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Preserve the Past for the Future – Terrestrial Laser Scanning for the Documentation and Deformation Analysis of Easter Island's Moai

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Summary: Since 1995, the Moai of Easter Island, the island's huge volcanic rock statues, have been protected as UNESCO (United Nations Educational, Scientific and Cultural Organization) World Cultural Heritage monuments, but so far, although the Moai are increasingly at risk of damage by exposure to wind and weather or by vandalism, they were never digitally documented and copied using an appropriate technique. The Department Geomatics of the HafenCity University Hamburg (HCU) started the documentation of the Moai in 2007 in cooperation with the German Archaeological Institute (DAI), Bonn, when the first three Moai sites were recorded by terrestrial laser scanning. In 2008 eight more Moai complexes were scanned. The long term goal of the project is to document and to catalogue the remaining Moai as well as assemble all relevant data into a Geographic Information System (GIS). Additionally, the analysis of possible deformation and the monitoring of conservation activities for selected Moai is an objective of the project. The recording of the statues by terrestrial laser scanning, the modelling into meshed 3D models and the texture mapping using high-resolution imagery are described in this paper. Furthermore, first tests for deformation analysis by 3D comparison of selected Moai were carried out. However, so far significant changes could not be detected for the short time interval of one year.

Zusammenfassung: *Bewahre die Vergangenheit für die Zukunft – Terrestrisches Laserscanning für die Dokumentation und Deformationsanalyse der Moai von der Osterinsel.* Seit 1995 stehen die Moai der Osterinsel, die sehr großen vulkanischen Steinfiguren der Insel, als Weltkulturerbe der UNESCO (Organisation für Ausbildung, Wissenschaft und Kultur der Vereinten Nationen) unter Schutz, aber bis heute wurden sie nie digital mit einer geeigneten Aufnahmetechnik dokumentiert und kopiert, obgleich die Moai in zunehmendem Maße der Gefahr einer Beschädigung durch Erosion von Wind und Regen oder durch Vandalismus ausgesetzt sind. Das Department Geomatik der HafenCity Universität Hamburg (HCU) begann die Dokumentation der Moai 2007 in Zusammenarbeit mit dem Deutschen Archäologischen Institut (DAI) in Bonn, als die ersten drei Moai-Stätten durch terrestrisches Laserscanning erfasst wurden. 2008 wurden weitere acht Moai-Stätten gescannt. Das langfristige Ziel des Projektes ist, die verbliebenen Moai zu dokumentieren und zu katalogisieren, um alle relevanten Daten in einem Geoinformationssystem (GIS) zusammenzufassen. Zusätzlich ist die Analyse möglicher Deformationen und die Überwachung geplanter Konservierungsmaßnahmen für ausgewählte Moai eine weitere Zielsetzung des Projektes. Die Aufnahme der Statuen durch terrestrisches Laserscanning, das Modellieren durch Dreiecksvermaschung und deren Texturierung mit hoch auflösenden Bildern werden in diesem Beitrag beschrieben. Außerdem wurden erste Tests einer Deformationsanalyse durch 3D-Vergleich ausgewählter Moai durchgeführt. Jedoch konnten bis jetzt keine signifikanten Änderungen für den kurzen Zeitabstand von einem Jahr ermittelt werden.

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1 Introduction

One of the most unique – and remote – areas on Earth, Easter Island was named for the day Dutch Admiral Roggeveen first discovered the island in 1722. How the island initially became inhabited remains speculative; legend claims Polynesian King Hoto Matua and others sailed double-hulled canoes to begin occupying the island around 1000 AD. The island's huge volcanic rock statues – called Moai by the islanders – have also puzzled ethnographers, archaeologists and island visitors. On average standing 4 m (13 ft) high and weighing 14 tons, the Moai are believed to have been carved, transported and erected between 1400–1600 AD. Most archaeologists believe the Moai are standardized representations of powerful leaders on early Easter Island, or Rapa Nui, the name given to their land by islanders. Today, the German Archaeological Mission is seeking to help document and conserve these historical monuments. Using terrestrial laser scanning systems, the expedition team is helping preserve the past for the future – today.

A triangle of volcanic rock, Easter Island lies about 3,800 km (2,361 mi) west of Chile in the Southeast Pacific Ocean. A Chilean province, the 163 km^2 (63 mi^2) island has more than 800 Moai remaining, yet most are in poor condition. The statues were almost all erected singly or in a few groups along the coast on stone platforms known as Ahu. The Moai and Ahu are increasingly at risk of damage by exposure to wind and weather or by vandalism; most of the statues have been toppled due to human activity or natural events – such as tsunamis – and lie face down on the ground. Since 1995, the Moai have been protected as UNESCO (United Nations Educational, Scientific and Cultural Organization) World Cultural Heritage monuments, but so far they were never documented via digital copies.

Risk of damage is one reason the German Archaeological Mission conducted four weeks of field studies on Rapa Nui in each of February 2007 and in February/March 2008. The expedition is a cooperative project between the German Archaeological Institute (DAI), Bonn; the Geomatics Department of HafenCity University, Hamburg (HCU); and the Bavarian State Department of Monuments and Sites, Munich. Work was closely coordinated with Chile's Consejo de Monumentos Nacionales, Santiago, and local island authorities. The project's objective is to further research the island's history, its inhabitants and the still largely unknown Moai. In addition, the DAI will document and catalogue the remaining Moai as well as assemble all relevant data into a Geographic Information System (GIS) (Kersten & Lindstaedt 2007, Vogt et al. 2007). Furthermore, the project will test whether deformations on the Moai can be clearly identified using the terrestrial laser scanning technology. Additionally, conservation processes could be monitored at specified time intervals by TLS.

As known from the literature a terrestrial laser scanning system was used for the first time on Easter Island, when amongst other the Moai at the Museo Antropologico P. Sebastian Englert and the petroglyphs at Orongo were scanned by a CYRAX 2500 in 2003 for the University of Hawaii, Department of Anthropology (Wellman 2003).

2 System Used for Object Recording

The scanning of the objects was performed with the following terrestrial laser scanning systems: Trimble GX (2007), Trimble GS101 and the IMAGER 5006 from Zoller & Fröhlich (2008). Additionally, some of the Moai (Vaihu, Huri A Urenga and Akapu) were documented by photographic image acquisition using a commercial digital SLR camera Nikon D40 (28mm lens).

The 3D terrestrial laser scanning systems GX and GS101 (cf. Fig. 1 left), which are manufactured by Mensi S.A., France for Trimble, consist of a laser scanner (weight 13.5 kg), accessories (consisting of a backpack and a notebook for controlling the unit during data acquisition) and appropriate software for data acquisition and post processing. The IMAGER 5006 (weight 14 kg) is produced by the German company Zoller + Fröhlich. This scanner can be used as a stand-alone system or with a notebook. The optimal scanning range is between 2 and 100 m for the GS101 (with the option OverScan up to 150 m), and up to 200 m

Tab. 1: Summary of technical specifications of the laser scanning systems used.

Scanner / Criterion	Trimble GX	Trimble GS101	Z+F IMAGER 5006
Scan method	Time-of-flight		Phase shift
Field of view [°]	360 × 60		360 × 310
Scan distance [m]	< 200 (<350)	< 100 (<150)	< 79
Scanning speed	≤ 5000pts/s		≤ 500000pts/s
Angular resolution [°]	0,0017		0,0018
3D scan precision	12mm/100m		2.5-7.5mm/50m[1]
Camera	integrated		add-on option
Inclination sensor	yes	no	yes

[1] range noise depending on object colour

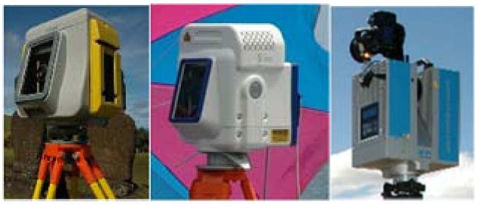

Fig. 1: Terrestrial laser scanner Trimble GX (used in 2007), Trimble GS101, IMAGER 5006 from Zoller & Fröhlich (both used in 2008).

for the GX (with the option OverScan up to 350 m), while the IMAGER 5006 (cf. Fig. 1 right) is only able to scan up to 79 m. All scanners used are panoramic view scanners (field of view 360° horizontal, 60° vertically for GX/GS101, and 360° × 310° for the IMAGER 5006). The laser beam has a diameter of 3 mm at 50 m distance (GX/GS101) and 14 mm at 50 m distance for the IMAGER 5006, whereby the 3D scan precision is 12 mm at 100 m distance (GX/GS101), and 10 mm at 50 m distance (IMAGER 5006). The distance measurements are performed by pulsed time-of-flight laser ranging using a green laser (532 nm, laser class II or III) for both Trimble scanners, while the IMAGER 5006 is a phase-shift scanner with a red laser. The GX/GS101 is able to measure up to 5000 points per second, but in the practical use on Easter Island the scanner was not able to scan more than 1000 points per second. In contrast to this slow scanning speed the IMAGER 5006 offers high speed scanning with up to 500,000 points per second.

The technical specifications and the important features of the three used laser scanners are summarised in Tab. 1. The three scanners represent two different principles of distance measurement: Z+F IMAGER 5006 uses phase shift method, while Trimble GS101/GX scans with the time-of-flight method. In general it can be stated that the phase shift method is

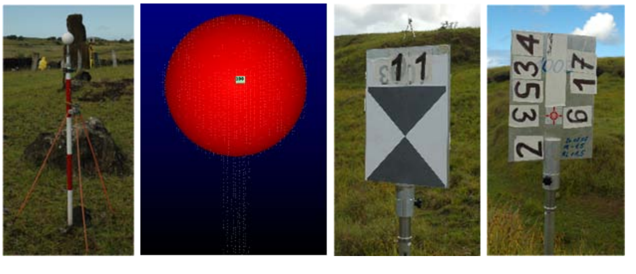

Fig. 2: From left to right: Marked point with white sphere for registration and geo-referencing of scans from GX/GS101, scanned and recognised sphere for GS101, front side of the target for IMAGER 5006 and back side of the same target for geodetic point determination and a flexible numbering system.

fast but signal to noise ratio depends on distance range and lighting conditions. If one compares scan distance and scanning speed in Tab. 1, it can be clearly seen, that the scanners using the time-of-flight method measure longer distances but are relatively slow compared to the phase shift scanner. For the GS101/GX power supply the Honda power generator was necessary, while for the IMAGER 5006 two internal batteries were available, which offers high flexibility for scanning in the field for approx. 4 hours.

For all of the scanned objects spheres (GX/GS101) or targets (IMAGER 5006) were used for registration and geo-referencing of the scans from different scan stations (cf. Fig. 2). The diameters of the spheres used were 76.2 mm. To obtain centre positions of the spheres and targets, the point clouds representing the sphere were automatically fitted using algorithms of the Trimble software PointScape or RealWorks Survey, while for the determination of the target centre the software LaserControl from Zoller + Fröhlich was used.

3 The Scanned Objects – Moai of Easter Island

The Moai are monolithic statues carved from rock on Rapa Nui (Easter Island). Nearly half (397) of the 887 Moai are still around the main Moai quarry (Rano Raraku), but 288 were transported from there and set on Ahu (platforms) which were mostly close to the sea at the island's perimeter. 92 Moai are on a route to an Ahu. Almost all have overly large heads three fifths the size of their body. The Moai are the 'living faces' and representations of chiefly, deified ancestors, sitting on their Ahu with their backs to the sea. Nowadays, most are toppled due to earlier tsunamis, earthquakes and conflicts between different clans on the island. The tallest Moai erected was almost 10 metres (33 ft) high and weighed 75 tonnes; the heaviest erected was a shorter but squatter Moai at Ahu Tongariki which weighed 86 tons; while one unfinished sculpture, which is still in the quarry at Rano Raraku, would have been approximately 21 metres (69 ft) tall with a weight of about 270 tons.

The distribution of Moai on Easter Island, which were scanned in 2007 and 2008 by the Department Geomatics from the HafenCity University Hamburg, is illustrated in Fig. 3. The Moai at Vaipu, at Hanga Mea, and at Akahanga are toppled, while all other scanned Moai stand erect.

In total, eleven object sites were scanned in the two field campaigns 2007 and 2008, whereby three Moai sites (Akivi, Ko Te Riku, and Vaihu) were scanned in both years for deformation analysis of statues. The list of Moai

Fig. 3: Distribution of Moai on Easter Island, which were scanned in 2007 and 2008, illustrated in Google Earth.

Tab. 2: List of Moai scanned in 2007.

Object	Scanner	Date	Scan time
Vaihu Moai	GX	07.02.2007	½ day
Ahu Akivi	GX	09.–10., 12.–14.02.07	3 ½ days
Ahu Ko Te Riku	GX	13./20.02.2007	2 days

Tab. 3: List of Moai scanned in 2008.

Object	S	Date	Scan time
Vaihu Moai	a	19.02.2008	½ day
Huri A Urenga	b	19.02.2008	½ day
Tongariki	a, b	20.02.2008	1 day
Ahu Akivi	a	21.–22.02.2008	2 days
Ahu Nau Nau	b	25.–26.02.2008	2 days
Ahu Ature Huki	a	26.02.2008	½ day
Ahu Akahanga	b	28.02./02.–03.03.2008	3 days
Hanga Kio'e	a	28.02.2008	1 day
Represa Vaipu	a, b	29.02./04.03.2008	2 days
Hanga Mea	a	03.03.2008	1 day
Tahai, Ko Te Riku	a	04.03.2008	1 day
S = Scanner, a = GS101, b = IMAGER 5006			

scanned in 2007 is summarised in Tab. 2, while the scanned Moai in 2008 are listed in Tab. 3.

4 Object Recording

Prior to this project, the only available documentation of the Moai had been in the form of pictures and drawings, combined with sketches of a few selected figures. To perform a comprehensive analysis of weathering and erosion for all the Moai, the three above-mentioned scanners were used to record the objects. The choice of a non-contact measurement method was very important as walking on the Ahu or touching the Moai is not permitted. As the local surroundings of some Moai were also to be scanned, it was necessary to use a scanner that had a wide range as well as high measurement precision. The goal was to produce exact 3D models of three selected Moai (Akivi, Ko Te Riku, and Vaihu) to record the deterioration process within millimetre accuracy by follow-up scanning on an annual basis. The focus of this paper is on these three Moai, which were scanned with Trimble scanners. The data of all other sites scanned with IMAGER 5006 is still in the processing phase.

Using the Trimble scanners the 3D geometry of the different Ahu and Moai could be scanned and the intensity values of the laser beam and the RGB values of the internal video camera were also stored for each 3D point. Firstly, the initialization of the scanner and the definition of the relevant scanning station were performed using the scanning program Point-Scape V3.1. After scanner initialization the scanning area was specified in real time via the displayed video frame from the scanner's internal camera. This process is particularly recommended, in order to avoid unnecessary data volumes from the environmental area of the sites and to optimize scanning time. To ensure complete object scanning different scanner stations around the object were needed.

Fig. 4: Moai on Easter Island, which were scanned in 2007 and 2008 for deformation analysis: Vaihu (top), Akivi (centre), and Ko Te Riku (bottom).

Fig. 5: Representation of point cloud with intensity values, which were scanned from one scanner station at Ahu Nau Nau with the terrestrial laser scanning system Z+F IMAGER 5006.

Furthermore, spheres (cf. Fig. 2 left) were placed on all marked points in the field for use in registration and geo-referencing and these were scanned from each scanner station. The scanned spheres could be automatically recognised in the point cloud by the software (cf. Fig. 2). In total approximately one hour scanning was required for each scan station.

The scanning strategy using the Z+F IMAGER 5006 was different to the scanning with the GX/GS101. Due to the huge data volume of each scan it was more appropriate to use targets for direct geo-referencing of each scan (cf. Fig. 2 right). Therefore, at least three, but in the most cases four, well-distributed targets were included in each scan. The coordinates of the targets were determined simultaneously by a total station using a special red target on the back side of the laser scanning target (cf. also Fig. 2 right), while the scanner position could be determined by measuring an eccentric 360° prism on top of the scanner. All targets are determined by polars in a local geodetic network, which will later be transformed to the network of the island using GPS measurements. The precision of the direct geo-referencing is in the range of 1 to 5 millimetres. The parameter for scan resolution was set to high or super high with low noise depending on the distance to the object. In total 25 minutes were used for each scan station. This included the geodetic measurements of the total station and the move to the next station. Direct geo-referencing was performed in 10 minutes per station in the post processing phase. In summary, 112 scan stations were used to scan the objects listed in Tab. 3, which yielded 31.3 GB of data and 1.8 GB of digital images using the add-on camera Nikon D40. The digital images could be used in a post processing procedure to integrate the imagery as RGB values into the point cloud. Fig. 5 illustrates a scan of the IMAGER 5006 representing some Moai of Ahu Nau Nau. The data evaluation of IMAGER 5006 scans is planned for 2009.

4.1 *Vaihu*

The single Moai at Vaihu (cf. Fig. 4 top) was the first statue scanned in 2007 and in 2008 using the Trimble scanners. Just four scanner positions were necessary for scanning the Moai each year, using four spheres for registration and three of them for geo-referencing. For geo-referencing three points were marked with wooden sticks sunk into the ground and measured by GPS. The same points were available for both 2007 and 2008. In total 2.3 million points were scanned with a grid density of 7 mm each year.

4.2 *Ahu Akivi*

The stone figures of Ahu Akivi (cf. Fig. 4 centre) were scanned in 2007 and in 2008 using the Trimble scanners. This group of seven Moai, about 4.5 m (15 ft) tall, is one of the few statues looking out to the ocean; most statues face inland. The group was restored and set upright again in 1960 a few kilometres inland from the coast. The figures symbolize the seven scouts, which according to legend were sent across the ocean by Polynesian chief Hotu Matua to locate Rapa Nui.

To fully document the Moai (with a scanning grid size of 5–20 mm at 10 m distance) and surroundings, a total of 9.5 million points were recorded from twelve scanner stations in 2007. The Ahu, the remains of two cremation chambers behind the Moai, and the open space in front of the statues were also scanned. Eleven control points (spheres) around the object were marked and determined by differential GPS (DGPS), so an identical coordinate system could be recreated for the subsequent scans in 2008. In 2008 only the Ahu and the seven Moai were scanned with grid size of 20 mm at 50 m distance from six scanner stations (3.7 million points) using four of the marked control points. The Moai are illustrated in different states (as point cloud with RGB values of the internal video camera, as point cloud with intensity values, and as meshed 3D model) in Fig. 6.

4.3 *Ko Te Riku*

The third object scanned was the single Moai Ko Te Riku at the Tahai Ceremonial Complex, located on the coast in Hanga Roa, the island's only settlement. Due to its head covering (Pukao) of reddish volcanic rock, this Moai could not be completely surveyed using the four scanner positions on the ground. Due to a crash of the laser scanning system Trimble GX on February 20th 2007, which could not be repaired on the island, the scanning of Ahu Ko Te Riku could not be completed, i.e. ca. 20% of the Moai was not scanned. Therefore, only 730,000 points were available for the Moai, which was scanned with grid size of 5–7 mm at 10 m distance for the back of the statue.

In 2008 the Moai and its Ahu were scanned from six scanner stations (grid size 10 mm at 30 m distance, 1.2 million points) using nine spheres on marked control points, which were well-distributed around the object, for registration and geo-referencing.

4.4 *GPS Measurements*

For the geo-referencing of the laser scanning data and for the geodetic documentation of all excavation sites in the island's coordinate system SIRGAS (Fortes et al. 2006, González 2007) at least three points were marked in the field per object site. All marked points were determined by differential GPS measurements (interval 15 seconds) using two Ashtech ProMark2 instruments simultaneously, one as a reference station on a reference point of the coordinate system SIRGAS and one as a rover on marked points. Therefore, the coordinates have been determined by post processing using additional GPS data from the local permanent GPS station ISPA. For the transformation of the GPS measurements into the island´s coordinate system SIRGAS the six reference points were measured. The determination of the WGS84 coordinates of all points from 2007 yielded a standard deviation in sxy = 5 mm (max. 18.5 mm) and sz = 10 mm (max. 29.1 mm), while for the transformation into the UTM coordinate system of the island a precision for sxy = 10 mm and for sz = 50 mm was achieved.

5 Data Processing and Modelling

5.1 *Registration and Geo-referencing of Scans*

The automatic sphere-based registration of the three-dimensional point clouds of each laser scanner station for the GX/GS101 was accomplished with the software RealWorks Survey 5.1 (RWS). The number of scanner stations, number of marked points used, number of points per point cloud per object and the precision of the registration and geo-referencing are summarized in Tab. 4.

Only three spheres were available for geo-referencing of Ko Te Riku (cf. Tab. 4), while for all other sites all spheres could be used for geo-referencing. For the IMAGER 5006 scan data the direct geo-referencing was tested exemplarily for some scans in the local geodetic network to see the precision potential, which was in the range of 1 to 5 millimetres as mentioned before. It was decided to perform the direct geo-referencing of all IMAGER 5006 scans only when the GPS data have been processed and all absolute coordinates of all targets are available.

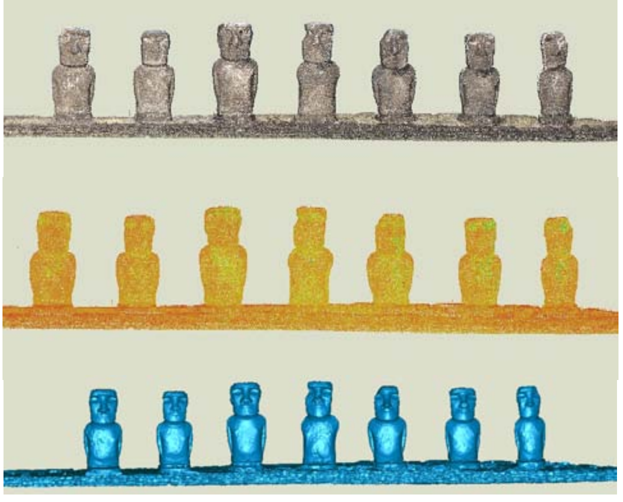

Fig. 6: Ahu Akivi represented as point cloud with RGB values of the internal video camera, as point cloud with intensity values, and as meshed 3D model.

Tab. 4: Precision of registration & geo-referencing for three objects scanned in 2007 with GX and in 2008 with GS101.

Site	System	# station/ spheres	# points [mio.]	Precis. registr. [mm]	Precis. geo-ref. [mm]
Vaihu	GX	4 / 4	2,3	2	6.8
Akivi	GX	12 / 9	8,9	5	8.3
KoTeRiku	GX	4 / 6 (3)	0,7	5	6.5
Vaihu	GS101	4 / 4	2,3	3	12.2
Akivi	GS101	6 / 4	3,7	6	21.0
KoTeRiku	GS101	6 / 9 (3)	1,2	9	9.0

5.2 *Modelling of the Point Clouds*

After registering and geo-referencing the scans the entire point cloud of each object will be segmented in RealWorks Survey 5.1, i.e. all points, which do not belong to the object or which are not necessary, will be deleted. Thus, the point cloud can be slightly reduced. Another option to reduce the point cloud is resampling into regular point grid spacing. The point clouds were exported in an ASCII format, in order to transfer the data to the modelling software Geomagic 10. Here, the point clouds were additionally resampled by decreasing the grid spacing, e.g., 20 mm, which offers faster visualisation performance on a standard notebook. The quality of the point cloud can be improved by filtering and following elimination of blunders, which could cause a further reduction of 10% for the point cloud. Finally, a triangulation (meshing) of the point cloud results in 3D models of the Moai, which are shown in Fig. 7. These models (cf. Fig. 6 bottom) can now be used for further investigations such as volume calculations, cutting slices, etc. and also for visualisation tasks using texture mapping as shown in Fig. 10. Furthermore, these models are the basic data set for deformation analysis, thus it is possible to analyse the changes on the Moai between 2007 and 2008, caused by erosion, weather or other climatic aspects.

Additionally, scanning the surrounding area enables both a site plan and a terrain model to be generated, providing the archaeologists with important base-line data for later excavation work.

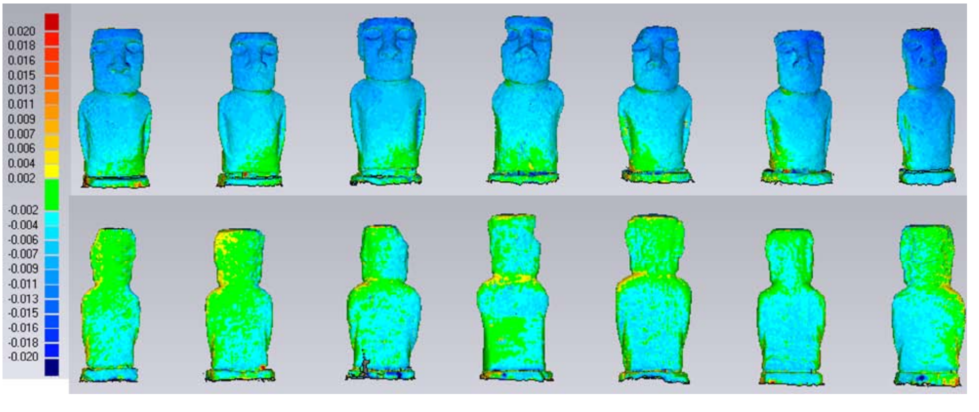

Fig. 7: Front and back view of the Moai at Ahu Akivi illustrating the differences between two 3D models from 2007 and 2008.

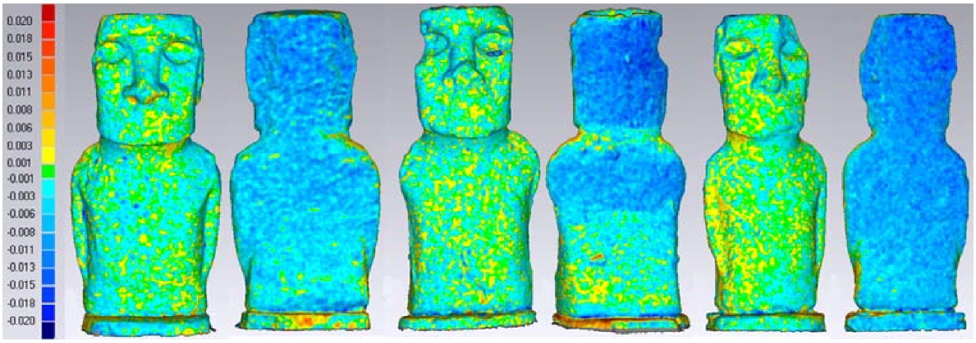

Fig. 8: Front and back view of three Moai (left, centre, right) at Ahu Akivi illustrating the differences between two 3D models from 2007 and 2008 (after separate model-to-model registration for each Moai).

5.3 *Deformation Analysis*

To analyse changes and deformation of the Moai within a specified time interval a 3D comparison of the two triangulated meshes of both epochs using Geomagic is required. The 3D model-to-model registration was computed based on the ICP algorithm (iterative closest point) using just the 3D models of each epoch and not any GPS data for the geo-referencing. Therefore, the figures were modelled using a high-resolution point cloud with a point grid of 5mm for the Moai at Vaihu and 2mm for Ahu Akivi. This 3D comparison could allow signs of existing erosion to be clearly identified or changes from conservation to be explicitly monitored; more significantly, it will enable future scanning at set time intervals to quantify possible erosion processes and show the progress of conservation measures applied to statues.

Currently, it is difficult to specify the range of expected changes/deformations on the Moai, but it could be a change of some millimetres in a ten year period. Changes or deformations can be caused by erosion or weather conditions, which could leave traces on the whole bodies of the statues. On the other hand unstable ground from the renovation of the platform could cause slightly increasing incli-

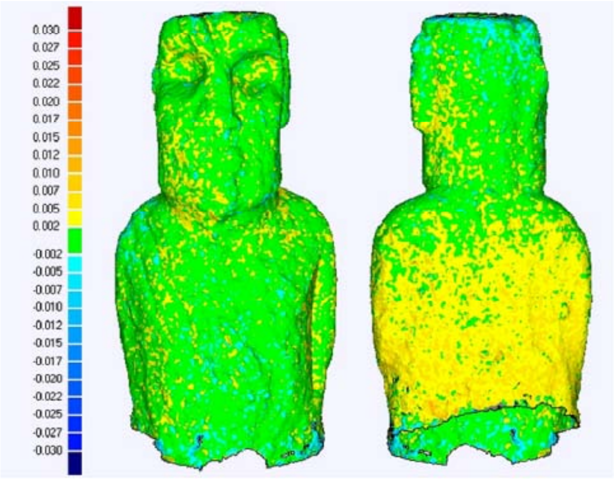

Fig. 9: Presentation of differences (± 2 mm in average) between two 3D models of the Moai at Vaihu (2007–2008).

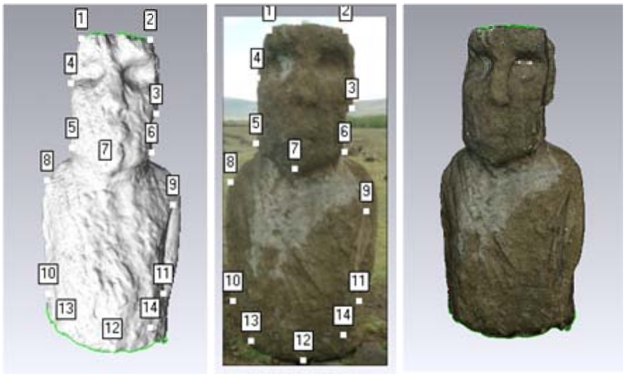

Fig. 10: Texture mapping of the front part of the Moai at Vaihu using the software Geomagic Studio 10.

nation or/and a vertical shift of the erect Moai, which could only be detected if the two temporally different 3D models could be compared in the same fixed coordinate system. Therefore, a precise geodetic network is required, although it has not yet been established. Fig. 7, 8, and 9 represent the model-to-model differences between 2007 and 2008 for Ahu Akivi and the Moai at Vaihu. The deviation was 5 mm on average for all models, which is the absolute value of the precision of the systems. Due to slight systematic effects, which can be seen in Fig. 7, an additional model-to-model registration was carried out for three individual Moai (left, centre and right statue). Fig. 8 illustrates the results of the 3D comparison for the three Moai as front and back view. It is obvious, that the back part of the Moai could be slightly eroded, but this effect is still within the precision of the systems. These deviations are influenced by the precision of the laser scanning systems, by errors from the registration, and possibly by blunders from the 3D modelling in Geomagic. Currently it is difficult to explicitly address an error source to a specific effect. To prove significant changes in the statues more investigations are required.

5.4 *Texture Mapping*

The texture mapping of the Moai using high resolution imagery could be applied with two different methods: (i) by registration of the photo and the meshed 3D model via measured control points (cf. Fig. 10 left) or (ii) by automatic texturing using the orientation parameters of each photo, which are in the same coordinate systems as the scanned point cloud, and its related camera calibration parameters (Abdelhafiz & Niemeier 2006).

First tests for texture mapping were carried out using the software Geomagic 10. Therefore, a triangulated mesh of the point cloud was created and the Moai was textured by registration of high-resolution images from the Nikon D40 and the meshed 3D model (cf. Fig. 10). The results were not satisfactory due to unexpected white patterns on the textured model (see right eye of the Moai in Fig. 10 right) and due to smearing effects in the overlapping area of photos, which might be caused by bad registration. Therefore, further different software packages, e.g., QTSculptor from Polygon Technologies, will be tested to generate textured 3D models of the Moai.

6 Conclusions and Outlook

Terrestrial laser scanning offers an efficient technique for the documentation of Easter Island's cultural heritage – the Ahu and Moai. In the past the statues were mainly toppled by natural disasters like earth quakes and tsunamis, today's disasters are ignorant tourists, who do not respect the cultural heritage and even destroy the Moai by vandalism, as it happened in March 2008, when a Finnish tourist damaged one statue of Ahu Nau Nau. This demonstrates clearly that it is absolutely essential to scan the Moai for documentation and to generate 3D models as a digital copy of the Moai from scanned point clouds. In 2007 and 2008 eleven object sites (Ahu and Moai) were scanned with Trimble and Z+F scanner, whereby three objects were scanned in both years for testing deformation analysis by 3D comparison. As expected no significant changes on the Moai could be detected within the short time interval of one year. Nevertheless, the same Moai will be scanned in the next years to document possible deformations and to estimate it's possible deformation range. Nevertheless, the scanning of the top of a Moai is not possible due to the height of the statues compared to the low scanner stations.

During the scanning project the importance of proper preparation for local weather conditions became clear. Hot temperatures – 27–33° C or 81–91° F – caused scanner operating temperatures of more than 40° C (104° F) at times. The scanner worked absolute perfectly the entire time in 2008, but the island's heat, wind and sudden showers added to the project's challenge. Due to a close position of most platforms to the sea the scanner also needed to be positioned close to the ocean when scanning the back of the Ahu/Moai. Here, the salty humidity trickling off the glass plate of the scanner caused problems (no returned signals) for the Trimble scanners during scanning.

The generation of 3D models for the scanned Moai is still in progress. Here, the challenge is to model the Moai with geometrical correctness although the data volume needed to be reduced to an accepted minimum while the meshed models should be visualised interactively with high resolution photo-realistic texture mapping. However, some software packages will be tested for texture mapping of the models of the Moai.

Finally, the scanning of all erect Moai outside the quarry in Rano Raraku could be finished during the next German expedition in 2009. The scanning and documentation of all 887 Moai might take some more years.

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