App Physics 167 | Act 8

DIGITAL HOLOGRAPHY

Johnenn R. Manalang

CONTENTS

OBJECTIVES

1. Extract the phase and amplitude from an actual digital hologram.
2. Use 2D unwrapping to produce the actual phase image of a digital hologram.

METHODS

Displaying log scale shifted FFT

The recorded digital hologram, as shown in Figure 1 courtesy of Dr. Percival Almoro, was utilized in this activity. Using MATLAB, the image was converted to grayscale, and its FFT was obtained using the fft2 function. To reposition the zero-frequency component of the FT to the center, the fftshift function was employed. Figure 2 displays the shifted FT of the image in a logarithmic scale containing a central bright spot corresponding to the DC term and two symmetric peaks about the central spot which contains both the amplitude and phase.

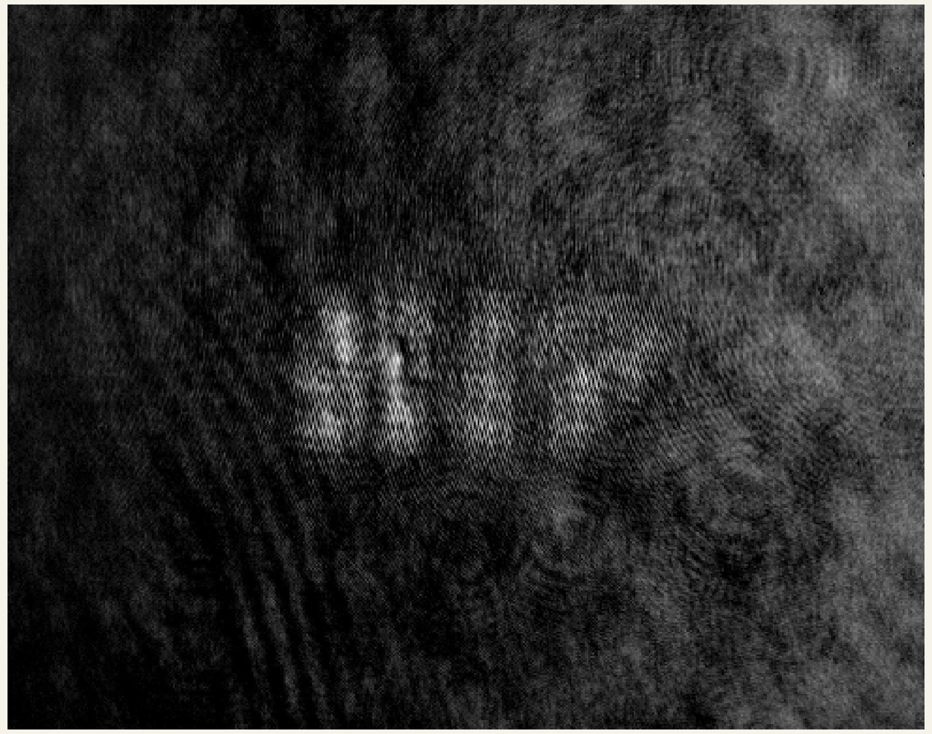

Figure 1. Recorded digital hologram courtesy of Dr. Percival Almoro.

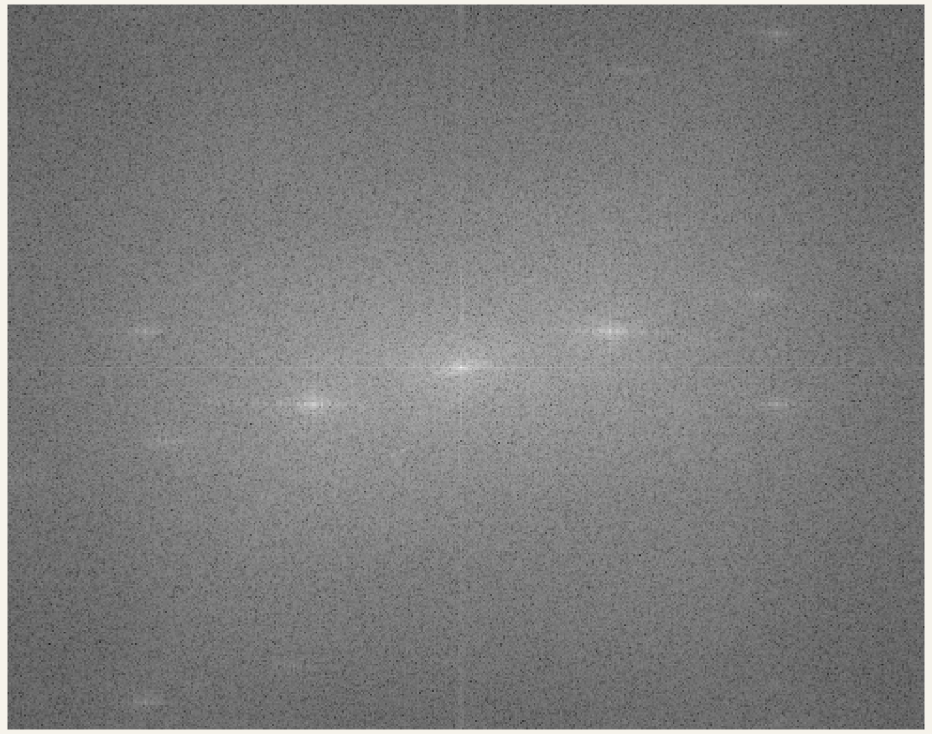

Figure 2. Shifted FFT of the digital hologram in logarithmic scale.

METHODS

● Cropping one of the peaks

$$I = |O|^2 + |R|^2 + 2or\cos(\phi_o - \phi_r) \qquad (1)$$

Equation I is the intensity of the added object beam O and reference beam R. The convolution of the cosine term and the object's FFT results to the symmetry of the location of the two bright peaks about the central spot. To get the amplitude and phase, one of these peaks were cropped using the imcrop function as shown in Figure 3.

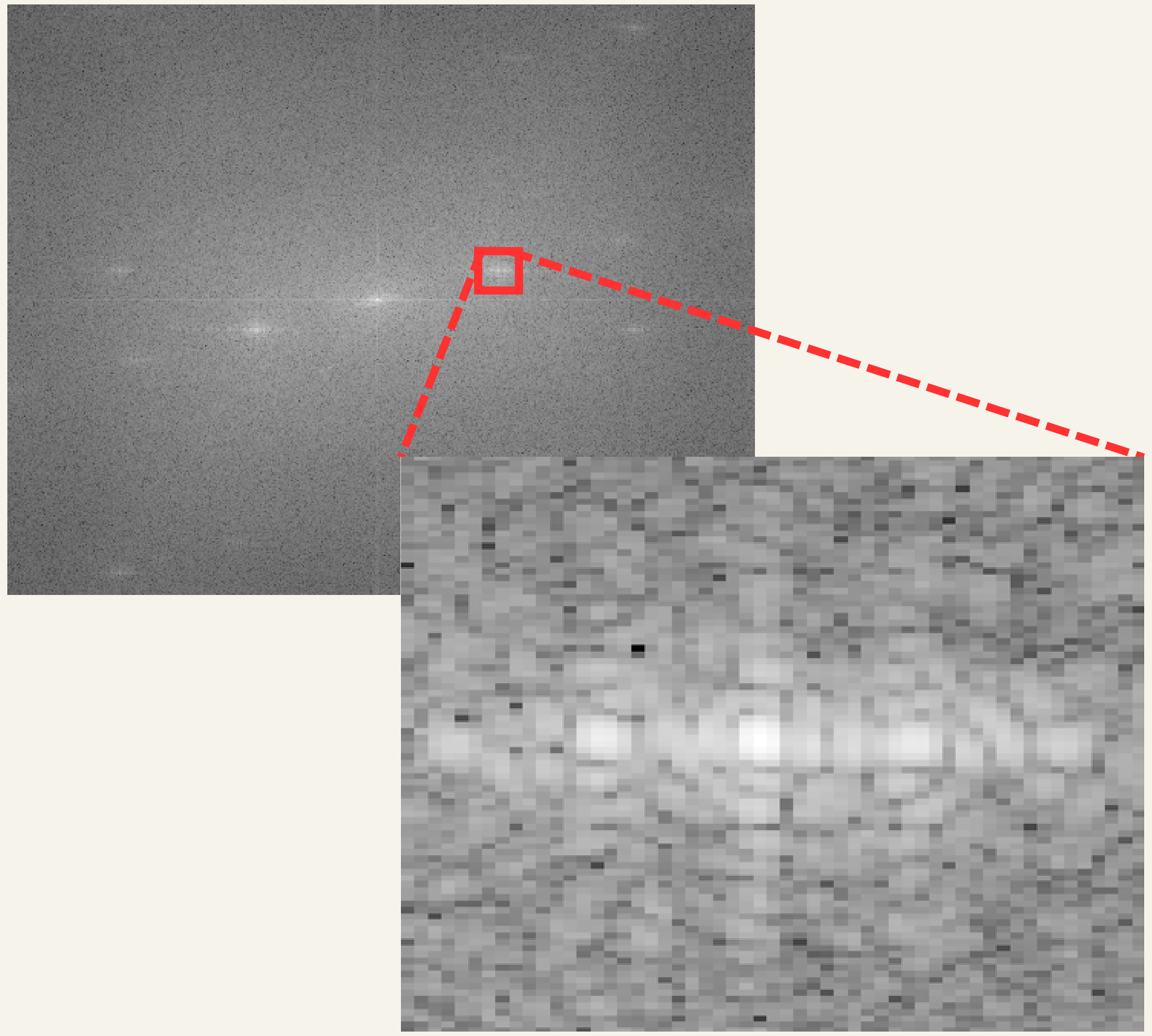

Figure 3. One of the symmetric patterns cropped out for magnitude and phase extraction.

METHODS

- ## Centering extracted FT and getting inverse FT

Using the dimension of the cropped image, the actual FT from the image was extracted. Then, the extracted FT was placed in the center of a blank matrix which is the same size as the original image. The complex matrix was created by element-wise multiplying the matrix containing the magnitude with the exponential of the imaginary unit multiplied by the matrix containing the phase. Finally, the inverse FT of the complex matrix was obtained [1]. Further unwrapping was done to produce the actual phase image using the Fast 2D phase unwrapping MATLAB implementation by Kasim based on the algorithm of Herraez, et. al [2,3].

RESULTS & ANALYSIS

The magnitude and phase of the image were extracted by performing the inverse Fourier Transform (FT) on the complex matrix. Figure 4 displays the region of interest (ROI) along with the corresponding extracted magnitude and phase. The magnitude, depicted in Figure 4b, provides detailed information about the object's shape and edges. Although somewhat blurry, the silhouette of the letters N, I, and P is visible. The phase, on the other hand, carries details about the depth or distance of various parts of the object from the hologram plane. As shown in Figure 4c, the letters at the center remain visible. The unwrapped phase, depicted in Figure 4d, presents an enhanced representation of the phase image, revealing more pronounced letters at the center.

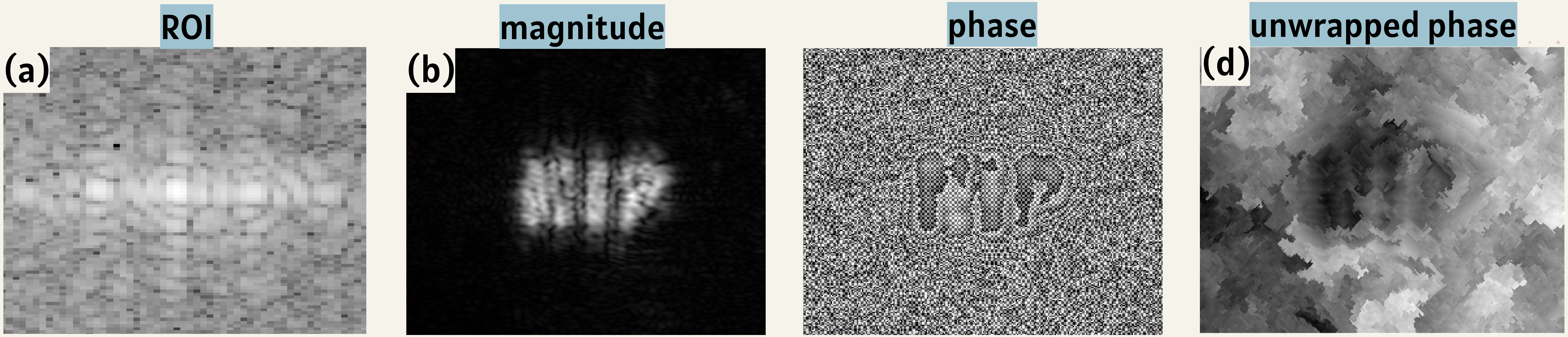

Figure 4. (a) Region of Interest used to get the (b) magnitude and (c) phase of the inverse Fourier transform of the complex matrix. (d) Unwrapped phase using Fast 2D phase unwrapping.

RESULTS & ANALYSIS

The size of the cropped region from the FT can influence the quality, resolution, and information content of the reconstructed image in terms of its magnitude and phase components. Figure 5 shows the extracted magnitude and phase using a smaller ROI. In contrast to Figure 4, the magnitude image has a higher resolution but contains bits of airy patterns from the center going outwards, which is also evident in the phase image. The unwrapped phase shown in Figure 5d also contains the letters at the center. This shows that the selection of ROI significantly affects the extracted magnitude and phase image. Adjusting the crop size allows for emphasizing certain features while sacrificing information outside the selected area, impacting the overall quality and content of the reconstructed image.

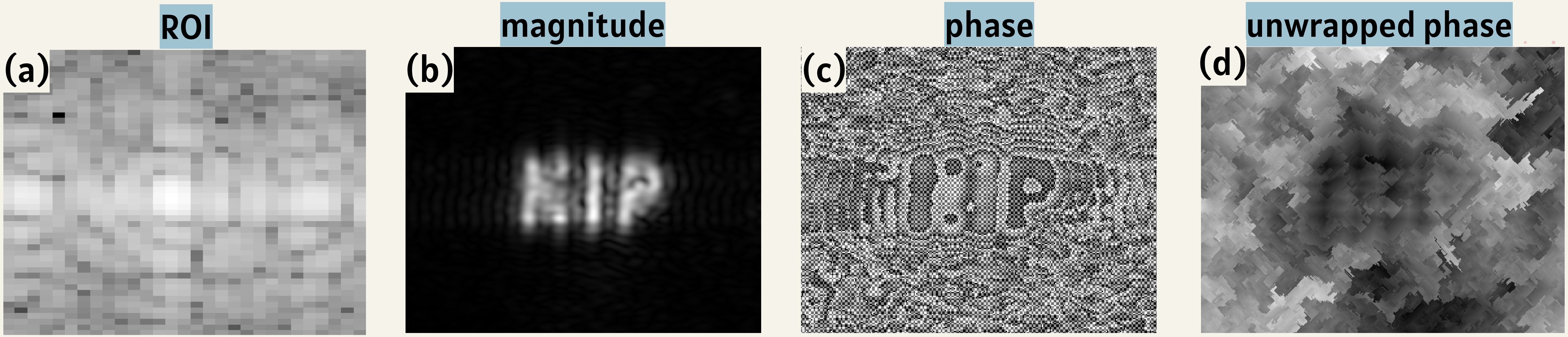

Figure 5. (a) Smaller region of Interest used to get the (b) magnitude and (c) phase of the inverse Fourier transform of the complex matrix. (d) Unwrapped phase using the Fast 2D phase unwrapping.

CONCLUSIONS

The process involved extracting both magnitude and phase information from an image by conducting an inverse Fourier Transform on a complex matrix. The magnitude revealed object shapes with some blurriness, showing recognizable letters like N, I, and P. Meanwhile, the phase conveyed depth information, emphasizing central letters and providing enhanced details in the unwrapped phase. Varying the region of interest significantly affected image quality; a smaller region offered higher resolution but introduced airy patterns, impacting both magnitude and phase images. This highlighted the importance of region selection, allowing feature emphasis while potentially sacrificing information beyond the chosen area, influencing the overall image quality and content.

BONUS

For this segment, I utilized an image captured during our Physics 192 laboratory class for the phase shift profilometry experiment. The image features an etched foam board with a projected sinusoidal pattern. After loading the image in MATLAB, it was converted to grayscale. Subsequently, only the region of interest was selected for the purpose of 3D reconstruction as shown in Figure 6.

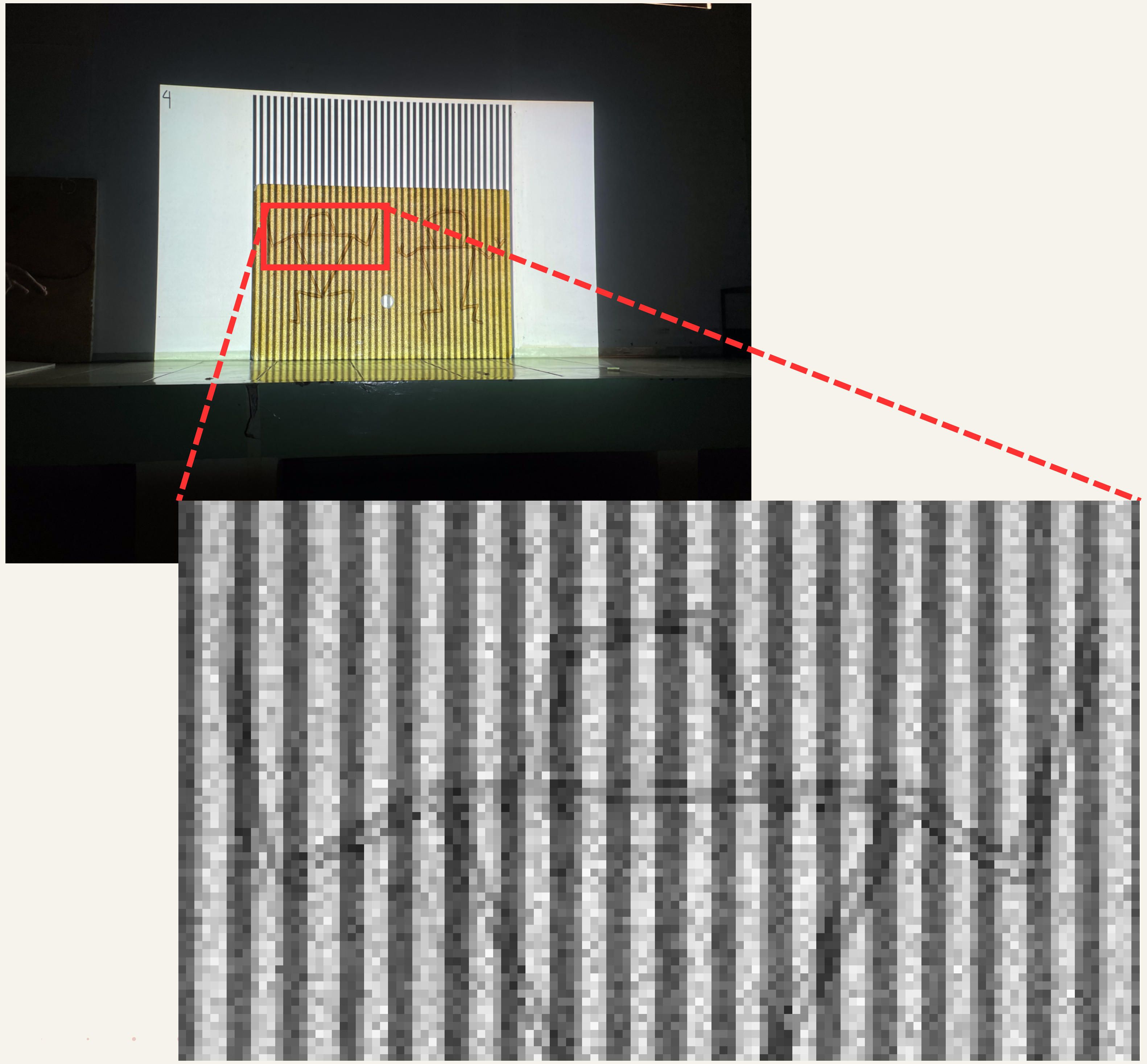

Figure 6. Cropped image for 3D reconstruction.

BONUS

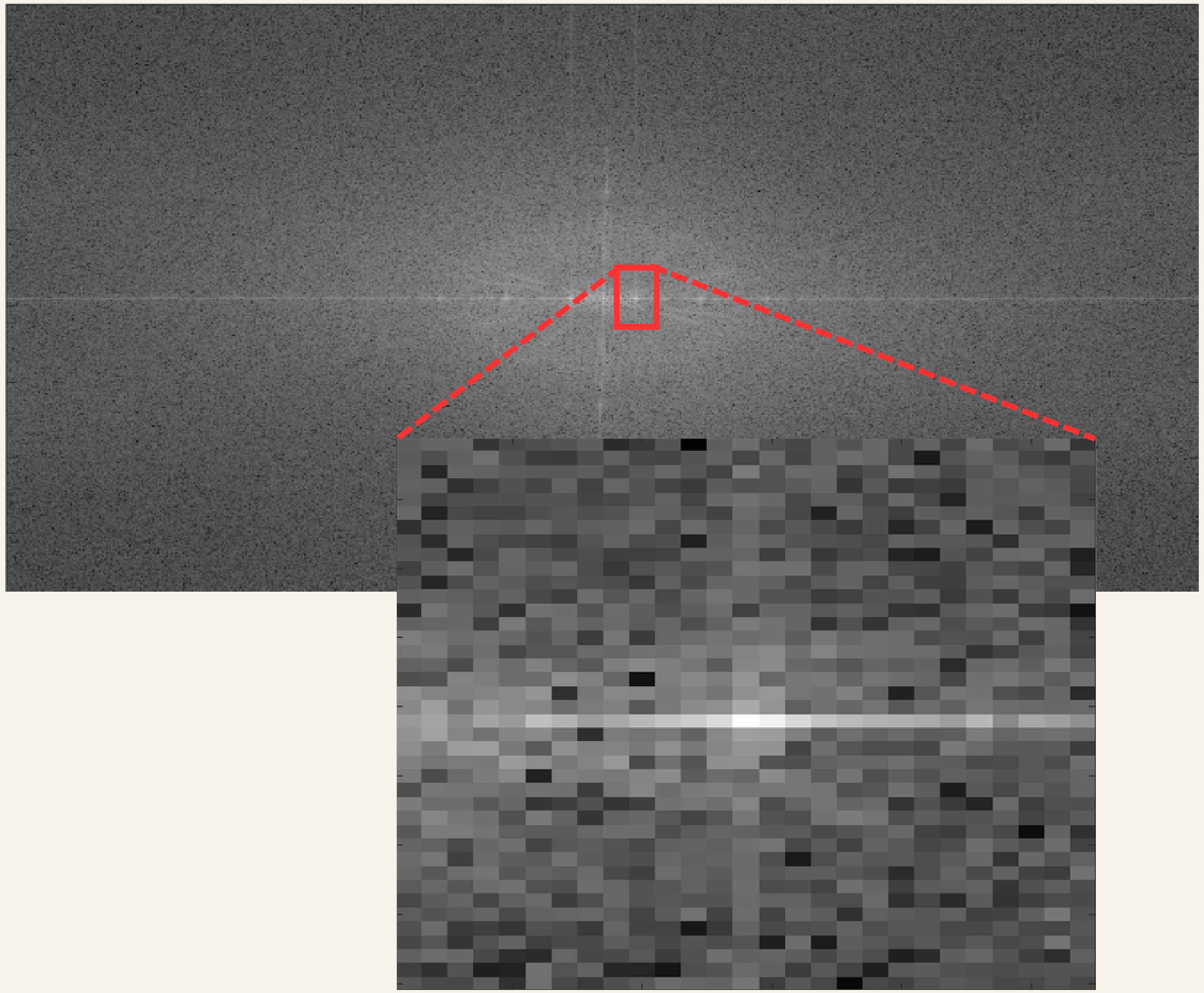

Figure 7. Region of Interest (ROI) from the Fourier transform of the sample image.

Figure 7 displays the Fourier Transform of the sample image. There is a bright central spot corresponding to the DC term, along with two symmetric bright peaks along its horizontal axis, representing the sinusoidal pattern within the image. These peaks encompass both the amplitude and phase information of the image. Following the same procedure, one of the peaks was cropped, centered on a blank matrix, and then subjected to an inverse Fourier Transform. Subsequently, the phase and magnitude were extracted from this transformed data.

BONUS

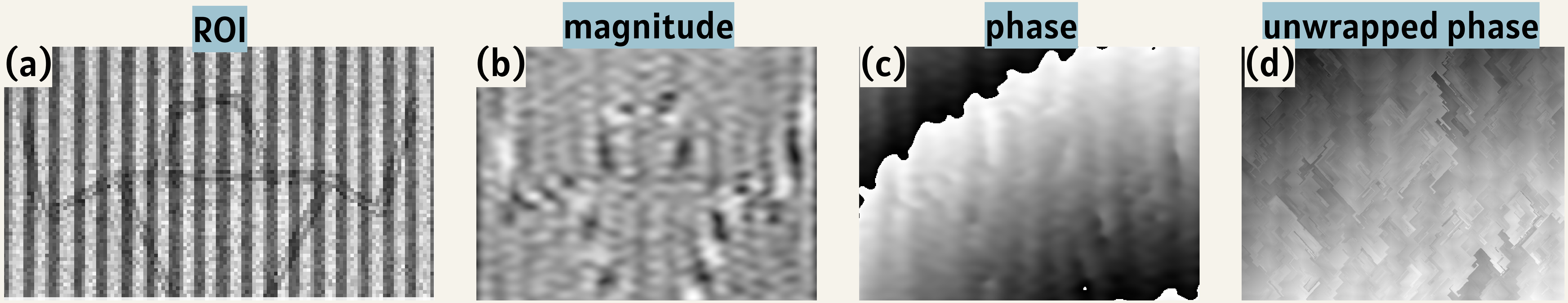

Figure 8. (a) Region of Interest used to get the (b) magnitude and (c) phase of the inverse Fourier transform of the complex matrix. (d) Unwrapped phase using the Fast 2D phase unwrapping.

Figure 8 illustrates the extracted magnitude and phase resulting from the inverse Fourier Transform of the complex matrix. The magnitude, as shown in Figure 8b, reveals a silhouette of the etching within the Region of Interest (ROI), which is also discernible in the phase, although it might not be immediately noticeable. Due to this, the etching is also not that noticeable in the unwrapped phase.

BONUS

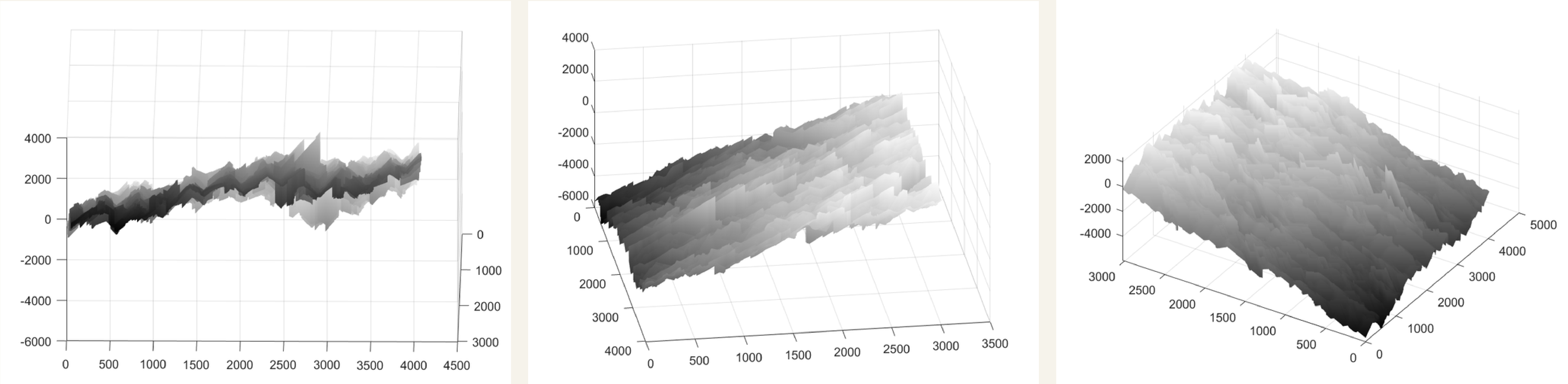

Figure 9. Different views of the 3D reconstruction of the sample image using the unwrapped phase.

Because the etching lacks clarity in the unwrapped phase, the resulting 3D reconstruction, as depicted in Figure 9, exhibits considerable noise. This noise may stem from the image quality. To mitigate this issue in future experiments, enhancing the image quality becomes imperative. Additionally, considering alternative objects rather than a flat foam board could also prove beneficial. I observed that the resulting reconstruction improves notably when there is greater prominence in the bends of the lines.

REFLECTION

The activity seemed relatively straightforward as the code was already provided, yet I didn't merely copy and paste it. Instead, I took the time to comprehend it step-by-step and made various adjustments along the way. However, I encountered a challenge concerning the cropping of the Region of Interest (ROI) from the Fourier Transform of the image. I noticed that the selection of the ROI significantly impacts the quality of the extracted phase and magnitude. Therefore, meticulous selection of the best ROI became crucial. This issue persisted in the bonus part of the activity as well. After numerous attempts, I speculated that perhaps the image quality itself was influencing the results, rather than a flaw in the code. These realizations guided my analysis and helped me better understand the concepts.

Overall, the activity proved to be intuitive and engaging. I only wished we had more time to conduct the experiment ourselves and capture the holography images.

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 credit as I successfully met all the objectives of this activity. Moreover, even if the code is already provided, I tried to make some adjustments to better implement it. I also did the bonus part by 3D reconstructing one of the sample images that we have from our experiment in phase shift profilometry.

GITHUB REPO HERE

REFERENCES

1. Soriano, M.N. (2024) Activity 8 - Digital Holography, UVLE. Available at: https://uvle.upd.edu.ph/pluginfile.php/1056902/mod_resource/content/1/Activity%208%20Digital%20Holography.pdf (Accessed: 05 January 2024).
2. M. A. Herraez, D. R. Burton, M. J. Lalor, and M. A. Gdeisat, "Fast two-dimensional phase-unwrapping algorithm based on sorting by reliability following a noncontinuous path", Applied Optics, Vol. 41, Issue 35, pp. 7437-7444 (2002).
3. M. F. Kasim, "Fast 2D phase unwrapping implementation in MATLAB", https://github.com/mfkasim91/unwrap_phase/ (2017).