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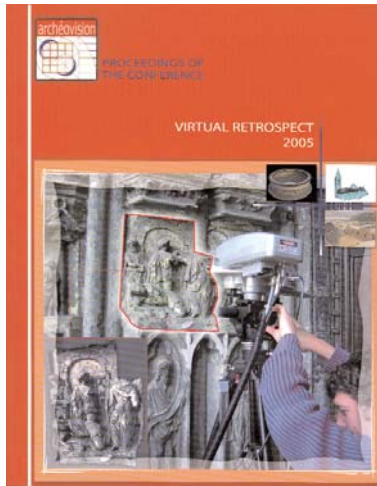
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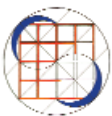
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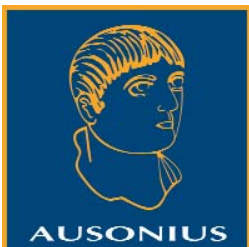
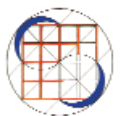
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## A NEW TOOL FOR 3D ARCHAEOLOGICAL AND EPIGRAPHIC RECORDING

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**Abstract :** Regarding the technological and epistemological problems raised by the necessity for Archaeology to record the precise shape of the objects of its study, the OSIRIS (Optical Systems for Interferometric Relief Investigation and Scanning) project aimed to develop a device that allows, by optoelectronic processes, an accurate, quick and easy to use recording, dedicated to the specific and very demanding needs of archaeological research. The article explains how this new innovative device takes advantage of monochromatic light projection, polarization states splitting technique and interferometry principles to reach that goal. Some examples of its application to archaeological recording problems are also given.

**Keywords :** archaeology — epigraphy — 3D recording — moiré — interferometry.

**1 Introduction. The problems of archaeological recording.** Archaeology, as the Science which studies the material remains of human behaviour, is permanently confronted with the problem of reading, recording and conserving these material traces of human behaviour which constitute its investigation field. These recordings needed by the different aspects of the archaeological research have a double aim: the creation of a medium making it possible to publish in the more accurate way the studied object; and the virtual conservation of this object, or, at least, the conservation of the historical information (in the broadest sense of the expression) it reveals and preserves. This last aspect of the problem, the conservation of information, is far from being a simply theoretical matter. Indeed, in its very process of revealing the relics of the Past, Archaeology is by definition destructive: it always destroys the container of the object it aims to reveal, and the thus revealed content is then exposed to new aggressions of its surrounding world, which in many cases will damage it irreparably over a relatively short period of time, in comparison to its age. No monument can avoid this

phenomenon of deterioration and, finally, of destruction. The case of Ancient Egyptian archaeological Heritage, whose study is at the root of the OSIRIS project, clearly exemplifies this: the especially dry, chemically and hygrometrically stable desert ground of Egypt naturally allows the long-lasting preservation of archaeological objects, even the more fragile ones, like millenary papyrus, wooden artefacts or textiles. But, once exposed to the open air, to its climatic variations, to today's pollution and to human aggressions of all kind, these relics of the Past decay at a very impressive speed, even those made in very hard stone [1] (fig. 1).



*Fig. 1: An Ancient Egyptian granite false-door of king Amenhotep II, as discovered in 1939 and the same in 1985, according to Bell 1987, pl. 1.*

To fulfil this necessity of recording, Archaeologists have, since the dawn of their discipline, at the very beginning of the Renaissance, relied upon techniques of transcribing in two dimensions objects which, nonetheless, have three dimensions. This is how graphical recording, in different forms and variations, has become, since Leon Battista Alberti (1404-1472 AD), the almost unquestioned standard for the publication of archaeological monuments, usually complemented by classical photography since the XX<sup>th</sup> century, and, over the past few years, by digital photography. But all these techniques inevitably induce, from an epistemological point of view, thinking in two dimensions objects that actually are three-dimensional. We are all accustomed to apprehend the reconstruction of a building by combining plans, sections and elevations, although each of us knows examples for which the 3D combination of these 2D representations generates inaccuracy and inconsistency. On a more microscopic level, most of the scholars who study the pictorial handwriting of artists focus on strokes, bands of colours, brushwork or compositions, but fail to take into account the three-dimensional geometry of the painting material itself. Seeing and thinking of cultural Heritage in 3D is still an essential epistemological issue for archaeology and related scientific disciplines, an issue that has just started to be approached.

Finally, – and this brings us back to the central thematic of this symposium, – the use of VR technologies for archaeological purposes implies and needs an accurate, precise and efficacious 3D recording of the data. So, to sum up, recording the material remains of human behaviour is still one of the most fundamental methodological issues for archaeology.

## 2 The available techniques for archaeological recording

As mentioned above, the traditional recording techniques in archaeology and cultural Heritage studies nowadays are all based on two common methods for the visual reproduction of reality: drawing and photography. These two means of capturing the shape and the materiality of any object, – whether archaeological or not, – offer obvious advantages for the publication and the diffusion of an object, but they also raise serious problems regarding their ease of reading and interpretation, their flexibility of realisation and use, their speediness (and, thus, cost), and their accurateness (directly linked to speediness), without mentioning – again – the fact that they always fallaciously reduce the volume of the objects to a 2D picture. To overcome these inherent constraints of traditional recording techniques, it is necessary to use new technologies of recording, processing and storing the data that define the precise 3D shape of any archaeological object.

Optical recording – that is without contact – of the relief or the 3D shape of an object can be achieved by using two principles: stereoscopy and triangulation (which are, actually, based on the same concept). These two principles have permitted the development of today's three most common techniques used to record any 3D object digitally: photogrammetry, laser scanning and moiré. These technological solutions, initially

invented for purposes very far from those of Archaeology, have given very good and usually impressive results, but their use remains rather limited in cultural Heritage studies. Indeed, when they are to be exploited in real archaeological working conditions (*in situ*, with intense and varying ambient light, heat, dust, ...), they often quickly reveal limitations, – different from one technique to the other, – which prevent their systematic and extensive utilization.

It is in this precise context that the Department of Ancient Egyptian Art History and Archaeology of the University of Liège (Belgium) and the Hololab Laboratory of applied Optics, of the Department of Physics of the same institution, launched the OSIRIS (Optical Systems for Interferometric Relief Investigation and Scanning) project, under the auspices of the European Centre for Archaeometry at the University of Liège. The main originality of this project was to consider the problem differently, that is to no longer try to use a device initially developed for other uses and purposes, but, on the contrary, to start with the precise and specific requirements of field archaeology, epigraphy and history of art, and to investigate consequently the physical principles that allow optical 3D recording of an object [2]. This approach led on to the development of an innovative and very versatile device, protected by a patent, illustrating the fact that archaeology can play a part in technological evolution through the specificity of its objectives, methodology, needs and working conditions, which, in this case, permitted to push aside the limitations accepted in industrial contexts of development.

## 3 The OSIRIS 3D recorder and its exploitation through DEIOS company

As explained above, all the currently available and exploited techniques allowing the optical recording of the 3D shape of an object – whether archaeological or not – rely on the triangulation concept and can be reduced to 3 methods :

— Photogrammetry: different pictures of the same object but taken from different points of view are used to reconstruct, via the analysis of the parallax deformations, the geometry of the object;

— Laser scanning: a laser line (or a spot moving on a line) is projected on the studied object and its distortion by the relief of the object is used to deduce the 3D shape of the latter;

— Structured light projection: instead of a line (or a spot), that has to be mechanically moved on the whole surface of the object, a full frame pattern, made by alternatively light and dark lines, is projected; the combination of its deformation by the relief of the object with its unaltered original image produces a fringe pattern directly connected to the geometry of the object; so, this fringe pattern can be algorithmically interpreted to deduce the 3D shape of the analysed object.

The comparison of these three methods (fig. 2) reveals that, even if laser scanning and structured light projection appear to be better adapted to the needs of 3D recording of archaeological objects, the three of them have significant disadvantages.

Triangulation methods			
	Photogrammetry	Laser scanning	Structured light projection
Speed	☹	☹	☑
Accuracy	☹	☑	☑
Insensibility to ambient light	☒	☑	☒
Insensibility to texture	☒	☑	☹
Texture Acquisition	☑	☹	☑

Fig. 2: Comparison of triangulation techniques.

An ideal solution would be to combine the advantages of laser scanning and structured light projection techniques, while skirting their own respective limitations. This is why the OSIRIS project aimed to develop a set-up that could produce a laser structured light.

The structured light projection techniques allow robust, precise and fast whole-field acquisitions. Furthermore, they benefit from the well-established procedures developed for interferometric systems such as phase-shifting [3] and phase unwrapping algorithms [4].

The required features for a good projection pattern are: a perfect sinusoidal irradiance function, a very high contrast, high irradiance and a large depth of field. Conventional projection technologies such as spatial light modulator or slide projector hardly ever satisfy all these qualities. The problem of contrast is especially critical when ambient light cannot be shut down, for instance in outdoor conditions, which is usually the case for archaeological applications.

An attractive alternative to a spatial light modulator is given by interferometric fringe projection systems [5]. Young's interference pattern is a theoretically perfect sinusoid that can have a very high contrast. In addition, interferometric fringes are non-localized which means that the irradiance function and contrast remain unchanged, whatever the projection distance, so there is no depth field problem.

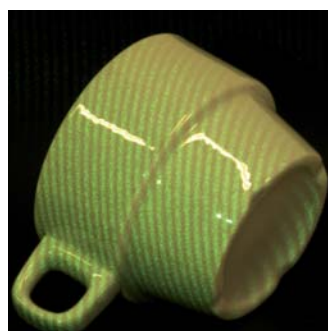
Compared to a spatial light modulator, dynamically shifting or scaling interferometric projection pattern could be a real challenge. It often requires precise and complex electromechanical or optoelectronic systems whose repeatability and robustness is not assured. Internal vibrations are also a possible cause of trouble that compromises fringes stability.

On this basis, the OSIRIS research team developed an original monolithic device that allows fringe generation and phase-shifting without any moving parts. Simplicity, robustness, insensitivity to vibrations and low-cost are among the principal qualities of this innovative setup. It also makes it possible to create a large variety of pattern fringe spacing for multiple range measurement and temporal phase unwrapping [6].

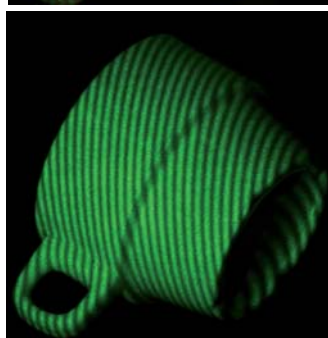
The use of monochromatic laser light is also a beneficial approach for filtering relevant signals from ambient light and

other illumination disturbances. In front of the acquisition camera, different filters can be set in order to improve the image quality. Classical structured light projection systems are unable to work correctly in daylight conditions because of the poor fringe contrast. Laser light has the advantage of a very narrow spectral band (< 1 nm). Using an interferential spectral filter adapted to the laser frequency it is possible to drastically reduce upsetting light while preserving the fringe image. Specular or partially specular objects are also known to be especially difficult to digitalize because of the saturation effect due to the rays that are directly reflected to the camera. Polarization properties of the projected laser fringes can help to overcome these specular reflections. Indeed the polarization state of a ray is preserved by specular reflection whereas diffused rays are depolarized. A linear polarizer upstream of the camera lens can absorb all specular rays and transmit 50 percent of the diffused light coming from the object, thus resolving the problem caused by saturation. Figure 3 illustrates these enhancements allowed by joint use of laser fringe projection and image filtering.

Fig. 3: Contrast restoration and saturation reduction by spectral and polarization filtering:



a) projected fringes under ambient lighting without filtering;



b) image restoration by filtering;



c) 3D object reconstruction from filtered images.

The device thus developed is now industrialized, exploited and commercialized by a new start-up company named DEIOS (Development and Enhancement of Interferometric Optical Systems). The next section presents a few interesting results of 3D digitalization performed on monuments from the Egyptian Department of the British Museum that illustrate the capabilities of this set-up. These examples demonstrate that the structured laser light profilometer is a powerful tool, not only for preservation, but also for scientific investigation of features that remain almost unrevealed by visual inspection.

#### 4 New advantages and perspectives for archaeological and Cultural Heritage research

##### 4.1 Geometry versus texture

A 3D recording makes it possible to distinguish and isolate the real geometry of an object from its purely chromatic characteristics, two features that are always merged in our ocular perception of reality. It is often interesting to map the chromatic or texture information on the recorded geometry of a digitalized object, but in some cases, it might also be very useful to separate these two material characteristics of the object. Such is the case, for example, of a fragment of a naos now preserved in the Egyptian Department of the British Museum (BM EA 1106), on which the colours of the stone – Egyptian pink granite – and the damages caused to the monument make the inscription visually barely readable (fig. 4a). Every sign or figure becomes easy to read on the grey scale height map produced by the DEIOS device, a purely geometrical representation of the same object, without any chromatic information or, in this case, disturbance (fig. 4b).

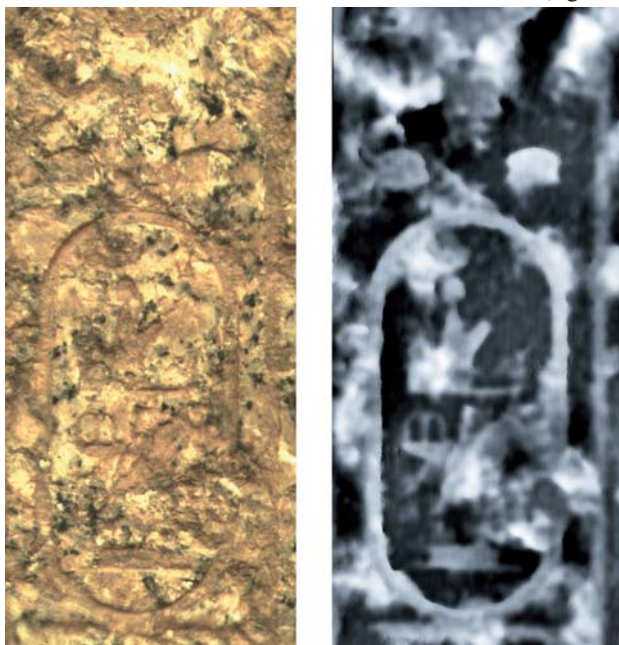


Fig. 4: 3D digitalization of a damaged hieroglyphic inscription on an ancient Egyptian granite monument (BM EA 1106) :  
 a) Traditional photograph ;  
 b) Greyscale height map revealing the hieroglyphs.

Since the engraving of these images is intentional, they are situated almost at the same depth from the surface of the stone and appear in the same grey level, with sharp outlines; on the contrary, the damages caused to the monument have necessarily variable depth and look like clouds, with variable grey values. It is thus easy for the specialist to recognize the royal title and name of the last indigenous Pharaoh of Egypt, king Nectanebo II, in the dedication inscription of this badly damaged naos.

##### 4.2 In situ digitization

The ancient Egyptian portrait presented in figure 5 is a part of a large bas-relief depicting the prince Rahotep, a son of king Kheops, the famous builder of the greatest pyramid at Guiza, who lived more than 45 centuries ago. This commemorative monument is currently on display in the upper galleries of the British Museum (BM EA 1242). It was digitized by DEIOS company in normal museum working conditions, which is in the public galleries, with natural and varying ambient daylight (because of the windows in the roof of the gallery) and through its protective glass. The 3D renderings, either in grey or a false colour scale, make it possible to determine the actual (and measurable) depth of any carved area of the monument. For example, a tiny depression, barely perceptible, but here clearly identified and measured, can be seen all around the head, carved by the sculptor to enhance the relief without too much effort by lowering the whole surface around the figure.

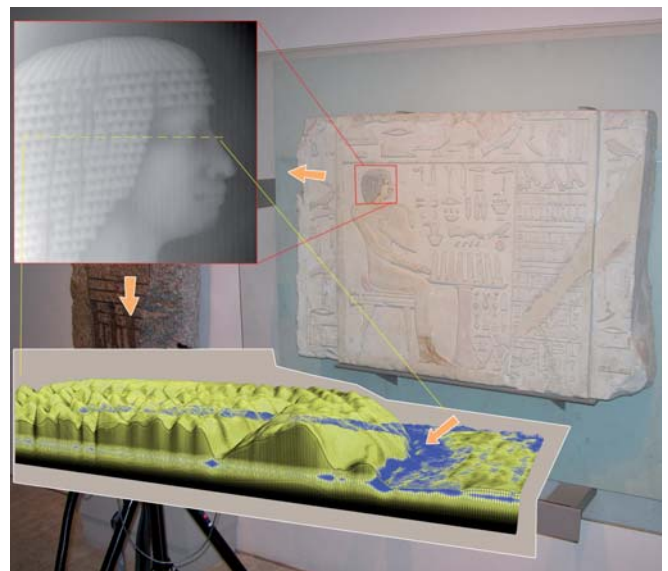


Fig. 5: 3D digitization of the Rahotep slab-stele BM EA 1242, with a greyscale heightmap of the face and a depth expanded representation of a side of the same.

##### 4.3 Real 3D reading

Some archaeological artefacts are in such a state of preservation that it is almost impossible to handle them without causing damage. It is precisely the case of the Middle Kingdom stela BM EA 224 (fig. 6).

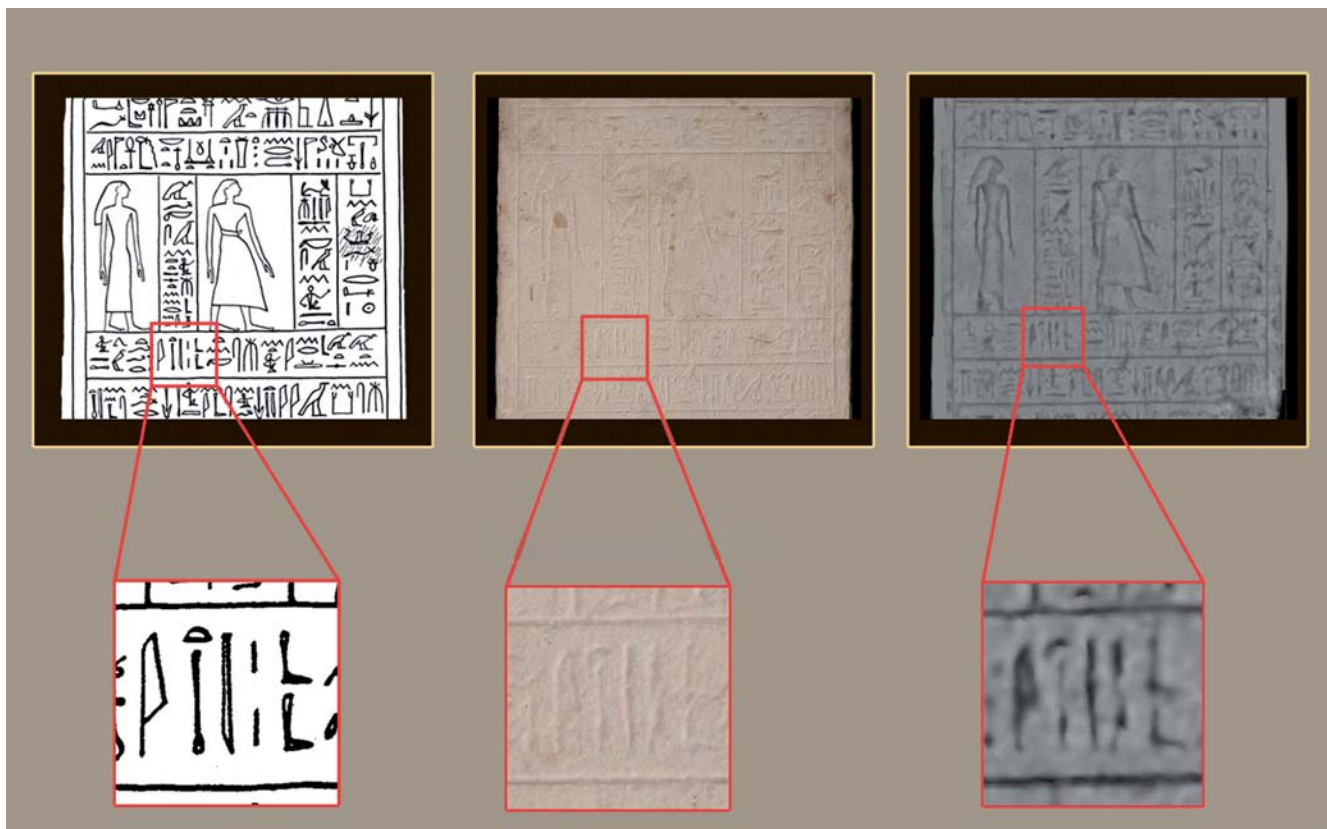


Fig. 6: 3D digitization of the ancient Egyptian Middle Kingdom stele BM EA 224 :  
 a) Published traditional handmade copy;  
 b) Picture under grazing incident lightening;  
 c) Greyscale height map.

It was carved in poor quality limestone and, because of its old age, is now decaying. Even on a photograph with especially good low-angled light, the very faint carvings of the decoration are not easily recognizable. The 3D capture made by DEIOS and represented here in a grey scale height map made it possible to correct the reading of the hieroglyphic inscription made by Egyptologists more than a century ago, when the stela was in a much better state of preservation (two reed leaves instead of two simple strokes, a detail that changes the reading of the personal name referred to in the text). The 3D recording is obviously much more accurate, reliable and, thus, useful than the traditional drawing, even if the latter was made long ago, at a time when the object was much better preserved. Furthermore it allows free use and manipulating of the virtual object as if it was the real one, but without any risk for the latter.

### 5 Conclusion

The completely portable innovative setup developed by the OSIRIS – DEIOS research team takes advantage of the physical properties of polarized laser light to allow the quick and accurate digital 3D recording of any Cultural Heritage object in real archaeological working conditions (fig. 7), in outdoor daylight, behind a protective glass or even with partially specular disturbances. Thus, global, large scale and systematic projects of 3D digitization of ancient artefacts can be envisaged, in order to record, analyze, measure and even duplicate – virtually or physically – Cultural Heritage and endangered traces of the Past.

This new 3D recording technology, precise, easy to use and quick, also permits us to imagine for the near future new possibilities for the scholarly publication of ancient monuments, that is in an interactive digital 3D virtual reality, and new standards for the diffusion and study of the materialized Past. Furthermore, on a methodological and epistemological level, the combination of VR technologies and efficacious 3D recording technologies will allow, finally, archaeologists and cultural Heritage specialists to picture archaeological monuments in 3D and no longer in inappropriate 2D representations.



Fig. 7: In situ 3D digitalization of the external sculptures of a portico at the Tournai Cathedral (Belgium) by DEIOS.

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## Notes

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