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Review of Ph.D. thesis

Surface Topography and Multiscale Complexity: A Study from Materials to Works of Art

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1. Introduction

The surface topography is the fingerprint of the manufacturing process. Some finishing processes affect surface texture in machining. Surface topography is functionally important. Some properties, such as contact mechanics, sealing, friction, lubricant retention, and wear resistance, are related to surface topography. Therefore, the results of surface topography measurement and analysis are important for both manufacturers and tribologists. The classical methodology in surface metrology is related to the modification of the machining processes and the optimisation of surface functionality.

The author of the Ph.D. thesis **"Surface Topography and Multiscale Complexity: A Study from Materials to Works of Art"** presented a methodological approach related to surface metrology.

The purpose of this thesis is to study the informational aspects of a spectrum called the 'Surface Information Acquisition Spectrum' (SIAS) at all scales. This thesis started from the General Introduction. Then five chapters are shown. Chapter 1 presents a terminological system for surface description. Chapter 2 analyses the complexity of heraldic systems. Chapter 3 presents problems with digital characterisation artifacts using the Von Koch snowflake. Chapter 4 shows original method of fractal characterization using the Sdr parameter and Gaussian filtering. Chapter 5 presents an application of this method to art objects. This thesis included 4 articles published by Ph.D. student and coauthors and is finished by General Conclusion. Appendix A contains a list of articles with extracted vocabulary for surface description. Appendix B contains a description of Heraldic vocabulary. The list of references includes 165 positions.

2. Scope of the dissertation

Chapter 1 entitled **'Description of Surface Topography. A Terminological Ontology for Surface Metrology"** is focused on terminology in surface metrology. The problem is that there are different names of the features of surface topography, which is related with difficulty with their differentiations. For example, surface texturing is a method of improving functional properties of machine elements by creating cavities on typically one of surfaces in sliding. However, these cavities can be named oil pockets, holes, or dimples in technical literature. The other elements of textured surfaces are called grooves, scratches, or valleys. The question arises of what is the difference between grooves and dimples? Textured surfaces are characterised by dimple dimensions and pit area ratio. However, this ratio is also called texture density or oil pockets (dimples) density. But this different terminology could lead to serious errors. The pit area ratio is the ratio of the area occupied by dimples to the entire (assessment) area, but the density of oil pockets can be interpreted as the ratio of the number of oil pockets to the assessment area. Therefore, special terminology should be used to reduce errors of surface features meanings. Accurate terminology is essential for clear interpretation and reproducibility of the results. In surface metrology, surface texture means surface topography after form removal. However, sometimes in technical papers the term surface texture means surface texturing which is related with creation of holes. In Tables 1.1 and 1.2 some topography applications and manufacturing processes are mentioned. However, not all the existing possibilities were included. For example, some abrasive processes were not mentioned in Table 1.2 such as honing or lapping.

The Ph.D. candidate presented methods of surface topography visualisation and descriptions of surface roughness, waviness, and form. Then the parameters of the areal surface texture were presented. The Morphomeca research platform was shown. Next, optical measurement devices were described: focus variation microscope and coherence scanning interferometer. Then, the terminologies in surface metrology according to three standards were compared. It was found that these standard employed terminologies based on different logics without terminological interoperability. The other conclusion was that these standards were related to industrial contexts and not suited to natural or biological surfaces. Non-standard terminologies in surface metrology were also presented and compared. The Ph.D. candidate based on more than 100 articles analysed the vocabulary used. The list of papers is provided in Appendix. A strong relation between terminology and visual representation occurred. The author of the Ph.D. thesis developed an ontology based on WOL (web Ontology Language). The ontology encodes the taxonomy of topographical phenomena as classes. This ontology of surface phenomena will be a tool for researchers that focuses on information on available definitions. A class is a group of individual objects. The class includes four subclasses: Bioinspired, Depression, Elevation, and Discontinuity. Bioinspired surfaces take inspiration from natural phenomena. Depressions and elevations have two subclasses distinguishing between linear and non-linear phenomena. Discontinuities are related to local breaks in surface continuity. Supplementary information on surface features includes orientation, position, shape, and spatial pattern. Information about the measurement method should be added. Three examples of schematic representation of surface encoding are given.

Critical comments

The author of Ph.D. thesis concentrated mainly on textured surfaces. He neglected the parameters of the areal texture in surface description. However, for surfaces machined by the usual techniques, these parameters give information about the character of the surface. The isotropic surface character was mentioned in the thesis. It can be precisely described using the texture aspect ratio Str. The value of Str near 0 testifies that the surface was anisotropic, but near 1 isotropic. However, it would be good to distinguish between surfaces of isotropic, anisotropic, or mixed character. The author did not mention the difference between random and deterministic surfaces. However, the values of skewness Ssk and kurtosis Sku can present information on the surface character. Division between one-process and multi-process surfaces (having traces of more than one process) is also significant. Multi-process surfaces are functionally important. The surface character could be assessed using the Ssk parameter. It would also be good to propose classification of surfaces. So, I think that the analysis performed in Chapter 1 has not been finished yet. In my opinion, the number of surfaces analysed (3) is not enough. More examples should be studied. For the surface presented in Figure 1.26, the diameter and depth of the dimple should be presented, not only the width of the ridge.

Chapter 2, entitled **'Complexity of Heraldic Systems. Taking Coats of Arms as a 2.5D Surface'** is related to formalisation of the heraldic surface as a 2.5D information system and quantification of its complexity. The definition and history of heraldry was presented. The PhD candidate hypothesised that heraldry is a multiscale structure different from traditional fractal objects. The basic rules of heraldry were presented. To carry out the experiment, two corpora were used. The relationship between the complexity of a coat of arms and its frequency using two sets was analysed. The curves presenting number of coats of arms versus complexity order were modelled, using gamma distribution, exponential distribution and a power law. The author of Ph.D. thesis found that the gamma model performed the best, especially it accommodated both extremes. Of course, to test if the results remain consistent, additional corpora of coats from different periods should be analysed. Heraldy was found to follow a statistical trend consistent with the principle of economy.

Critical comments

Not all information on the approximations of curves shown in Figures 2.12-2.16 was presented. Details should be given. Have you analysed other functions? How have you obtained the parameters? What were the relative errors of the approximations?

The next chapters are devoted to fractal analyses.

Chapter 3, entitled **'Von Koch Complexity. Methods to Compute Fractal Dimensions of Fractal Curves "** related to fractal description of Von Koch Island is based on the article **"Evaluating the Fractal Pattern of the Von Koch Island Using Richardson's Method"** published in MDPI journal Fractal and Fractional in 2025 by 3 authors: Maxence Bigerelle, Francois Berkmains and Julie Lemesle.

Before presenting an article, the relevance of the fractal approach was shown. Fractals are substantial in numerical simulation, especially for modelling contact, turbulence, diffusion, or surface topography. This study analysed the fractal pattern of The Von Koch Island using Richardson's method. The Koch snowflake is the repetition of the Koch curve, which appeared in the year 1904 by the Swedish mathematician Helge Von Koch. With a known fractal dimension, the Koch snowflake was frequently used to assess the correctness of fractal calculation algorithms. The discrepancies in fractal dimension calculations are caused by the fact that data sets are finite, and true fractals have infinite resolutions. The authors of article proposed eight methods to calculate the fractal dimension of the Koch snowflake. These methods were applied to the approach used in surface topography characterisation, being the Yardstick method, introduced by the mathematician Richardson and the revisited by Maldenbrot in paper "How long is the coast in Britain". This approach called the compass method is based on observation that the measurement length of the complex curve depends on the yardstick size applied to measure it. Software for generating fractal curves and fractal analysis system were presented. Discretization errors introduced artifacts, especially for large yardstick sizes. The attempts were made to minimize these artifacts. All methods for calculating fractal dimensions were described. They were applied to snowflake-like fractals of dimensions ranging from 1.1 to 1.9. It was found that the Self-Convolution Pattern Research (SCPR) method accurately estimated the fractal dimension, but other methods were sensitive to the chosen yardstick range. Generally, Richardson's method was found to be effective for estimating fractal dimension of self-similar structures. This paper contains two appendices.

Critical comments

The discussion in the article **'Evaluating the Fractal Pattern of the Von Koch Island Using Richardson's Method'** is too short. Errors in determining fractal parameters using the eight methods should be presented. Please state clearly, which methods of fractal computations are original.

Chapter 4, entitled **'New Fractal-Based Method'. Using the Sdr parameters from ISO 25178-2 standard and the Gaussian filter'** is also related with fractal description of surfaces, it introduced a new method of a characterization of sandblasted surface using the Sdr parameter and the Gaussian filter.

The bootstrap methodology was shown. The available sample data were treated as a proxy for the population to approximate the sampling distribution of a statistic. Analysis of Variance (ANOVA) was used to find the most discriminating parameter that best differentiated between groups of surfaces. Chapter 4 is based on article **'Two 3D fractal-based approaches for topographical characterization: Richardson Patchwork versus Sdr"** published in MDPI journal Materials in 2024 (authors: F. Berkmans, J. Lemesle, R. Guibert, M. Wieczorowski, C. Brown, and M. Bigerelle). In this article, the Richardson patchwork method was compared with a new method, based on the Sdr parameter with a low–pass Gaussian filter for multiscale surface characterisation. This comparison was performed on TA6V surfaces after grit blasting. It was found that relative areas were similar after using these two methods.

In this article, the Introduction presented multiscale characterisations of surfaces. Information on the grit blasting process and surface topography measurement and analysis was provided. The patchwork method, developed by professor C. Brown in the early 1990s, was presented. The novel method based on the Sdr parameter calculation using the low-pass Gaussian filter was also shown. The relative areas were similar after using two methods. The computational time using the Sdr method was shorter. Appendix A of this article presented visualisation of filtered surface after grit blasting. The Sdr method gave a more stable fractal dimension than the classical Richardson patchwork. These methods were also compared in a second paper **'Uncertainty-based scale identification and process-topography interaction analysis via Bootstrap: application to grit blasting'** published in MDPI journal 'Fractal and fractional" in 2025 (authors: F. Berkmans, J. Lemesle, R. Guibert, M. Wieczorowski, C. Brown and M. Bigerelle). Similarly to the first paper, fractal philosophy, grit blasting, and surface topography were mentioned in the Introduction. Then, the grit blasting process, surface topography measurement and analysis, and methods of relative area calculation (patchwork and Sdr) were presented. The finding suggested the pertinent scale of 10,000 μm^2 for the patchwork method and 120 µm cut-off length for the Str method. When pressure increased, the relative area also increased. The R^2 value needed to describe the area/pressure link should be greater than 0.83 to be significant for the threshold of 5%. The Appendix presents contour plots of unfiltered surface topographies after blasting using various media and pressures.

Critical comments

Why have not you analysed the other hybrid parameter Sdq, related to Sdq for reasonable sampling interval?

Why have you not analysed the effects of other grit blasting parameters on relative areas?

In **Chapter 5** entitled **'Van Gogh and Fractal. A New Perspective for Surface Topography in Art',** the Sdr parameter applied for the fractal description was tested for artistic substrates. Fractal characterisation was applied to study the style of Vincent Van Gogh. The application of surface topography analysis in the field of painting is relatively new. The author of Ph.D. thesis compared fractal dimensions of ten paintings. Among them, nine were Van Gogh artworks. The attempt was made to determine if the fractal description can serve as a metric for artistic authentication. A conversion process transformed the high-resolution image into topographic data. The colour images were converted to gray scale. Light intensity values were interpreted as height data. The entire artwork and their specific details were analysed. Linear regressions were calculated for different paintings to represent the relation between the Sdr parameter and the scales. From the slope of these regressions, fractal dimensions were obtained. These dimensions of the nine authentic paintings followed a Gaussian distribution, whereas the other painting The Plowmen was not included in this distribution. It obtained significantly smaller fractal dimensions than other paintings. The results suggested that The Plowmen is a forgery.

Similar results were obtained using the box-counting method. Results were presented in the article **'Preserving Van Gogh's Painterly heritage: Topographical and Fractal Insights in Authentication'** submitted to IOP journal Surface Topography: Metrology and Properties. Similarly to the method based on the Sdr parameter, the fractal dimensions of the whole paintings and of the extracted areas were obtained. The measurement was the same using both methods. In the box-counting method, boxes were counted, and log-log graphs presenting the dependence between the box size and the number of boxes were determined. Some difficulties in using the box-counting method were mentioned. They are related to material aspects of painting and some problems in image processing such as the type of lighting. In the future, multifractal analysis can be an expansion of the box-counting method. The results obtained supported the analyses of the Van Gogh Museum in Amsterdam. The analysis of fractal dimension was one of the complementary techniques for artwork authentication. The Appendix provided views of selected areas extracted from painting for calculation of the fractal dimension.

Critical comments

On page 179 information is given that for the study of Van Gogh paintings, the method based on Sdr + Gaussian filter was used. However, in Chapter 5 no information on the Gaussian filter was presented.

The rejected painting from the PhD thesis is called "The Plowmen" but in article "The Ploughmen".

The differences in fractal dimensions obtained using two methods should be discussed.

General Conclusion

Conclusions related to each chapter were presented. The last part describes the work done by the PhD candidate over 3 years.

3. Remarks

There are many advantages of this work. The proposal of a description of the topography of the surface is very interesting. I highly assess the method of using the Sdr parameter for fractal parameter determination – this is the novelty of this work. The application of this methodology to topographic analysis of art objects is also new. References contain many positions. This publication is written in good English (only minor errors were found), and the figures presented are of high quality. Generally, I highly asses this PhD thesis.

However, there are also some disadvantages to this work. There were mentioned earlier after descriptions of chapters.

This study was carried out in the discipline of Mechanical Engineering, especially Chapter 2, Chapter 3 and Chapter 4. Some parts are related to History and Civilizations: history and archaeology of ancient and medieval worlds.

4. **General conclusion**

Based on work entitled "**Surface Topography and Multiscale Complexity: A Study from Materials to Works of Art**" I am fully convinced that the PhD Candidate has enough knowledge and experience to be able to go through his doctorate procedure. For these reasons, I give a favourable opinion to his thesis defense for the Ph.D. degree.

The doctoral dissertation presents the candidate's general theoretical knowledge in the discipline of Mechanical Engineering and the ability to conduct independent scientific or artistic work.

The subject of a doctoral dissertation is an original solution to a scientific problem, an original solution in the application of the results of one's own scientific research in the economic or social sphere, or an original artistic achievement.

I hereby declare that the doctoral dissertation meets the requirements of the Act of July 20, 2018 - Law on Higher Education and Science (Journal of Laws 2018, item 1668) and I request that it be admitted for public defense.

Paweł Pawlus