SCIENTIFIC RESEARCH

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SURFACE MICRO-ROUGHNESS, CLEANING, AND PERCEPTION

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ABSTRACT
The appearance and perception of objects are determined in the physical sense by their surface properties, in particular, color and surface texture. Color and color changes have been and continue to be studied and debated extensively. Recently, developments in non-contact profilometry (roughness measurements) have allowed the determination of changes in micro-roughness directly on objects themselves, and their affect on object appearance. However, perception testing indicates that many of the measured changes are difficult, if not impossible to see by the observer. Recent work on various types of objects is reviewed and discussed in light of issues surrounding cleaning and perception, perception in the broadest sense of the word.

RÉSUMÉ
L'apparence et la perception des objets sont déterminées sur le plan physique par leurs propriétés de surface, en particulier leur couleur et leur texture. La couleur et les variations de couleur ont été et continuent d'être l'objet de discussions nourries. Récemment, des progrès dans la profilométrie sans contact (mesure de la rugosité) ont permis de déterminer des variations de la microrugosité directement sur les objets, qui ont un effet sur l'apparence de l'objet. Toutefois, les tests de perception indiquent qu'une grande part des variations mesurées est difficile, voire impossible à distinguer à l'œil nu. Des travaux récents sur différents types d'objets sont passés en revue et discutés à la lumière des problèmes concernant le nettoyage et la perception, dans la plus large acception de ce dernier terme.

INTRODUCTION

The treatment of objects of art and cultural heritage has been a subject of ethical debate for decades, if not, centuries. Given that most objects are unique in their own way, the debate revolves around issues of whether or not an object may be treated, what effect an eventual treatment has on the condition and appearance of the object, and what changes in appearance are allowable, if any.

An object's appearance is determined by the interaction of light with its surface and near-surface layers, and their chemical and physical properties. These include properties such as chemical composition, the optical properties of the layers (e.g. color, transparency) and surface roughness. Such properties can be measured to almost atomic/molecular levels and are generally considered to be "objective" in nature.

On the other hand, how the effects of treatments on appearance are perceived depends on a combination of the limited resolution of the human eye, and, among others, the background, experience and state of mind of the observer. Such "properties" of perception are generally considered to be "subjective" in nature and are much more difficult to measure and characterize, in particular because the semantics of perception vary between individuals, job functions, and classes of objects.

While the ethical debate can never be resolved – there is, in principle, no such thing as the "correct" decision for the treatment of an object – the various parties to the discussion can be brought closer together through better mutual understanding of the "objective" and "subjective" sides of the field. Critical to the debate is how to relate "objective" technical measurements to the "subjective" perception of object appearance, and, at a deeper level, to ask whether certain scientific measurements or subjective judgments are even useful to the discussion.

The Netherlands Institute for Cultural Heritage (formerly the ICN and now the RCE) is conducting research into this issue in a project, "Cleaning and perception", within its research program "Object in Context". The effect of cleaning is being studied through the use of case studies on objects including paintings, photographs, and outdoor sculpture. Current work is looking at the relationship between measurements of the micro-roughness of the object surfaces before and after cleaning on the one hand, and

RESUMEN

La apariencia y percepción de objetos está determinada en sentido físico por las propiedades de su superficie, en particular el color y la textura de la superficie. Se ha estudiado mucho y se sigue estudiando y debatiendo cuestiones sobre el color y los cambios de color. Recientemente, el desarrollo de la perfilometría (medidas de la rugosidad) sin contacto ha permitido la determinación de cambios en micro-rugosidad directamente en los propios objetos, así como su efecto en la apariencia del objeto. Sin embargo las pruebas de percepción indican que muchos de los cambios medidos son difíciles, o imposibles, de percibir a simple vista. Se revisan y discuten los trabajos recientes en varios tipos de objetos, teniendo en cuenta cuestiones relacionadas con la limpieza y la percepción, una percepción en el más amplio sentido de la palabra.

the opinions (perception) of observers on the other hand. Examples of work to date involving acrylic paints and face-mounted photographs are presented here and discussed within the framework of the debate.

EXPERIMENTAL TECHNIQUES

The cleaning procedures for the objects and materials are given briefly in the corresponding sections below. An initial psychological test conducted to determine how cleaned face-mounted photographs are perceived is also described.

In all cases, the micro-roughness was measured before and after cleaning, at exactly the same position on the samples or objects. Roughness measurements were conducted using a commercially available confocal white light profilometer, the µSurf, developed and manufactured by NanoFocus AG, Oberhausen, Germany. It is noted that profilometry has been a standard quality control procedure in industry for decades, and is performed using a fine needle, like those used for old-fashioned phonographs. White light (and also laser) confocal profilometry was developed 15 to 20 years ago as a non-contact technique for micro-roughness measurements. It has much better depth (roughness) resolution, in the order of nanometers (nm) under ideal conditions, and measurements of representative areas (instead of just lines) of an object of several square millimeters are possible within minutes. For conservation research, it has the distinct advantage that it is possible to mount the instrument so that non-contact measurements can be made at any position of interest on an object (Wei et al. 2008).

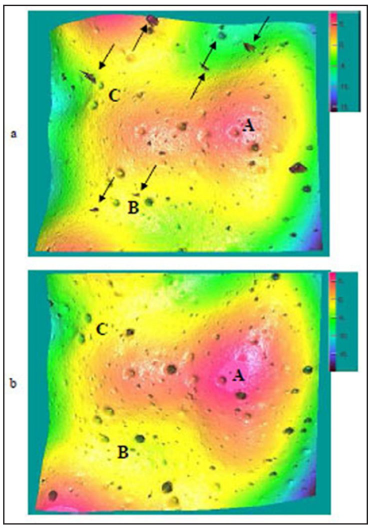
The principle of confocal profilometery has been described in detail earlier (see Wei et al. 2007), and references cited therein. Roughly speaking, the technique makes use of the motion of the objective lens when focusing on an area of interest in a light microscope. For a rough surface, one can only focus at certain levels by moving the objective lens up or down with the focusing knob, which is a height measurement. The confocal profilometer essentially steps through the surface for a given area, and focuses automatically, recording contour lines of height, which are the roughness data. Larger areas are measured by automatically stitching the required number of single areas together. The data can be presented as topographic maps in false color, analogous to geographic contour maps. Traditional line profiles can also be produced through any section of the topographic map, and standard roughness parameters can be calculated.

In this paper, false color contour maps are shown with two different color scales, one progressing from blue (low), through green and yellow, to red (high), and one being a gray scale progressing from black (low) to white (high). Note that the color/height scales give heights relative to an arbitrary zero line set by the profilometer software. It is the height difference which is important for interpreting roughness data. Color shifts between the figures in this paper are due to shifts in the zero line between specimens.

ACRYLIC PAINTS

Introduction

The debate about the treatment of objects has been arguably most intense when it comes to the cleaning (including varnish removal) of paintings. The discussion is now shifting towards modern and contemporary paintings, among others, to the cleaning of unvarnished acrylic paintings. There has been a considerable amount of research done on the chemical effects of cleaning of acrylic paints, and some SEM work on changes in surface topography (see e.g. Jablonski 2003 and Ormsby 2006). A micro-roughness study of the effect of cleaning on the surface topography of acrylic paint is being conducted to supplement this literature. 25 × 25 mm samples of glossy Golden and matte Daler Rowney paints were cast on commercial canvas boards. After drying and natural aging for several weeks, the roughness was measured on areas approximately 0.8 × 0.8 mm in size using the µSurf with a 20x/0.6 objective lens, and a step size (depth) of 0.1 µm (micrometer). The samples were then cleaned using various wet or dry methods and the roughness again measured at the same location.



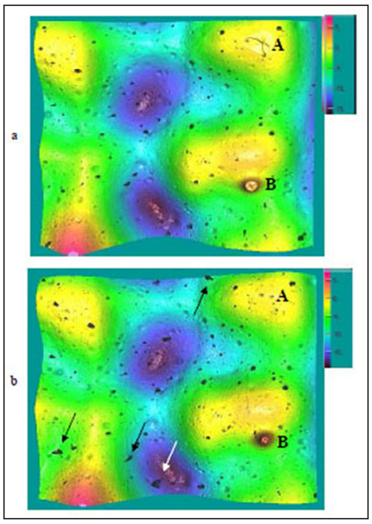


Figure 1
Micro-roughness measurement of a 0.8 × 0.8 mm area of an acrylic paint sample (Golden Phtalo Blue) a) before and b) after cleaning with a cotton swab and distilled water. Arrows in a) indicate dust particles; A, B, and C indicate the same location in a) and b)

Figure 2
Micro-roughness measurement of a 0.8 × 0.8 mm area of an acrylic paint sample (Golden Phtalo Blue) a) before and b) after cleaning with a Wishab® sponge. Arrows in b) indicate dust particles; A and B indicate blisters

Results

Examples of roughness measurements are shown in Figures 1–3. In Figure 1, the roughness of a glossy Golden Phthalo Blue sample is shown before and after cleaning with a cotton swab and distilled water. It can be seen that several particles of dust have been removed, see arrows in Figure 1a. On the other hand, a comparison of the “bubbles” in both images, for example, at locations A, B, and C, and the fine structure of the glossy surface show that the roughness has not changed, at least not at the 0.1 µm depth resolution of the measurement.

Figure 2 shows the results for dry cleaning the same kind of paint with a Wishab® sponge. In this case, it appears that the sponge has left some tiny particles, see arrows in Figure 2b. Also, what appear to be blisters at peak locations, A and B, have been worn down or removed (compare Figures 2a and 2b).

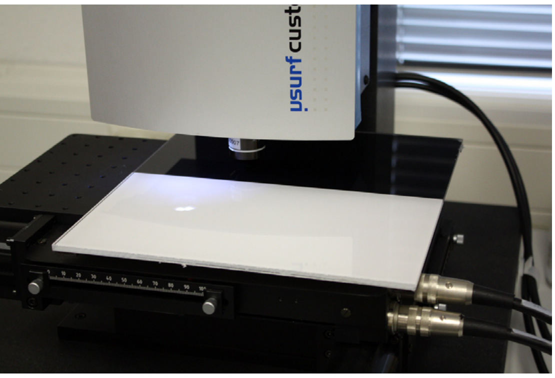
For both the distilled water cleaning and cleaning with the Wishab® sponge no apparent difference in the appearance of the samples was seen visually. Similar results were obtained for cleaning of various Golden and Daler-Rowney paints using Triton X-100 (Sigma Aldrich), or a Mars plastic eraser. In fact, only cleaning with acetone, an extreme test case, produced roughness changes visible to the naked eye.

FACE-MOUNTED PHOTOGRAPHS

Introduction

Another area of concern in the treatment of contemporary art is the cleaning of plastics. For example, face-mounted photographs are photographs on which a sheet of poly(methyl methacrylate) (PMMA) is glued in order to saturate colors and provide depth (Pénichon and Jürgens 2005). By gluing the PMMA to the photograph, the PMMA becomes part of the object and is thus subject to all considerations of treatment ethics given to objects of cultural heritage.

It is well-known that PMMA easily attracts dust and is very sensitive to scratching, making cleaning a very difficult issue when thinking in the long term (many years). An international network is looking at the effect of various cleaning methods on the condition, appearance and readability of face-mounted photographs (Wei 2008). Initial cleaning tests were conducted using various "wet" and "dry" methods on small samples of around 5 × 5 cm in size. Cleaning was conducted up to 25 times per sample. The samples were compared before and after cleaning using light microscopy and visual observation. All specimens exhibited some evidence of scratching and/or residues. However, no distinct differences between cleaning methods could be discerned visually, and there were questions as to how deep the scratches and residues were, and how the results could be applied to real face-mounted photographs which can be up to 2 × 2 m in size.



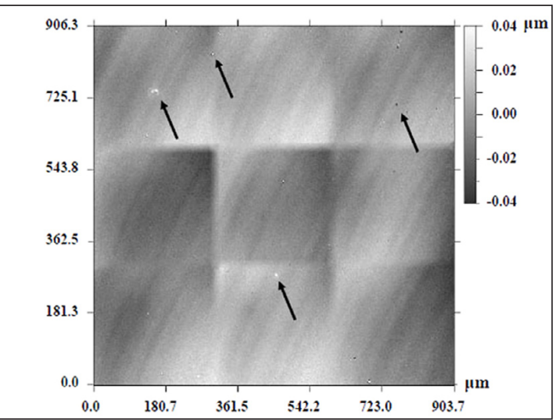


Figure 3
Black and white face-mounted photograph being measured using white light confocal profilometry

Figure 4
Roughness measurement of a 0.9 × 0.9 mm area of a face-mounted photograph in the as-received condition

Cleaning tests are thus being performed on larger specimens. Thirteen "wet" and "dry" cleaning methods (details will appear in a future publication) were used to clean 22 × 25 cm black and white face-mounted photographs (Figure 3). Each method was applied up to 100 times using fresh materials for each cleaning, thereby simulating up to 100 real-life cleanings. Roughness measurements were taken at two locations on each photograph within the "field of view" of the observer. An area of approximately 0.9 × 0.9 mm was measured using a 50x/0.8 objective lens with a vertical step size of 0.023 µm.

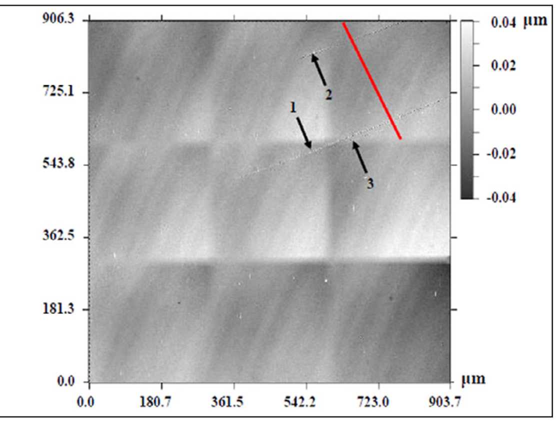
A perception test is being carried out in order to determine how viewers judge the effects of cleaning on the appearance of the face-mounted photographs. The samples are hung up along with three non-treated photographs under various "gallery" conditions. Participants with various backgrounds, ranging from conservators and curators to (conservation) scientists and the general public are asked to rank the photographs in terms of condition from "best" to "worst", in whatever terminology they want to use, and to make comments about their rankings and individual objects.

Results

Typical results of roughness measurements are shown in Figures 4–6. Note that in all cases, the depth (roughness) scale has a range of 0.08 µm (micrometers), that is 80 nm (nanometers), indicating that the PMMA is very smooth compared to most other materials such as the acrylic paints (Figures 1–2). This results in two artifacts in all of the figures. Visible borders can be seen between the sub-images due to the fact that the lack of details makes it difficult for the profilometer software to match the sub-image boundaries. Furthermore, bands can be seen running from the lower left to upper right of each of the sub-images. At this magnification, this is due to the curvature of the objective lens systematically affecting the measurements.

In Figure 4, the (lack of) roughness of an as-received reference photograph is shown. The arrows in the figure show dust particles and tiny surface defects. The image in Figure 5 shows the roughness of a photograph "dry" cleaned with a Modern Magic Blue Suede cloth. Three scratches can be seen at the upper right (arrows). A line profile (Figure 6), taken across the scratches (red line, Figure 5) shows that the deepest scratch (1) measures about 50 nm from peak (piled up material) to valley (scratch depth). The other two scratches (2 and 3) measure 10-20 nm.

Figure 7 shows the roughness of a photograph "wet" cleaned with the Blue Suede cloth and deionized water. No apparent scratching can be seen. However, there is a series of vertical streaks (arrows) which appear to be residue left after drying. This is confirmed by roughness profiles (Figure 8). A number of peaks without valleys around 10 to 30 nm high can be seen (arrows) which correspond to the white streaks cut by the red line (Figure 7).



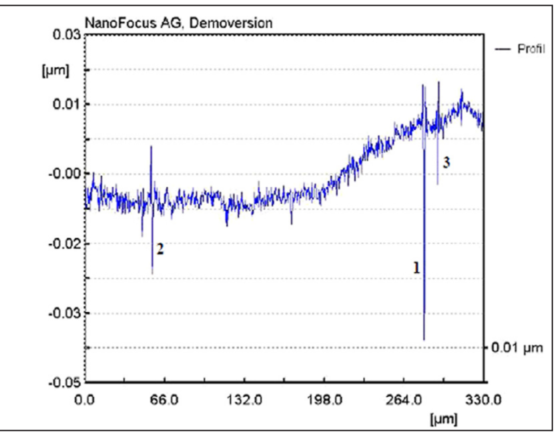


Figure 5
Roughness measurement of a 0.9 × 0.9 mm area of a face-mounted photograph after "dry" cleaning 100 times with Modern Magic Blue Suede Cloth. Arrows/numbers indicate scratches; the roughness profile in Figure 6 follows the red line

Figure 6
Roughness profile along the red line shown in Figure 5. Numbers refer to scratches shown in Figure 5

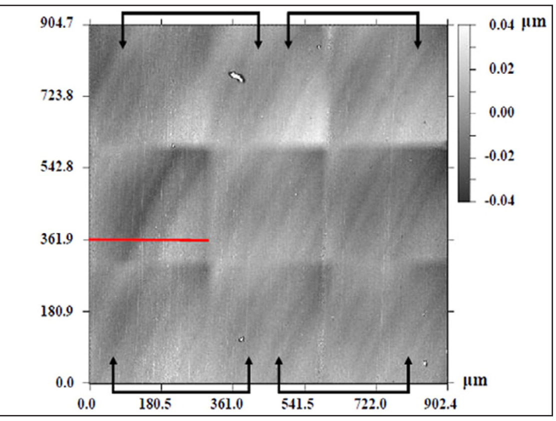
DISCUSSION

The technical results show that non-contact roughness measurements are an excellent tool for determining whether or not a particular cleaning treatment is changing the surface roughness of an object. Changes in the order of tens of nanometers have been clearly identified for specific cleaning treatments on acrylic paints and the PMMA on face-mounted photographs. As a conservation scientist, the author could begin a dissertation on what this "damage" might mean for the future condition of the objects. In fact, there are countless examples in the literature where scientists will go to great lengths to interpret such small or even smaller changes in terms of future (or past) degradation of objects. This is not to say that the literature is right or wrong. However, in the present case, the changes are the result of a simulation of many generations and were not apparent upon visual examination of small samples. The question is then, can such changes be seen, and are they even important, on larger, more realistic objects?

At the time of writing, perception tests had already been carried out on face-mounted photographs in a gallery at the Metropolitan Museum of Art and at the ICN/RCE. While the photographs are not "large", they are representative of the increasing number of "standard" sized photographs now being face-mounted. 15 conservators, one scientist, one curator, one art historian, and three lay persons have taken part so far. (Further tests are planned at the Nederlands Fotomuseum, Rotterdam, and the Fotomuseum Antwerpen in Belgium.) Although the analysis is far from complete, an initial examination of the results reveals how complex the issue of perception is.

Not surprisingly, the conservators went to great lengths to record their observations about the photographs. There appeared to be some agreement that one of the reference photographs (Figure 4) and the "wet" cleaned photograph (Figures 7–8) were among the best, in spite of the residual film left on the latter. The "dry" cleaned photograph (Figures 5–6) ranked somewhere in the middle. In general, dry cleaning was ranked slightly lower than wet cleaning. However, there was total disagreement in ranking for three other cleaning methods. The three lay observers, on the other hand, finished looking at the photographs within minutes and saw little difference between any of them.

This perception study thus far shows that serious discrepancies can arise between "objective" technical measurements of surface changes on objects and the "subjective" interpretation of the effect of such changes on appearance. The average conservator often asks what use certain types of "fundamental" research have in practical situations, but becomes immensely concerned if a nano-change is detected after a particular treatment. On the other hand, many conservation scientists, including the author, go to great lengths to develop new (nano-)techniques to measure the smallest of changes, and then fail to show the applicability of such measurements in practice, resulting in the classic "solution looking for a problem". This "perception" that minute (nano-)changes are extremely important to conservation ethics then runs up against the results of the initial "perception" tests which indicate that many of these changes, covering several (simulated) generations, are not visible to the observer. Given that many objects are only cleaned or treated once in several decades, and are kept in "good" climates, one could reasonably question the need for nanometer-scale research in conservation science. On the other hand, the industrial corrosion literature shows that nano-scale oxidation processes are precursors to more damaging corrosion later. Such information would certainly be interesting for corrosion protection of metal objects.



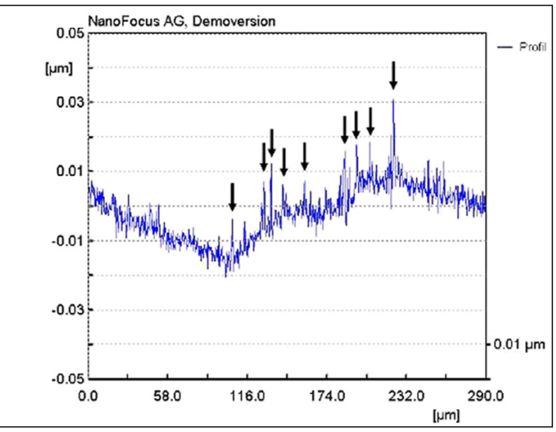


Figure 7
Roughness measurement of a 0.9 × 0.9 mm area of a face-mounted photograph after "wet" cleaning 100 times with Modern Magic Blue Suede Cloth and deionized water. Arrows indicate residue bands of residue; the roughness profile in Figure 8 follows the red line

Figure 8
Roughness profile along the red line shown in Figure 7. Arrows indicate peaks corresponding to the residue bands

What level of detail is then relevant to the debate on restoration ethics? The answer to that question is complex and is not just a matter of providing some number or tolerance to measurements. Consider the perhaps prescient thoughts of the philosopher Nelson Goodman in his search for an answer to the question of whether or not one could learn to distinguish between a forgery and an authentic painting,

> ... one might think of some delicate scanning device that compares the color of two pictures at every point and registers the slightest discrepancy. What, though, is meant here by 'at every point'? At no mathematical point, or course, is there any color at all; and even some physical particles are too small to have color. The scanning device must thus cover at each instant a region big enough to have color but at least as small as any perceptible region. Just how to manage this is puzzling since 'perceptible' in the present context means 'discernible by merely looking', and thus the line between perceptible and non-perceptible regions seems to depend on the arbitrary line between a magnifying glass and a microscope. If some such line is drawn, we can never be

> sure that the delicacy of our instruments is superior to the maximal attainable acuity of unaided perception." (Goodman 1976)

Certainly, further multidisciplinary work is required to reduce this discrepancy in perception, perception of technical results and of appearance. There is no "right" answer, but such work can provide a better atmosphere and basis for the debate. To quote Hedley (1993), "The point is that neither science nor art has a monopoly of facts or beauty. Their interaction can be far richer than that of the wolf with the lamb, and certainly of more mutual benefit".

CONCLUSION

White-light confocal profilometry was used to measure the roughness of various types of objects, for example, acrylic paints and PMMA. It has been shown that changes down to sub-micron levels in surface topography due to long-term cleaning can be clearly identified. However, the initial results from perception tests indicate that the observer has great difficulty in seeing and interpreting these changes. Further multidisciplinary research is required to better relate the results of such "objective" (nano-)technical measurements with the "subjective" perception of the observer and apply them to discussions of conservation ethics.

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