3D-SUTRA – INTERACTIVE ANALYSIS TOOL FOR A WEB- ATLAS OF SCANNED SUTRA INSCRIPTIONS IN CHINA

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ABSTRACT:

Buddhistic stone inscriptions (8th-12th centuries) are important cultural assets of China which need to be documented, analyzed, interpreted and visualized archaeologically, art-historically and text-scientifically. On one hand such buddhistic stone inscriptions have to be conserved for future generations but on the other hand further possibilities for analyzing the data could be enabled when the inscriptions would be accessible to a larger community, for instance the understanding of the historical growth of Buddhism in China could
In this article we show innovative techniques for the documentation of stone inscriptions located in the province of Sichuan - south-west of china. The tasks to be performed comprise capturing of stone inscriptions by using high precision measuring techniques to generate copies of the original inscriptions and the processing of the data enabling the improvement of the legibility of characters and thus supporting the interpretation of the inscriptions. We show the concept and features of the image processing applied on the captured inscription. In order to present the outcome to a large community and to allow individual interpretations, the results of the stone inscription reconstruction, the interpretation and additional 2D / 3D maps are published within an interactive web platform.

1. INTRODUCTION

The religious tradition of the buddhistic teachings was originally based on verbal communications and had been replaced by written documentations in a later stage. The written buddhistic teachings are called Sutra. The Sutra is usually concerned with a certain topic as for example with the perfection of the wisdom, which is brought out as a central theme in the Diamond Sutra and in the Heart Sutra.

Sutras are already published in the 1st century AD using wood panel printing techniques. For a permanent preservation buddhistic monks began to engrave the Sutras into stones. These Sutras give an incomparable view into the groves of the Buddhism (Ledderose, 2006), why our project “3D-Sutra” tries to document the texts and to present them to the scientific public.

The Sutras in the province Sichuan so far are not very well studied by Chinese side. These inscriptions light up the history of the Buddhism in China from another side and clarify its growth, thus its adaptation to the Chinese culture and its conflict with the secularized state (Ledderose, 1981). The goal of our research project is the documentation, improvement, analysis and interpretation of these important Chinese inscriptions on an archaeological, art-historical and text-scientifical base. This project is an interdisciplinary cooperation of experts from different disciplines like sinology, cartography, geoinformatics and surveying.

In the province Sichuan are approximate 80 Sutras with more than 600,000 characters at six different sites located. Among them are such important Sutras as Diamond Sutra, the Heart Sutra and the Nirvana Sutra.

The buddhistic stone inscriptions will be documented with high resolution structured light 3D scanning. Such scanning data provides precise virtual copies and makes the texts accessible to computer based treatments. Especially due to the spatial characteristics, the digital models might be virtually analyzed using 3D computer graphics based processes as texture, lighting and shading. This allows a close-to-reality presentation of the Sutra and individual analysis steps without the need to access the original, but with quality potential close to a real work in front of the rocks.

An appropriate processing chain for the 3D data will be presented using methods of digital image processing. It provides preprocessing tasks indispensable due to structure and volume of the data, and conversions into special products which supports interactive analysis steps. Furthermore special processing algorithms are useful to improve the legibility of the texts and allow an acceleration of the text decoding or may contribute by structural analysis procedures dedicated to make certain characteristics of individual characters visible.

2. DOCUMENTATION OF THE INSCRIPTIONS

Traditionally the stone inscriptions are documented using rubbings (Ledderose, 1981). These rubbings represent an analogue copy of the stones surface and its features which are reproduced on paper. This is performed by stitching a paper on the stone and rubbing by means of a carbon pencil, what copies the engraved inscriptions onto the sheet of paper. As a result, all parts in contact to the wall appear in black, while the engraved inscriptions remain white. The disadvantage of this technique is that the physical impact damages the stone and its inscriptions.

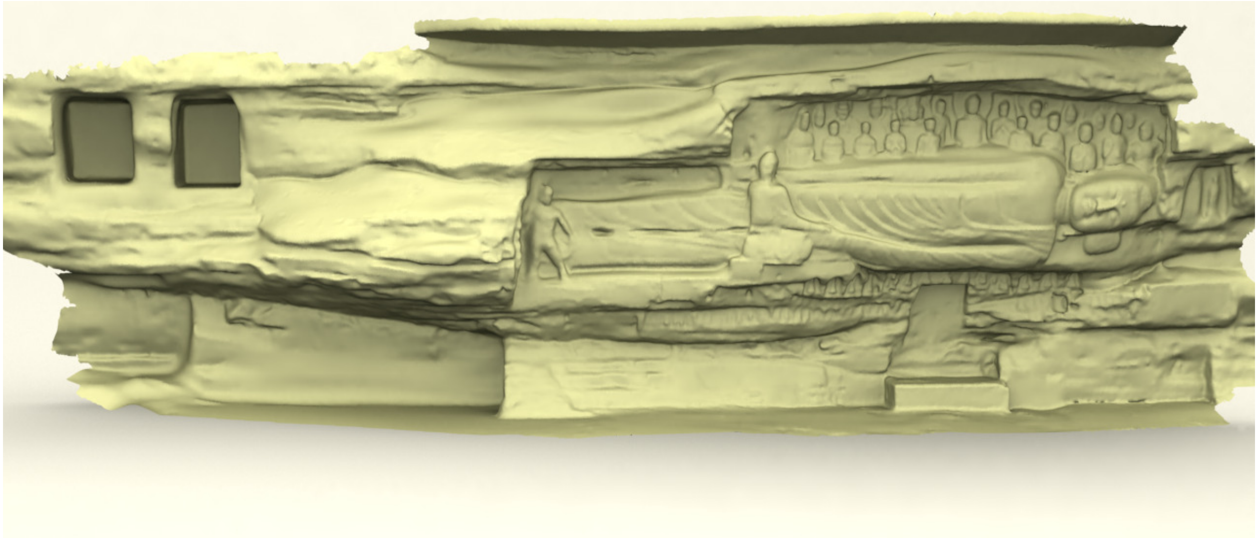

Figure 1. 3D model of the topography

These problems will be avoided by non-contact 3D-measuring techniques, like fringe projection, for example. But the advantages of modern 3D techniques are not limited to an objective documentation capability. Simple changes of the equipment may change scale and resolution comparably and allow further documentation approaches. So, precise detailed models might be complemented by local and regional models permitting further analysis processes and spatial considerations thus extending the potential for art-historian research.

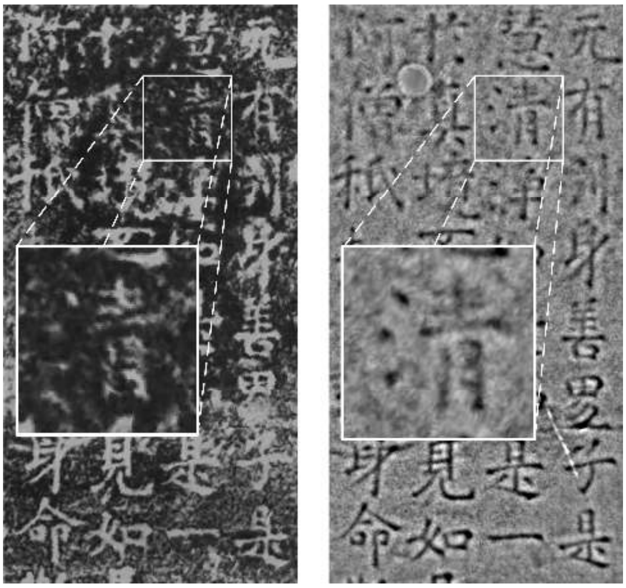

Figure 2. Comparison of rubbing (left) and processed results of the fringe projection (right)

With respect to the high resolution 3D technique the data collection provides an exact geometrical copy of the original inscription offering better results in legibility of each character compared to the traditional rubbing (see Figure 2). Moreover it gives a more objective base for analysis and has less impact onto the sometimes sensitive and eroded surfaces. Furthermore the 3D data of the Sutras allows more and other possibilities in processing and gives better preconditions for the interpretation. In regard of the local context, geometrical relations between inscriptions or parts thereof may simplify their interpretation and offer to model the spatial and regional context of the different Sutras among each other. That's why it is of general value to use various measuring techniques in the field in order to optimize the framework for the documentation and analysis of art-historical objects (Boochs et al. 2006).

Present-day measuring technique for local and regional investigations is Terrestrial Laserscanning. It is used to capture the 3D geometry of the environment around the inscriptions. The resulting 3D pointcloud documents the topography so that the relative position of the inscriptions on each other can be expressed. Based on the point clouds a precise 3D model can be created (e.g. Figure 1), which is used to analyze the spatial relationships of the Sutra sites and also allows to visualize the objects in a virtually environment.

For high resolution scans a fringe projecting system can be used allowing the capture of 3D geometries in size of less than 1 m³. It offers a close-to-detail 3D pointcloud of the inscriptions (Böhler et al. 2004). This provides more possibilities in processing and supports the interpretation by different methods of 3D visualization (Hanke, Böhler 2004) as shown in Figure 3. The buddhistic stone inscriptions which have an extension of up to 3x4 m are scanned with a lateral resolution in the order of 0.25 mm. The Sutra characters are round about 1 cm².

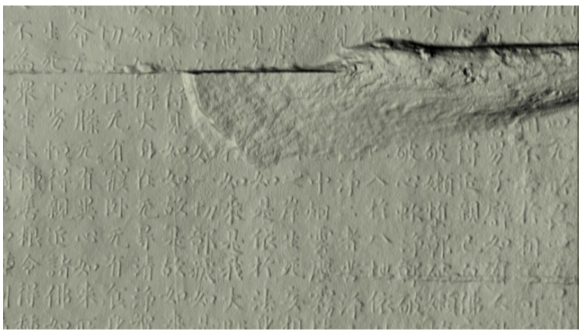

Figure 3. 3D model of the inscriptions

In addition to Laserscanning and structured-light 3D scanning we used Polynomial Texture Mapping (PTM), Stereo Photogrammetry and Panoramic Photography for the documentation of the inscriptions and their environment. They represent an alternative with different information content and use (Hoffmann et al. 2006). These techniques can be an alternative if an object is not reachable with the high-tech equipment e.g. the Terrestrial Laserscanner or structured-light scanner. In that case Stereo Photogrammetry offers good visual information and a precise basis for measuring, but needs good contrast for optimal results. This might not be the case for damaged and eroded characters .Also, the spatial information is only implicitly included, why it might be necessary to apply manual or automatically post processing when the spatial information of the character is explicitly needed.

Polynomial Texture Mapping (PTM) mainly provides a plastic visualization which is used for the manual interpretation (Malzbender et al. 2010). PTM is used for displaying an object under various lighting direction. The PTM is created by photographing an object multiple times with various lighting directions. These PTMs provides a deeper look onto each character which supports the interpretation of the inscription in an additional way. However, this kind of data is only two-dimensional.

3. PROCESSING

The original 3D data sets represent a large data volume. An effective use of these data can only be realized if they are condensed and prepared in an adequate way. This means the reduction of the data volume, minimizing disturbing influences and emphasizing relevant information. The preparation of the data should offer a good base for a manual interpretation performed by the sinologist and also serve as base for an automated interpretation achieved by algorithms like template matching (Steinke 2009). On the other hand the data should be prepared for a performant presentation to a wider community via internet.

3.1 Handling the Amount of Data

Due to the high resolution – the texts will be represented by spatial elements of some microns in size - areas of some square meter will generate millions of spatial elements, which have to be handled and processed. Thus it is essential to have a closer look into aspects of data reduction and / or efficient data handling. Therefore additional processes have been applied allowing reducing the data volume, to minimize interfering influences as well as to enhance the relevant information.

As additional aspect, the size of the data has to be checked with respect to the needs of a web based publication. A native 3D model of an inscription of 2x2 m^2 may result in a data volume of ~4.32 GByte, when a spatial resolution of 0.25mm will be used. This amount of data cannot be transferred over the internet in an acceptable manner. The data volume has to be reduced considerably before it might be transferred to the client in a common rate.

As conventional compression algorithms result in a loss of information, more intelligent strategies are necessary. In this context only the individual letters are important for us. As the spatial characteristics of the rock itself has many times higher variations than the texts themselves only special approaches lead to considerable improvements (Schmidt 2009): The spatial background information has to be eliminated leaving only spatial variations for each individual element of the inscription. This will be achieved by planes fitted into the model and the projection of the original 3D points onto this reference plane. In principle, this corresponds to a transformation of the complex 3D data into a 2½D space. Based on the 2½D data we can apply common image processing tools and generate a raster based model, called Digital Elevation Mode (DEM), without having a substantial information loss. The possibility to use procedures from digital image processing furthermore simplifies following steps and avoids the handling of a complex vector based 3D model. Furthermore we are able to reduce the volume of raster data by a factor 100 (4.3GByte to 40MByte) which is impossible to be achieved by other compression strategies.

3.2 Data Preparation

The reduction of the data volume achieved by transforming the 3D spatial data in 2½D raster data (DEM) leads to insufficient legibility of the characters (see Figure 4). This is based on the fact that the walls surfaces show strong spatial variations. Thus the characters are represented by less information so that the influence of the walls surface has to be reduced.

Figure 4. 2½D raster data (DEM)

We distinguish three main image processing steps to increase the legibility of the characters especially the damaged ones. These process steps are the transformation from the absolute heights to relative heights, the elimination of the surface topography and a further reduction of the data set.

By the unevenness of the walls and sometimes existing fractures in the walls large differences in height are present. Most imaging applications are just able to handle 8bit per image channel. This leads in the raster based DEM to the fact that the substantial information of the engraved characters on the walls are not recognizable. For this reason an image normalization algorithm is accomplished, whereby a smoothed variant of the raster-based DEM is subtracted from the original.

A very important part of this step is the filtering algorithm used for the smoothing operation. The intention of the smoothing operation is to get a model of the wall within all its characteristics but without the engraved character. Thus it separates the characters from the wall by subtracting the original and smoothed images. The properties of the filtering algorithm are clearly defined. The type of the filter is a low-pass filter with a small size so that it filters the image in a local way. Furthermore it has to be applied several times to even all characters the weathered one as well as the well-preserved one.

In different analysis it clarifies that the size and number of appliances which provides best results is a low-pass filter with size 11x11 pixel and number of appliance of 6 (cp. Figure 5 and Figure 6). The high number of appliances (in our case 6) can also be replaced by using a large combined filter and applying it once. However the combined filter is not used because the other proceeding is less complicated to create and implement. These properties conduce to highly smoothed characters and less smoothed sites of fracture.

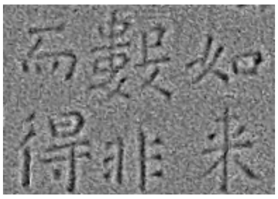

Figure 5. 3x3 filter applied two times

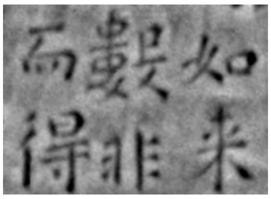

Figure 6. 11x11 filter applied six times

By subtracting both images, the original and the smoothed one, the heights are transferred on the basis of absolute heights related to the local coordinate system of the cave into relative heights related to the smoothed raster based DEM. Thus it is reached that mainly the small differences in height are left which contains the well-preserved and weathered characters as well as the roughness of the surface. Caused by the bad handling of boundary pixels in the smoothing operation some large differences in height still exist but without containing any substantial information. As an intermediate result the improvement of the legibility of the characters can be emphasized, but at this point a huge amount of gray scale values got lost for displaying irrelevant information.

This fact requires the second processing step. With the help of a histogram clamping the engraved characters are extracted as relevant information whereas the difference in height of the wall is limited. This limitation of the height range goes back on limit values, which are defined by means of statistic values.

Defining the limits of the second processing step influences the appearance of the image and therefore the legibility of the characters. Thus the tasks are to define the extent or the placement of the substantial information in the histogram of the images so that an extraction of the characters is enabled. The analysis of the histogram and statistics of the images leads to a definition of the limits based on statistic values, because of adapting best to the properties and characteristics of each image. The standard deviation is an appropriate value to define the limits but it separates a range of height still being to large. By reducing the standard deviation to a fraction a range of height can be defined representing only the relevant information. This conduces to an upper limit accepting a value of plus an eighth of the standard deviation and a lower limit receiving a value of minus an eighth of the standard deviation.

The application of these defined limit values reduces the complete height differences to a representation of the characters and the surface of the wall. All heights lower and higher than the limits are replaced by the limits itself so that these areas in the raster based DEM are flattened. The raster based DEM is limited to a difference in height from before approx. 100 cm to now approx. 3 cm. Thereby the influences resulted from subtracting the original and smoothed image are minimized and the characters are emphasized, the well received and the weathered ones.

Finally by a histogram stretching it is reached that the extracted height range of the raster-based DEM is transferred on the grey value range of an 8-bit and/or 16 bit image (see Figure 7). This process step allows a reduction of the data volume and the color depth.

The implementation of the histogram stretching is based on the standard function for transferring grey values. By using the minimal and maximal grey value of the image all grey value are stretched to the required range of grey values from 0 to 255 / 0 to 65536. This conduces to the fact that differences in height less than 1 mm can be differentiated and so the characters itself are rich in contrast. The general problem resulting is that not only the well-preserved and the weathered characters are emphasized but also the roughness of the walls surface. Because of their differences in height which contain the same range in the weathered characters and the roughness of the walls surface these characters can barely be differentiated.

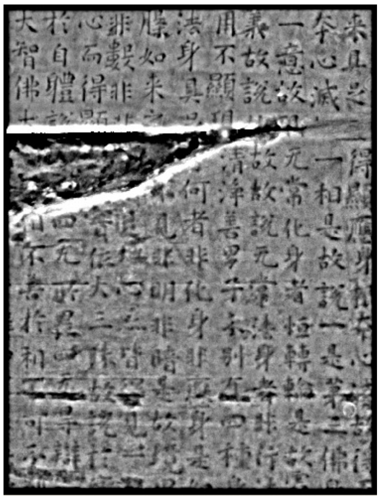

Figure 7. Processed DEM

However the processing steps provide an enormous increase of the legibility of the characters and a good base for the manual and automated interpretation and for the visualization of the data via internet. Because of the data structure and the quality of data a further processing can be accomplished using simple image processing libraries for implementing the algorithms for automated interpretation and for realizing the planned web application.

4. MATCHING

The interpretation of the inscription is the main task of the sinologists. Up to now the interpretation of the inscription is a manual process which is divided in reading, translating and extracting the information of each character like size and position in the documented inscription. According to the mass of inscriptions (approx. 80) and characters (approx. 600,000) this procedure is unsuitable in our project. That leads to the fact that the interpretation should be done more automatically. This can be realized with template matching that is applied on results of the previous data processing (see section 3). The resulting images contain no perspective deformations and are rich in contrast.

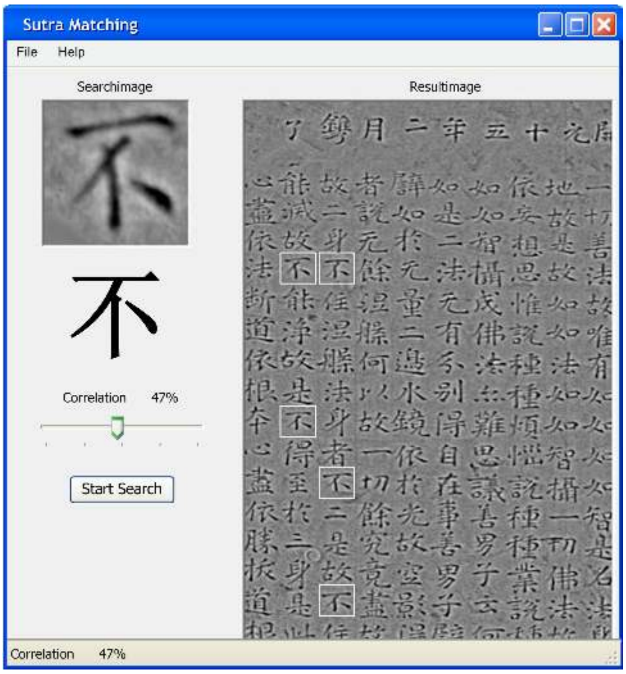

Figure 8. Automatic character extraction using template matching (e.g. for the character 不, “no”)

The benefit of the template matching during the interpretation process is the identification of each character in the whole inscription based on a digital text reference. The digital reference the so called *taisho* contains all Sutra texts in a digital form and can be requested via internet. In a first step, the matching locates individual characters, which then will be searched in the text reference. A comparably small number of connected letters already defines unique text passages, which then can definitely be found in the reference. The idea of this processing is to merge the power of matching algorithm applied to well-preserved characters with the knowledge contained in the reference library *taisho*. The matching might be based on natural templates extracted from the processed data or onto generic templates provided by Unicode characters defined in the Chinese alphabet (see Figure 8).

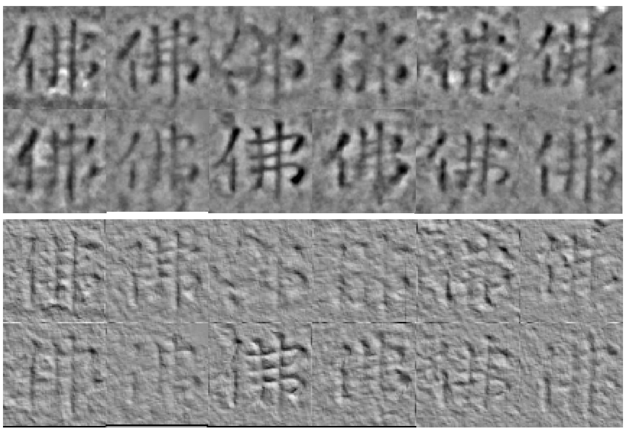

Figure 9. Group of extracted characters using template matching for the Buddha (佛) character; Top: DEM image. Bottom: shaded model

Additional potential for the template matching might result from a support for further interpretation processes, concerned with the calligraphy. By extracting structural elements of each character and grouping them into different classes it could be possible to identify different authors or different techniques of the manufacturer (see Figure 9). Furthermore the template matching provides mass processing of the interpretation and simplifies the pre-processing in the interpretation.

5. WEBAPPLICATION

As the final goal of the project is to present the Sutra texts to a large community using modern means of the internet we want to show the general concept of the web application together with a view into individual elements of the solution. In the web application the general information of the Sutra sites are accessible for the user. Additionally we integrated 2D & 3D GIS (Zipf 2007) techniques for presentation and analysis. In order to give a closer look to the connection of the Sutra texts they are linked with virtual 3D Sutra and GIS. In the following we present different visualization concepts allowing supporting the end user during his process of interpretation and understanding of the inscriptions.

The results of the documented Sutra texts and already achieved interpretations of different buddhistic inscriptions are made accessible over the internet by means of a web portal and serve as a flexible tool for the sinologist. The web application (see Figure 10) is designed to show the virtual copy of the inscription and the results of its interpretation. The user can inspect the virtual copies of whole inscription boards - we call it the 3D Sutra - using web based techniques for 3D computer graphics procedures. These allow manipulations of parameters like texture, lighting and shading and are designed to give a close-to-reality presentation of the Sutra. Individual modifications are possible to improve the subjective impression by the user trying to support him in his process of interpretation. Examples are interactive changes of the light source, directly affecting the shading of the surface and providing a better idea of the 3D surface of the Sutra. Using dynamic virtual water filling, the user is able to get an even better impression on the depth of the characters.

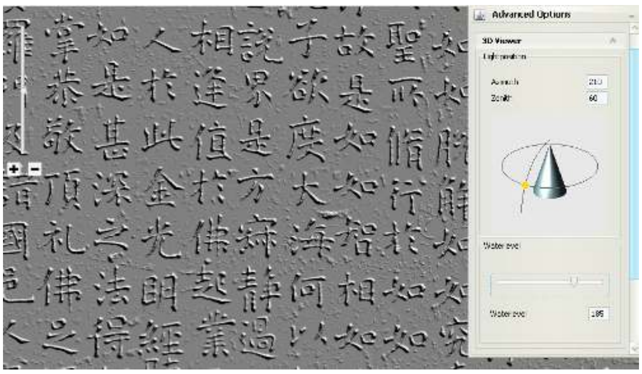

Figure 10. Web application

In addition to the above mentioned visualization aspect, the web application shows the user the available interpretations of the inscriptions. This simplifies an understanding for not experienced user or provides the experts with an alternative version of interpretation. Technically this is performed by an interactive overlay of the digital copy with an interpreted text of the 3D Sutra. The overlaying information is generated out of the matching algorithm and is linked between the text and the 3D character in the Digital Elevation Mode (DEM) automatically.

6. CONCLUSION

Modern precision measuring techniques open up new perspectives for archeological and art-historical questions. This assumes that the objects are accessible for the equipment and can be captured with high precision. The captured data opens up various processing chains and enables the presentation on the internet, whereby important cultural treasures are made accessible to a wider community.

For the stone inscriptions we used fringe projection technique to document the inscriptions and laser scanning for their environment. Compared to the traditional rubbing the high resolution scanner allows us to create a nondestructive virtual copy of the stone inscription. The digital copies of the original inscriptions offer better results in legibility of each character as has been shown in section 2.

However this high resolution measuring techniques produce huge data sets which cannot be handled by the user who interprets the Sutras directly neither can it be transferred over the internet without further processing. Therefore we have shown in section 3 a process chain in order to prepare the data for the interpretation and also for the visualization on the internet. In spite of the good result achieved with the processing for the interpretation there is a need for an algorithm separating the weathered characters from the walls surface and emphasize them.

We presented an approach (see section 4), for automated indexing of the Sutras, which may replace the current manual procedure of indexing the individual characters. With the presentation on the internet sinologists are capable to work with the Sutras and to have an in depth look at the 3D characters from any place of the world like being on site in China.

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8. ACKNOWLEDGEMENTS

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