A PHOTOGRAMMETRIC ANALYSIS OF CUNEIFORM TABLETS FOR THE PURPOSE OF DIGITAL RECONSTRUCTION

A. Lewis, E. Ch'ng

IBM Visual and Spatial Technology Centre, Institute of Archaeology and Antiquity, University of Birmingham, Edgbaston, Birmingham, B15 2TT – (axl148, e.chng)@bham.ac.uk

KEY WORDS: Cuneiform Reconstruction, Photogrammetry, Assyriology, Archaeometrics , VISTA-CR

ABSTRACT:

Despite the advances made in the recording and cataloguing of cuneiform tablets, there is still much work to be done in the field of cuneiform reconstruction. The processes employed to rebuild cuneiform fragments still rely on glue and putty, with manual matching of fragments from catalogues or individual collections. The reconstruction process is hindered by inadequate information about the size and shape of fragments, and the inaccessibility of the original fragments makes finding information difficult in some collections. Most catalogue data associated with cuneiform tablets concerns the content of the text, and not the physical appearance of complete or fragmented tablets. This paper shows how photogrammetric analysis of cuneiform tablets can be used to retrieve physical information directly from source materials without the risk of human error. An initial scan of 8000 images from the CDLI database has already revealed interesting new information about the tablets held in cuneiform archives, and offered new avenues for research within the cuneiform reconstruction process.

1. INTRODUCTION

The term cuneiform is often used to describe an ancient logographic script that has it's origins in Mesopotamia, the area of the Tigris-Euphrates river system that includes modern day Iran and Iraq. Cuneiform script is distinguished by the characteristic wedge-shaped impressions that form the sub-elements of each symbol. Cuneiform is most frequently found on clay (or stone) tablets, seals, and markers from the ancient near east.

Cuneiform tablets vary in size from approximately an inch to (in some cases) over a foot in length(Anderson, 2002). Despite the implications of their taxonomy, the term 'tablet' may refer to one of a number of shapes. The most notable deviations from the expected form of a clay tablet can be found in collections of seals and stamps, which may be cylindrical or even spherical in their geometries. Other 'tablets' may be conical, cubic, prismatic, or rectangular in appearance(Walker, 1987).

The historical data contained within the clay tablets is diverse, as would be expected from a civilized culture in the height of its development. Cuneiform is used to convey information on mathematics, law, medicine, contemporary events, shop inventories and orders, educational matters, royal decrees, and certificates of authenticity from traders.

The intellectual diversity of the tablet contents is matched only by the considerable variation in their physical structure and condition. Depending on the contents of the inscription, a clay tablet might have been sun dried or kiln fired to preserve it. Unfortunately for modern scholars, sun dried tablets are chemically unstable, and are susceptible to damage from a multitude of sources. Aside from the obvious risk of water or shock damage, some types of clay contain mineral salts that can crystallize on the surface of tablets over many years. If left untreated, these crystals can cause irreparable damage to the inscribed surfaces of a tablet(Organ, 1961). Even fired tablets are not immune to damage, and special handling procedures are necessary to prevent damage to the fragile artefacts (The British Museum, 2011). The range and quantity of cuneiform tablets collected during the 19th and early 20th century mean that the need for proper referencing and documentation is paramount. Unfortunately, the pioneering scholars of cuneiform studies had limited tools for the recording of finds, and individual scholars familiarity with the collections led to some delay in the creation of detailed catalogues.

At the British Museum, the Kuyunjik collection represents a clear example of the effect of delays in cataloguing. Although excavated in the 1850s, many of the tablets were uncatalogued for several years. It was only the intervention of Samuel Birch, the Keeper of Oriental Antiquities at the British Museum, that lead to the development of a cataloguing system for cuneiform artefacts.

The matter of cataloguing the thousands of items in the department of Oriental Antiquities was not a simple one. Finds from different excavations had been mixed together over time, and there was (at that time)little to distinguish finds from the Kuyunjik mound at Ninneveh with those from other sites (Reade, 1986). Birch was no expert in the translation of Cuneiform text, and despite raising the issue of a catalogue several times, it would be over 30 years before a beginning was made by Birch's replacement (Sir Peter le Page Renouf).

Complete catalogues of the Kuyunjik collection were produced between 1889 and 1896, and provide a 2500 page record of the of 22,220 tablets (Budge, 1925). The tablet descriptions in the Kuyunjik catalogue are detailed, but there are no illustrations of physical shape for the tablets fragments, and only basic measurements of the physical size are included. While this is

Modern recording efforts by the CDLI (Cuneiform Digital Library Initiative) include clear, high resolution colour scans of

the Kuyunjik collection, but, like so many other records, the sizing information included with the database is incomplete.

Images frequently lack scale information, and although some sizing information may be included in a catalogue, the units of measurement may be omitted. Furthermore, the measurements given may be the product of human approximation rather than scientific method, and the descriptions in a museum catalogue can be as vague as "approx. 2 inches across".

A greater understanding of the physical properties of cuneiform tablets is necessary for anyone wishing to facilitate their reconstruction. Without an appropriate template for a complete cuneiform tablet, the process of fragment matching becomes unbounded and difficult to predict.

3D scanning of fragments can provide accurate geometric data that can be manipulated and tested in a virtual environment, but the process of 3D scanning is time consuming.

Since a large number of 2D photographic records are already accessible within the CDLI database, it makes sense to gather as much information as possible from them using the process of photogrammetry.

This paper describes a results of a preliminary scan of over 8000 tablets from the CDLI database, for the purposes of facilitating automatic, semi-automatic, and manual reconstruction as part of the VISTA-CR (Virtual Imaging, Sorting and Transmission Algorithms for Cuneiform Reconstruction) project at the University of Birmingham.

VISTA-CR aims to facilitate the automatic, semi-automatic, and manual reconstruction of cuneiform fragments using collaborative interaction through a web based interface.

2. METHOD

There are three reasons why the CDLI database at UCLA presented a practical resource for automatic photogrammetric analysis:

1) A sufficiently large body of complete tablets were available for study with appropriate copyright attribution.
2) The tablets were for the most part scanned into the computer using a flatbed scanner, not a digital camera on a stand.
3) EXIF data was present in the stored images, and appropriate DPI information could be extracted from the data.

A Python script was used to parse through the records in the CDLI database. The Python language was chosen because it is a modular, cross-platform language, and is easy to program. The python script was able to download, examine, and store images of cuneiform tablets that were candidates for further analysis. Candidacy was determined by the size (pixel-count) of the downloaded images and by the qualities of the image histogram. Files of less than 20 kilobytes, images with a DPI lower than 150, and achromatic (black and white) images were all discarded automatically.

Unfortunately, it was not practical to differentiate between complete tablets or fragments automatically, so manual sorting

of source images was employed to separate fragments and remaining invalid images from valid sample data.

The final image set consisting of 8078 samples was passed into another Python script, which scanned each image vertically and horizontally using a simple threshold measure based on the background colour of the image. The largest values from scans in the X and Y axis were used to determine the width and height of the tablet, using the DPI of the scanned image to facilitate the conversion from pixels to millimetres.

The accuracy of the photogrammetric measurement script was tested by direct comparison with known correct data from the CDLI database. In all tested cases, the data was found to be accurate within approximately one millimetre of the recorded values. The resulting data was sorted by period, and analysed using simple statistical methods.

3. RESULTS

After some basic processing, the photogrammetry data reveals that the average size of a cuneiform tablet is 43mm wide by 51mm high. The likelihood that any given tablet from the sample set has a diameter between 23mm and 62mm is over 88%, and a similar range between 25mm and 76mm for the height of a tablet yields a probability of roughly 85%. **Figure 1** shows the distribution of width and height for the X and Y axis.
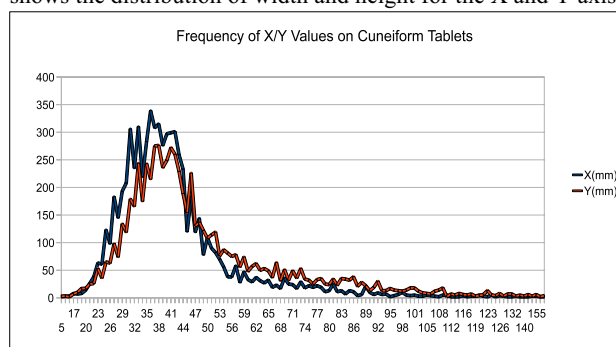

Figure 1: Graph showing the frequency of width and height values (in millimetres) for complete cuneiform tablets

An analysis of ratio between width and height for each tablet has shown that the shape of tablets is far from random. The sample shows a marked bias towards an approximate width to height ratio of 1:1 and a lesser bias towards a golden ratio conjugate of 0.625:1. The graph shown in Fig. 2 illustrates this relationship between width and height.
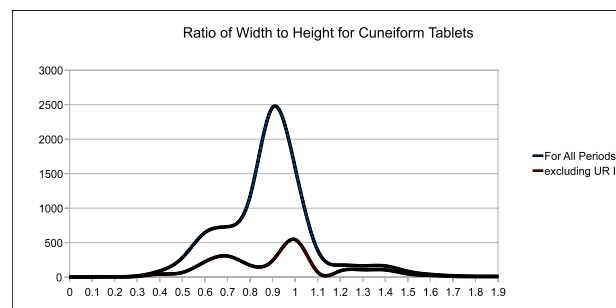

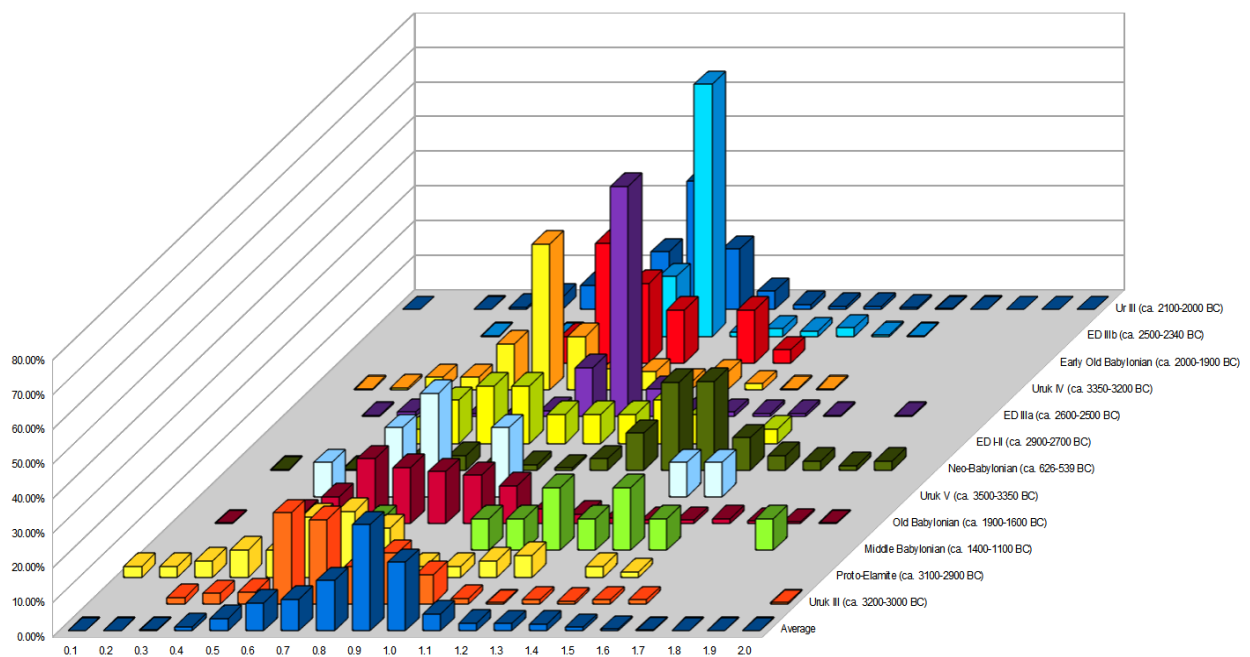**Figure 2:** Graph showing the ratio between the width and height of cuneiform tablets.

Figure 3: Graph showing the ratio between the width and height of cuneiform tablets separated by period.

It is important to note that a large proportion (approximately) of the analysed tablets are from the period UR-III. In order to ascertain whether the ratio bias was a phenomenon associated primarily with the period UR-III, a separate analysis was made that excluded results from this period. As the graph in **Figure 2** shows, the 1:1 and 0.6:1 trend still seems to be present in the filtered subset of data.

The graph in **Figure 3** provides a deeper analysis of the ratios by era, showing that the range of ratios does seem to cluster around the averages of 0.6:1 and 1:1 depending on the period.

4. DISCUSSION

As has already been stated, the primary motive behind the metric analysis of complete tablets was to provide a basis for further research into fragment reconstruction via the VISTA-CR reconstruction project.

The information presented here does provide statistically significant evidence that the shape and size of complete cuneiform tablets is to some extent predictable, and this provides an important clue for the reconstruction process.

A broad measure of the likelihood of a match between multiple fragments can be predicted by the simple addition of individual fragment sizes. Given the information above, the probability of a match should decrease as the combined fragment sizes deviate from the average size of a complete tablet.

It is also likely that the ratio of width to height can be used in a similar way to reduce the number of possible matches in cases where a complete exterior side is preserved in a tablet fragment.

Although the initial photogrammetry has been performed in 2D, it is hoped that an analysis of fragments in 3D will provide additional scope for matching and presorting metrics. This

theory is supported by preliminary investigations using a limited set of 3D models, which have shown that the approximate orientation of a fragment in 3D can be calculated by the simple analysis of a point cloud's absolute minimum bounding box.

The nature of complete cuneiform tablets (and larger fragments) is such that the absolute value of $Z_{(max)}$ - $Z_{(min)}$ will most likely be significantly less than the values for $X_{(max)} - X_{(min)}$ and $Y_{(max)}$ - $Y_{(min)}$. This means that orienting the fragment such that the bounding box Z axis is parallel to the world Z axis should orient larger fragments so that the main inscribed surfaces are near parallel to the X and Y axis.

A customised scanning platform was created to facilitate the acquisition of 3D range and surface data from cuneiform tablets using structured light rather than lasers. Low intensity structured light was used to minimize some of the more difficult problems associated with laser based systems (such as quantum speckle and subsurface scattering) while still allowing for a high level of detail from multiple layers of contrast and phase analysis. An example scan from the new scanning system can be seen in **Figure 4**.

The scanning platform is built around a telescopic photographic copy stand, with a wide aluminium flash bar holding an Acer C10 projector and Canon EOS 600D camera. The camera and projector are connected to a laptop computer using a USB connection. Although designed for structured light scanning, the setup can also be used with a laser wand to generate a conventional laser scan of objects. A ball-jointed camera mount has been added to the top of the copy stand to allow for free mounting of the scanning head. The free range of motion of the head makes it easy to scan in vertical or horizontal configurations.

At the time of publication, the VISTA-CR scanner has been used on a small number of cuneiform fragments and assorted paleolithic objects, but a larger scale scanning effort will begin in late 2012 as part of the ongoing VISTA-CR project.

Figure 4: Sample tablet scan from the customised 3D scanner.

The accuracy of the VISTA-CR scanner depends on a number of factors, including the hardware used and the size of the object being scanned. The specifications of the camera and the projector most important, since the resolution of these devices will determine the maximum number of points that the scanner can sample in one scanning pass. If the maximum size of a scanned object is 1000mm square, then the maximum resolution of the scan using an 800x600 webcam and projector will in theory be (800*600)/1000, or 480 samples per mm. In practice however, this resolution would probably be lower, as it is unlikely that the projector and camera could be calibrated perfectly together.

The scanning process is fast (usually under 30 seconds per scan), and multiple scans of a surface can be taken in under one minute. A complete cuneiform fragment can be fused together from 8 scans in approximately 10 minutes, and then exported in a format that the VISTA-CR system can process.

Practical experimentation with the system has shown that the principal disadvantage of the structured light scanning process is a sensitivity to incidental light. The intensity of structured light projections is much lower than laser line projectors, and environmental lights will reduce the ability of the scanner to capture clean data. For this reason, scanning is carried out in a light controlled environment, away from direct sunlight.

5. FUTURE WORK

Following on from the process of orientation by bounding box, the pre-orientation of tablet fragments using the cuneiform markings as a reference point may provide a significant speed boost to the assisted and automatic fragment matching process.

Since text direction will be consistent across the surface of a cuneiform tablet, it is reasonable to presume that orientation based on text direction will provide a uniform starting position for many matching algorithms.

The popularity of OCR software has ensured that a number of language independent methods exist for the orientation of written data (Hochberg, 1995; Lu, 2006), and it is probable that these can be adapted to suit the cuneiform text found on the tablets. The characters themselves can be retrieved using a relatively simple thresholding filter that can create a 2D map of the rate of change of height across the surface of the tablet. This method of surface feature detection has been used successfully in Stanford's Forma Urbis Romae project. (Koller, 2006; Koller, 2004; Laugerotte, 2004)

The identification of 'good' and 'bad' edges or surfaces could also lead to a radical reduction in the amount of data that needs to be processed during the reconstruction process. If we assume that an intact, undamaged edge or surface on a tablet is 'good' and a broken edge is 'bad', we can discard (or at least severely reduce the importance of) those 'good' edges from the matching process.

A 'bad' edge will always connect with another 'bad' edge, and the relative positions of the 'good' edges can be examined to improve the certainty of a match. Detection of these 'bad' edges may not be difficult. Physical markers like asymmetry should provide a strong marker broken edge, and such asymmetry be detected quite easily. Analysis of the fractal dimension (Wong, 2005) of an edge might also provide a useful method for detecting 'good' and 'bad' edges. It may even be possible to use the fractal index of a 'bad' edge to generate potential fragment matches by modifying the techniques exploited by Papaioannou & Karabassi (Papaioannou, 2002), although this will need to be tested experimentally.

A simple count of the number of surfaces that have markings can also be used to reduce the number of cycles required to generate a match. If a tablet has markings on both sides, and has been chosen as a potential match based on it's physical dimensions, it may be that a simple 180 degree rotation around the match surface could make the difference between a good or bad match. This scenario is most likely in the case of a shear break that runs across a tablet, nearly perpendicular to the 'good' edge of the tablet.

Further pre-processing of data can be used to generate a list of the angles for all corners of a tablet fragment. These low volume lists of angles could be searched quickly to identify potential matches (Onsjo, 2009; Schatz, 2007), or used to generate simple polygon models as shown by Konoh and Kato(Masayoshi, 2001-06).

The manual and automatic processing of fragments will take place on the VISTA-CR server. VISTA-CR is a 2D and 3D reconstruction framework that aims to provide a robust system for the automatic, semi-automatic, and manual reconstruction of cuneiform tablets. The framework is designed to use techniques taken from complexity science (specifically emergence and stigmergy) to facilitate the interaction of multiple concurrent, pattern, edge, and surface matching algorithms in a distributed and collaborative way.
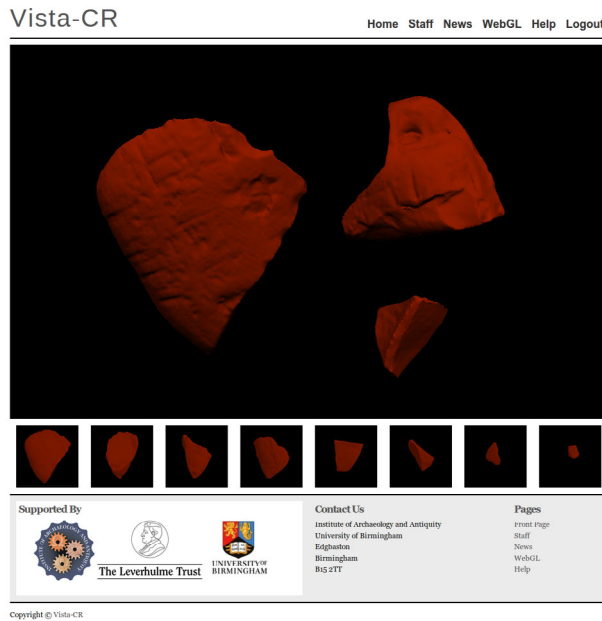
Figure 5: The VISTA-CR 3D web interface.

The web based VISTA-CR interface (shown in **figure 5**) has been created to facilitate human interaction with cuneiform fragments online. The interface is designed to run on the Google Chrome platform, under Windows, Linux, and Apple Mac computers with an appropriate pointing device. The display currently supports 2D and 3D monitors with shutter or passive glasses, and future development will improve the interface of the system for multi-touch devices.

Although the hardware requirements for visualisation are higher than most websites, the interface performs as expected on a computer or laptop of moderate power, with a normal connection to the internet. Data transactions are minimized by local caching, and further improvements will be made to increase performance in this area as the project advances.

6. CONCLUSIONS

We have shown that there are areas of predictability within the size of cuneiform tablets, and explained how these predictable features can be exploited to improve the speed and accuracy of suggested matches between cuneiform fragments in the VISTA-CR system.

By implementing these different algorithms as agents within a framework for stigmergic collaboration(Elliott, 2007), it is hoped that fast, accurate methods for distributed cooperative reconstruction of cuneiform and other archaeological fragments can be developed to assist the digital heritage community.

7. ACKNOWLEDGEMENTS

8. REFERENCES

Anderson S & Levoy M. 2002. Unwrapping and visualizing cuneiform tablets. *IEEE Computer Graphics and Applications* (**22**): pp.82-88.

Budge E. 1925. The rise and progress of assyriology. M. Hopkinson & co., ltd.

David Koller, Jennifer Trimble, Tina Najbjerg Natasha Gelfand & Levoy M. 2006. Stanford's digital forma urbis romae project. pp. 237-252.

Elliott M. 2007. Stigmergic collaboration: a theoretical framework for mass collaboration. University of Melbourne, Victorian College of the Arts, Centre for Ideas

Hochberg J, Kerns L, Kelly P & Thomas T. 1995. Automatic script identification from images using cluster-based templates. *IEEE Transaction on Pattern Analysis and Machine Intelligence* (**19**): pp.176-181.

Koller D & Levoy M. 2004. Computer-aided reconstruction and new matches in the forma urbis romae.

Laugerotte W, Warzée, e, N, Chrysanthou Y, Cain K, Silberman N & Niccolucci F. 2004. An environment fot the analysis and reconstruction of archaeological objects. p. 165--174.

Lu S & Tan CL. 2006. Automatic document orientation detection and categorization through document vectorization.

Masayoshi K, Shohei K & Hidenori I. 2001-06. Earthenware reconstruction based on the shape similarity among potsherds. *Forma* (**16**): pp.77-90.
Onsjo M & Aono Y. 2009. Online approximate string matching with cuda. *Technology* pp. 1-4.

Organ RM. 1961. The conservation of cuneiform tablets. *The British Museum Quarterly* (**23**): pp. p. pp. 52-58.

Papaioannou G, Karabassi E & Theoharis T. 2002. Reconstruction of three-dimensional objects through matching of their parts. *IEEE Trans. Pattern Anal. Mach. Intell.* (**24**): pp. p. 114--124.

Reade JE. 1986. Archaeology and the kuyunjik archives. *Cuneiform archives and libraries: papers read at the 30e Rencontre Assyriologique Internationale, Istanbul: Nederlands Historisch-Archaeologisch Instituut te Istanbul* pp. 213-222.

Schatz MC & Trapnell C. 2007. Fast exact string matching on the gpu.

The British Museum. 2011. Handling the cuneiform collection.

Walker C. 1987. Cuneiform. University of California Press

Wong A, Wu L & Gibbons PB. 2005. Fast estimation of fractal dimension and correlation integral on stream data. pp. 91-97.