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Surface topography of cuneiform tablets

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SIMG-503

Senior Research

Surface Topography of Cuneiform Tablets

Final Report

Monica Barbu
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Rochester Institute of Technology
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Surface Topography of Cuneiform Tablets

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Surface Topography of Cuneiform Tablets

Monica Barbu

Abstract

Ancient Cuneiform tablets consists of one of the oldest forms of writings in the world. These clay tablets act as a link between our time and a time thousands of years ago.

The surface of these Cuneiform tablets consists of wedge shaped characters and cylinder seal impressions. These features present many challenges to photographers as well as epistolary scholars. Modern technology and state of the art equipment can ease these hindrances and unlock secrets of past civilizations. Using surface topography techniques previously applied to intaglio prints and lithic artifacts as well as implementation of modern digital image processing techniques, images of the Cuneiform text are displayed in their highest potential of detail and clarity. These techniques not only provide a qualitative result of the surface topography, but more importantly, they present a quantitative analysis of the surface of the tablet. From the study of the surface topography of the Cuneiform tablet it was concluded that five thousands years ago scribes were using contemporary image techniques such as edge enhancement to provide a clear display of their work.

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This report is accepted in partial fulfillment of the requirements of the course SIMG-503 Senior Research.

Title: Surface Topography of Cuneiform Tablets

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Surface Topography of Cuneiform Tablets

Monica Barbu

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Surface Topography of Cuneiform Tablets

Monica Barbu

Introduction

History is essential to human existence, not only because it holds a record of our past but it also teaches us about the present and can offer a window into the future. Ancient Cuneiform tablets consist of one of the oldest forms of writings in the world. These clay tablets act as a link between our time and a time thousands of years ago. The term Cuneiform, which originates from the Latin word *cuneus* meaning wedge shaped, evolved from early pictographs. [\(1\)](#)

These tablets originate from the lower valley of the Tigris and Euphrates River in Mesopotamia, what is known today as Iraq. The Cuneiform text is considered one of the first forms of writing. The structure of this text did not match the syntax of a spoken language. They were restricted to dealing in lists and categories, as opposed to sentences and narratives used in spoken language today. Most of the Cuneiform tablets were documents about property, inventory and taxes. [\(2\)](#) Along with the wedge shaped marks, these five thousand years old documents bear a feature called cylinder seal impression. The seal impressions consist of different design elements, which serve to identify their owner or distinguish a specific deity.

Reconstruction of ancient documents such as the Cuneiform tablets and stylus tablets provide scientists and scholars with the challenge of transforming their three dimensional characteristics to a two dimensional plane. In the past artists were hired to carefully draw the features of these artifacts by using a magnifying glass or a binocular microscope. This was not only time consuming, but arguably, very subjective. Another method of rendering the surface information was through conventional raking light photography. However, because the surface of the Cuneiform tablet subsists of uneven curves and features of various degrees of depth they present many problems to photographers as well as epistolary scholars who try to read and represent these images.

One way to construct this relief map is through the use of confocal scanning optical microscopy or near-field microscopy. Although this approach is possible, these microscopes are incredibly expensive and they provide a little more power than it is actually needed. [\(3\)](#)

Another recent attempt in rendering the three dimensional topography on a two dimensional plane was through the use of stereovision. [\(4\)](#) Although the idea seems promising, since it has been used in astronomical imagery, it does not seem to be applicable in the cases analogous to that of the Cuneiform tablet. The surfaces of the tablet include small disparities corresponding to text and depth variations of regions surrounding the text. These differences and subtle variations require extreme care in choosing correct lenses, baseline separation between the two cameras, as well as the appropriate camera mounting apparatus. It is evident, that calculating the topography of the Cuneiform tablets from digital images is a great deal more simple and more affordable.

Calculating the topography of the Cuneiform tablets from digital images is a distinct way to extract contour measurements of the wedge shaped characters and

cylinder seal impressions found in their surfaces. Using surface topography techniques previously applied to intaglio prints and lithic artifacts as well as implementation of modern digital image processing techniques, images of the Cuneiform text are displayed in their highest potential of detail and clarity. These techniques not only provide a qualitative result of the surface topography, but more importantly, they present a quantitative analysis of the surface of the tablet.

Theory

Surface Topography:

The following concepts in regards to surface topography are based on previous work completed by J. S. Arney and D. Stewart.⁽⁵⁾ Topography is described as a variation in height, $h(x)$, across a horizontal dimension, x . In order to relate the characteristics of the surface of an object to the variations in irradiance, $I(x)$, detected across the film plane of the camera, it is crucial to have an optical model that relates the two. In this case the irradiance, $I(x) = [h(x)]$. In this optical model two assumptions are made. First assumption is that the surface of the object is a Lambertian reflector, which means that the irradiance at the film plane will be independent of the angle of viewing and will depend only on the angle between the surface and the source of illumination. The second assumption is that the object surface is a diffuse reflector.

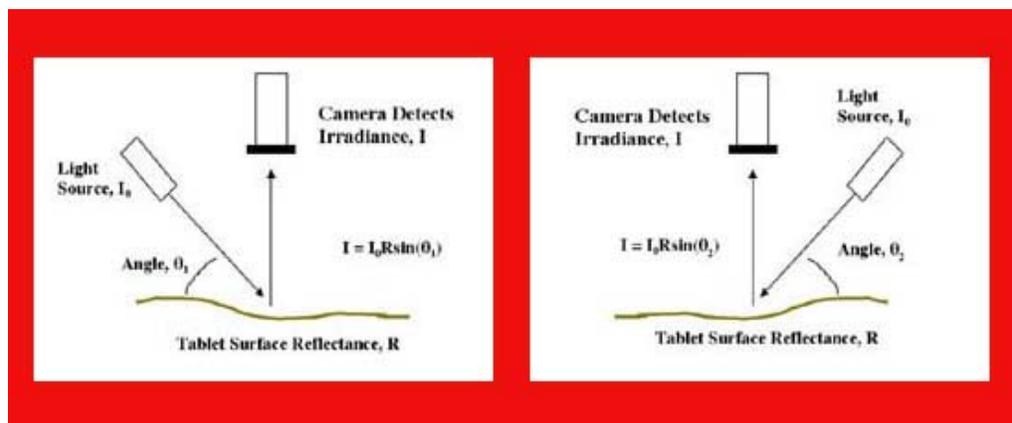


Figure 1. Image capture of surface topography.

As a result the light reaching the detector as illustrated in Fig. 1 is controlled by I_0 , the irradiance of the light incident on the surface of the object, the reflectance factor of the object, R , and the angle of illumination. As a result of these assumptions, one can generate Eq. 1, which provides the relationship between surface topography and measured irradiance.

$$I = I_0 R \sin(\theta) \quad (\text{Eq. 1})$$

Topography can be described in point by point variation in the angle, $\alpha(x)$, between the object and the mean surface of the object. The height variation at a certain location is related to the surface angle through the derivative.

$$\frac{d[h(x)]}{dx} = \tan[\alpha(x)] \quad (\text{Eq. 2})$$

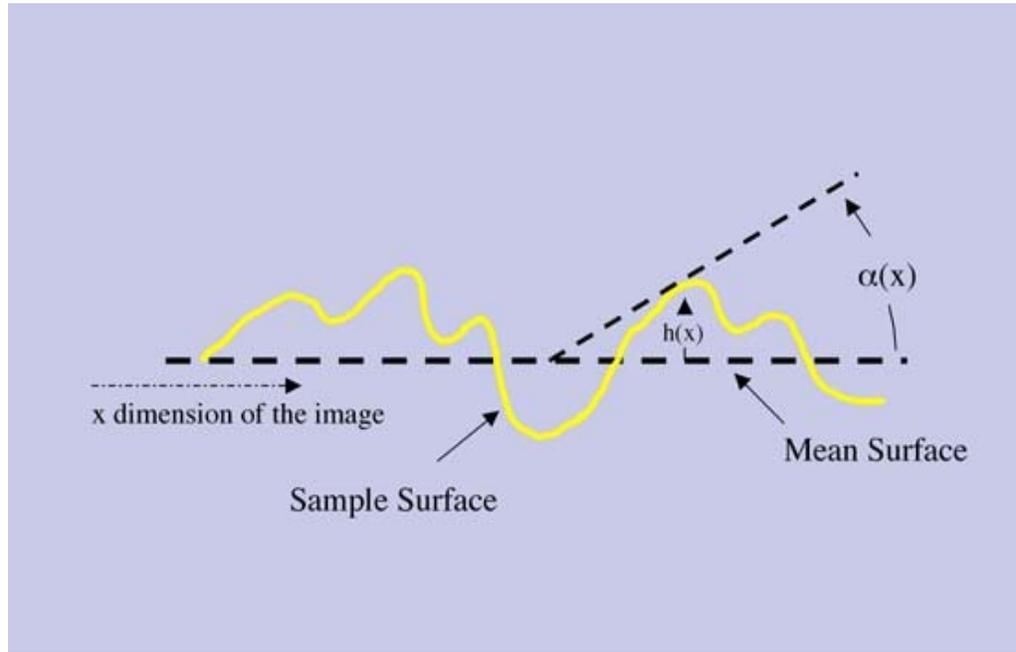


Figure 2.

Illustrates the relationship between a horizontal slice of an object and the variation in angle, $\alpha(x)$.

Furthermore, because of the Lambertian assumption, the variation in the angle, α acts as a variation only in the illumination angle θ . Therefore, topographic information can be related to the irradiance of the camera as follows:

$$I(x) = I_o(x)R(x)\sin[\theta(x)] \quad (\text{Eq. 3})$$

The angle $\theta(x)$ in the equation above is the sum of the angle of illumination, θ_o , and the mean surface angle, $\alpha(x)$. As a result from the analysis above a quantitative relationship between the observed irradiance, $I(x)$ and the topography of an object, $h(x)$ can be derived.

The term $R(x)$ in Eq. 3 can be separated from the topographic information, $\sin[\theta(x)]$, by taking the ration of two images captured at two different angle of illumination. The characteristics of the two images in one dimension would be the following:

$$I_1(x) = I_o R_1(x)\sin[\theta_{o1} + \alpha(x)] \quad (\text{Eq. 4})$$

$$I_2(x) = I_0 R_1(x) \sin[\theta_{02} + \alpha(x)] \quad (\text{Eq. 5})$$

In Eq. 4 and Eq. 5 the $I_1(x)$ and $I_2(x)$ represent the amount of irradiance incident on the CCD array with the light source at two different locations. I_0 is the irradiance of the light source. $R(x)$ is the reflectance factor at a certain location. θ_{01} and θ_{02} are the angles of illumination. $\alpha(x)$ contains the topographical information.

As a result of taking the ratio between Eq. 4 and Eq. 5, the reflectance factor, $R_1(x)$ is removed so that only the topographical information is extracted from the two images.

$$\frac{I_1(x)}{I_2(x)} = \frac{\sin[\theta_{01} + \alpha(x)]}{\sin[\theta_{02} + \alpha(x)]} \quad (\text{Eq. 6})$$

Solving Eq. 6 for the topographic features in terms of $\tan[\alpha(x)]$ by using appropriate trigonometric identities the following expression is derived.

$$\tan[\alpha(x)] = \frac{I_2(x)\sin(\theta_1) - I_1(x)\sin(\theta_2)}{I_1(x)\cos(\theta_2) - I_2(x)\cos(\theta_1)} \quad (\text{Eq. 7})$$

The values of $\tan[\alpha(x)]$ are pixel by pixel topographic information of the object under investigation. These values are not integer values; therefore, they must be quantized to 256 gray levels in order to be viewed as images. Taking Eq. 7 along with Eq. 2 the topographic height function can be obtained.

$$h(x) = \sum \tan[\alpha(x)] \Delta x \quad (\text{Eq. 8})$$

Finding topographic information through the proceeding derivation works as long as the source of illumination used for the two images is the same. A novel device was build to help solve this problem. Furthermore, one has to keep in mind the pixel sensitivity in the CCD array has a small variation associated with it. As a result, each image used in the experiment was corrected for this inconsistency by using flat fielding. Flat fielding removes the variation in brightness, which can be caused by the non-uniform illumination and small "dark currents" in the array.

Methods

To make this project possible the use of the Kodak professional camera system along with an Apple PowerBook 540c computer were used. The camera is equipped with a Nikon Nikkor 60mm lens. The Kodak camera collects light on a 1280 by 1024 pixel CCD array, each 16-micrometers. Each image is 8-bit and therefore is 1.3MB large. Additionally, the image analysis and image processing were performed in IDL (Interactive Data Language, Research Systems Boulder, CO) on a Power Macintosh 8600/200 system in the Digital Image Restoration Technology Lab at the Chester F. Carlson Center for Imaging Science.

In order for this experiment to work, the images captured are required to have the same source of illumination. As a result a new device was designed and built that consists of a single light source adjustable to any degree from the surface of the object under investigation. Fig. 3 illustrates the unique light source apparatus.

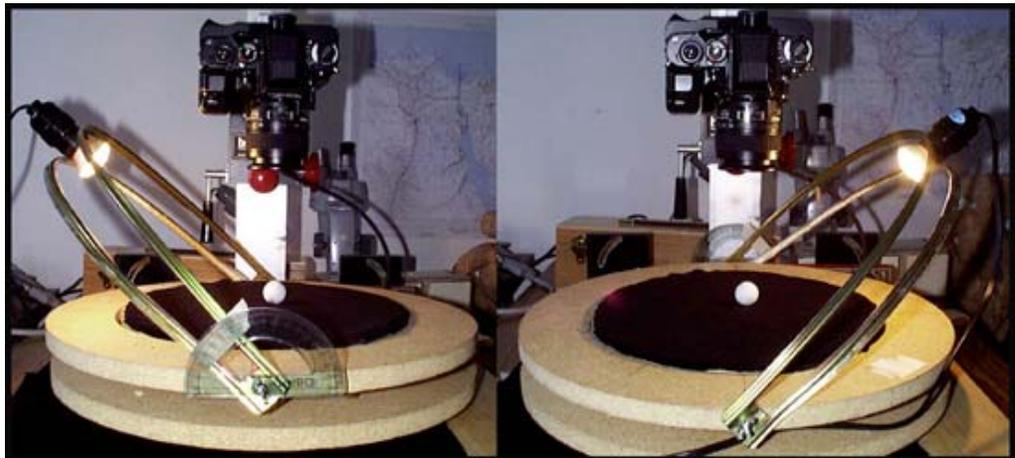


Figure 3. Illustration of lab setup.

As is depicted in Fig. 3, the light source is attached to a graded arc. The light source has the ability to move anywhere along the arc. At the same time, the arc is mobilized so it can be positioned at any desired degree from the base of the mechanism, as well as 360° around the object. The object under investigation is placed in the center of a circular platform that holds the arc. In order to take as many images as desired in where the only variable is the position of the source of illumination, the object is stable in the center of this circular platform.

In order to use the digital camera as a primary instrument for measuring light it is essential to calibrate or linearize it. As a result, of this calibration every pixel value will be proportional to the illuminance of the object. This type of calibration is better known as a "Flat Fielding" procedure. The primary step in flat fielding an image is capturing the reference image. To achieve this, the camera's field of view was adjusted to about 25mm, while the light source was located 30° from the horizontal and about 6cm from the focal point of the camera. The sample object used in this case was a piece of paper

with a smooth surface.

Before converting the pixel values into information characteristic to the object, it was necessary to calculate the Tone Transfer Function of the Kodak camera. Fig. 4 represents the relationship of reflectance and pixel value. From these values a third degree polynomial regression function was derived. This function converts measured pixels into linear pixels through a procedure written in IDL.

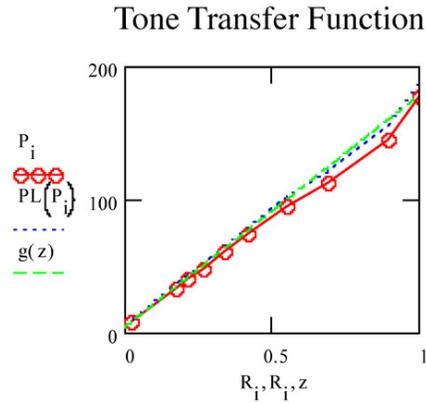


Figure 4. Tone Transfer Function for Kodak camera. Pixel value versus Reflectance.

By measuring the mean pixel value for the reference image, and assuming that the reflectance of the reference object is equal to 1.0 the following equation for individual pixels in the image was derived:

$$R(x, y) = \left[\frac{P(x, y) - P_d}{P_{ref}(x, y) - P_d} \right] R_{ref} \quad (\text{Eq. 9})$$

In the preceding equation $R(x, y)$ refers to the reflectance at each location in the image. Furthermore, $P(x, y)$ and $P_{ref}(x, y)$ are the pixel values in the image and in the reference image respectively. P_{ref} represents the mean pixel value of all the values of $P_{ref}(x, y)$. When Eq. 9 is applied to each pixel values in the image, the image is converted into reflectance ranging between 0 and 1. In order to keep the image in integer units from 0 to 255, the expression below is applied.

$$P(x, y) = \left[\frac{P(x, y) - P_d}{P_{ref}(x, y) - P_d} \right] (P_{ref} - P_d) \quad (\text{Eq. 10})$$

Eq. 10 is the "Flat Fielding" equation, where $P_{ref}(x, y)$ represents the individual pixel values in the image, while P_{ref} is the mean value from the histogram of the image. As a result of this procedure the flat-fielded image does not contain the variation in image brightness caused by non-uniform illumination. In other words, the flat field calibration removes experimental artifacts and produces data about the object itself only. This is notable because pixel values are a characteristic of the CCD camera system and the source of illumination, while the reflectance, R , is a characteristic solely of the object

under examination.[\(6\)](#)

Once the procedure for flat fielding was established, the next step in the experiment was to capture images of an object with known topographical characteristics. Because the surface of the Cuneiform table consists of notoriously variable features, which are virtually impossible to measure, it would be difficult to test the validity of the experiment with them. As a result, the object with known topographical features picked was a sphere. The surface geometry of the sphere was calculated and then compared to the experimental results.

Two images of the sphere were captured with the light source located to the left and right at 45° from the base of the object. Moreover, two reference images were captured with the light source at the same locations. Fig. 5 and Fig. 6 represent examples of these images. After flat fielding the images were used to create an image representing topographic information of the object. Fig. 7 represents angle, $\alpha(x)$, scaled and quantized to 256 gray levels. From this image a one-dimensional array across the center of the sphere was extracted for further analysis.



Figure 5, 6, and 7:

Fig. 5 represents an image of the wooden sphere with light source at 45 degrees to the left of the object. Fig. 6 is the reference image with light source at the same location. Fig. 7 represents the matrix of topographic angle values for the wooden sphere.

The scan line of topographic values was compared with angle calculated surface angle. Using geometric relationships the calculated surface angle of the sphere was derived. Refer to Fig. 8 for these relationships.

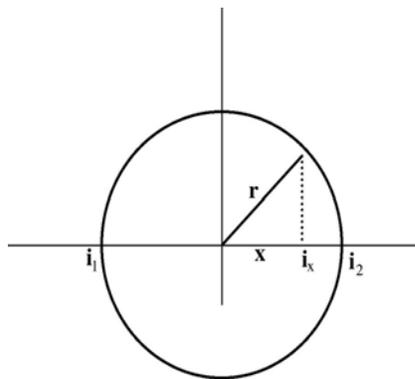


Figure 8: Schematic illustration of the geometry of the sphere

$$\cos \theta = \frac{x}{r} \quad (\text{Eq. 11})$$

$$\cos \theta = \frac{2i_x - (i_2 - i_1)}{i_2 - i_1} \quad (\text{Eq. 12})$$

$$\cos \theta = \frac{2i_x}{i_2} - 1 \quad (\text{Eq. 13})$$

The calculated angle of the sphere can be determined by using Eq. 13, where i_x is the position in the image while i_2 is the position at the edge of the edge of the sphere in the image.

Results and Discussion:

The primary objective of this experiment was to generate an image consisting only of topographic information of the surface of the wooden sphere and more importantly of the Cuneiform tablet. The image of the topographic angle, $\alpha(x)$ represents the Cuneiform writing as well as the seal impressions qualitatively and quantitatively. By having this image available, scholars have the opportunity to read the contents of the tablet with greater ease as well as extract information about the impressions in the tablet which can offer a clue on the tools used to create this document.

This method of extracting topographical information becomes erroneous when the topography of the object is greater than the angle of illumination. If the angle of illumination exceeds the surface angle than shadows are introduced. Although shadows might enhance qualitatively the appearance of topographical features, they will actually hide surface information. (7)

As the angle of illumination is increased more topographical information becomes available. This is evident in Fig. 9 and 10.



Figure 9: Surface topography of the tablet at a 60° angle of illumination.



Figure 10: Surface topography of the tablet at a 70° angle of illumination.

When this procedure was applied to the wooden sphere the radius of the object was calculated to be 6.44mm. The measured radius of the sphere was approximately 6.5mm. These two results are satisfactory, considering that small random error in the angle $\alpha(x)$, results in large error in the height, $h(x)$.

The height characteristic of the wooden sphere is illustrated in Fig. 11.

Topographic Height Across the "Scan" Line

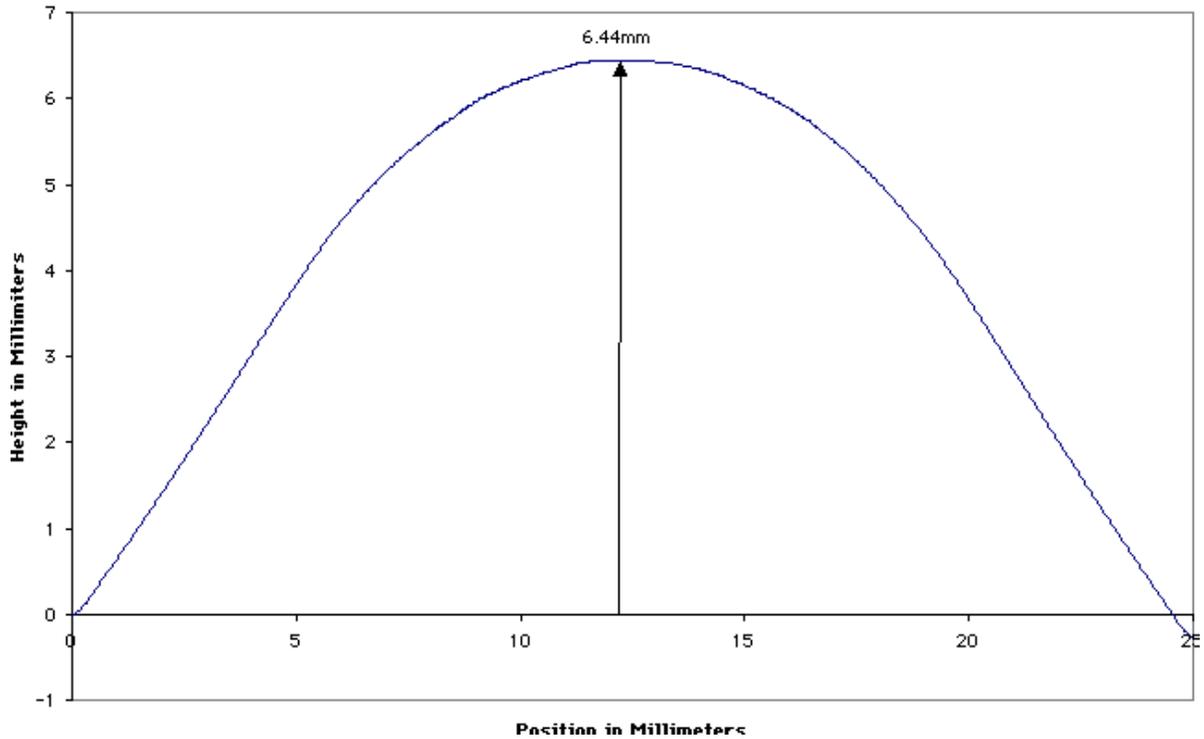


Figure 11: Topographic height across the scan line of the wooden sphere

A similar approach was applied to the surface of the cuneiform tablet. Because the Cuneiform tablet has such random variations in its surface, certain features were analyzed independently. One particular region under investigation was the cylinder seal impression, which measures 15mm in length and 6mm in width. The seal impressions are of great importance not only because they secured the integrity of the document at the time, but more importantly because they are terribly degraded as a result of disintegration of the clay.



Figure 12: Surface of Cuneiform tablet before processing



Figure 13: Surface of Cuneiform tablet after processing

An array of alpha angles was extracted from the topographical matrix of the Cuneiform tablet. The array of angles was plotted against the length of the feature. Fig. 14 illustrates this plot.

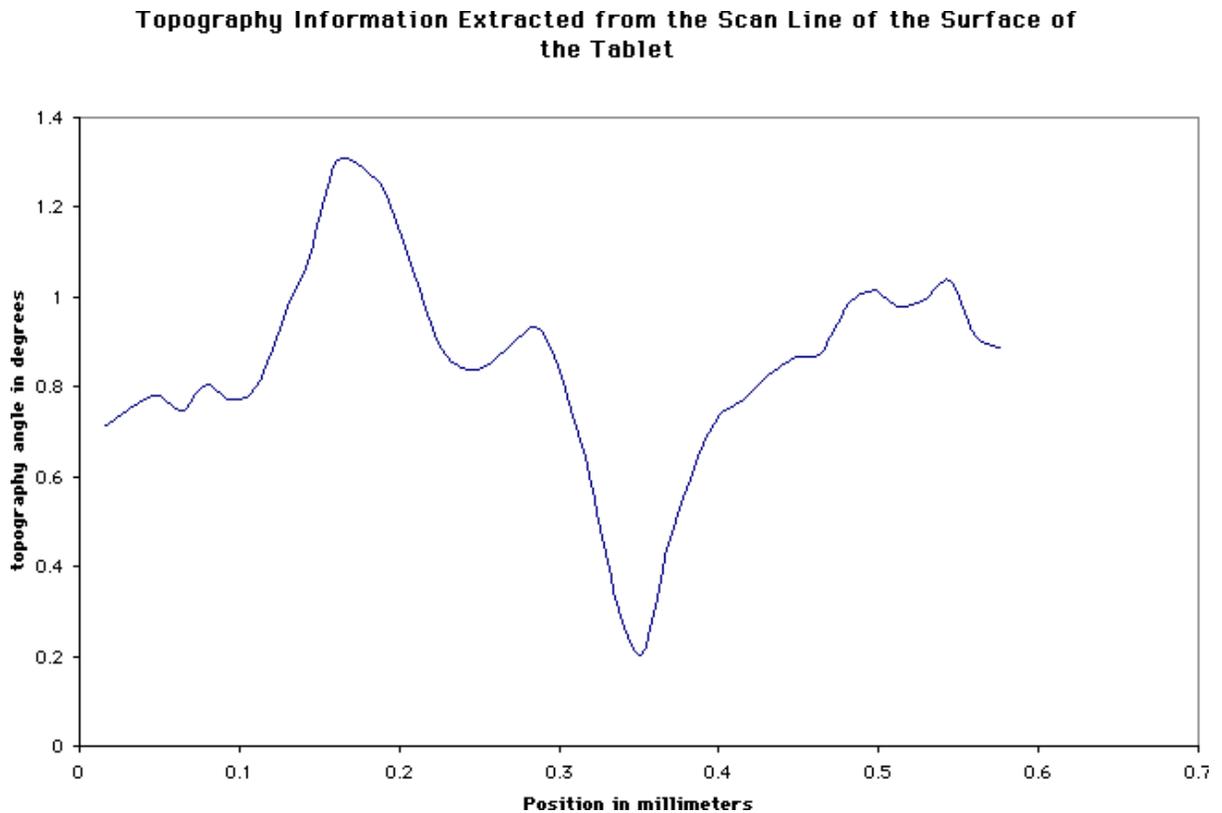


Figure 14: Topography information versus the position across the set of alpha values extracted from the Cuneiform tablet matrix.

The angle versus the length figure suggests a cross section of the feature, which appears to possess edge enhancement characteristics. This plot illustrates an obvious increase of the transition at the edge as well as an overshoot on either side of the edge. The edge enhancement attribute is a significant find considering that this form of writing is pre-hieroglyphic and edge enhancement is a tool used only in recent years. One of the primary goals in analyzing artifacts is to get an idea of how people in the past lived and worked. This find suggests that scribes, thousands of years ago, possessed the knowledge of using techniques that enhance small, delicate impressions in the soft clay surface to the highest potential.

Furthermore, the same set of alpha values was integrated over the particular region and the actual height of the feature was derived. Fig. 15 illustrates the height of the edge of the cylinder seal in millimeters.

Height Information Extracted from the Scan Line in the Surface of the Tablet

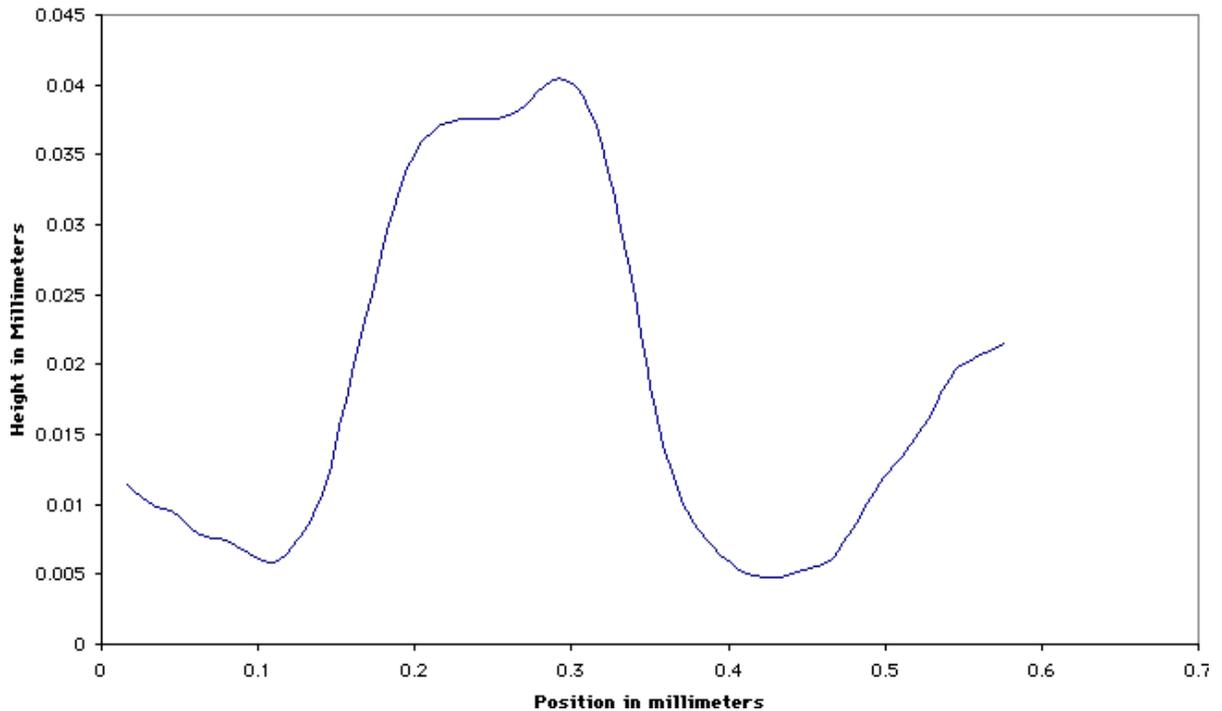


Figure 15: Topographic height across the scan line extracted from the matrix of the Cuneiform tablet.

Conclusion

Future projects applying surface topography analysis would be in surfaces of paintings, Indian rock-art, as well as forensic investigations, such as firearm serial numbers. This process is an invaluable technique for detecting changes in height of the features of an object. Because surface topography characterizes the height of an object, this technique would be beneficial in analyzing its characteristics over a period of time. It would be useful to get angle or height information in the surface of the Cuneiform tablets ten or twenty years from now and compares the results in degradation. Since surface topography offers a way of measuring changes in the surface evolution of an artifact or a piece of artwork, conservators and archaeologists are presented with a clue in these changes. Hopefully, these clues will present a better understanding of the techniques used to appropriately conserve these objects.

Surface Topography of Cuneiform Tablets

Monica Barbu

References

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2. Wilford, John Noble. Who Began Writing? Many Theories, Few Answers. New York Times. 6 Apr. 1999. [URL:www.nytimes.com/library/national/science/040699sci-early-writing.html](http://www.nytimes.com/library/national/science/040699sci-early-writing.html).
3. Bowman, AK; Brandy, JM; Tomlin, RSO "Imaging Incised Documents" Literary & Linguistic Computing: Journal of the Association for Literary and Linguistic Computing. 169-176 (1986).

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Surface Topography of Cuneiform Tablets

Monica Barbu

IDL Code

This is the IDL code written to create the surface topography matrix .

```
PRO linearize
;This program takes each image and runs it through the TTF of the Kodak camera
read_image = DIALOG_PICKFILE(/read)
image = READ_TIFF(read_image)
linear_image = 0.032+0.964*image+0.0009068*image^2-0.000002999*image^3

file = DIALOG_PICKFILE(/write)
WRITE_TIFF,file,linear_image
END

PRO flat_fielding
;This program takes each image along with a reference image and corrects for irregularities in illuminations.
read_image = DIALOG_PICKFILE(/read)
read_referanceimage = DIALOG_PICKFILE(/read)
image = READ_TIFF(read_image)
referance_image = READ_TIFF(read_referanceimage)
print, size(image)
print, size(referance_image)
Pd=2.86
Pref = 94.65
flatfield_image = ((float(image)-Pd)/(float(referance_image)-Pd))*(Pref-Pd)
window, 0
tvsc1, flatfield_image
file = DIALOG_PICKFILE(/write)
WRITE_TIFF, file, flatfield_image
END

FUNCTION divide_images, image_one, image_two
;This function takes two images and finds their ratio.
new_image = image_two
index = where(image_two EQ 0.0, count)
```

```

if count GT 0 then image_two[index] = 0.000001
new_image = float(image_one) / float(image_two)
maximum = max(new_image)
minimum = min(new_image)
return, new_image
END

PRO topography2, h
;This program find the topographic matrix of two images illuminated at two different angle, theta_one and
theta_two.
read_first_image = DIALOG_PICKFILE(/read)
read_second_image = DIALOG_PICKFILE(/read)
image_1 = READ_TIFF(read_first_image)
image_2 = READ_TIFF(read_second_image)

theta_one = 60*!Pi/180
theta_two = 150*!Pi/180
result = divide_images(image_1,image_2)

!p.multi = [0, 1, 3]
plot, image_1[* , 362], title='image one'
plot, image_2[* , 362], title='image two'
plot, result[* , 362], title='result of divide'
!p.multi = 0
result_one = (SIN(theta_one) - (result)*SIN(theta_two))/((result)*COS(theta_two) - COS(theta_one))
window, 3 & plot, result_one[* , 362], title='result 1'
result_two = ATAN(result_one)
window, 4 & plot, result_two[* , 362], title='result 2'

print, min(result_two), max(result_two)
result_three=(float(result_two)-float(min(result_two)))*255.0/(float(max(result_two))-float(min(result_two)))

WRITE_TIFF, 'topography_image.tif',result_three
END

PRO extractline
;This program extract a specified array of data from a chosen image.

```

```
file = DIALOG_PICKFILE(/read)
image = READ_TIFF(file)
section = image[935:950,240]
file_in = DIALOG_PICKFILE(/write)
openw, 1, file_in
num = N_ELEMENTS(section)
FOR i = 0, num-1 DO BEGIN
printf, 1, section[i]
ENDFOR
close,1
END
```

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