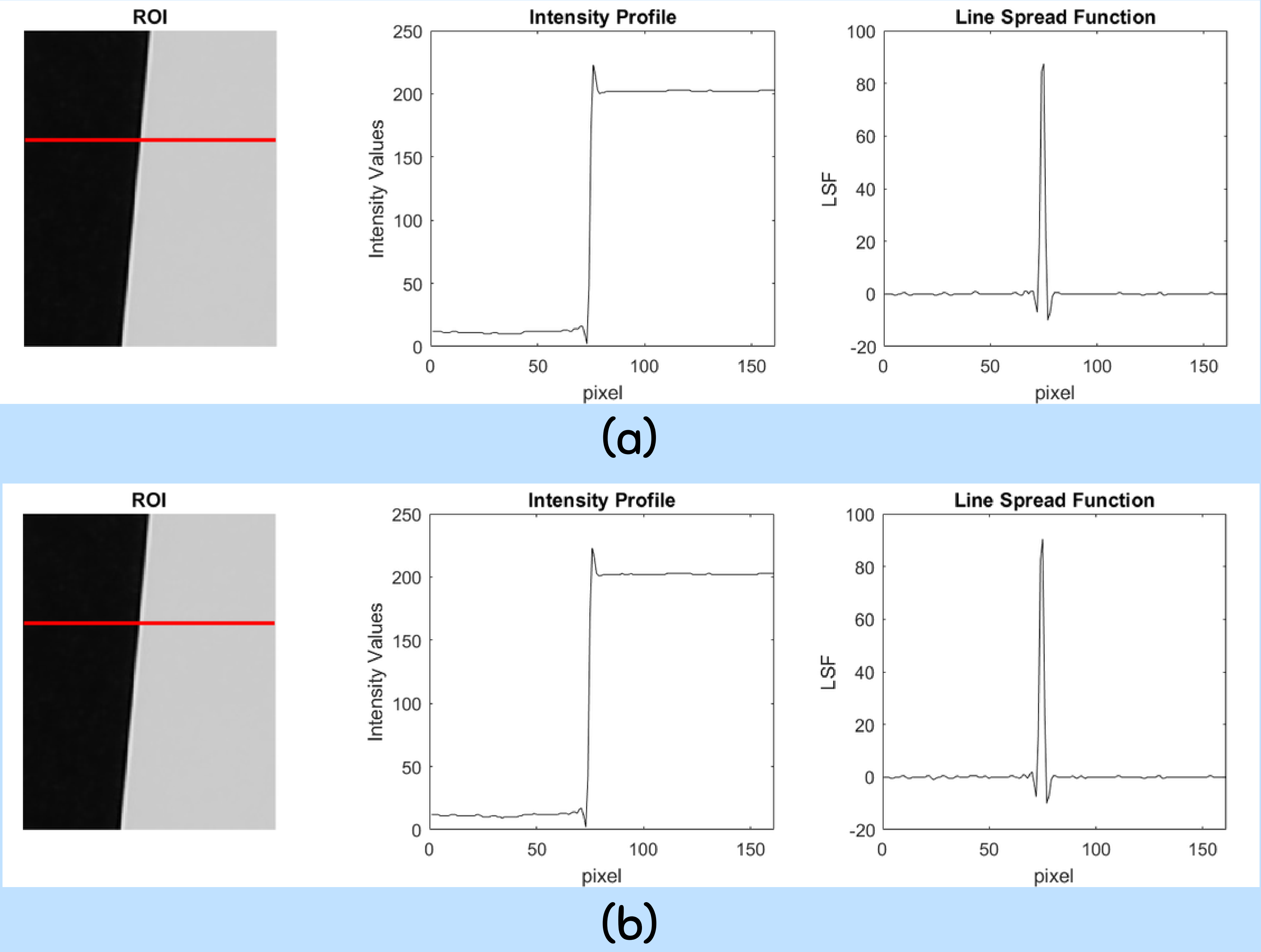
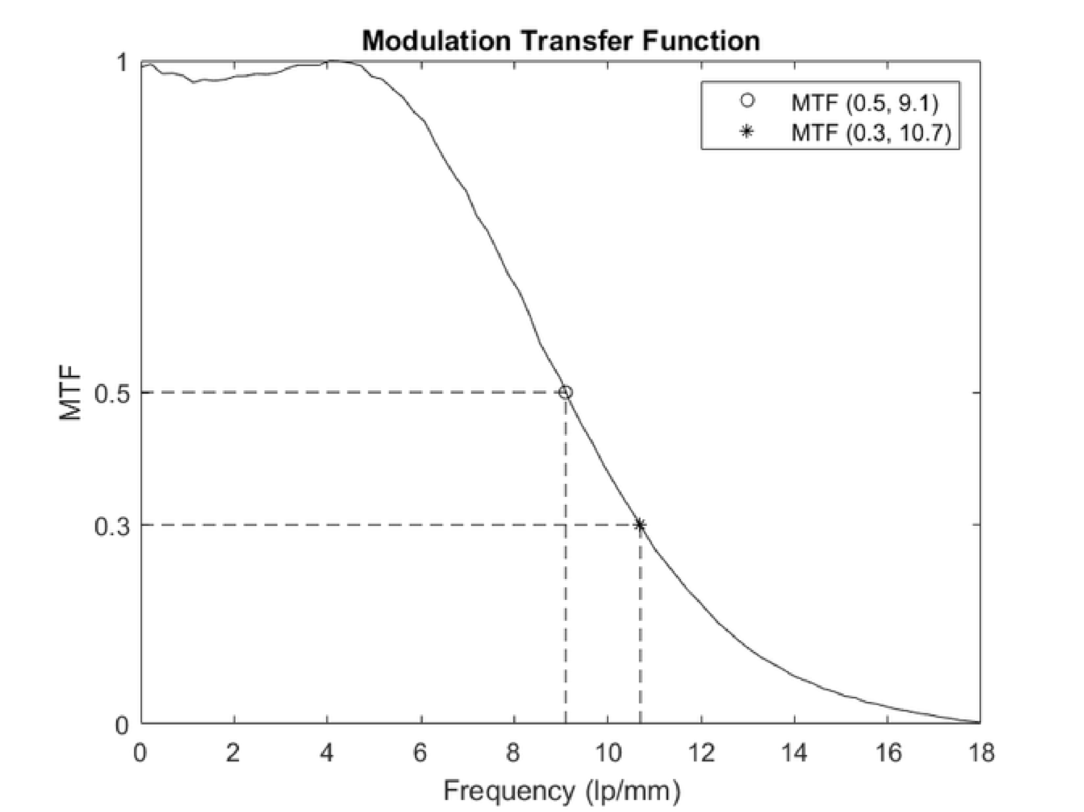
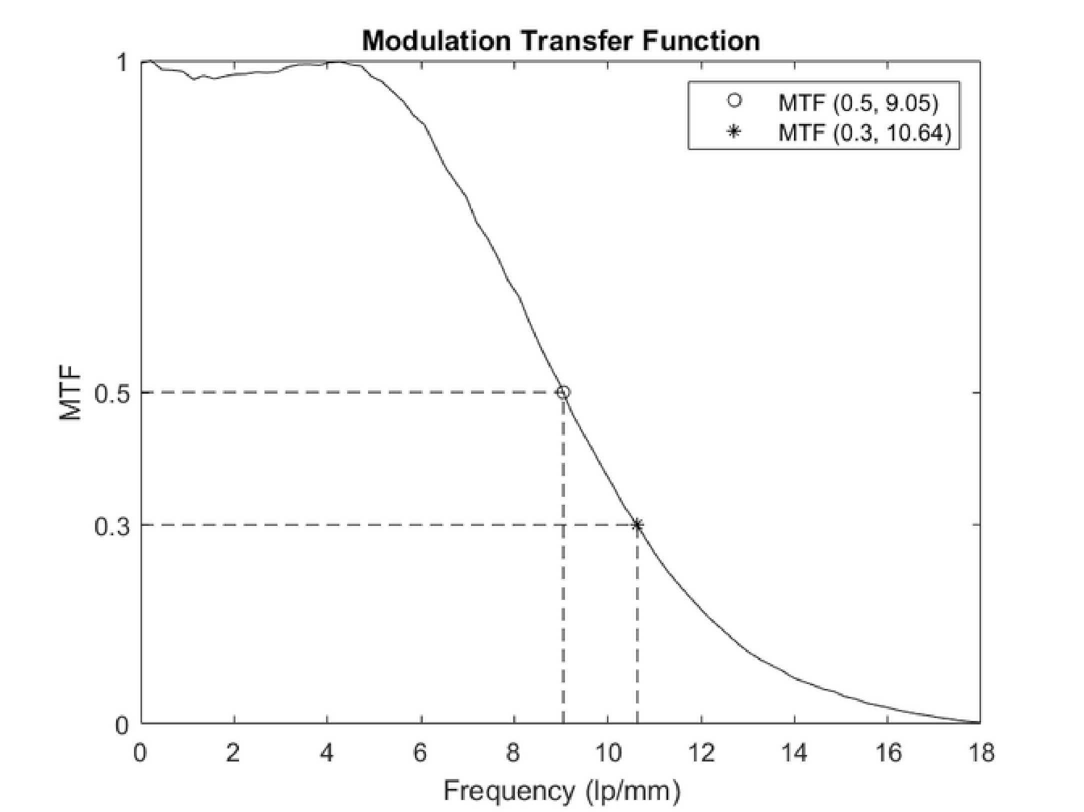


Figure 4. The resulting intensity profile and line spread function of line 70 for stacked image of (a) ORB keypoint matching and (b) ECC maximization.

Results & Analysis



(a)

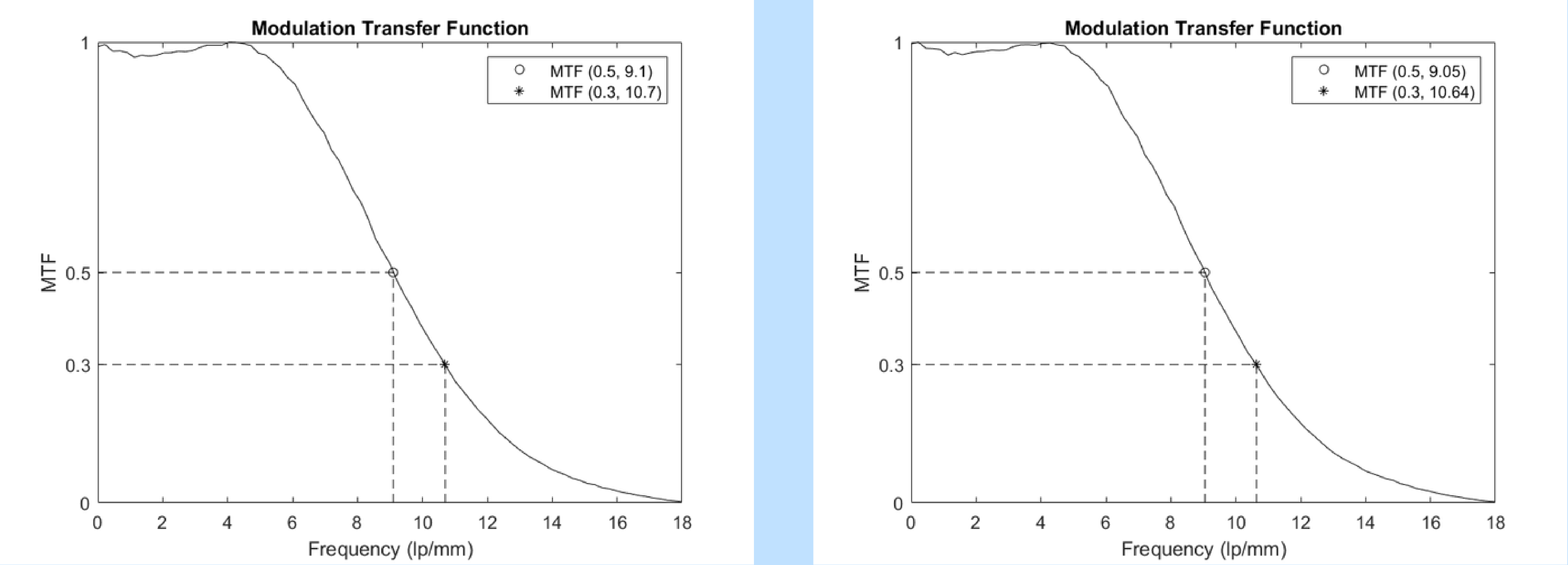


(b)

Figure 5. The normalized modulation transfer function of the camera using the stacked images of (a) ORB keypoint matching and (b) ECC maximization.

Upon acquiring the modulus of the FT of the lines, performing calibration, and achieving normalization, the normalized MTF of the camera for both images is presented in Figure 5. In particular, the MTF value at 0.5 of the ECC maximization stacked image stands at 9.1 lp/mm. This value directly corresponds to the resolution of the phone camera, denoted in line pairs per millimeter. In theory, a higher MTF value indicates the camera's ability to resolve finer details, thus signifying its enhanced imaging capabilities [2].

Results & Analysis



(a) (b)

Figure 5. The normalized modulation transfer function of the camera using the stacked images of (a) ORB keypoint matching and (b) ECC maximization.

Conversely, the value of 0.3 is associated with the capability of an imaging system to replicate finer details perceptible to the human visual system. As illustrated in Figure 5, the MTF at 0.3 for the ECC maximization stacked image is notably higher, measuring 10.7 lp/mm. However, it's important to note that the discrepancies between the MTF values of both the images are relatively small. This variance can be attributed to the distinct algorithms employed by these techniques. ORB keypoint matching is recognized for its speed, whereas ECC maximization is renowned for its precision [3].

Results & Analysis

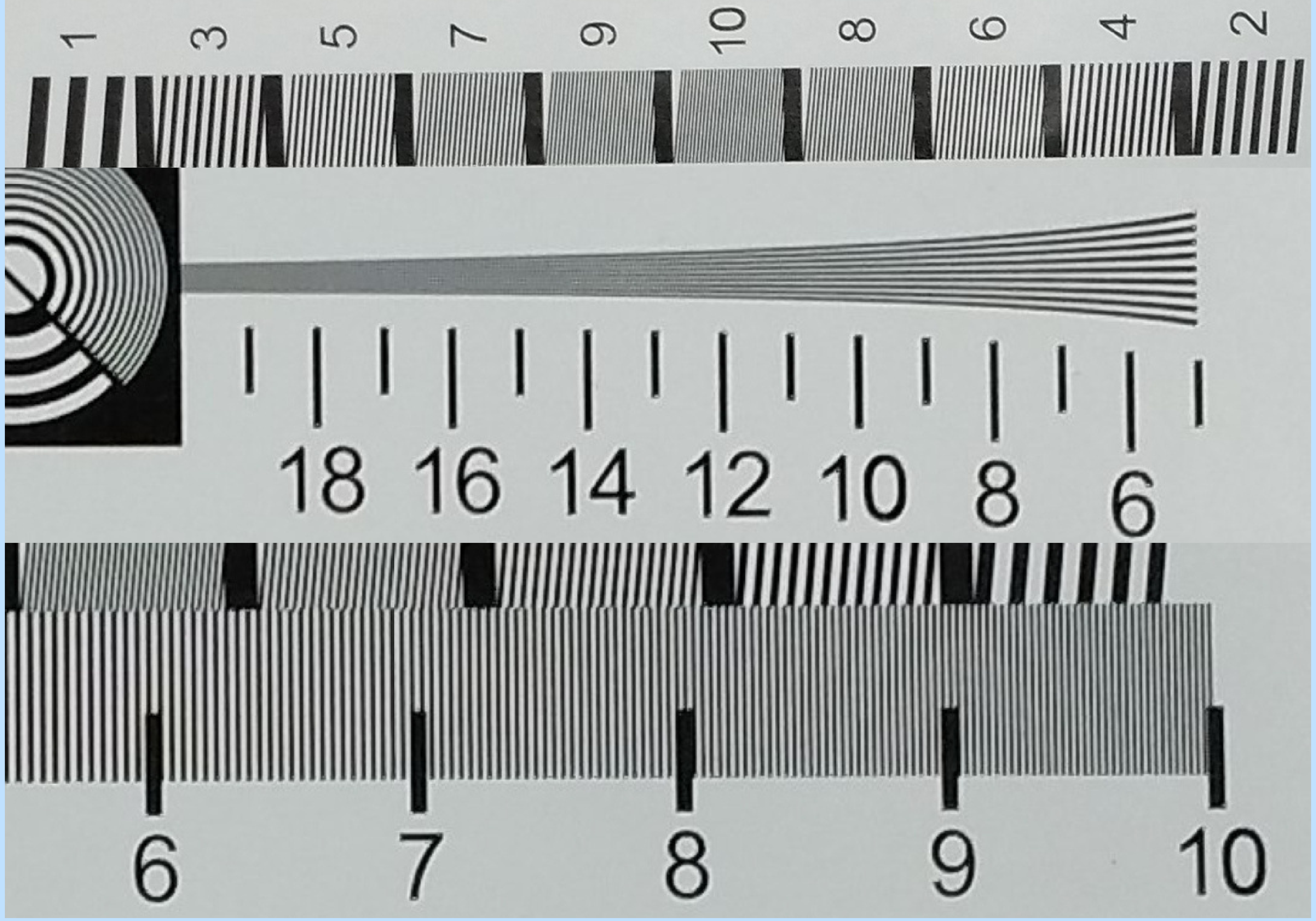


Figure 6. Sample line pair images.

Figure 6 provides snippets of line pair images captured using the phone camera. It is apparent that the line pairs remain discernible within the range of 9 to 10 line pairs per mm. Nevertheless, as the lp/mm value increases, the level of detail gradually diminishes. Consequently, it can be reasonably inferred that the MTF values derived from Figure 5 correspond to these observations.

Conclusions

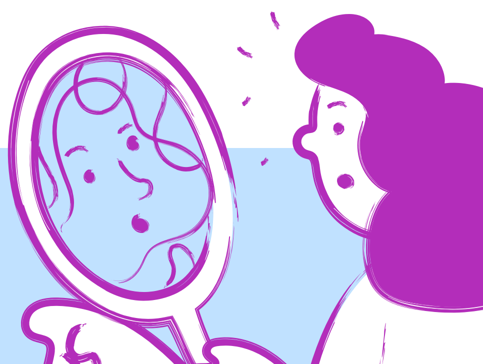
In conclusion, the measurement of the modulation transfer function (MTF) has provided valuable insights into the camera's imaging capabilities. The MTF values in Figure 5 reveal the camera's ability to resolve details. The MTF at 0.5, representing camera resolution, is 9.1 lp/mm. The MTF at 0.3, relevant to human perception, reaches 10.7 lp/mm. The line pair images in Figure 6 corroborate these findings, showcasing the camera's ability to maintain detail visibility in the 9–10 lp/mm range. This assessment emphasizes the camera's strong imaging capabilities and the importance of accurate image alignment.

Reflection

The execution of the activity is challenging but was easy to perform, provided a solid grasp of the underlying MTF concepts. Furthermore, the instructions are lucid and straightforward. One notable obstacle that I encountered pertained to the last part, where calibration of the frequencies in lp/mm was necessary. Gratefully, with the invaluable assistance of my fellow labmates and access to the provided MATLAB code in UVLE, I managed to successfully complete this aspect.

Another challenge arose from noisy nature of the image I obtained, stemming from the merging of multiple images captured using the burst feature. This resulted in a correspondingly noisy MTF curve. Julian, one of my labmates, proposed the utilization of a stack image algorithm, discovered online, to align the images and enhance the quality of the average. Following the application of this algorithm sourced from GitHub, there was a marked improvement in the MTF curve. Hence, it is imperative to ensure precise alignment before proceeding with subsequent steps.

In summary, this learning experience proved both enjoyable and instructive. It also allowed me to appreciate the capabilities of my Android camera, which, while not the absolute best, certainly holds its own.



Self-Grade

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

I give myself full credit for this activity. I believe that I have accomplished all the objectives of this activity and have presented good results. Moreover, I generated all the codes that I used except for the stacked image part.

References:

1. Sundholm, M. (n.d.). Automatic Image Stacking in OpenCV. GitHub. https://github.com/maitek/image_stacking
2. Soriano, M. N. (2023). Measuring Modulation Transfer Function. UVLê. https://uvle.upd.edu.ph/
3. Aguilar , R. A. P., & Soriano, M. N. (2017). Phase-shifting profilometer resolution limit estimation via modulation transfer function analysis. Proceedings of the Samahang Pisika ng Pilipinas. https://drive.google.com/file/d/0B5kakuzS5GWzSDRSbDRmRUVtV1k/edit?fbclid=IwAR2wzxCLhWCCFuRNAdGlQez3VSKFEwfID1OshIbzKOcdoQkYOHXkwcG1i5g&resourcekey=0-RyzmpvqRnRq3c5cH7m-S5Q