CLOSE-RANGE 3D IMAGING FOR DOCUMENTING AND MONITORING DYNAMIC DETERIORATION PROCESSES IN WALL PAINTINGS

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Abstract

3D imaging techniques applied to cultural heritage for recording position, dimensions and/or shape, are proliferating rapidly. Although most are based on laser scanning and photogrammetry, one of the newer options with considerable potential is structured light 3D imaging. This paper presents the application of a low-cost PicoScan 3D close-range scanner, based on the principle of structured light phase measuring profilometry, to record deterioration processes in wall paintings. The PicoScan 3D close-range scanner consists of a standard Canon DSLR camera, combined with a Pico projector mounted on the hot shoe. A sinusoidal light, coded as a gray level fringe pattern, is projected on the object surface. The phase measurement is achieved by recording the distortion in the sinusoidal signal from the object and is used to reconstruct the object shape with sub-pixel accuracy.

In this study the 3D imaging technique was used as a tool for recording deformation of wall painting surfaces due to activation of salts. It was aimed to generate precise geometric data in order to monitor the dynamic processes of transformation and decay. Time-lapse recording under induced changes in environmental parameters was carried out to record real-time information on salt transformations. The results obtained from the in-situ study demonstrate that dynamic transformations such as crystallisation/deliquescence of salt efflorescence etc. can be recorded qualitatively as well as quantitatively.

1. Introduction

Three-dimensional imaging is increasingly being used as a tool for investigation and digital documentation of cultural heritage. 3D imaging systems are relatively new, highly precise measurement tools and provide a high-resolution 3D data of an object's topography with measurement accuracy to the sub-millimetre level. 3D graphic representations of the object provide an extremely accurate record of an object's physical structure, unlike flat, 2D photographic representations.

There are many types of 3D imaging technologies, however, the most common systems that are used for close range imaging of cultural heritage are structured (white) light and laser triangulation scanners. In structured light 3D imaging a sequence of organised patterns of light (e.g. grids, dots, or stripes) is projected onto the object and the deformation of the pattern on the object's surface is analysed. The scanning system's camera is specially aligned with the light projector, which simultaneously records the distortion of the light patterns and a complex algorithm calculates the distance of every point. (Wachowiak and Karas, 2009;

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Zhang and Huang 2006). The structured light imaging records the spatial data and RGB colour values together and therefore, he colour information is registered exactly with its corresponding coordinate (xyz) point. The application of structured light 3D imaging has widely being used for recording and documentation of cultural heritage (Rocchini *et al*. 2001; Wachowiak & Karas, 2009; McPherron *et al*. 2009; Akca, 2012; Pashaei & Mousavi, 2013; Lapp & Nicoli, 2014).

2. Research Context

The deterioration of wall paintings is a dynamic process and therefore, monitoring and documentation of condition becomes extremely difficult and challenging. Salts are one of the most widespread factors causing deterioration of wall paintings. Crystallisation of salts leads to powdering and flaking of the paint layers and support, resulting in severe deterioration. Salts undergo phase changes – dissolution, crystallisation, hydration and dehydration under varying environmental conditions, and the kinetics of these changes has a significant impact on the rate of deterioration of the original materials. Since the variations in environmental conditions are very frequent, these kinetic transformations are also rapid and therefore, very difficult to monitor and document. While laboratory investigations into these deterioration phenomena have often been undertaken, such investigations do not account for the vast heterogeneity of the response of in-situ wall paintings resulting from variability in their materials, physical histories and environmental conditions.

The dynamic processes responsible for the deterioration of wall paintings and other objects of cultural heritage are difficult to record in real time. High-resolution digital imaging has been conventionally used for condition mapping and to record deterioration processes. Carefully targeted, high-resolution digital imaging can be carried out as a preliminary imaging solution for in-situ documentation. Precise, repeatable 2D macro imaging have been undertaken periodically as preliminary investigation, in order to generate reproducible sets of images for comparative analysis of transformations that have taken place during imaging intervals. The results of periodic imaging carried out in this research indicates that it is possible to differentiate major changes visually from consecutive images, however, minor changes probably remained unnoticed and precise measurement of the extent of deterioration was not possible. The application of image differencing software was also trialled on these images for precise visualisation of alterations but it was not possible to compare the differences due to differences in pixel data in two consecutive images. Although, the images were captured using the same rigorously applied imaging protocol, even the slightest deviation in camera position, distance, angle etc. introduced errors that were registered by the image-differencing software as transformations in the painting. Such errors can be eliminated if the camera position is fixed for the entire duration of the imaging, however, varying lighting conditions can still result in errors. An imaging protocol of automated 2D time-lapse recording with fixed camera position was developed at ETH, Zurich (Schoch *et al*, 2007; Zehnder and Schoch, 2009), which represents an important step in developing in-situ monitoring of the behaviour of materials in uncontrolled environments. With the differencing software it is possible to quantify transformations in x and y directions; however, the changes in z-axis could obviously not be quantified from 2D images.

3. Experimental Technique

It was evident from the previous research that both quantitative and qualitative data is necessary to understand the dynamic deterioration of wall paintings. While the methods used

in previous studies provided information in two dimensions, a 3D-imaging system was considered most appropriate for this application. The main criteria for 3D imaging were suitability for use in situ, close range application, repeatability, spatial resolution, portability, quantitative data output, reproducibility, data processing and interpretation, system cost and end-user friendly operation.

3.1. PicoScan Structured Light 3D Scanner

The Pico Scan is an entry-level 3D-scanner based on structured light, phase-measuring profilometry. A standard Canon D1100 DSLR camera is combined with a Pico projector mounted on the hot shoe (Figure 1) and is controlled by the Mephisto 3D scan engine software. A sinusoidal light, coded as a gray level fringe pattern, is projected on the object surface (Figure 2). The phase measurement is achieved by recording the distortion in the sinusoidal signal from the object and is used to reconstruct the object shape with sub-pixel accuracy. The PicoScan captures 13 images with projected light patterns plus one RGB image, which are used to generate 3D scan data. It is simple, portable and affordable, yet produces high quality scan data.

Figure 1: PicoScan system (image source: http://www.4ddynamics.com)

Specifications provided by the manufacturer are in Table 1.

Main geometry camera	Canon EOS 1100D
Standard lens	Canon 18-55 mm lens
Resolution Geometry	968 x644 pixels, 8 bits
Standard Texture Resolution	1936 x 1288 pixels, 8 bits
Projector resolutions	800 x 600 pixels
Projector brightness	40 Lumen
Working range near	150 mm

Working range far	800 mm
Acquisition time	20 seconds
Point to point distance	0.16 mm
Point accuracy	0.1 mm (average)

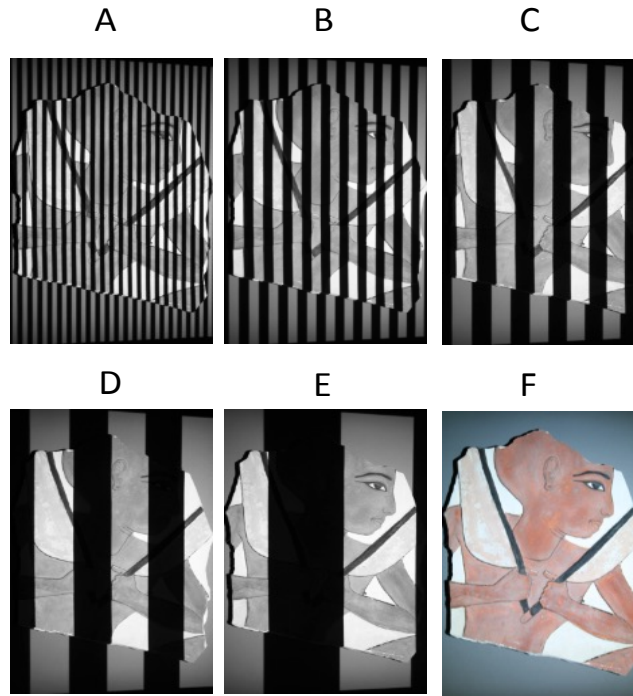*Table 1: PicoScan technical specifications (Source:* http://www.4ddynamics.com*)*

Figure 2. Examples of projected light patterns: 13 images with light patterns plus one image for the colour texture map are captured for each model.

Since the main components of the PicoScan are not custom designed, an external calibration is required. PicoScan geometric calibration determines the intrinsic and extrinsic scanner parameters: focal length and distortions of both the camera and projector lenses and the relative position of the camera and projector to one another. The PicoScan uses a sophisticated and unified calibration code based on a planar calibration board with printed purple and green checkerboard pattern. To perform system calibration the board is positioned in the field of view of both the camera and the projector, both focussed at the centre of the board. The projector projects its own black and white patterns onto the calibration board. Six to seven calibration images are captured in with the calibration board in different positions. For each calibration position, the PicoScan captures two images: one for the camera and one for the projector. The PicoScan software determines the 3D positions of the calibration board and computes the lens properties and distortions of both camera and projector. Several laboratory-based trials were conducted with PicoScan on small fragments of wall paintings to assess the capabilities and application parameters and also for comparison with data obtained from other 3D techniques.

3.2. Laboratory Trials and Comparison with Arius 3D Colour Laser Scanner

A comparative evaluation of imaging produced by PicoScan with that of the Arius 3D laser scanner, was carried out. Arius 3D laser scanner is a state-of-the-art system comprising a

laser scanner and a control system for moving the camera. The system characterises each measurement point according to its colour and location in 3D-space using the principles of high resolution, low-noise, three-colour laser triangulation and optically synchronised scanning (http://www.arius3d.com). Surface recording is carried out by a scanning head, which emits a focused laser beam composed of red, green, and blue wavelengths. It simultaneously measures colour reflectance and geometry by triangulation between the laser and a camera. A calibrated 'white cube' is used for colour calibration. The scanner is able to deliver 3D coloured point data at a sampling interval of 0.1 mm and a depth resolution of the order of 0.025 mm over the surface of an object (Hess *et al.* 2011).

The PicoScan laboratory trials were carried out on small fragments of wall paintings. Since Arius 3D is one of the highest quality 3D colour laser scanners, the data obtained from PicoScan are compared here with that from Arius 3D. The single scan models from PicoScan and Arius 3D are given in Figure 6. In the meshes in Figure 6, the PicoScan has generated 427647 faces, and 219942 vertices for sample 4247, and 257404 faces, and 129984 vertices for sample 4281. The Arius 3D scanned meshes have 644123 faces, and 322818 vertices for sample 4247, and 385 747 faces, and 193 514 vertices for sample 4281.
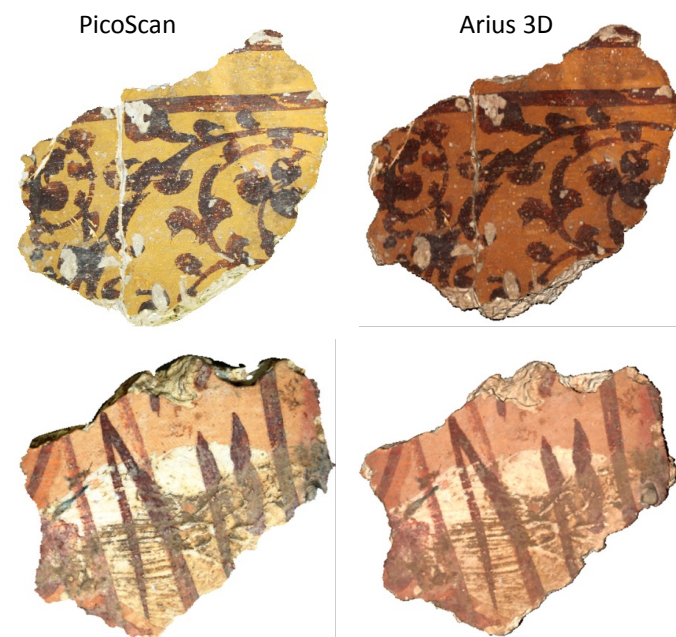

Figure 3: Single scan meshes from PicoScan and Arius 3D. Top: sample 4247; bottom: sample 4281.

To evaluate the metric accuracy of the data obtained from PicoScan a comparison was undertaken with reference to Arius 3D data. The data from both the scanners was aligned in Geomagic Qualify 12 (a software product, used for quality control in industrial engineering, now renamed as Geomagic Control), and a full-colour deviation map was created comparing the levels of variance in the PicoScan data with those from Arius 3D. The colour deviation maps indicate that most of the surface deviations were less than 0.5 mm and that the maximum upper and lower deviations were at the edges where data quality was poor (Figures 4 & 5). The metric data obtained from PicoScan scanner is comparable to that of Arius 3D scanner.
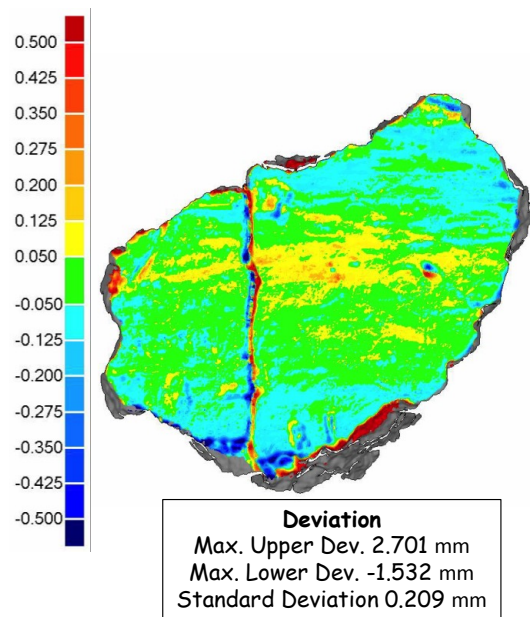
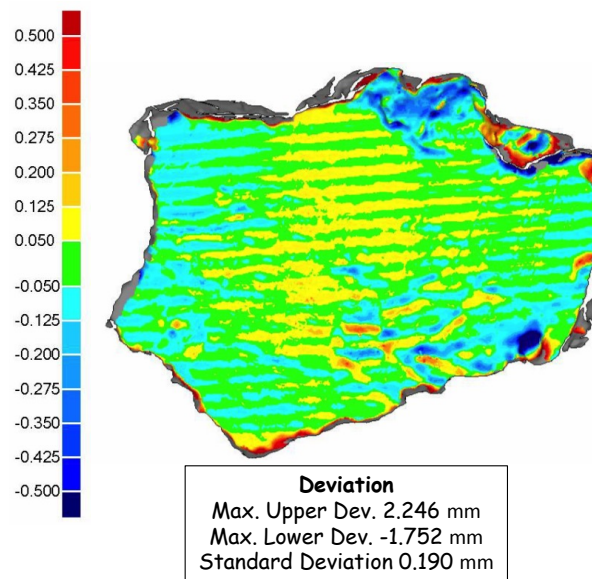*Figure 4: Colour deviation maps of Arius 3D scanner and PicoScan data: sample 4247.*

Figure 5: Colour deviation maps of Arius 3D scanner and PicoScan data: sample 4281

4. In-situ application for monitoring salt-phase changes

In-situ studies were conducted to assess the capability of PicoScan in recording surface alterations accurately. A small area of wall painting with visible salt crystallisation was scanned as a reference. The environmental conditions were then altered locally by increasing relative humidity to provoke deliquescence of surface salts, resulting in a dimensional change. Scanning was undertaken at fixed time intervals during the provoked environmental change to produce successive 3D models of the surface in order to evaluate transformations

in real time (Figure 6a & b). The 3D meshes were then aligned and compared in Geomagic Qualify 12 software to generate colour deviation maps. A deviation map of the first scan (reference) and the last scan (test) is given in Figure 7. It clearly shows the areas of change, including the changes that are not easily discernible to the naked eye, and indicates a maximum deviation of 0.37 mm to -0.40 mm (table 2). The annotations in figure 7 indicate total 3D deviation and individual deviations at the three axes.
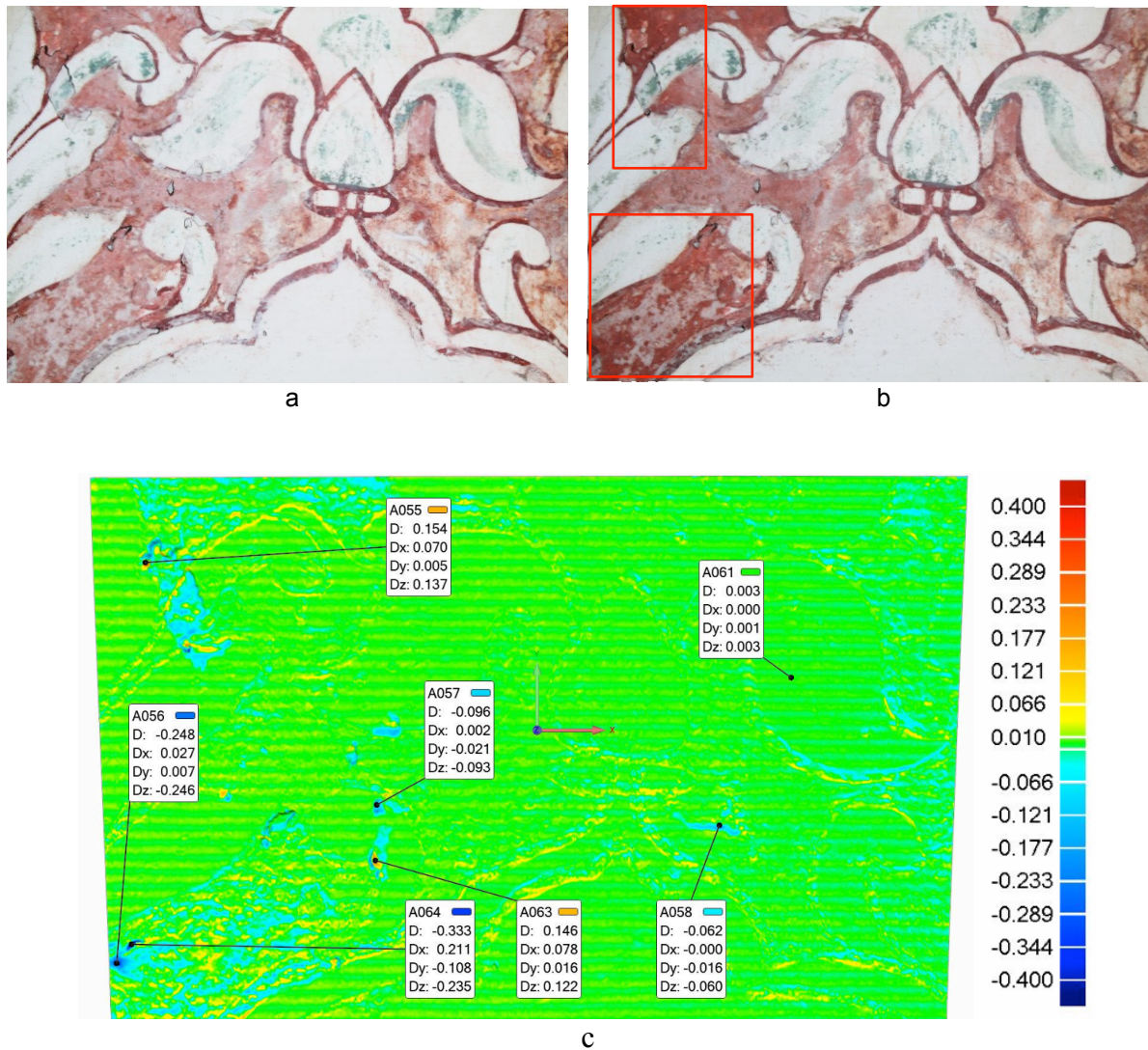

Figure 6: (a) 3D scan of wall painting surface with salt efflorescence, (b) 3D scan showing reduced salt efflorescence after induced environmental change and (c) 3D scan comparison showing extent of alteration. The annotations indicate measurements of alteration in x, y and z-axis.

Deviation	
Max. Upper Deviation	0.372
Max. Lower Deviation	-0.409
Average Deviation	0.012 / -0.013
Standard Deviation	0.018

Table 2: 3D deviation measurements of induced alterations in wall painting scans in figure 6(a) and (b).

5. Conclusions

The application of digital documentation techniques to record the condition and to monitor the deterioration process in art and cultural heritage obejcts is an important step in their conservation. The incorporation of 3D imaging introduces a significant degree of understanding that makes the integration of information an invaluable and incomparable addition to the documentation repertoire. The purpose of this paper is to assess the technical capabilities of a low-cost 3D imaging techniques in the monitoring and documentation of dynamic deterioration processes in wall paintings. A number of imaging techniques are currently in use, each with its own advantages and limitations. 2D imaging techniques are excellent in qualitative recording of dynamic deformations in wall paintings, but the lack of quantitative data is a major disadvantage.

This research has demonstrated that PicoScan is an efficient system for close-range in-situ metric data recording and is able to generate precise and detailed 3D surface models. The advantage of the PicoScan scanner is that it is simple, fast, very flexible and cost-effective 3D data capture system with less effort for transportation of the equipment in comparison to laser-based systems. The results obtained from the in-situ trials demonstrate that dynamic transformations such as crystallisation/deliquescence of salt efflorescences can be recorded qualitatively as well as quantitatively. Although the resolution of data obtained from PicoScan is lower than that of the Arius 3D (especially in the z axis), it is surprisingly good in relation to cost, and provides adequate resolution for the current application.

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