Three dimensional survey of paint layer profile measurements

E. Pampaloni, R. Fontana, M.C. Gambino, M. Mastroianni & L. Pezzati
Istituto Nazionale di Ottica Applicata (CNR – INOA), Firenze, Italy

P. Carcagnì, R. Piccolo & P. Pingi
Istituto Nazionale di Ottica Applicata (CNR – INOA) – Sez. di Lecce, Arnesano (LE), Italy

R. Bellucci & A. Casaccia
Opificio delle Pietre Dure (OPD), Firenze, Italy

ABSTRACT: The quantitative morphological analysis of a painting surface allows to evidence form defects and thus to study their influence on the stability of the paint and preparatory layers, as well as on the support. Therefore a three-dimensional survey can be very useful in planning the restoration intervention of a painting. In this work we present the results of the surface analysis carried out on the painting “Ultima Cena” by Giorgio Vasari. This panel painting is severely affected by paint film wrinkling produced as a consequence of the flood that occurred in Florence in 1966. Our analysis, accomplished to quantify the lengthening of the paint layer with respect to the one of the support, was made in order to plan the restoration intervention, which was performed on 25 profiles separated each by 10 cm to cover the whole painting surface. A data analysis, based on morphological filtering named “Rolling Ball” transformation, was used to evaluate the length difference between the paint layer and the panel support along each profile.

1 INTRODUCTION

Shape represents highly significant data for the historical and artistic evaluation, the diagnostic analysis and the conservation of an artwork. The possible scenarios involved in the use of 3D digital models range from the monitoring of deterioration due to pollutants, to the realization of digital archives, from reverse-engineering to fast-prototyping, and from the analysis of the conservation state to the monitoring of restoration interventions. Moreover, it is possible to monitor the form of variations by computing the differences between measurements at different times.

At present, a variety of instruments is available on the market for surface measurement. The commonly used techniques for in situ roughness measurements are contact techniques and they make use of stylus profilometers. The sample surface is investigated by means of a stylus or needle (often a diamond point) that is moved along the surface, its profile is then recorded. The system is usually calibrated with a known flat surface and the depth information is obtained by calculating the difference between sample and reference measurements. These profilometers have a very good axial resolution (up to some tens of nanometers), whereas lateral resolution depends on stylus diameter. The typical measured areas extend to a few tens of square millimeters. This method is suited for measuring hard surfaces, but it is not applicable for surveying frail and precious objects like paintings, as stylus sharpness can damage the surface causing micro-scratches. In the diagnostics of paintings the non-contact characteristic is a mandatory step; this requirement makes the optical techniques particularly suitable for this purpose. That is why they are widely used and extremely well received in the field of conservation together with their effectiveness and safety (Bertani et al. 1990, Fabbri et al. 2000, Fontana et al. 2003, Carcagnì et al. 2007, Bellucci et al. 2007).

Optical techniques for shape measurements are often derived from industrial metrology but the peculiarity of an artwork does not allow for a straightforward application. In fact, industrial manufacture is generally regular in shape, with uniformly coloured surfaces. On the contrary, artworks are unique in their shape, having polychrome and highly contrasted surfaces such as painting surfaces.

Conoscopic micro-profilometry is particularly well suited for surveying the surface of paintings due its unsensitivity to color contrast, it enables measurements on surfaces with almost any reflectivity and it allows the survey of microscopic details working with an incident angle very close to grazing incidence.
2 INSTRUMENTS

Our conoscopic micro-profilometer is composed of a rangefinder (Conoprobe 1000 by Optimet) mounted on a high-precision scanning system. The Conoprobe is substantially a video camera within which, between objective and CCD, is placed the conoscopic module, consisting in a uniaxial birefringent crystal sandwiched between two circular polarizers (Fig. 1). The probe working principle is as follows: a light beam, projected by a diode laser, is both reflected and back scattered by the sample surface and then is collected by the lens. The conical light beam, after impinging on the crystal is split into two beams, the ordinary and extraordinary one. These two beams running along slightly different optical paths produce an interference pattern that depends on the beam aperture angle and is related to the distance of the object. By measuring the fringe spacing, the distance of the investigated point from the conoscopic probe can be retrieved (Sirat et al. 1985, 1988, Charlot 1988). The probe is equipped with a 250 mm lens setting an axial resolution better than 15 µm and a measurement range of ±90 mm at a stand-off distance of about 240 mm. The overall accuracy is better than 100 µm and the transversal resolution of about 100 µm. The system allows measurements on a maximum area of about 1.5 × 1 m². The device has a maximum acquisition rate of 800 points/s, but due to downtimes and scanning parameterization, the typical acquisition rate ranges from 100 to 500 points/s. The whole system is computer controlled (Fig. 2).

3 MEASUREMENTS AND DATA ANALYSIS

3.1 Painting surface measurement

We performed a profile analysis on the surface of a panel painting severely affected by paint film wrinkling and colour raisings. This crumpling of the paint layer is the consequence of the flood caused
by the Arno river in Florence in 1966. The painting entitled “Ultima Cena” realized in 1546 by Giorgio Vasari for the monastery “Le Murate” in Florence, is currently under restoration at the laboratory of the Opificio delle Pietre Dure in Florence, where it arrived in 2004 after a period characterized by a long wandering in several restoration laboratories without success. The conservation aim is both the historical reconstruction of unlucky vicissitudes suffered by the panel painting and its restoration. Our analysis, accomplished to measure the amount of lengthening of the paint layer with respect to the support, allows the restorers to plan an appropriate restoration intervention.

Because of the painting huge dimensions, we performed our surface analysis only on the second panel constituting the artwork (Figs. 3, 4), that is representative of the conservation status of the whole painting. In order to achieve information useful for planning the restoration intervention of the painting surface and not excessively time-consuming, we acquired 25 profiles every 10 cm along the panel length (Fig. 5), with a sampling step of 0.25 mm (4 points/mm). Microprofilometry is a surface measurement that gives information on the painting layer and not on the morphology of the support. Measuring the rear part of the panel will not give the correct information because the two surfaces of the support are
not supposed to be identical. In order to evaluate the support length we need an appropriate data processing. The application of morphological transformations, like the “Rolling Ball” filtering, allows to discriminate the contribution of the wrinkled paint layer from that one of the support in the acquired profile curve. We implemented the “Rolling Ball” algorithm in the MatLab computing environment.

3.2 The Rolling Ball transformation

The “Rolling Ball” transformation is a mathematical morphological algorithm first proposed by Sternberg (Sternberg 1983) to minimise image background noises. It consists in the application of morphological openings or closings (Sternberg 1986, Hashim 1996, Lee et al. 2005) to grayscale images by using a spheric structuring element.

To best understand of this algorithm, we consider a grayscale image as a surface where bright areas are hills or peaks and dark areas are pits or valleys, and then we consider a large sphere rolling over the grayscale surface tracing a path as it rolls. This path represents the set of points where the ball fits the surface. This new surface is smooth relative to the original. By taking the grayscale difference image, we obtain an image of all the places where the ball could not fit into crevaces in the surface because it is too large. In this example, the “Rolling Ball” algorithm is a morphological transformation (closing, dotted line in Fig. 6a) followed by an image subtraction. Similarly, the morphological opening can be visualized as a ball rolling under the grayscale surface. In this case, any protrusions of high curvature, such as sharp edges and ridges, are lost by the procedure (opening, dashed line in Fig. 6a). Therefore the “Rolling Ball” transformation describes the smoother features of a surface. The grayscale difference image, obtained by subtracting the opening (closing) “Rolling Ball” transformation from the original surface, is called a “Top Hat” ("Bottom Hat") transformation (Fig. 6b). The main problem when using these morphological filters is to choose the right ball radius R to seize the desired surface features. In our case it was necessary to discriminate the crests of the wrinkled paint surface from the smooth surface of the wooden support and thus we used the “Top Hat” transformation. In order to choose the appropriate ball radius, we calculated the length of the curve L for each...
profile as a function of $R$, by means of the opening “Rolling Ball” transformation.

The typical result for the profile is shown in Figure 7a. Obviously, for an increasing $R$, the length $L$ decreases and for $R \to \infty$, $L(R)$ tends to the limit represented by the length of the projection of the profile on a horizontal line or equivalently by the sampling step length multiplied by the number of samples. But, for particular $R$ values, $L(R)$ decreases more slowly and presents a flex indicated by the arrow in Figure 7a. This, can be seen more clearly in the derivative $dL/dR$, where the curve presents a local maximum (the arrow in Fig. 7b). For this value of $R$ the Opening “Rolling Ball” algorithm extracts all the profile features corresponding to the smooth surface of the wooden support. For instance, Figure 8 shows the 22nd profile, compared to the “Rolling Ball” filtered curve(dashed line) for $R = 1250$ mm. The arrows indicate the union points between two adjacent planks. The ordinate scale is 10 times the abscissa scale.

Figure 4d shows that the panel support is constituted by four planks linked by wooden crossbars, as is also visible in Figure 8. In fact, there are three local minima in the “Rolling Ball” filtered curve corresponding to the union points between two adjacent planks. These minima are located near the abscissas at 400, 650 and 880 mm.

4 RESULTS

For each profile the lengths of the paint layer and the wooden support were computed, and their differences $\Delta L$ are shown in Figure 9. As the painting panel is composed by four planks, for restoration purpose, it is important to evaluate not only the length difference $\Delta L$ between paint layer and the wooden support over the whole panel, but we have also to consider how it is distributed on each plank. So all the profiles were subdivided into four parts, one for each plank, and the length differences between paint layer and support were calculated for each part.

Figures 10a–d, show the results obtained by this calculation. The first plank variations range between 0.3 and 2.9 mm for the first ten acquired profiles, however in the other profiles it ranges between 4 and 8 mm. The maximum value for the deformation in this plank is 8.2 mm, for the profile number 21, which is the profile with the maximum dimensional variation between pictorial film and support (near 20.03 mm). In the second plank, dimensional variation is ranging between 1.5 and 4 mm (there is a maximum of 6 mm in the profile number 18 where detachments are more easily discernible). The third plank shows variations ranging between 0.4 and 3 mm which are nearly uniform along the whole plank. The fourth plank presents a more complex situation, the profiles from 1 to 10 have a dimensional variation ranging between 1 and 3 mm, however, the profiles from 11 to 16 have a variation ranging between 3 to 4 mm. Finally the profiles from 17 to 23 have a deformation ranging between 3 to 7 mm. Clearly we have more variations in the first (28.5 cm long) and in the fourth (38.5 cm long) plank; probably due to the different working process used for their preparation and to their spatial position which
allows them to deform more easily. The two planks in the middle, being linked to the others, present less deformations (Figs. 10a–d).

From the acquired profiles it is possible to obtain not only quantitative information about dimensional variations of the support with respect to the preparatory layer and to the painting layer, but also about the heights of the wrinkled paint layer. Considering the results shown in Figure 9, we estimate the difference between the paint layer length and the whole surface of the plank in contact with the preparatory layer. This difference is about 21.03 mm and its probably due to the planks shrinkage after the drying process. Wood dimensional variation is not constant along each plank due to the natural anisotropy of this material and to its different permeability. When the amplitude of wrinkling is greater, the shrinkage of the planks is also greater. Moreover the lower part of the panel is more affected by wrinkling (near 15 mm).

These bigger deformations are surely due to the different water absorption of each plank and consequently to the wrinkling of the paint layer.

5 CONCLUSIONS

In this work we have presented the results of a surface analysis performed on 25 profiles of the “Ultima Cena” by Giorgio Vasari, a panel painting severely affected by paint wrinkling, consequence of the flood occurred in Florence in 1966. These profiles were surveyed by means of an optical high resolution micro-profilometer.

The results of the data analysis, based on the “Rolling Ball” morphological filtering, were used to evaluate the difference length between the paint layer and the panel support along each profile. This allowed also the evaluation of the height of each single wrinkle. This investigation produced a lot of useful informations to plan the restoration intervention in order to decide whether to substitute integrally the original panel support or to keep it with a few interventions.
REFERENCES


