

Comparing two 3D measurement techniques for documenting painted wooden panels surface deformations on a real test case: “Mystical Marriage of Saint Catherine” by Renaissance artist Piero di Cosimo

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Abstract. Ancient wooden panel paintings are an essential part of our cultural heritage. Wood as artworks support has always been very popular and painted panels are largely diffuse in many churches and museums. However, depending on conservation conditions, the wooden panels shape may vary and, if not properly controlled, may lead to some severe damage to the artworks. This paper presents the results of a study on the measurement of paintings surface deformation carried out using two different three-dimensional acquisition devices both making use of structured light. The main goal was to highlight and measure the reliability of such 3D measuring techniques to evaluate deviations from planarity due to the curving and warping of the wood and to document spatial deformation suffered by the painting and monitoring its conservation status.

1. Introduction

The long history of panel paintings had a production peak in period from the Middle Ages to the Renaissance when a large number of them, sometimes of impressive dimensions, were produced. Many historically relevant and beautiful exemplars are still present in many European churches and museums. However, such environments are only rarely equipped with climate control systems and, often such artefacts suffer there from highly variable climatic conditions. Being wood a "living" material, it responds to different temperatures and humidity values and may significantly change its shape [1]. Such variations, which sometimes happen over a short period of time, induce stresses and strains that can, in the long term, irreversibly damage the painting [2][3]. In the past, it was believed that such movements had to be totally avoided and therefore a fixed frame was inserted into the back of the panel. However, time has proven this theory wrong, and sometimes, as in the case presented here, the wooden frame applied during a previous restoration intervention had to be removed, since it was causing unwanted cracks on the painted surface. To control the changes induced by this operation and to quantify the strain and stress applied to the wooden frame panel over time, shape measurements have been proposed to analyse how the panel modifies itself [4][5]. Shape analysis could allow researchers and restorers to accurately evaluate and prevent possible panel damages and help them in choosing the most suitable technique to control dangerous movements. Such new possibility is therefore envisaged to raise large interest, provided that it is possible to achieve it at reasonable operational costs, in terms of time and budget.



The use of three-dimensional scanning technology [6], so far applied to Cultural Heritage mainly for modelling of sculptural artworks [7][8], are reported to be able to provide a detailed map and a quantitative measurement of the painting deterioration; however the case studies presented in literature are mainly reporting on highly costly equipment results, and no before and after comparisons of induced deformation are described.

2. Experimental setup

The main purpose of the present study was to evaluate relative accuracy, and reliability, of two 3D measurement devices, (and of the commercial software provided to shape the model) for this sort of applications where the final accuracy has to be in the order of 1 centimetre and the acquisition time should not exceed half a day operation time. The two devices belong to very different price categories, although they are both based on structured light projection, one in the visible range and the other one in the infrared range.

2.1. Test object

The case study was a large wooden panel (210cm x 190cm) by Piero di Cosimo and painted in the fifteenth century. This large artwork, recently resurfaced, had been restored several times and a large cradle had been applied to its back.



Figure 1. The “Mystical Marriage of Saint Catherine” by Piero di Cosimo, Fifteenth century

In particular, three horizontal wooden battens were inserted on the rear with the intent of flattening the artwork (see Figure 2). However, nowadays restores deem important that the wooden panel may move spontaneously, although in a controlled environmental condition to limit such movements to a minimum.

The wooden support was expected to deform after the battens removal, however none could predict how much. Such a parameter is instead crucial to assess the deformation and monitor its evolution and to timely allow intervention before irreversible damage takes place.

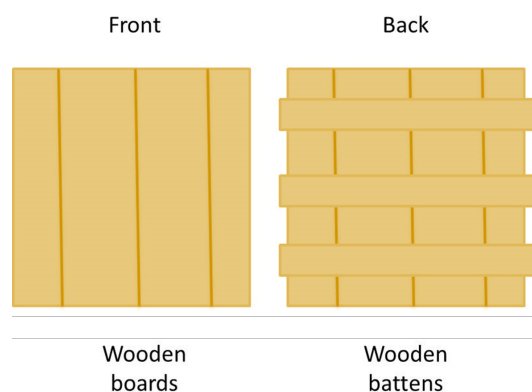


Figure 2. For large panel paintings, the artwork support is produced joining several wooden boards. In the illustration a schematic representation of the front and of the rear, where the three battens introduced during a restoration intervention are also depicted

2.2. Tested devices

The first device tested was a professional structured light-based scanner, the ScanProbe LT by Scan Systems (see Figure 3), while the second was a depth camera based on an infrared sensor system. The first scanner, working according to a method described in literature [9], makes use of a 3D triangulation system based on projecting onto the object under study eight black and white patterns in the visible spectrum at increasing frequency; the stripes projected on the surface warp depending on the surface surveyed and a camera records the images which are then processed. The price range of such sort of scanners is around the 20Keuros.



Figure 3. Data survey setup with the ScanProbe LT by Scan Systems

The second scanner (Kinect sensors family) consists of an infrared laser emitter, an infrared camera and an RGB camera [10]. The measurement of depth is a triangulation process in which the laser source emits a single beam which is split into multiple beams by a diffraction grating to create a constant pattern of speckles projected onto the scene. This pattern is captured by the infrared camera and is correlated to a reference pattern. When a speckle pattern is projected onto an object of which the distance from the sensor is smaller or larger than that of a known reference plane, the position of the speckle in the infrared image captured will be shifted in the direction of the baseline between the laser projector and the perspective centre of the infrared camera. These shifts are measured for all speckles by a simple image correlation procedure, which yields a disparity image. For each pixel the distance to the sensor

can then be retrieved from the corresponding disparity. Such system costs currently around 150 euros. For both devices, since a single range map taken at high resolution covers a limited surface, the number of images to be merged together in order to generate a complete three-dimensional model of the artwork has to be increased as the resolution grows. Another element to be taken into account is represented by measurement uncertainty, which depends on the squared distance between the camera and the object: a high precision is achieved by suitably limiting this distance, and thus the framed area.

2.3. Acquisition procedure

For the first acquisition campaign and the ScanProbe device, the scanner was approximately 90 cm far from the painting and 105 range maps were achieved to cover the entire area in 6 hours as shown in Figure 4. Much longer was the processing time. This is already an indication that at the current state of the art, this procedure has large drawback as routine monitoring. In order to refer all the acquisitions to the same reference system, adjacent range maps are aligned by means of specific software procedures that minimize the mean square deviation or find a best match between overlapping points. Such procedures, indicated in the literature as Iterative Closest Point (ICP) algorithms [11], use a cost function, for example consisting of the mean square deviation between groups of homologous points, that have to be minimized starting from a pre-alignment manually imposed by an operator.



Figure 4. The wooden painting (210cmx190cm), surveyed with 105 scans. The final 3D model contains approximately 50 million faces.

The function value decreases steeply to a well recognizable absolute minimum in the case of surfaces with evident 3D features such as bumps or extrusions. It becomes less peaky, with many local minima, when the surfaces to be aligned have no evident 3D details, as on the flat surface of the front painting side. In the latter case the manual pre-alignment is a crucial step that influence the failure/success of the final convergence, the minimization becomes also much slower. Since in this case the aimed precision was not less than one centimetre, a decimated version of the 3D model was considered to perform such registration.

After the battens were removed, we then scanned the artwork both with the Scanprobe and with the Kinect infrared sensor system. In this second acquisition campaign the scanner was positioned 3 meters far from the painting. This allowed to obtain in a couple of seconds the model reported in Figure 5a. In fact, this depth sensor has the advantage of having a very big field of view thus allowing a very fast acquisition of the entire painting at once. In our experiment since the area to be covered was more than 2m x 2m, a distance of about 3 meters was needed to fully cover it.

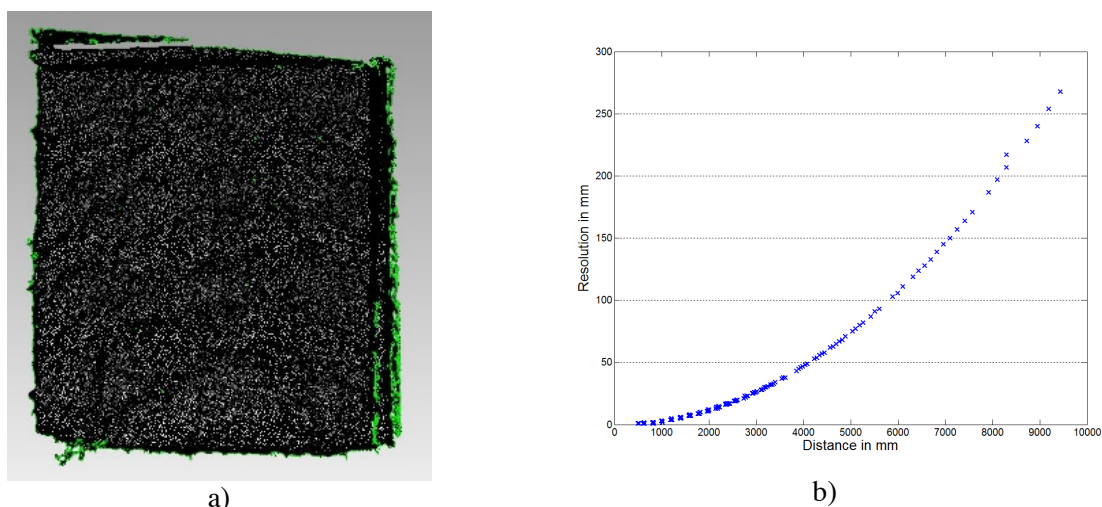


Figure 5. a) The complete Kinect sensor acquisition of the painting b) The depth resolution is a function of distance and is getting coarser as the distance increases

3. Results

Using the Kinetic device would be the cheapest, easiest and fastest way to achieve a 3D model of such a panel painting, for a non-professionally trained operator. However, the resulting accuracy cannot be the same as with the Scan Probe, not only because of the less accurate system but also because for every device, the accuracy of the measured data decreases with the squared distance (see Figure 5b). Arguably one could also stick together more acquisitions of the Kinetic camera, however the reverse would not be possible, i.e. we could not acquire the whole panel surface with one acquisition covering the whole painting surface. Moreover we intended to challenge the low-cost system, in order to test its factual limits.

In order to perform a quantitative analysis, once the models were generated they were used to evaluate the painting deformations with respect to a planar reference. The reference was created by identifying the best-fitting plane of the cloud of points associated to the 3D model. The painting deformations, represented by the distances of the model points with respect to the reference plane, are here presented using color coding. The acquisition performed with the ScanProbe device before the battens removal, shows, as expected, a rather flat surface.

In Figure 6 is depicted the deviation from a local best-fit plane as acquired with the ScanProbe scanner; in the four corners of the painting (as we supposed, the corners are the more stressed areas). Only small variations (± 3 mm almost everywhere) from local planarity are observed and the vertical wooden board are slightly visible. In Figure 7 is depicted the deviations from a local best-fit plane in the four corners of the painting after the battens have been removed, local deformation although not so pronounced (± 7 mm) are to be observed, and it is clearly to be seen how the stress is focused mainly around the vertical wooden boards as expected).

The 3D model obtained by the less expensive system, after the battens removal, still retains the basic shape of the painting and its main structures (like the vertical wooden boards). However, due to intrinsic Kinetic system distortions (like the typical circular ripple [12] as visible in Figure 8), it is not possible to quantify the warping induced by removing the wooden battens; nonetheless this low-cost depth sensor allows a qualitative evaluation of the suffered warping as shown in Figure 9 (the four corners of the 3D model after removing the battens) in which the local Euclidean distance before and after the intervention is reported.

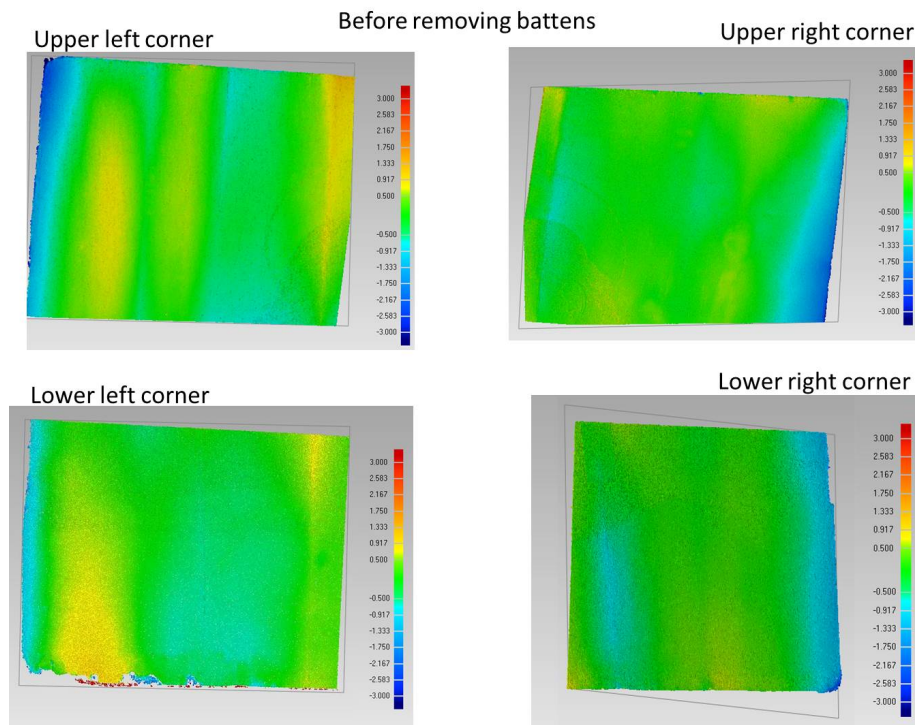


Figure 6. Image of deviations (mm) from the best-fit plane before removing the wooden battens

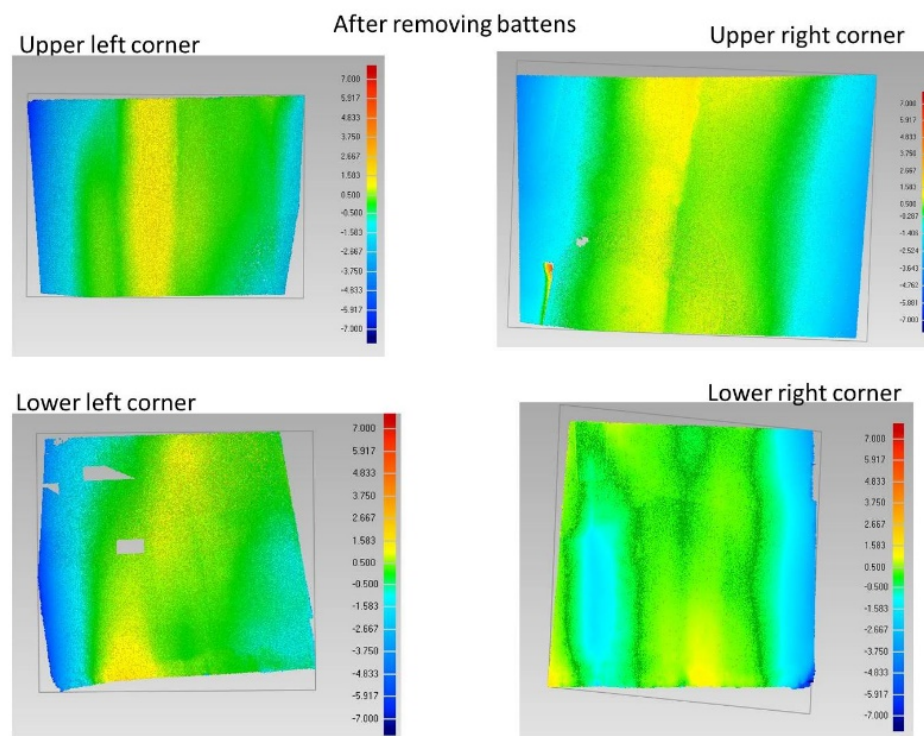


Figure 7: Image of deviations (mm) from the best-fit plane after removing the wooden battens

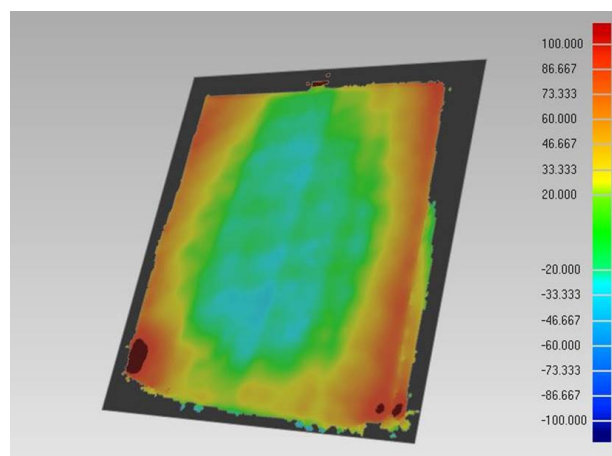


Figure 8. The low-cost Kinect sensor based acquisition compared to an ideal plane shows that depth estimate varies in the image as a “circular” ripple

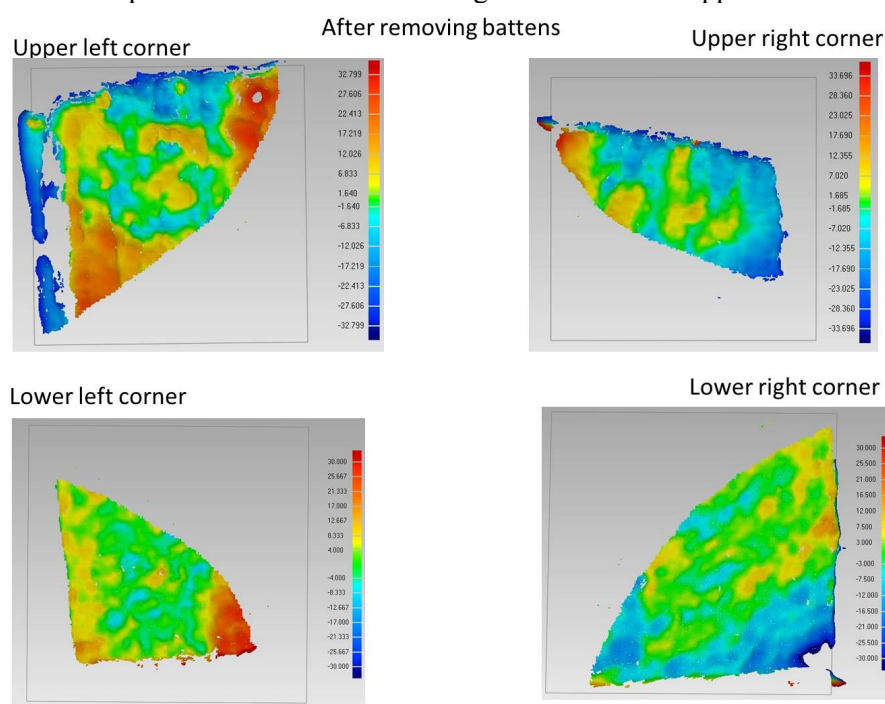


Figure 9: Kinect sensor deviations (mm) from planarity after removing the wooden battens at the four corners.

4. Conclusions

Typically, deformations of large wooden panels, which are a large part of our cultural heritage, are in the order of a few centimetres, thus not highly demanding in terms of measurements accuracy. The aim of the work presented in this paper was to assess the possibilities offered by the recently introduced depth camera system to be used as low-cost monitoring device for the deformation of such artworks. A more professional, high end system was also employed in order to have a reference measure. The wooden panel under test was a large XV century panel which was known to be likely to undergo some deformation after the battens introduced on the back during a previous restoration treatment, were to be removed. The test performed was carried out having in mind the simplest possibility which was a single shot acquisition from a fairly large distance. Such test showed that this low-cost device can be employed

for qualitative monitoring, however, no quantitative data are to be inferred due to the intrinsic limits in measuring from far distances (as reported in Figure 5b). In order to have a higher accuracy more acquisitions from a shorter distance are possible, however this maybe not a suitable procedure for non-professionals. In order to have quantitative measures and assess the deformation properly the high-end scanner still proved to be the correct tool, although implying much higher costs and much longer processing time, together with the necessity of skilled and trained professionals.

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