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Ancient Cuneiform Text Extraction Based on Automatic Wavelet Selection

[1]Raed Majeed, [1]Zou Beiji, [1,2]Hiyam Hatem,1 and Jumana Waleed

[1]School of Information Science and Engineering, Central South University, Changsha, 410083, China
[2] Department of Computer Science, College of Sciences, Baghdad University, Iraq
raed.m.muttasher@gmail.com, bjzou@vip.163.com, hiamhatim2005@yahoo.com, jumana_waleed@yahoo.com

Abstract

Ancient Iraq was the home of a major urban civilization which developed during 4000-3000 BCE. The Sumerians, who lived in Mesopotamia in southern Iraq, invented the cuneiform system of writing, which was an essential element of Sumerians culture. The translation of cuneiform is a highly complicated process. It is only in comparatively recent years that the grammar has been scientifically established, while the lexical problems are still numerous and far from resolved. Furthermore, most of the Sumerians tablets lost only few old images left, some of it saved in a special collection or worldwide museums. In this paper, we present a novel method used to obtain the cuneiform text from old Sumerian clay tablets, proposed method based on automatically select wavelet bases which it is essential and critical issues for wavelet algorithm implementation. Our procedure offers the archaeological and Cuneiformest an easy, fast and active method for extracting the cuneiform sentences. Experimental results of sample images show that the proposed system has superior result.

Keywords: *Sumerians, Cuneiform Tablets, Cuneiformest, Wavelet Transform, Digital Library*

1. Introduction

Sumerian is a language spoken in southern Mesopotamia, Its earliest cuneiform attestations date from the late 4th or early 3rd millennium BCE [1]. The obvious writing material in Sumer was clay. Clay was widely available and easily molded into suitable shapes (cushion or pillow-shaped ‘tablets’), and writing utensils were easily made for it by sharpening pieces of reed (called a “stylus”). Cuneiform writing constructs Ridges and Grooves on the clay tablet surface. It is these short, mainly straight shapes which have given rise to the modern word “cuneiform” (from the Latin *cuneus*, meaning ‘wedge’) [2]. Archaeological analyst study the sensed data and attempt through a logical process in detecting, identifying, classifying, measuring and evaluating the significance of physical and cultural objects, their patterns [3].

At most Mesopotamian tables have two axes of organization: the horizontal axis to categorized numerical information, and the vertical axis, which the data are attributed to different individuals or areas [4]. The repetitive character of tablet texts is useful for explaining the Sumerian sentences and formulas [5]. Cuneiform Tablets provide an interesting about several topics like: trade, diplomatic journeys and military movements [6], industry, production and economic [7]. The inventory of Cuneiform Tablets was dramatically changed at the end of 2004, in the birthplace of cuneiform (Iraq), 200,000 previously unknown tablets were discovered in the basement of the Baghdad Museum. [8].

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Generally, Sumerian readings and meanings adduced from: Electronic Pennsylvania Sumerian Dictionary (ePSD) [9], Cuneiform Digital Library Initiative (CDLI) [10], Electronic Text Corpus of Sumerian Literature (ETCSL) [11] and from Jagersma 2010 [12].

In Section 2 we'll discuss the main technology used to represent and archive cuneiform tablets, rather than its disadvantages. Section 3 introduces wavelets transform and application. Section 4 explained our proposed method with all the steps involved. The experimental results are presented in Section 5. Finally, Section 6 concludes the paper.

2. Traditional and Modern Techniques

Cuneiformists have used two main techniques to represent and archive cuneiform tablets: hand-drawn copies (autographs), and Three-dimensional technology [13].

Autograph, The traditional registration of inscribed tablets and sealing is done with pencil, caliper and millimeter paper. Trained scholars meticulously measure and copy every detail of the original onto a line drawing, method success can achieved by those who have a thorough knowledge of the specific epigraphy of the script and/or iconography [14] The introduction of digital photography during 1990‟s, provided new opportunities. Software applications allowed for a variety of post-recording manipulations enhance the readability of the details on the images [15] since then, the arsenal of applicable enhancement algorithms has continued to grow and their outcome has become more accurate.

Three-dimensional technology had been applied since Cuneiform tablets are three-dimensional objects by writing on all six sides. Over the years, several solutions have been proposed aiming to obtain a complete 3D model of artifacts [16,8].

2.1 Autograph Disadvantage

It provides a representation of an author's interpretation of what the signs are on a tablet. Manually drawing autographs is a laborious, time consuming, error-prone, and highly subjective process requiring direct access to the tablets. Cuneiformists must apply for travel grants to visit the tablet collections in London, Philadelphia, Aleppo, etc. In addition, though the resulting autographs have the advantage of recording a scholar's interpretation of difficult to read the signs, both the quality of the interpretation and the quality of the drawing vary widely, and disputed readings are common. And in order to verify disputed readings, cuneiformists must apply for additional travel grants to inspect the tablets once again. The entire process is obviously slow, delicate, expensive, tedious, and, in the end, unproductive.

2.2 3D Methods Disadvantage

Time consuming; the 3D method need long time to scan single tablets, rather than the complexity of 3D software to obtain the final 3D shape. Hardware problem; hardware is complex to setup and need technical support. It might even mean that the work can only be done by specialist technician. The main goal of studying the cuneiform is the tablets content text not the color or dimension of the cuneiform tablets. Universally cooperation; Archaeological artifacts is stored all over the world in depots, museums, universities and private collections. The need to travel to many locations, restricted physical access and overall preservation issues are serious obstacles for scholars using any type of recording of artifacts [17, 18].

3. Wavelet Transforms

Wavelet Transform uses multi-resolution technique by which different frequencies are analyzed with different resolutions. Wavelet transform have been widely applied in image

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processing and pattern recognition, The DWT decomposes an input image into multiple subbands [19] .At a certain level of a wavelet transform, a two-dimensional basis consists of a two-dimensional scaling function.

$$\phi\ (x,y) = \phi(x), \phi(y) \tag{1}$$

And three two-dimensional wavelet functions,

$$\psi^{V}\ (x,y) = \phi(x), \psi(y)$$

$$\psi^{H}\ (x,y) = \psi(x), \phi(y) \tag{2}$$

$$\psi^{D}\ (x,y) = \psi(x), \psi(y)$$

After the wavelet transform is applied to an image, the above four functions $\phi\ (x,y)$, $\psi^{V}\ (x,y)$, $\psi^{H}\ (x,y)$ and $\psi^{D}\ (x,y)$ will be generated. They are denoted by functions *A*, *V*, *H*, and *D*, respectively. Function *A* is the trend of the image, and functions *V*, *H*, and *D* measure the fluctuations along the horizontal, vertical and diagonal directions.

Two-dimensional fast wavelet transform (FWT2) is computationally efficient. FWT2 decomposing an image (*m x n*) from level *j*+1 to level *j*. Two-dimensional inverse fast wavelet transform (IFWT2) is an inverse process of FWT2 which uses the scaling and wavelet vectors that are exactly the same as those of FWT2[20].

Also, we should consider two kinds of DWTs in the image processing field and they are the orthogonal wavelet and the compact supported wavelet.

- The orthogonality can provide the convenience in computations.
- A wavelet filter with compact support is non-zero only in a finite interval and the compact support decides the filter width. A wavelet vector $\{g_l : l = 0, \ldots, L-1\}$ with length L should have three basic properties [20]:

$$\sum_{l=0}^{L-1} g_l = 0 \tag{3a}$$

$$\sum_{l=0}^{L-1} g_l^2 = 1 \tag{3b}$$

$$\sum_{l=0}^{L-1} g_l g_{l+2n} = \sum_{l=-\infty}^{\infty} g_l g_{l+2n} = 0 \tag{3c}$$

For all nonzero integer n , $g_0 \neq 0$ and$g_{l-1} \neq 0$.

Figure. 1 shows an image and its Haar wavelet transform with both orthogonality and compact support.

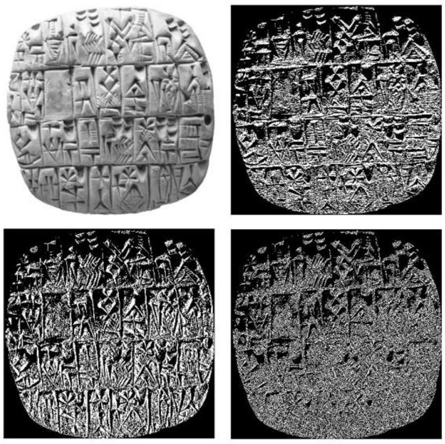

Figure 1. Cuneiform Tablet image with Haar Wavelet Decomposition

4. Proposed Method

Image processing is any form of signal processing for which the input is an image, such as photographs the output of image processing can be either an image or a set of characteristics or parameters related to the image. Cuneiform tablets often suffer from more than one problem due to several factors. Corrosion, dry clay is very sensitive material to the External influences. Sometimes, the cuneiform tablets are missing and only old archive photos with bad quality are exist. In addition, the difficulties of translation and extract text and matching cuneiform texts. Also, the Sumerian tablet presence in different places, *etc.*

Our proposed enhancement algorithm is designed to fix the main problems found in cuneiform tablets. We developed a novel approach for automatic selection of wavelet bases and parameters to extraced the cuneiform text from the Sumerian tablets. Wavelet transform gives attention to the features both in the space domain and frequency domain. Our method able to linking corroded symbols for more cuneiform text elicitation. Our proposed algorithm consists of seven major steps:

1) Wavelet coefficients: choose a specific wavelet transform to convert the cuneiform tablet image and obtain wavelet coefficients;
2) Adjust coefficients: apply filter to adjust the wavelet coefficients;
3) Wavelet Reconstruction: reconstruct wavelet transforms to map the result to the space domain;
4) Orientation estimation: This step determines the dominant direction of the ridges in different parts of the cuneiform tablet image.
5) Frequency estimation: This step is used to estimate the inter-ridge separating in different regions of the cuneiform text image.
6) Segmentation: a region mask is derived that distinguishes between 'recoverable' and 'unrecoverable' portions of the cuneiform tablet image.
7) Filtering: Using the context information consisting of the dominant orientation and separation of the ridges and grooves of the tablet surface, a band pass filter is used to enhance.

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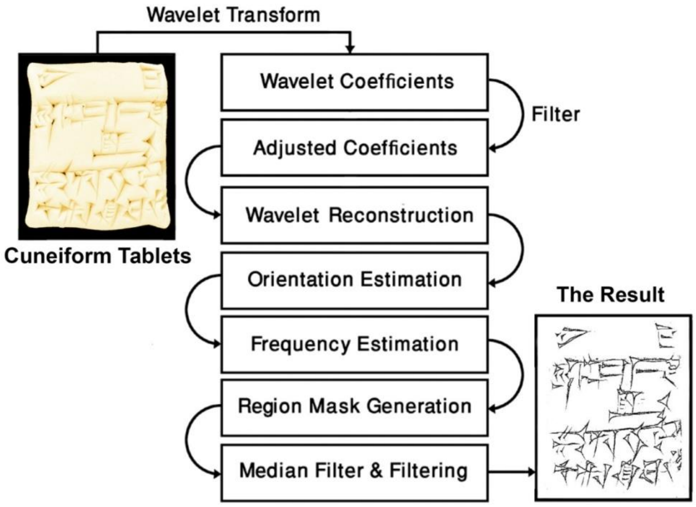

Figure 2. The Stages Involved in the Proposed Algorithm

4.1 Wavelet Coefficients

The selection of suitable DWT is very critical for implementing wavelet algorithms. All available wavelets in our experiments were able to perform contrast enhancement at a certain degree. The shift variance, regularity and number of vanishing moments will affect the wavelet selection [20].The choice of wavelet type made automatically according to the degree of contrast in the input image. Where, the proposed algorithm designed to choose wavelet with the smallest length among all applicable wavelets.

Table 1 lists commonly used compact support DWTs with orthogonal bases: Haar, Daubechies, Coiflets, Symlets and discreteMeyer wavelets.

Table 1. Wavelet Database

Wavelet Type	Parameter	Number of Wavelets
Haar	n/a	1
Daubechies	N. N = 1.2…..30	30
Coiflets	N. N =1. 2. 3. 4. 5	5
Symlets	N. N = 2. 3. …30	29
discrete Meyer	n/a	1

Wavelets in the database were applied to the images one by one, the coefficients of H ($\sum_{x\in H}|x|$) and V ($\sum_{x\in V}|x|$) were computed, and $\bar{x}$ is defined as:

$$\bar{x} = \frac{\sum_{x\in H}|x| + \sum_{x\in V}|x|}{2m \times n} \quad (4)$$

Here, x is the wavelet coefficients, and $m \times n$ is the size of H and V.

According to Eqs. (1) And (2), the coefficients of H and V are the measurements of the horizontal and vertical edges. If wavelet window size in horizontal direction is exactly matched with the section of objects in this direction, $\sum_{x\in H}|x|$ is 0 according to Eq. (3a), conclusion similarly holds in the vertical direction, $\sum_{x\in V}|x| = 0$. Therefore, the wavelet with the smallest $\bar{x}$ is the optimal wavelet which best matches the objects.

4.2 Adjust Coefficients

Wavelet coefficient adjustment done by using designed filter, this filter consists of three major steps. After the wavelet is selected, four parts *A*, *H*, *V*, and *D* at each level will be extracted. Fluctuation coefficients changed *(H, V,* and *D)* and Trend coefficient (A) leaves unchanged. For each part *(H, V,* and *D*) in the decomposition at level *j*, we applied the following designed filter:

Step a) Normalize the coefficients.

$$x^j_{\mathrm{nor}} = x^j_{\mathrm{old}}/MM \tag{5}$$

Where M = $\max\{|x^j_{\mathrm{old}}|\}$, x_{old} is original value at level *j*,

Step b) Adjusting the normalized coefficients:

$$x^j_{\mathrm{adj}} = \begin{cases} \left(\left|x^j_{\mathrm{nor}}\right|^p \cdot T^{1-p}\right)\mathrm{sign}\left(x^j_{\mathrm{nor}}\right) & 0 \le \left|x^j_{\mathrm{nor}}\right| \le T \\ \left(1-\left(1-\left|x^j_{\mathrm{nor}}\right|\right)^p (1-T)^{1-p}\right)\mathrm{sign}\left(x^j_{\mathrm{nor}}\right) & T < \left|x^j_{\mathrm{nor}}\right| \le 1 \end{cases} \tag{6}$$

Selection of Parameter $p \in (1,\infty)$, and p decides the enhancement strength. Because p is an exponential value, a standard linear model with two parameters is developed for estimating the value of p.

$$p = \beta_0 + \beta_1 \ln \bar{x} + \beta_2 \ln T \tag{7}$$

Where β_0, β_1 and β_2 are constants. We can easily observe that p should be greater than 1 for enhancement from Eq. (7). Therefore, if the estimate of p is less than or equal 1, the cuneiform image not enhanced.

Selection of Parameter $T \in [0,1]$, The selection of *T* depends on the wavelet function and the noise level in the original cuneiform tablet image. As mentioned above, after a wavelet transform is applied, noise is more distinguishable in wavelet coefficient *D* than other subbands. Since the threshold value *T* is mainly for eliminating noise, *T* could be computed as follows:

$$T = \frac{\sum_{x \in D}|x|}{m \times n \cdot max_{x \in D}(|x|)} \tag{8}$$

Where $m \times n$ is the size of *D*.

The regions whose wavelet coefficients are less than threshold *T* are de-enhanced, while other regions are enhanced. A larger p will make the image sharper; however, if p is too large, the image may be over-enhanced.

function *sign*(*x*) compute as:

$$sign(x)\begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

Step c) Compute enhanced coefficients by using the following formula:

$$x^j_{enh} = x^j_{adj} \cdot M \tag{9}$$

4.3 Wavelet Reconstruction

After modifying the approximation sub-image, we can reconstruct the final enhancement result cuneiform image, the wavelet used in reconstruction is the same as that used in the decomposition process. Figure 3 illustrates the process of reconstructing an image using IFWT2.

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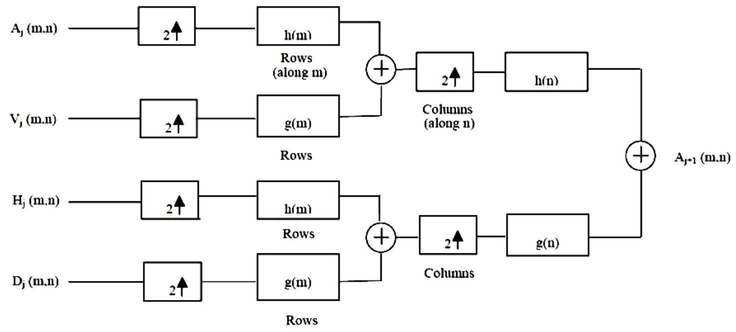

Figure 3. Reconstruction of the Inverse Fast Wavelet Transforms.

4.6 Orientation Image

The orientation image represents an intrinsic property of the cuneiform images and defines invariant coordinates for ridges and grooves in a local neighborhood. By viewing a tablets image as an oriented texture, a number of methods have been proposed to estimate the orientation field [21].

4.7 Frequency Estimation

In a local neighborhood where no symbols and singular points appear, the gray levels along ridges and grooves can be modeled as a sinusoidal-shaped wave along a direction normal to the local ridge orientation .Therefore; local ridge frequency is another intrinsic property of a cuneiform image.

4.6 Segmentation

Pixel (or a block) in an input cuneiform image could be either in a recoverable region or an unrecoverable region. Classification of pixels into recoverable and unrecoverable categories can be performed based on the assessment of the shape of the wave formed by the local ridges and grooves [21].

4.7 Filtering

The configurations of parallel ridges and grooves with a well-defined frequency and orientation in a cuneiform image provide useful information which helps in removing undesired noise. The sinusoidal-shaped waves of ridges and grooves vary slowly in a local constant orientation. Therefore, a bandpass filter that is tuned to the corresponding frequency and orientation can efficiently remove the undesired noise and preserve the true ridge and groove structures. Median filtering is a powerful instrument used in image processing. Traditional median filtering algorithm without any modifications gives good results [22].

5. Experimental Results

The propose method Implemented by using MATLAB version R2012a. The inputs cuneiform tablet images were selected from; Cuneiform library at Cornell University (Garšana collections), this archive consist of nearly 1600 records [23], rather than applied it on samples from Cuneiform Digital Library Initiative (CDLI) [10].

Through the selection of input cuneiform tablet images, we put into consideration the type of tablets like: (good, middle, bad quality). The Execution time was quite fast. The experimental results demonstrate that the proposed method is superior to extract cuneiform text; it's give the cuneiform actual texts sizes and dimensions *i.e.* largest

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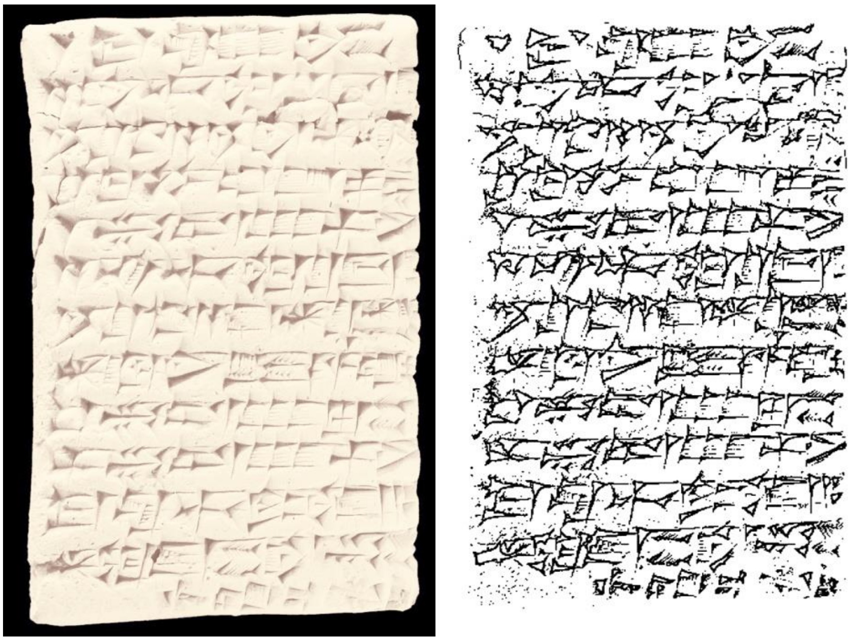
possible accuracy of Sumerian texts obtained as results, Rather than segment each symbol in variety of probability sentence to obtain the exact translation of cuneiform text. The experiment results indicate that noise in the cuneiform could be reduced significantly.

Selecting best bases of wavelets is critical and important for implementing wavelet algorithms. Wavelet transform utilizes local information to decompose an image. The maximum absolute value of each part of the coefficients is used for adjusting the coefficients. It should be noted that only 1-level wavelet is employed in the experiments. Because, the experiments show that in Multiple-level wavelets the improvement is not significant, and it is much more time-consuming to use high level wavelets. The bellow Figures show the input Sumerian tablet and result cuneiform text.

(a) (b)

Figure 4. a) Input Sumerian Tablet, b) Result Cunieform Text



(a) (b)

Figure 5. a) Input Sumerian Tablet, b) Result Cunieform Text

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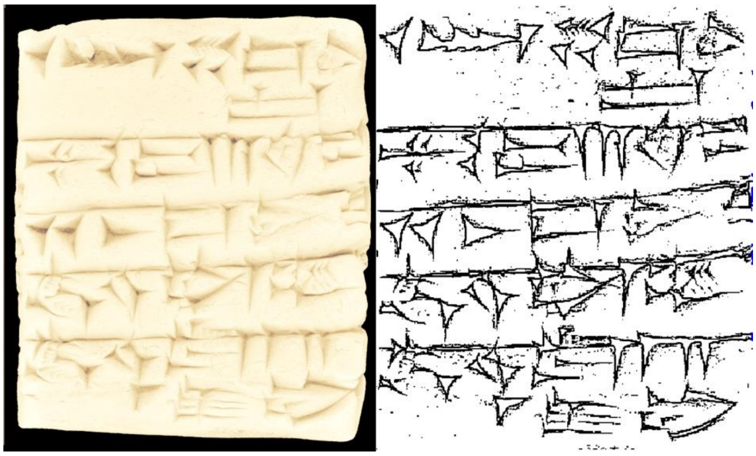
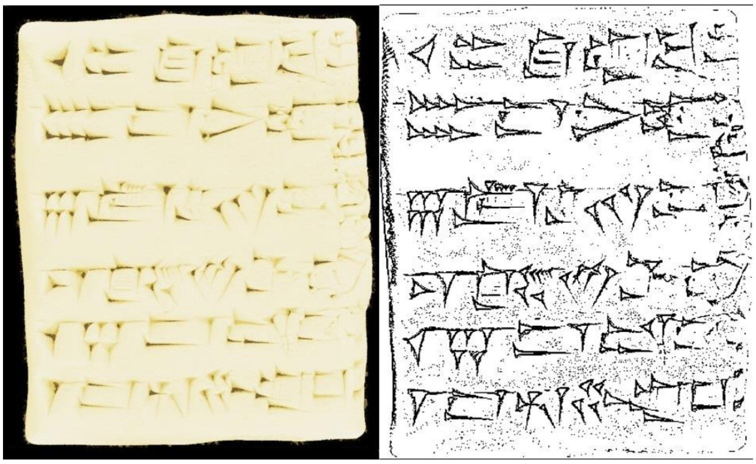


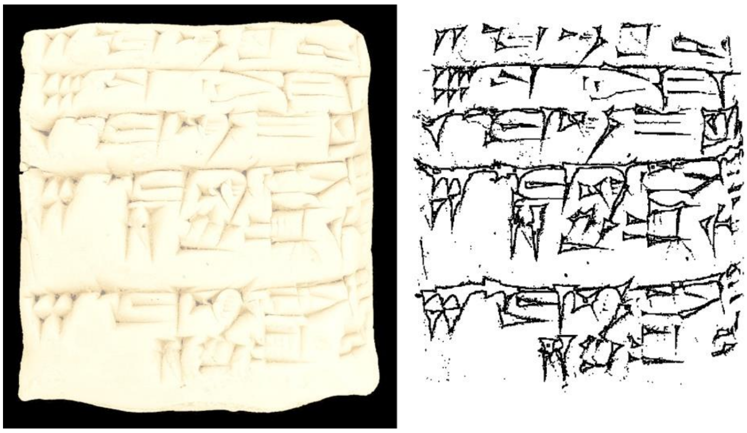
(a) (b)

Figure 6. a) Input Sumerian Tablet, b) Result Cunieform Text



(a) (b)

Figure 7. a) Input Sumerian Tablet, b) Result Cunieform Text



(a) (b)

Figure 8. a) Input Sumerian Tablet, b) Result Cunieform Text

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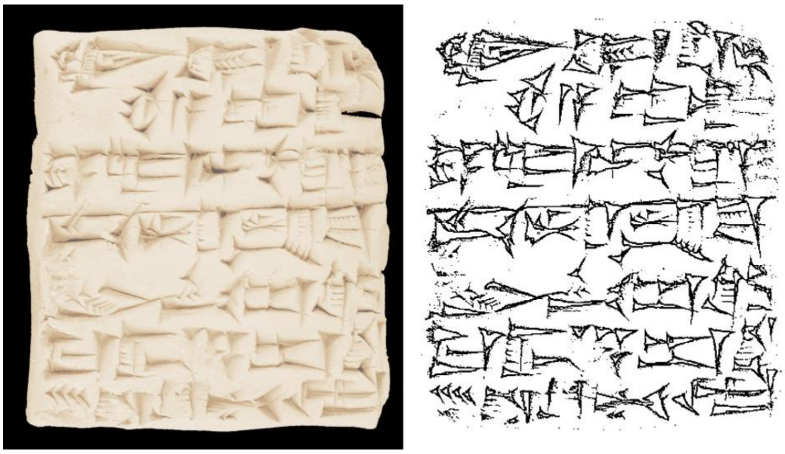

(a) (b)

Figure 9 a) Input Sumerian Tablet, b) Result Cunieform Text

6. Conclusion

Sumerian language is stands alone and seems to be unrelated to any other language; living or dead. Cuneiform systems of writing distinguished by its wedge-shaped marks on clay tablets, the translation of cuneiform are a highly complicated process even for archaeological and cuneiformest. The dry clay material is very sensitive to moisture and corrosion factors, some of the letters are worn, damaged, or missing. On other hands, modern and traditional techniques used to archive the cuneiform have some lacks in: reliability, accuracy, accessibility, time consuming, usability and hardware cost. There have few archives of distributed digital libraries, special collection and museums, and the recent discovery of over 200,000 unknown tablets in Baghdad museum in 2004. In most cases, Sumerian tablets provided with bad quality.

In this paper, we present reliable technology to support cuneiformest and archaeological researchers. Our proposed enhancement algorithm is designed to dealing with several defects found in cuneiform tablets, such as: Contrast and Brightness, the input cuneiform tablet image is normalizing the global statistics, *i.e.* the contrast and brightness of the Sumerian tablet image are normalized as a result. Wavelet transforms utilizes local information to decompose an image, and the maximum absolute value of each part of the coefficients is used for adjusting the coefficients. The Corrosion, our method employs contextual filters properties that have the ability to link broken symbols in the text, which would lead to more accurate in the future stages of the translation process. The proposed approach may be very useful for many applications in image processing, pattern recognition and could be applied for Egyptian hieroglyphics, Assyrians, Babylonians and Akkadians later.

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Authors

Raed Majeed Muttashe, he received his B.Sc. in Computer Science from Baghdad University, colleges of science, computer department in 2004. He received the Master Degree in applied computer technology from Wuhan University, school of computer in 2011, P.R. China. He is currently working toward his Ph.D. degree at Central South University, School Of Information Science And Engineering, P. R. China. His research interests include 3D

Object Recognition, 3D Modeling, Pattern Recognition, and Image Processing.

Zou Beiji, he holds a Ph.D. in Computer science and technology from Hunan University, China. He is currently a Professor in School of Information Science and Engineering of Central South University, China. He worked at Zhejiang University, China as a visiting scholar from Jul.1999 to Jun. 2000 and at Tsinghua University, China as a post-doctor from Jan. 2002 to Nov. 2003 respectively, engaged in research about Human Facial Expressional Recognition and Animation. He worked in the research field of Multimedia Technology at Griffith University in Australia from Dec. of 2003 to Dec. of 2004.Interest area of research: Digital Image Processing, Computer Graphics, Multimedia technology, Software Engineering.

Hiyam Hatem, she received the BS degree from the department of computer science, Baghdad University, Iraq, 2003.The master degree from Huazhong University of science and technology Wuhan, China, in 2010.Currently, she is a PhD student in School of information science and Engineering at Central south university, Changsha, China. Her research interests include face processing and recognition, object detection, pattern recognition, computer vision, and biometrics.

Jumana Waleed, she is a Ph.D. student in the School of information science and Engineering at Central South University, Changsha, China. Her research activity focuses on image processing, and information security working on digital watermarking. She received the B.S. degree in computers sciences from the Al-Yarmouk University College, Iraq, in 2004, and the M.S. degree in Computer Science/Data Security from the University of Technology, Baghdad, Iraq, in 2009.

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