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Review of the doctoral thesis Sunita Saha, M.Sc. Eng.

„ Automated Identification of Changes from Cultural Heritage Surfaces ”

The basis of preparation of the review:
Resolution of the Scientific Council of the Discipline of Mechanical Engineering of the Warsaw University of Technology from 07.12.2022 commissioned by the Dean of the Faculty of Mechatronics of the Warsaw University of Technology
Prof. dr hab. inż. Gerard Cybulski from 07.03.2022 sign: RWFIM.521.46.2022

1. General characteristics

The protection of cultural goods, including monuments, is a complex field, containing features of a social, political and aesthetic, educational and legal nature, and at the same time it includes, in the field of securing and preserving cultural heritage, many problems of a technical and simply functional nature. The research work carried out for the purposes of conservation is very diverse. They are a part of more general research and studies aimed at learning about cultural goods, in many aspects: artistic, material, and above all as a historical source. Therefore, conservation has a dual task: to study and document cultural goods for science and to preserve them for society and researchers. Since the conservation procedure always changes the previous state of the monument or work of art, each of them must be examined and documented before and during conservation works.

Monitoring changes occurring during the aging process and conservation procedures is essential for responsible care of monuments and works of art. The use of imaging technology as a tool to support this documentation and understanding of the state of preservation of surfaces and objects is becoming increasingly popular. Advances in data acquisition technology have made it possible to collect data in a non-invasive way and have significantly improved digital documentation.

The doctoral dissertation of Sunita Saha, M.Sc. Eng. devoted to automated identification of changes fits into the area of modern coordinate metrology falling within the mechanical engineering discipline.

2. Layout and content of the monograph:

The reviewed work was written in English, has 142 pages and consists of 5 chapters, including a table of contents, a list of concepts, tables and figures, a summary in Polish and English and a bibliography with 112 items.

Chapter 1 - The introduction contains the motivation as well as the purpose of the dissertation - in which the author draws attention to improving the documentation process by automating the method of detecting changes and quantifying changes by contrasting and combining measurements made at several points. Automating the method of assessing changes will help conservators plan in advance the necessary treatments, monitor the aging process or slow down individual degradation processes.

The author also defines the requirements that should be met by the methods she proposes, which she summarized as follows:

- development of segmentation methods to automate the method of detecting changes and quantifying visible changes on the CH surface caused by natural aging and restoration.
- development of a robust segmentation method, adapting solutions to the identified challenges. The accuracy, δ result of the method, was determined on the basis of expert knowledge from the traditional measurement of changes by conservators,
- achieving 98% accuracy of simulated data and over 90% in detecting changes from real CH surfaces.

She also formulated detailed scientific objectives of the work:

- Development of a segmentation method that can automate the process of detecting changes after evaluating local changes from the surface and correcting various defects. Measurement and comparison of geometry and appearance changes over time in more efficient and accurate way. Basing on how the changes behave in terms of local geometry and extraction of surface appearance features, the method classifies and categorizes them,
- One of the objectives is to standardize surface measurements made at different times, so that the method of detecting changes is unchanged in relation to the acquisition parameters,
- A user-friendly visualization of the color map showing the outcome of the development work will help everyday users to understand the detected changes, thus improving digital documentation.

Chapter 2 Literature Review - presents the state of the art in the field of image segmentation along with the further development and adaptation of imaging techniques and appropriate data processing methods. The chapter examines various imaging techniques in detail in terms of their improvement in providing surface information that a simple RGB image cannot reveal. In addition, advanced data processing algorithms for assessing changes in data from two measurements performed at different times were discussed and presented.

Chapter 3 Segmentation, Geometry Comparison- discusses the change-based segmentation method, which evaluates the differences between reference models and models with changed structure or geometry obtained at different intervals. This method involves the study of the histogram of local distances between the measuring points of the models. The whole procedure involves four stages, namely the alignment of two or more phases of geometry, global and local geometry analysis, segmentation and visualization. The author discusses in detail the issues and algorithms used in this task, such as: algorithm 1 P2P distance calculation algorithm, algorithm 2 P2P_Direction distance calculation algorithm, algorithm 3 P2P_AlongNV distance calculation algorithm, algorithm 4 P2P_ProjectionAlongNV distance calculation algorithm and algorithm 5 Change-based-segmentation algorithm.
In this chapter, the doctoral student describes the empirical tests carried out and conducts their in-depth analysis.
This chapter contains parts of the paper "Segmentation of change in surface geometry analysis for cultural heritage applications" published in Sensors 2021.

Chapter 4 Segmentation: Appearance Comparison - This chapter presents the evolution of the segmentation technique for analyzing changes in the appearance of Cultural Heritage (CH) surfaces over time. The author developed supervised segmentation of elements, features of the appearance of reflection transformation imaging (RTI) to automate the process of surface assessment to track and visualize changes over time or during conservation treatments through algorithm number 6 - Supervised segmentation of RTI appearance attributes algorithm.
In this chapter, the PhD student proposes and then conducts a number of tests using available tools such as: Blender program (version 3.1.0), LabelMe Image Annotation Tool - web software for marking objects on digital images creating data sets for computer vision research. Tests carried out on elements of various sizes, colours or damages, confirm the correctness of the algorithms used and adjust the effectiveness to specific cases.
This chapter contains parts of the paper "Supervised segmentation of RTI appearance attributes for change detection on cultural heritage surfaces" published in Heritage Science 2022.

Chapter 5 Conclusion and Final Remarks – presents an analysis of the algorithms used in dissertation. It presents their classification and systematizes their applications for individual applications. The chapter is a summary of the dissertation, in which it was stated that the developed methods and algorithms

have been successfully implemented into real solutions and verified by conservators.

3. Evaluation of the scientific concept adopted by the author and the way it is implemented

The developed segmentation method allows for identification and quantitative assessment along with visualization of changes in the surface of cultural heritage objects over a specific period of time. The methods developed by the PhD student include automatic and interactive processing of multimodal data on 3D geometry and characteristics of reflective materials on the surface.

The work of Ms. Sunita Saha M.Sc. Eng. It focuses on solving this problem by developing new methods and algorithms for segmentation, normalization and visualization that can automate the process of detecting changes after evaluating local changes from the surface and correcting various defects. The issues presented in it have been successfully implemented in a real environment and their effectiveness has been empirically proven.
However, analyzing the methods developed by the author and their possible practical use, they imposed some polemical issues on the reviewer that require explanation:
- In Chapter 3 of Results and Discussion, tests were carried out on standards prepared for this issue, were they dimensioned in any way? The author gives some errors in units of length, but I did not notice measurements on metrological devices.
- In section 3.2.2, the author works on a point cloud, which she calls reference data, were they obtained using a 3D scanner or other device connected to validated software such as PolyWorks, PC Dmis or GomInspect?
- Chapter 4.1.2 assumes a normal distribution in the multi-class discriminatory model that was built in MATLAB. What was the basis of this assumption?
- There are no descriptions on possibilities or the principles of operation of systems that were used in the work, and developed at the Warsaw University of Technology, so it is not entirely possible to verify the correctness of some validations. These include the 3D scanner from subsection 3.3.1 or the Frames software from subsection 3.2.1.
- How the traceability with the unit of measurement for all proposed algorithms can be assured?

Despite the doubts expressed by the reviewer that require clarification, the doctoral dissertation of Sunita Saha deserves a positive assessment because:

- The doctoral student formulated an original research problem consisting in the development of segmentation computational methods, namely a change-based segmentation and supervised segmentation of RTI appearance attributes for detecting, quantifying and characterizing changes in geometry and surface appearance, which automated the process of effectively and accurately measuring and comparing changes in geometry and appearance over a specific period of time.

- She developed a method to standardize data for assessing changes by adjusting surface parameters and surface reconstruction rates by normalization, which helped to make the method independent of data resolution and system acquisition parameters.
- She has developed solutions to conservation problems such as cleaning, restoration, deformation analysis, corrosion evolution, silver tarnishing, acid reactions, as well as environmental monitoring.
- She adopted a simplified representation of the result on the color map, which accelerated the acceptance of the method and automated it.
- Implemented the described methods in real applications and conducted tests of their correct functioning.

  The above achievements prove that the doctoral student has the ability to independently conduct research work and that she solved the research problem posed in the doctoral thesis and formulated the directions of further research on the development of the proposed methods.

4. Summary and conclusions

The reviewed work has considerable cognitive and practical value in the discipline of Mechanical Engineering. It brings important content to the issues of conservation and registration of changes in cultural monuments. On the basis of the reviewed dissertation, I can say that Sunita Saha presented herself as a mature researcher and is fully prepared for scientific and research work. The doctoral student demonstrated extensive knowledge in the field of imaging, in particular imaging elements of various colors, shapes and dimensions. The author's methods have been implemented in real systems of imaging damage to works of art and they can be successfully used not only in museology, but also in control vision systems, which may testify the multidisciplinarity of the presented methods. It is also worth mentioning that the results of the work were published in the form of articles in internationally reviewed journals: "Segmentation of change in surface geometry analysis for cultural heritage applications" published in Sensors 2021, "*Supervised segmentation of RTI appearance attributes for change detection on cultural heritage surfaces" published in Heritage Science 2022.*

To conclude the evaluation of the doctoral dissertation of Sunita Saha, M.Sc. Eng. " Automated Identification of Changes from Cultural Heritage Surfaces " I state that:

- the subject of the dissertation qualifies it for the scientific discipline of Mechanical Engineering,

- **The thesis meets the requirements for doctoral dissertations in accordance with Article 179 (2) of the Act of 3 July 2018 - Regulations introducing the Act - Law on Higher Education and Science (Journal of Laws of 2018, item 1669), in conjunction with Article 11(1), Article 14(1)(1), Article 14(** 2)(1) and Article 20 of the Act

of 14 March 2003 on academic degrees and title and degrees and title in the field of art (consolidated text: Journal of Laws of 2017, item 1789, as amended. amended) **and may be admitted to public defense.**

*Due to the outstanding publications and the maturity of the application work, I request **that the work be distinguished**.*

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