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Recording and modeling of cultural heritage objects with coded structured light projection systems

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1 Introduction

Active sensors (Blais 2004), based on coherent (laser) and non-coherent light, are nowadays used for many kinds of 3D reconstruction tasks and recently very much for the recording and 3D documentation of cultural heritage objects. They have become a very common source of documentation data, in particular for non-expert users, as they easily provide range data of surfaces in high resolution and with high accuracy. Compared to passive image-based approaches (Remondino and El-Hakim, 2006), active sensors provide directly and quickly 3D information of the surveyed object in form of range data (point clouds). Active sensors are suitable for different scales and objects. While the recording devices are still relatively expensive, important progress has been made in recent years towards an efficient processing and analysis of range data.

Structured light systems consist of one (or more) camera(s) and an active light source, which illuminates the object with a known pattern of light sequence. Based on the triangulation principle, the 3D object coordinates are generally recovered in ca. 2-3 seconds with a potential accuracy of 50 microns or even better.

This paper reports about two case studies where a coded structured light system (optoTOP-HE™ and optoTOP-SE™, Breuckmann GmbH) is used for the precise 3D digitization and documentation of Cultural Heritage objects. It includes all essential steps of the 3D object modeling pipeline from data acquisition to 3D visualization. The first study is the 3D modeling of a part of a marble Herakles statue, named "Weary Herakles" (Fig. 1a), which is on display in the Antalya Museum (Turkey), digitized with an optoTOP-HE system. The second study is about the 3D modeling of a Khmer head sculpture (Fig. 1b), which is in the collection of Rietberg Museum, Zurich (Switzerland), digitized using an optoTOP-SE sensor.

The next chapter introduces the scanner with emphasis on the working principle and technical specifications. The following third and fourth chapters explain the data acquisition and modeling workflow of the projects. The fifth chapter addresses the capabilities and the limitations of the used hardware and software.

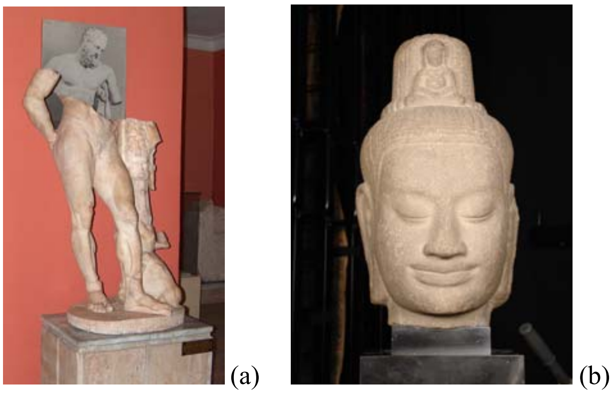
(a) (b)

Fig.1. (a) Weary Herakles statue (ca 1 m height) in the Antalya Museum, (b) the Khmer Head (ca 30 cm height) in the Rietberg Museum of Zurich.

A comparison of the used reverse engineering software (Geomagic Studio™ and PolyWorks™) is also reported. Another comparison performed on larger datasets is presented in (Boehm and Pateraki, 2006).

2 Data Acquisition System

2.1 Coded Structured Light System

The key feature of a structured light system is the replacement of one of the cameras with an active light source, which illuminates the object with a known pattern. This solves the correspondence problem in a direct way and many variants of the active light principle exist (Beraldin et al 2000, Beraldin 2004, Blais 2004).

The coded structured light technique, also called topometric technique, is based on a unique codification of each light token projected onto the object. When a token is detected in the image, the correspondence is directly solved by the de-codification technique. It requires a complex light projection system and many codification methods have been developed (Batlle et al 1998, Salvi et al 2004, Dipanda and Woo 2005).

The time-multiplexing, also called temporal codification, with a combined Gray code and phase shifting is the mostly employed de-codification technique. The used optoTOP-HE and -SE sensors apply the same technique.

A Gray code is a binary numeral system where two successive values differ in only one digit, i.e. 000, 001, 010, 011, … in natural (plain) binary codes, and 000, 001, 011, 010, … in Gray binary codes. It was invented and patented by Frank Gray (Gray 1953) in Bell Labs. For the case of coded structured light (or fringe projection) systems it is superior to the natural binary codification, since it resolves the ambiguity better at the edges of consecutive patterns (Fig. 2b and 2c).

A sequence of Gray coded binary fringe patterns is projected onto the object (Fig. 2a). This divides the object into a number of 2^n sections, where n is the number of pattern sequences, e.g. 128 sections for n=7. Thus each pixel is associated with a codeword, which is the sequence of 0s and 1s obtained from the n patterns. The codeword establishes the correspondences relating the image pixels to the projector stripe numbers. The object space point coordinates are calculated using the spatial intersection provided that system calibration is known. All pixels belonging to the same stripe in the highest frequency pattern share the same codeword. This limits the resolution to half the size of the finest pattern.

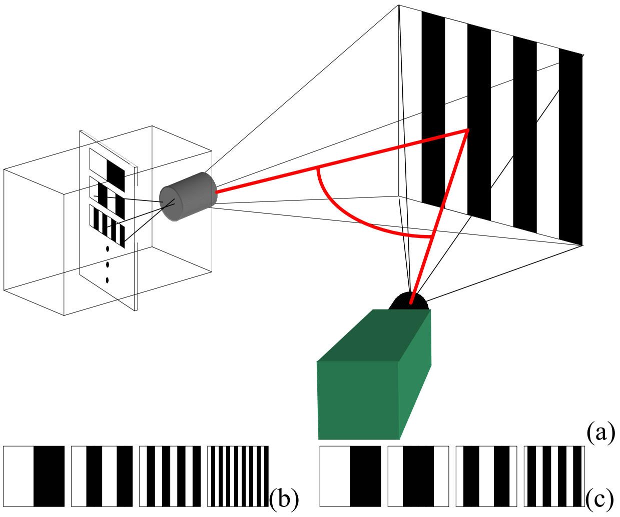

Fig.2. (a) Setup of a fringe projection system with the natural binary codification (courtesy of Dr. B. Breuckmann), (b) natural binary code, (c) Gray binary code.

Generally a periodical pattern is projected several times by shifting it in one direction in order to increase the resolution of the system. For each camera pixel the corresponding projector stripe number with sub-stripe accuracy is yielded by a phase shift method (Burke et al 2002).

2.2 Breuckmann optoTOP-HE and optoTOP-SE

The optoTOP-HE system (Fig. 3), as a high definition topometrical 3D-scanner, allows the 3-dimensional digitization of objects with high resolution and accuracy. The optoTOP-HE system uses special projection patterns with a combined Gray code and phase shift technique, which guarantees an unambiguous determination of the recorded 3D data with highest accuracy (Breuckmann 2003). The sensor of the optoTOP-HE system can be scaled for a wide range of Field of Views (FOV), by changing the baseline distance and/or lenses, typically between a few centimeters up to some meters. Thus the specifications of the sensor can be adapted to the special demands of a given measuring task.

Fig.3. The optoTOP-HE sensor.

The optoTOP-SE (Special Edition) series are the identical systems with the major difference that the sensors have only three different FOV with a fixed 300 mm base length. More details are given in Table 1.

Table 1. Technical specifications of optoTOP-HE and –SE sensors that were used in both projects

	optoTOP -HE	optoTOP -SE
Field of View (mm)	480x360	400x315
Depth of View (mm)	320	260
Acquisition time (sec)	<1	
Weight (kg)	2-3	
Digitization (points)	1280x1024[1]	1280x1024
Base length (mm)	600	300
Triangulation angle (deg)	30^0	
Projector	128 order sinus patterns	
Lamp	100W halogen	
Lateral resolution (µm)	~360	~340
Feature accuracy (relative[2])	1/15000	1/10000
Feature accuracy (µm)	~45	~50

(1) Current optoTOP-HE has a 1380x1040 dimension.
(2) According to image diagonal

3 Weary Herakles project[3]

The Weary Herakles is a marble statue of the Greek demigod which dates back to the 2nd century AD (Fig. 1a). It is a copy of an original bronze statue of Herakles sculptured about 330-320 BC by the Greek master Lysippos of Sikyon. Many artisans devoted their skills to replicating this original around that period. This particular example was probably carved in the Hadrianic or Antonine (Roman) period. The version is identified as the "Herakles Farnese" type on the basis of its similarity to a more complete copy in the Naples National Archaeological Museum (Italy).

The statue was broken in two parts. We do not know when and by whom it was done. The upper half was first seen in the USA in the early 1980s and nowadays it can be found at the Boston Museum of Fine Arts. The lower part was found by Prof. Jale İnan (İnan 1981, 1992) at an

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[3] http://www.photogrammetry.ethz.ch/research/herakles/

excavation site in Perge (Antalya, Turkey) in 1980. It is now shown in the Antalya Museum, along with a photograph of the top half (Fig. 1a). According to the Turkish law, Turkish antiques are state properties since Ottoman times 1906. The Turkish government has requested the upper part of the statue so that the two fragments could be joined together. The Boston Museum has refused to consider the Turkish petition. Nevertheless, in 1992, the two fragments were placed together and they matched perfectly. The Boston Museum says that the statue may have been broken in ancient times and that the upper torso may have been taken from Turkey before the Turkish law established the state ownership of archaeological finds (Rose and Acar 1995, Brodie et al 2000, Brodie 2003, Gizzarelli 2006).

Since both parts are unfortunately geographically separated, our aim was to record and model both the lower and the upper parts and bring them together in a 3D computer model, to be able to see the complete statue, appreciate and analyze it. With the help of the Turkish authorities and the Antalya Museum we were able to complete our work on the lower part, but access to the Boston Museum was denied.

The digitization of the lower part of the statue was done on 19-20 September 2005 in the Antalya Museum with a Breuckmann optoTOP-HE coded structured light system (http://www.breuckmann.com). The system was kindly provided by the Turkish reseller InfoTRON Co. (http://www.infotron.com.tr), Istanbul.

Fig.4. Frontal view of the textured model (left), frontal view (central) and back view (right) of the grey shaded model.

3.1 Scanning in the Antalya Museum

The scanning campaign was completed in one and a half days of work. The statue is around 1.1 meters in height. The whole object was covered with 56 scans of the first day work. The remaining 11 scans of the second day were performed to fill the data holes and occlusion areas. Totally 83.75M points were acquired in 67 scan files. The average point spacing is 0.5 millimeter.

The optoTOP-HE 3D digitization system is able to acquire one point cloud in nearly less than one second. However, orienting the scanner and planning the scan overlay needs careful preparation, especially for this kind of object with many concave and hidden parts. Due to the sensitivity of the sensor to ambient light, special attention was paid to environment lighting conditions. Two ceiling halogen lamps looking at the statue were turned off.

3.2 Point Cloud Registration

The registration of the acquired scans was done using an in-house developed method, called Least Squares 3D Surface Matching (LS3D) (Gruen and Akca 2005). The mathematical model is a generalization of the Least Squares image matching method, in particular the method given by Gruen 1985. It provides mechanisms for internal quality control and the capability of matching multi-resolution and multi-quality data sets.

The pairwise LS3D matchings are run on every overlapping pairs (totally 234) and the average precision of the registration was 81 microns. In the successive global registration step, performed with a block adjustment by independent models, orientation procedure well known in photogrammetry, gave 47 micron a posteriori sigma naught value.

3.3 Point Cloud Editing

After the registration, all scan files were merged as one XYZ file containing ca 36M points, discarding the scanner detected blunders. The file was imported to Geomagic Studio™ 6 (Raindrop Geomagic Inc., release 2004_05_11_B) for further editing procedures. The data set was cropped to include only the area of interest (AOI), i.e. deleting the background wall or other non relevant parts, concluding with 33.9 M points. A low level noise reduction was applied using the "Reduce Noise" function.

3.4 Surface Triangulation and Editing

As a first attempt, the surface mesh generation was performed with the original data resolution. The operation could not be performed, since the memory requested by the software exceeded the physical memory limit of 2 GB of the computer. Therefore, the number of points was reduced to 9 million by applying the "Curvature Sampling" function of Geomagic Studio™. This operation eliminates points in flat regions but preserves points in high-curvature regions to maintain detail. Afterwards, the surface triangulation was done by setting the number of target triangles to 5 million. Because of the complexity of the statue and occlusions, some inner concave parts could not be seen by the scanner. This resulted in several data holes on the wrapped surface. They were interactively filled with the "Fill Holes" option of the software. The final model contains 5.2 M triangles. In the final 3D model we were able to achieve a high level of realism, which can make a one-to-one scale production of the statue possible, if required (Fig. 4).

Worth to be mentioned is that the main portion of the editing effort was dedicated to the holes filling. It is a tedious work which takes the longest time among all the steps of the project.

3.5 Texture Mapping and Visualization

For a photo-realistic visualization of the 3D model, images acquired with a 4M pixel CCD Leica Digilux 1 camera were used for the texture mapping phase. The Weaver module of the VCLab's 3D Scanning Tool (ISTI-CNR, Pisa, Italy) was used. The VCLab's Tool comprises different modules for the 3D modeling from range data (Callieri et al 2003), including registration, editing and texturing.

The visualization of the final shaded model was done with the IMView module of PolyWorks™ (InnovMetric Software Inc., version 9.0.2) as it gives a better shading than Geomagic Studio™. The textured model was instead visualized with the viewer of the VCLab's Tool (Fig. 4).

4 Khmer head project

The earliest examples of Buddhist art on the mainland of Southeast Asia date from the 4th and 5th centuries and emerged under the influence of Indian and Sri Lankan art. During the 6th century the Khmer people established themselves in the fertile tropical plains of Cambodia, and as the dominating power in Southeast Asia in the 12th and 13th centuries. They built the stunning group of temples at Angkor. The Khmer rulers supported both Hinduism, displayed most magnificently at Angkor Wat, and Buddhism, whose most important monument is the Bayon temple, still admirable in the central area at Angkor Thom, Cambodia.

In our work, we modeled a bodhisattva head from the late 12th or early 13th century, carved in the Bayon style. It represents Lokeshvara or Avalokiteshvara, the "Lord of compassion who looks down (on the suffering of the world)," an emanation of the Buddha Amitabha as demonstrated by the seated Buddha on his hair ornament. Its serene expression and transcendent smile convey better than any words the sublime essence of the Buddhist teachings (Museum Rietberg 2006).

4.1 Data acquisition in Museum Rietberg

The head is made of sandstone and 28 centimeters in height. The data acquisition was done in Museum Rietberg on 4 May 2006. A Breuckmann OptoTOP-SE fringe projection system was used for this purpose. The scanning and imaging took four hours. The head was covered with 18 point clouds, totally 23.6 million points.

Fig.5. Scanning in Rietberg Museum.

4.2 Point Cloud Registration

The point cloud registration was done again with the LS3D surface matching method. 52 pairwise LS3D matchings for all overlaps gave an average sigma naught value of 60 microns. The global registration with the block adjustment by independent models solution concluded with 28 microns sigma naught value.

4.3 Surface Triangulation and Editing

The surface modeling was done using two commercial packages, namely Geomagic Studio™ and Polyworks™. The aim was to compare the capabilities of both software. The registered point clouds were imported in the proper formats. Accordingly, the registration steps were skipped in both software. Both software packages have different processing pipelines (Table 2).

Table 2. Modeling workflows in Geomagic Studio and PolyWorks.

Geomagic Studio™	PolyWorks™
Importing the point clouds	Importing the point clouds
Point cloud merging (??)	Surface triangulation
Defining the AOI	Surface merging
Noise reduction	Defining the AOI
Down sampling	Surface editing
Surface triangulation	
Surface editing	

Geomagic Studio™ offers fully automatic data import functionality provided that data is given in one of the appropriate point cloud formats. Totally 18 point clouds were imported, merged into one, which gave a very dense (denser than 50 microns inter-point distance at some locations) point cloud. After discarding the no data or scanner signed erroneous points and points belonging to background and other non relevant objects, 3.2 million points remained. The noise reduction ensures that points coming from different views in different quality will finally have the similar signal-to-noise ratio. In our case a slight (low level) noise reduction was applied. After this step, the model contains highly redundant points coming from the multiple views. The "Curvature Sampling" function with a 60% reduction rate reduced the number of points to 1.9 millions. Intentionally, a restricted reduction rate was selected, so that small details can be preserved.
The surface triangulation in Geomagic Studio is a fully 3D and automated approach, with limits the user interaction. Hence, the resulting mesh will have some topological errors and holes. On the other hand, it can preserve the high frequency details of the object geometry successfully by considering all points in one processing sweep. In general, surface triangulation quality is highly related to the point density and homogeneity.

PolyWorks™ has a significantly different workflow. Each step is represented as a module inside the package. Data import is not automatically performed. Each point cloud is individually imported, subsequently converted to the surface form by applying a 2.5D triangulation, similar to the terrain modeling case. Therefore, the user should interactively rotate the point cloud to a position where the viewing angle is close to the one at the acquisition instant. This substantially reduces the topological errors. On the other side, such a stepwise surface generation strategy does not utilize all the available information properly. For example, there might be some object parts with thin point distributions in individual views, whereas the combination of all views together provides a good solution. In the next step, separate surfaces were merged as one manifold using the IMMerge module. This part is highly automated, and additionally offers a noise reduction option. During the process, triangulation is also optimized especially at the overlapping regions by associating dense triangles to high curvature areas and sparse at flat areas. Finally the IMEdit module offers many surface editing functions, e.g. cropping the AOI, filling the data holes, correcting the wrong triangles, boundary cleaning, etc. However, it is less flexible and user friendly than Geomagic Studio™.

The resulting models from both software packages meet the project requirements. PolyWork model (0.6 million triangles) has substantially less number of triangles than Geomagi model (3.9 million triangles), thus having a better and optimized triangulation algorithm. However, the model from Geomagic Studio preserves the small details and structures slightly better than the model of PolyWorks (Fig. 6). Nevertheless, the shader of Polyworks represents better the geometry of the modeled object. More details can be found in Novák 2006.

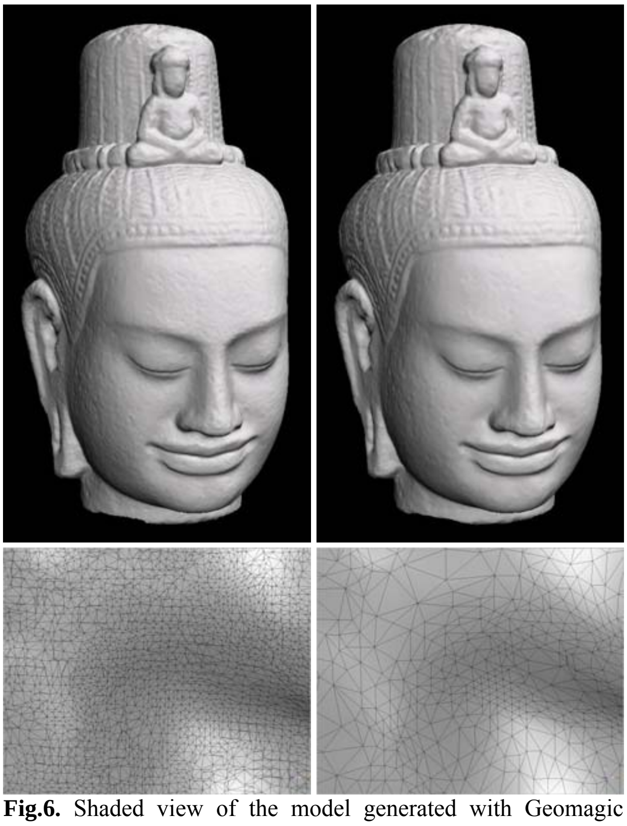

Fig.6. Shaded view of the model generated with Geomagic Studio (top-left) and PolyWorks (top-right). Closer view on the left side of the lip: the different meshes produced by Geomagic Studio (bottom-left) and PolyWorks (bottom-right).

4.4 Texture Mapping

Some digital images of the Khmer head were acquired with a photographer-type professional illumination system consisting of two diffuse lights on a tripod (Fig. 7). The system was used to reduce the radiometric differences between the images and shadow effects at the complex parts or object silhouettes. Images were taken with a Sony DSC-W30 6 megapixel digital camera. The 3D model generated with PolyWorks (at the original resolution) was used to produce a photo-realistic 3D result.

Fig.7. Illumination system used for the texture mapping.

Fig.8. Texture mapped model of the Khmer head.

Internal and external orientations of the images were computed using a photogrammetric bundle adjustment. The object space coordinate system was defined as the coordinate system of the 3D model. The common points were interactively identified both in digital images and in the intensity images of the scanner. Afterwards we used this information, in addition to the geometric model and the images, to conduct a visibility analysis for every camera position. The algorithm calculates the visible parts for every acquisition position, resolution independent and fully triangle-based in object space. Partly occluded triangles are subdivided and re-meshed into fully visible or fully occluded triangles. The resultant list of visible triangles is used to calculate the texture coordinates for every vertex of the mesh. The underlying algorithm uses a "best view" algorithm to evaluate the optimal texture for every triangle. The mesh consists of approximately 295 000 vertices and 585 000 facets. With the open source software "Blender", we found an adequate software package to handle this huge number of triangles to produce high quality renderings and movies. However, for online and real-time visualizations, this full-resolution model cannot be used. For this application area, we reduce the number of triangles, without degradation of the visual impression. The high quality textured model (Fig. 8) is useful for presentations on high performance computers (concerning the physical memory, CPU and graphic card) and basically to preserve the object for e.g. reconstruction purposes.

5 Capabilities of the used Hardware and Software

The optoTOP-HE and -SE sensors as a coded light projection system meet the project requirements satisfactorily. They have some distinctive advantages over the triangulation-based laser systems (Table 3).

Table 3. Triangulation based systems: Laser versus coded light.

	Laser	Coded light
Weight and price	Identical	Identical
Speed		Faster
Sensitivity to ambient light	Less	
Speckle noise		Less
Penetration into object surface		No
Imaging for texture mapping		Yes
Depth of view	Larger	
Eye safety		Better

The use of incoherent light reduces speckle noise and provides better surface smoothness (Blais 2004). Furthermore it does not penetrate into the object surface, unlike laser light whose penetration property is well known, e.g. for marble (Godin et al 2001). All these reasons make the system a suitable choice for Cultural Heritage applications. Unfortunately most of the coded light systems are very sensitive to ambient light, requiring almost darkness during the acquisition. Nevertheless, new developments and digital projectors allow 3D data acquisition also under normal light conditions.

Although surface digitization is a very easy and straightforward task, the surface triangulation and editing, which is the key step of the whole modeling chain, is still cumbersome and needs heavy semi-automatic or manual work. The management of large data sets is another aspect. Geomagic Studio™ crashed several times while filling the holes interactively, whereas PolyWorks™ did not. Geomagic Studio™ gives better details in surface geometry with the cost of large number of triangles. Table 4 gives a comparison of both software packages.

Table 4. PolyWorks versus Geomagic Studio.

	PolyWorks™	Geomagic™
Data import	Manual	Automatic
Surface generation		
Type	2.5D	3D
Optimality	Better	
Detail preservation		Better
Topological correctness	Better	
Automatisation		Better
Editing capabilities		Better
Performance	Better	
Visualization	Better	
User friendliness		Better
Stability	Better	

6 Conclusions

Nowadays active sensors are often used for many kinds of 3D object reconstruction tasks, one important area of which is 3D documentation of cultural heritage objects. This study presents the results of 3D modeling of two cultural heritage objects, where a close-range coded structured light system was used for digitization. In fact active sensing with coded structured light systems is a mature technology and allows high resolution documentation of cultural heritage objects.

The used instruments have acquired high quality point cloud data of the statues. The results of the processing (accuracy of about 50 micron and better) are in good agreement with the system specifications and project requirements. The heaviest user interaction is needed in the editing steps, e.g. for filling the data holes. We have used two commercial software packages in order to carry out the modeling. Each software package has its own particular advantages and functions. A unique package, which fulfills all requirements with sophisticated and automatic editing capabilities, is not yet available. In our opinion, the use of both packages can give the optimal modeling results. Texture mapping is another issue, which is not fully supported by either software.

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References

BATLLE, J., MOUADDIB, E., and SALVI, J. 1998 Recent progress in coded structured light as a technique to solve correspondence problem: A survey. *Pattern Recognition*. 31(7): 963-982.

BERALDIN, J.-A., BLAIS, F., COURNOYER, L., GODIN, G., and RIOUX, M. 2000 Active 3D sensing. *Modelli E Metodi per lo studio e la conservazione dell'architettura storica*. University: Scola Normale Superiore, Pisa, 10: 22-46.

BERALDIN, J.-A. 2004 Integration of laser scanning and close-range photogrammetry – The last decade and beyond. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 35(B7): 972-983.

BLAIS, F. 2004 Review of 20 years of range sensor development. *Journal of Electronic Imaging*. 13(1): 231-240.

BOEHM, J. and PATERAKI, M., 2006. From point samples to surfaces - on meshing and alternatives. *IAPRS*, Vol.36(5)

BREUCKMANN, B. 2003 State of the art of topometric 3D-metrology. *Optical 3-D Measurement Techniques VI*, Zurich, Sept. 22-25, Vol. II, pp. 152-158.

BRODIE, N., DOOLE, J., and WATSON, P. 2000 Stealing history: The illicit trade in cultural material. *The McDonald Institute of Archaeological Research*, Cambridge, pp. 31-32.

BRODIE, N. 2003 Stolen history: looting and illicit trade. *Museum International*. 55(3-4): 10-22.

BURKE, J., BOTHE, T., OSTEN, W., and HESS, C. 2002 Reverse engineering by fringe projection. *Interferometry XI: Applications*, SPIE vol. 4778, pp. 312-324.

CALLIERI, M., CIGNONI, P., GANOVELLI, F., MONTANI, C., PINGI, P., and SCOPIGNO, R. 2003 VCLab's Tools for 3D range data processing. *VAST'03*, Brighton, pp. 13-22.

DIPANDA, A., and WOO, S. 2005 Efficient correspondence problem-solving in 3-D shape reconstruction using a structured light system. *Optical Engineering*. 44(9): 1-14.

GIZZARELLI, C. 2006 'Weary Herakles': Looters vs. Archaeologists, www.bellaonline.com/articles/art28239.asp (accessed September 2006).

GODIN, G., RIOUX, M., BERALDIN, J.-A., LEVOY, M., and COURNOYER, L. 2001 An assessment of laser range measurement of marble surfaces. *Optical 3-D Measurement Techniques V*, Vienna, Oct. 1-4, pp. 49-56.

GRAY, F. 1953 Pulse code communication. *US Patent no. 2,632,058*. March 17, 1953.

GRUEN, A. 1985 Adaptive least squares correlation: a powerful image matching technique. *South Afr. J. of Photogrammetry, Remote Sensing and Cartography*. 14(3): 175-187.

GRUEN, A., and AKCA, D. 2005 Least squares 3D surface and curve matching. *ISPRS Journal of Photogrammetry and Remote Sensing*. 59(3): 151-174.

İNAN, J. 1981 Perge kazısı 1980 çalışmaları. *III KST, DSİ Basım ve Foto Film İşletme Müdürlüğü Matbaası*, Ankara, sayfa 43-48 (in Turkish).

İNAN, J. 1992 Heraklesstatue vom Typus des "Herakles Fernese" aus Perge. *Festschrift für Max Wegner Zum 90. Geburtstag*, Bonn, pp. 223-232.

ROSE, M., and ACAR, O. 1995 Turkey's war on the illicit antiquities trade. *Archaeology*. 48(2): 45-56.

MUSEUM RIETBERG 2006 Exhibition Brochure.

NOVÁK, D. 2006 3D Object modeling by use of a close range active sensor. *B.Sc. Thesis in Photogrammetry and Remote Sensing*, Summer Semester 2006, Institute of Geodesy and Photogrammetry, ETH Zurich.

REMONDINO, F. and EL-HAKIM, S., 2006 Image-based modelling: a review. *The Photogrammetric Record*, 21(115).

SALVI, J., PAGES, J., and BATLLE, J. 2004 Pattern codification strategies in structured light systems. *Pattern Recognition*. 37(4): 827-849.