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Report of review of the PhD thesis of Maciej Karaszewski

Given my appointment to be a reviewer of the PhD thesis of Maciej Karaszewski entitled « Automated system for high resolution 3D shape digitization » for the degree Doctor of Philosophy prepared in the faculty of Mechatronics at the Technical University of Warsaw, I herewith submit my report

Overview

Six chapters including an Introduction and a Conclusion constitute the manuscript composed of 158 pages, excluding the bibliography pages. The bibliography is rich; I counted more than 250 entries mixing references of standard articles, websites and technical documentation. The chapter 1 is under the form of an introduction giving the motivation of the work, the research claims and the outline of the manuscript. Chapter 2 is devoted to a large survey of existing systems for 3D shape digitization commercially available or described in the literature. In chapter 3, the principal hardware and software elements of an automated digitization system are presented along with a literature review related to each element. Chapter 4 presents in details the proposed new digitization system. This presentation includes the tree main parts: hardware elements, the proposed algorithm of Next Best View calculation and finally the two stages for measurement directions calculation to achieve high resolution digitization. In the chapter 5 many examples of reconstruction results are presented and evaluated with regards to 5 criteria and when applied compared to the results obtained by skilled human operator. Chapters 4 and 5 constitute the core contribution of this thesis (Analysis of the existing systems, development of a new system and proposal of its evaluation on la age variety of real cases). The chapter 6 is

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the Conclusion which takes the form of a brief discussion of the results, research claim fulfillment, and research and application objectives. At the end of the conclusion some potential directions of research are drawn.
The main goal of this thesis is to propose a full automated and performant system devoted to high resolution 3D shape digitization. The problem is mainly addressed in the context of tangible Cultural Heritage objects but it meets many research questions studied in other fields of applications but still challenging and topical. The proposed solution even though evaluated only on cultural heritage objects it does not loses its interest for many other application in the field of robotics, engineering and reverse engineering, computer graphics, entertainment industry, etc.).

In the course of the development and exploitation of the proposed system the candidate dealt with a few scientific and technical problems for which he proposed novel, useful, pragmatic and smart solutions following a thorough and rigorous methodology.

The core contribution of this this thesis is twofold: research and application. With regards to the first point, the main achievements are:

- development of a method for the determination of the optimal set of measurements necessary for the reconstruction of HR 3D model with high surface coverage of objects without a priori knowledge (digital model) (chap. 4)
- development of a method devoted occlusion and collusion detection and avoidance (Chap. 4)
- setup of an evaluation framework of the proposed NBV algorithm (various object classes, various metrics, various SoTA methods) (Chap. 4 and Chap. 5)

With regards to the application goals, the achievements are:

- design and construction of the full automated digitization system including the measurement head, the robot arm and rotary stage (Chap. 4)
- Implementation of the software tools for the joint control of the robot and the table as well as a library with methods from the literature for NBV calculation in addition to the proposed one (Chap. 5)
- Validation on variety of CH objects as well as technical ones (from industry) and comparison with human experienced operator (Chap. 5)

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Critical analysis

My overall evaluation is that this thesis presents an original and very useful experimental research work. The methodological approach is relevant and consistent: extracting the scientific background from what seems to be initially an applied problem, modeling it and solving it guided by a concern for usability and experimental validation. The technical and algorithmic solutions and their subsequent optimization are justified. The results presented and their discussions are convincing. Only in few cases the parameters values are set empirically and based on the intuition of the author. The long experience of the author justifies this but it could be advantageously automatized or at least supervised.
In a higher level of thought, I want to discuss with the candidate the paradigm on which the work is founded: This paradigm is that the most important is the measure and the measurements. However, one can consider the measurements as a data to be used or transformed or combined with others kind of data in order to reach or to model the function or the role that the surface has to play (e.g visual appearance, mechanical properties, etc.).

I noted a few shortcomings here and there which I present in the following:

(I) In the first chapter (introduction and motivation) the bibliography is abundant, taking a form of succession of items which does not ease the read and does not allow to put those cited article in perspective.
(II) it's obviously difficult to establish a complete benchmark between all systems but it would be useful that the candidate propose a theoretical framework for comparison (time, resolution, other attribute) and draw on it a summarizing table.
(III) Chapter 3 contains a rich review on methods, instruments of positioning and command. This allows to fully justify the choices made by the candidate on the following chapters. However, I lack of a little explanation of tolerance based methods (P.65) even if they seem not fully appropriate for the application.
(IV) section 3.3.2 (NBV without CAD models). Here is an interesting review but I feel it lacking of figures and illustration explaining notions like Voxels, trajectories, etc.
(V) I am wondering if all algorithms are concerned with the problem of collision avoidance?
(VI) Does the fact of positioning the the sensor on a sphere does not guarantee collision avoidance?

(VII) Page 79: the figure is ambiguous: between a) and b) there is a ratio of 25 and no visible difference but between b) and c) only a ratio of 4 and there is a huge visual difference!

(VIII) description of the functionalities on p.86 and p. 87 lack of mathematical formulation and/or illustration.

(IX) Figure 49 deserves more explanation and better resolution.

(X) Page 94: the way of determining R_n and C_{tresh} seems convincing regarding the experience. But something should be said about the ratio 3: is it linked to the targeted resolution (2500pts)/mm^2) uniformly?

(XI)Page 103 and Page 107: Poisson-based equation for triangulation has to be explicited since the results appear spectacular.

(XII)Page 107: Figure 67.(d) does not exist!

(XIII)Page 113: the bi-dimensional histogram requires more explanation, a more developed caption for the figure and legend for the axes.

(XIV)Figures 74 and 75 could be switched to ease the read.

(XV)Page114: Figure 76 would be clearer with more explanation in the caption

(XVI)Page124: Figure 80 needs more work and more explanations

Finally, despite some little criticisms, I believe that the dissertation brings original and valuable information in the field. The length of the dissertation corresponds to the amount of work done and is presented in a balanced way. My overall evaluation is then very positive and I believe that the amount and the quality of the work as well as the publications fulfills and even exceeds the requirements of a doctoral thesis in the field of Machine design and maintenance.

To conclude, the PhD thesis of Maciej Karaszewski is of high quality and meets the international level for a PhD degree. Moreover, given the high record of publications in very good and specialized journals and conferences where the candidate is the first author, and given the huge amount of work for experimental design and validation I would recommend a distinction for the candidate for his thesis.

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