3-DIMENSIONAL DIGITAL FINGERPRINT OF PAINTINGS

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ABSTRACT

Paintings are typically considered as more or less flat objects with color as the most relevant information. Therefore, they are mainly documented with conventional 2D techniques, which cannot record the 3D relief. However, there are many paintings, especially those with a 3D relief in the mm range, where this relief is an important feature

- containing additional information about the style and brush stroke of the painter
- influencing the overall visual impression of the painting and
- defining, together with the color, an individual and unique fingerprint of each painting.

High Definition 3D scanners, based on fringe projection technique, allow the synchronous recording of both color and 3D with an accuracy in the µm-range and a spatial resolution of 10 µm. The paper discusses the state of the art of this technique and shows various examples of the 3D documentation of famous paintings and frescos.

1. INTRODUCTION

Motivated by cultural heritage, industry and medical applications, advanced 3D scanners and post-processing systems have been developed within the recent years for rapid and precise documentation of surfaces with curvature. The 3D-models recorded with these systems can be used for virtual reality visualization, measuring and inspection, and for scientific analysis. Typical examples for using 3D-models in cultural heritage are:

- Documentation and archiving of art objects
- Virtual reconstruction of art objects
- Virtual presentation in museums and in the internet
- Manufacturing and rapid prototyping of scaled copies and replicas
- Scientific analysis of paleontological and archaeological findings
- Quantitative mapping of damages on sculptures and monuments
- Generation of Identity Cards and Digital Fingerprints
- Manufacturing of tailored transportation packages

Especially, these systems enable the documentation of even the smallest deviation of seemingly flat surfaces like paintings and frescos, which are typically recorded with a spatial resolution of about 50 - 100 µm, corresponding to 500 (250) dpi for flat objects. This enables the documentation of important features for restoration like small fractures or the topology of paint-strokes for scientific research. The data acquisition with topometrical 3D scanners can be done in-situ, radiation-free, contactless and non-destructive, using a structured (coded) light-source and digital cameras.

2. CHALLENGES ON HIGH DEFINITION 3D SCANNERS

Although the scanning of paintings is not a big issue from a principal point of view, there are a lot of challenging demands in the practical realization:

- Extremely high accuracy and resolution of color and 3D data
- Limited access to valuable paintings
- Difficult and non-controllable environmental conditions

For these reasons, the scanning of paintings, especially under the restrictions in museums, requires a mobile scanner with a stable system setup and an easy to use workflow, which allows data recording in a short time.

To meet these requirements, we are using high definition topometrical 3D scanners, based on fringe projection [Creath 1988], [Malz 1989], [Breuckmann 2009]. The smart*SCAN*^{3D}-HE system from Breuckmann is equipped with two 5 MP color cameras (see figure 1), allowing the recording of both 3D features and color with a resolution and accuracy in the µm-range in depth and up to 2.400 dpi (~10 µm) for spatial resolution. Table 1 shows the specifications of this system for two measuring fields (FOV), 125 mm and 300 mm, which are mainly used for the scanning of paintings.

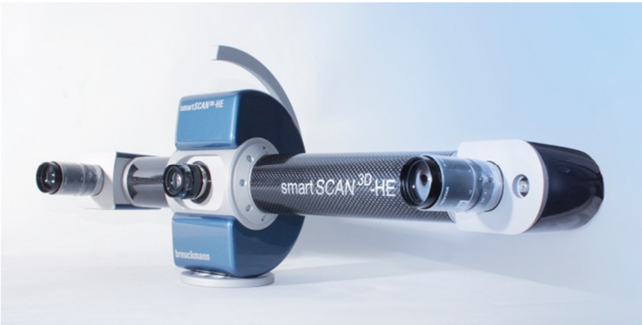

Figure 1 – The smart*SCAN*^{3D}-HE system

	FOV 125	FOV 300
Camera Resolution	5 MP	
Light source	100 W halogen	
Acquisition time (fast mode)	1 sec	
Modified HDR acquisition mode	available	
Spatial Resolution	~ 40 µm (~ 600 dpi)	~ 100 µm (~ 240 dpi)
Feature Accuracy	~ 5 µm	~ 10 µm
Scanning time for a painting of 0.5 x 1 m	~ 2,5 hours	~ 30 min
Number of scans	~ 150	~ 30

Table 1 – Technical specifications of typical FOV´s of the smart*SCAN*^{3D}-HE system

The calibration process of this system, which takes only a few minutes, includes:

- The optical and geometrical calibration of the complete sensor by means of a certified calibration plate
- The white balance of the two color cameras
- The color calibration by means of a color chart
- The determination of all kind of optical distortions, including vignetting of the camera lenses

This kind of extended calibration routine allows a most accurate alignment, e.g. using an ICP approach, and merging of a large number of scans with minimized stitching errors in both color and 3D even for nearly flat objects (see figure 2 as an example for severe stitching errors).

Figure 2 – Scan of a painting with severe stitching errors caused by insufficient sensor calibration

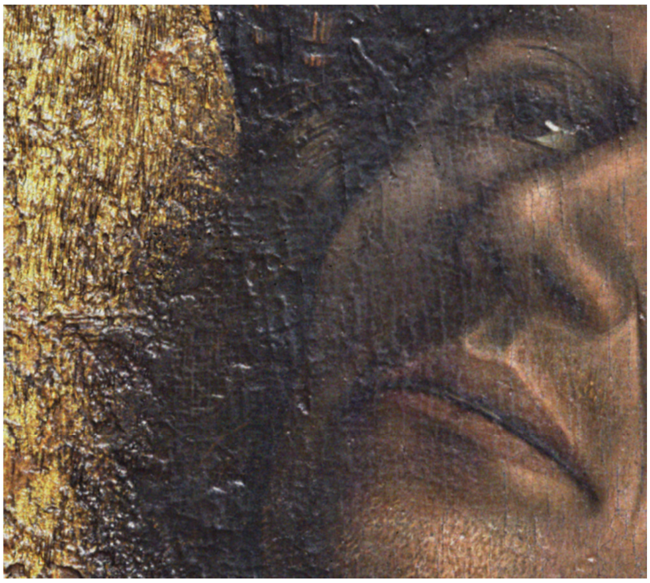

Figure 3 – Example of a painting with very dark and bright, including shiny golden colors, recorded with a modified HDR technique

To overcome the limited dynamic range of digital cameras, we have developed a modified High Dynamic Range (HDR) technique for recording the 3D relief of paintings with very dark and bright colors (see figure 3).

We also have developed a fast and easy workflow, which guarantees, that a painting can be scanned in short time under typical conditions in a museum. Thus it is possible to scan a painting of about 1 sqm with a resolution of 100 µm in about one hour, if the scanner is operated manually. The acquisition time can be further reduced to about 20 min by moving the scanner with an automatic X/Y station.

3. THE DIGITAL FINGERPRINT

Within the last two years we have scanned a small collection of paintings, mainly by VanGogh, with the described equipment. Unfortunately, those data are not yet released for a detailed publication. Therefore, the advantages and possibilities of the high definition 3D scanning technique shall be demonstrated and discussed on the example of a Monet painting, Water Lilies, oils on canvas, 1916. We have scanned this painting, which has got a size of 2 x 2 m, in February 2008 in the Kunstmuseum in Winterthur with a 1.4 MP smart*SCAN*^{3D} -duo system, using two different spatial resolutions, 350 µm and 80 µm resp. Figure 4 shows a photograph of the painting with our 3D scanner.

Figure 4 – Water Lilies, Monet, 1916, Kunstmuseum Winterthur, with the 1.4 MP smart*SCAN*^{3D}-duo

Figure 5 shows a visualization (3D model) of one of the water lilies in the middle part of the painting (about 25 x 30 cm), which has been recorded by about 10 single scans with a spatial resolution of 80 µm. Figure 6 shows the polygon mesh of another water lily in the lower part of the painting, with and without texture, also recorded with a resolution of 80 µm.

Figure 5 – Visualization of 3D data of a part of the textured polygon mesh (about 25 x 30 cm)

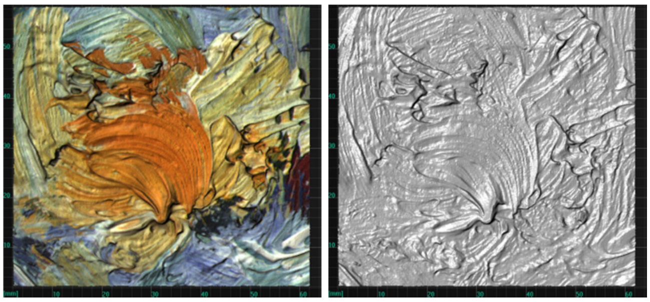

Figure 6 – Different visualizations of a small area of the painting (about 6 x 6 cm), with/without texture

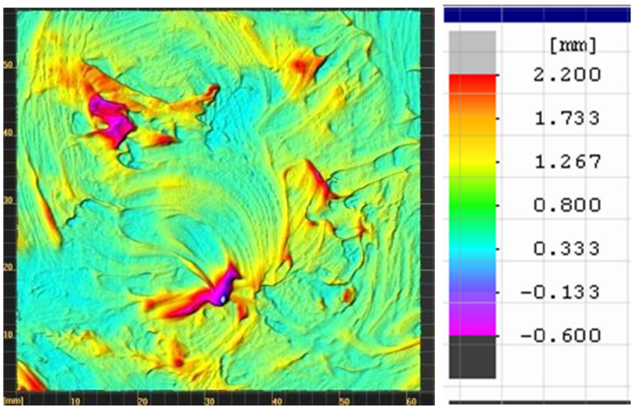

Figure 7 – Visualization of the 3D relief as depth plot with corresponding scaling bar

This demonstrates one major advantage of the 3D scanning technique: the possibility to virtually remove the texture from the 3D data just by rendering it without color information. This allows the analysis of details of the 3D relief independently from its color.

Figure 7 shows an alternative visualization of the 3D relief: the height is displayed as pseudo color plot, where the different colors represent different z-values as defined by the corresponding color scale. The reference for this depth map can be a best-fit plane, a polygon approximation of the surface or a globally smoothed mesh using only the low frequency domain of the relief.

This also offers the possibility to analyze the structure and shape of the canvas or the wooden panel of the painting. This is demonstrated in figure 8 for another painting of Monet, oil on canvas, private collection, which has been scanned by Tondo Bt. with a resolution of 80 µm. In this case, the high frequency parts of the painting have been smoothed and the resulting low frequency domain is compared to a best fit plane.

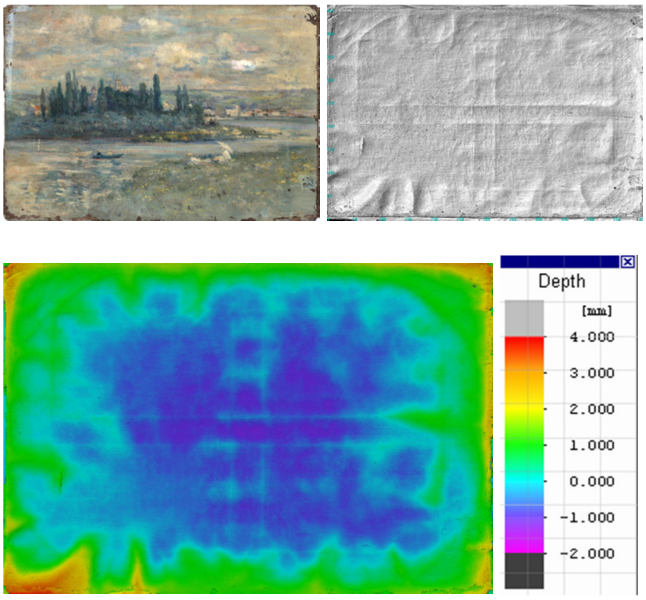

Figure 8 – Quantitative visualization of the shape of the canvas of a Monet painting

Figure 9 shows the 3D relief of the hat of the woman in the same painting after compensation of the low frequency domain.

Please note that the thickness of the color of this painting is only in the range of about 50 µm, but several mm for the first painting.

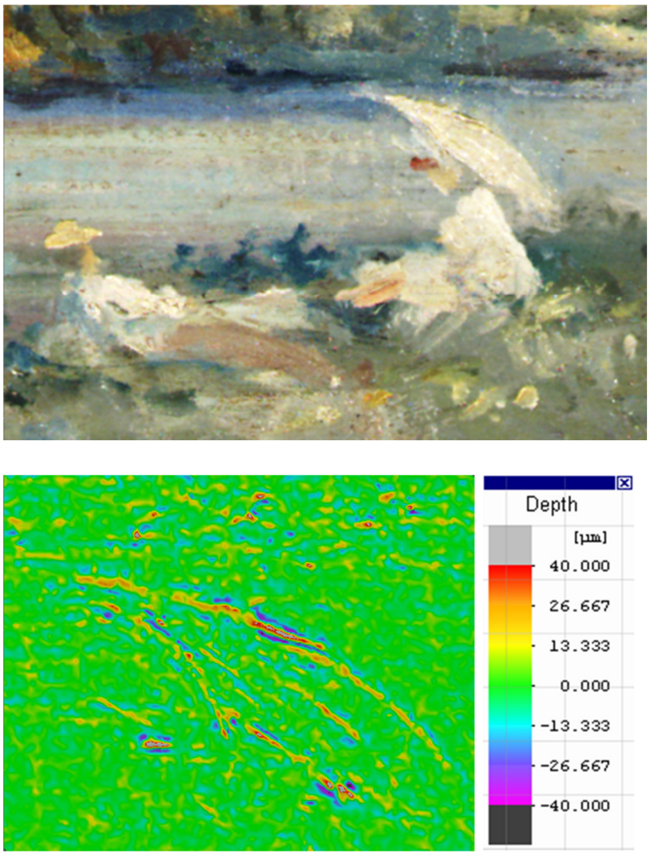

Figure 9 – 3D relief of the hat of the woman after compensation of the low frequency domain

4. CONCLUSION AND OUTLOOK

We have demonstrated the possibilities of high definition 3D scanners for the documentation of paintings recording a unique fingerprint with highest resolution.

There are also further applications of high definition 3D scanning techniques for the 3D documentation of art works. Figure 10 shows the visualization of a 3D model of one of the nail reliefs of Günther Ücker. The embossed printing with a size of about 50 x 70 cm has been recorded with a resolution of appr. 100 µm. By zooming into the 3D data one can even visualize fine details of the structure of the hand-made paper.

It should be pointed out, that this 3 dimensional scanning technique exceeds all kind of photographic techniques, because it can record not only the color but also smallest details of the 3D relief of a painting. This enables not only the documentation and analysis of the artistic content of a painting, but also its production technique, the brush stroke of the painter and the shape of the canvas or wooden panel.

As demonstrated earlier [Végvári 2008, Mara 2009], 3D scanning can be combined with multi-spectral scanning using monochromatic light sources from IR to deep blue. This allows in some cases the revealing of hidden structures in paintings and frescos as well as the analysis of the depth of color layers.

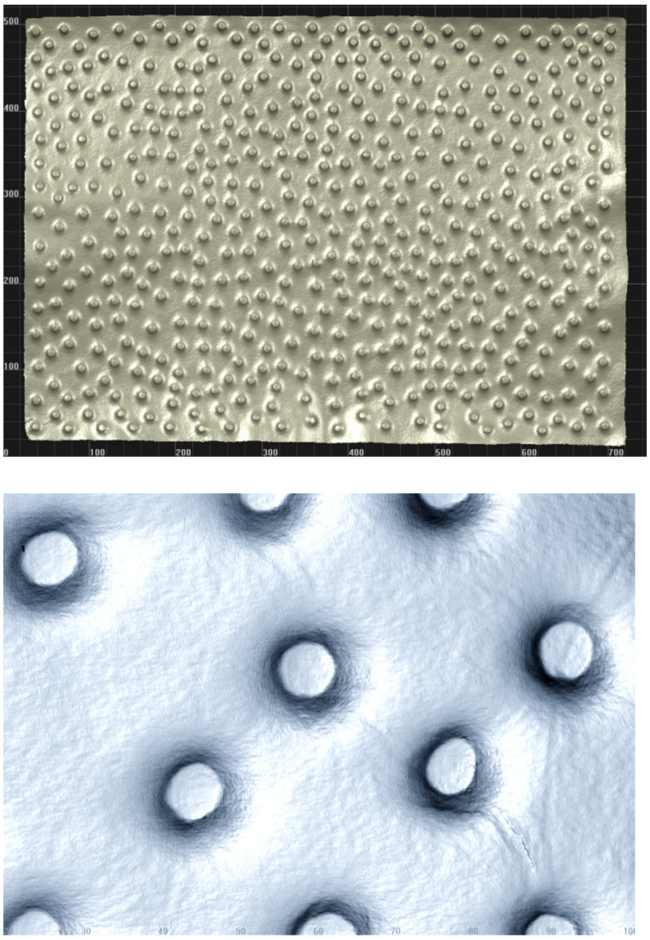

Figure 10 – Visualization of a 3D model of an embossed printing of one of the nail reliefs of Günther Ücker

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