Review of Dissertation Thesis

Title: Curvature-based shape chracteristics of geometrical objects and their use in computer graphics
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I was given to review the above stated Ph.D. thesis dated from April 2019. The thesis has 146 numbered pages and consists of eleven chapters (1. Introduction, 2. Basic terms, 3. Interpolations, 4. Curvature, 5. Existing methods for curvature computation, 6. Other shape characteristics, 7. Screen space curvature, 8. Estimation of differential quantities using Hermite RBF interpolation, 9. Curvature-based feature detection for human head modeling, 10. Symmetry aware registration of human faces, 11. Conclusion).

The work mainly focuses on computing the curvatures of surfaces for various purposes, including rendering and registration. One could say that computing the curvatures is a classical topic that is known for nearly two hundred years. However, if we see it from the point of view of useful practical algorithms, the area cannot be regarded as closed. The efficient algorithms are still sought for. Therefore, I generally regard the work as useful and corresponding to today's needs. In essence, the work can be divided into two parts. In Chapters 1-6, the author provides the reader with the necessary background. In Chapters 7, 8, 9, 10, the contributions of the author to the area are presented. The introductory part (Chapters 1-6) is nicely written. Only sometimes, it seemed to me that it was possible to express better the main ideas of certain algorithms (instead of the sentences that can hardly be understood without having the original paper). The reader could be simply surprised that now, after reading this work, he understands the main ideas of the previously known methods even better than before. (Would not it be nice?) In the rest of the review, I will focus on the chapters describing the contribution of the author.

In Chapter 7, the author focuses on computing the curvatures in so called screen space, which means that the curvature is estimated from the rendered image. In essence, a method based on the fundamental forms of the surfaces is proposed. The shape operator (Weingarten map) is found, which is followed by computing its eigenvalues giving the main curvatures. The author elaborates this known approach for the environment of triangulated surfaces in the screen space. The needed formulas are derived in the chapter. The possibility of introducing the level of detail is discussed too. The algorithm is tested by evaluating the mean and Gaussian curvatures for various datasets. A comparison with the algorithm proposed by Mellado is provided.

In Chapter 8, the curvatures are computed by making use of the Hermite radial basis functions (HRBF from now on) that are used for the description of the surface in the neighbourhood of each particular point. Once the mentioned approximation is available, the computation may run according to the known formulas. The key problem is to obtain the gradient and the Hessian matrix from the HRBF representation, which, as I understand, is the main contribution of the author in this chapter. The algorithm is appropriately tested and compared with four other algorithms. Mainly synthetic data is used for testing generated by several either explicit or implicit functions. If the exact normals are available, the precision of the algorithm seems to be substantially better than the precision of the remaining four algorithms included into testing. The author himself sees the need for the exact normals as a certain limitation of the algorithm. According to my opinion, the exact normals are relatively strong requirement. They could be available only in some special situations (e.g. if a CAD model is available), but if we have data from, for example, a depth sensor, the situation is different. In the environment of noisy data (noisy point coordinates), the question arises how the curvature computation should be carried out in this case. Or perhaps, reformulated in another words, it would be interesting to know how good the theoretically well-based algorithms are (using fitting the patches or interpolation and computing the main curvatures exactly as they are theoretically defined, similarly to the algorithm presented in this chapter) in comparison to the algorithms arbitrarily computing something what, strictly speaking, are not curvatures, but apparently correspond to them in a clear way (e.g. the algorithm for comuting the "curvatures" from the Point Cloud Library). Was the algorithm presented in this chapter used for computation in a practical environment?

In Chapter 9, a certain method for detecting the parts of human head is presented. The method is built on using the descriptors derived from curvatures, and on certain assumptions on how the head is situated in the space, and how the particular parts of head are situated relatively to one another. The feature points of eyes, nose, and mouth are detected (among others). The method is based on the observations about the shapes of particular head areas, especially their curvatures. From this point of view, the method seems to be built on a logical and acceptable basis. However, it seems to me that the environment which has been chosen by the author is too much academically simplified. I mean that the author apparently works with a very precise model of head, which, moreover, is situated in the space that is empty otherwise. On page 111, for example, we may read that the point P_{top} can be found as a point with a maximum y-coordinate. The question then could be: What about the situation that the head is not the only object that is present in the scene? Similarly, the existing depth sensors are not very perfect these days. Small changes of the useful signal that should give a wanted decisive value of a descriptor are often overshadowed by noise. Determining the feature points in a predefined order one after another could be improved by detecting more candidates, which could be followed by combinatorial global fitting, which is not too exceptional in similar context. It would probably increase the robustness of the method. When it comes to testing, it seems to me that it could be done from a broader point of view. If the primary goal was to detect the head and its parts for some purpose, at least some of the algorithms that exist for this purpose today could be mentioned and used for comparison. Some of them work with "normal images" only, not with the depth maps or the point clouds, which is probably due to not so good parameters of the depth sensors that are available now. However, they usually have no restrictions on the content of the scene and on the position of the head.

In Chapter 10, the author presents a symmetry-aware registration method for the registration of human faces. The author claims that he improves the known FPFH descriptor. In this chapter, it seems to me that the problem and the goals should be better defined and the main ideas should be better explained at the beginning of the chapter, before diving into the formulas and other details. For example, what are the values of F_S for some typical points and their neighbourhoods (e.g. elliptic, hyperbolic, parabolic and planar points of a surface). If F_S could possibly be zero for a certain important class of keypoints, how does it correspond to the modifications of the FPFH descriptor in Section 10.1.3? Regarding the method from Subsection 10.1.2, I am slightly in doubts. The points with the minimum and maximum mean/Gaussian curvatures should be found in the neighbourhood of keypoint. The volume that is computed afterwards clearly fundamentally depends on this selection. This selection step may be generally regarded as potentially dangerous. The descriptors are usually constructed with the goal to make the final values not too much dependent on a value from a particular point in the neighbourhood. The construction of PFH descriptor may be especially illustrative from this point of view. The technique relying on selecting two particular points in the neighbourhood goes against the philosophy of how the descriptors are usually constructed. For real-life data, I can imagine that the values of volume that is computed may be substantially influenced by noise. I understand that, in essence, the method proposed in ZPK16 is used, which is combined with a modification of the FPFH descriptor. In that case, at least the basic ideas and basic steps of the method from ZPK16 could be summarised somewhere in the thesis since the method differs from the classical process presented in Fig. 2.3. However, I note that the general registration pipeline from Fig. 2.3 should be inherently resistant to partial occlusion, which is more or less normal situation in recognising the 3D objects. Also, unless the face is cut into exact halves, it should not allow to fit the left part to the right part (or vice versa) too easily. From another point of view: If the data themselves admits two positions of fitting, what is the general idea of excluding one of those positions from the same data without adding any new information? Do PFH, FPFH ignore something? Where does it happen? (This should be a topic for the discussion at the beginning of the chapter.)

Summary: The thesis focuses on important and demanding topics. The author has proven his ability of research work. He proposed solutions to the problems that were opened in the thesis. The solutions have been evaluated experimentally, the experiments have shown that the solutions are useful and often outperforming other approaches. The ideas presented in the thesis were appropriately presented in conference and journal papers. If I had comments and remarks, they were only of a minor or perhaps a partial importance. On the basis of all this, *I do recommend the thesis for the defense.*

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doctoral thesis review

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Curvature-based shape characteristics of geometrical objects and their use in computer graphics

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In visual computing, there are still many open problems, including the optimal shape description. Graphics objects are usually not defined formally, the shape of their geometric support is given by an infinite subset of Euclidean space and influenced by the subjective and application requirements in four universes (reality, model, representation, implementation). However, the infinite subset is often measured only, e.g. by a finite point cloud or mesh (discrete surface approximation). The author – under the supervision of Prof. Dr. Ivana Kolingerová in study program Computer Science and Engineering – focused on a curvature-based approach. The goal of the dissertation is to study the tradeoff between fast or high-precision curvature estimation, to use the estimate combined with another shape characteristics for scanning and/or modeling of human heads (p. 18). **The subject of the thesis is relevant to current needs of the scientific community, which is indicated by multiple internationally recognized publications and, moreover, the doctoral thesis research is highly actual for practical use, as well.**

The well-written English text of the extraordinary long submitted thesis consists of 11 numbered parts: 1 Introduction, 2 Basic terms, 3 Interpolations, 4 Curvature, 5 Existing methods for curvature computation, 6 Other shape characteristics, Screen-space curvature, 8 Estimation of differential quatities using Hermite RBF interpolation, 9 Curvature-Based Feature Detection for Human Head Modeling, 10 Symmetry-aware registration of human faces, 11 Conclusion. The Bibliography (not given in p. 9, Contents, pp. 135-143) refers to 112 items. Apendix A offers an overview of Professional Activities (pp. 145-146). There are no List of Figures, no List of Symbols, no List of Algorithms, and no Index.

The methodology of this research project combines selected advantages of well-studied and understood methods, which are fully adequate and fit perfectly to the main stream reserach in the field (the methodology of mathematic modeling, computational geometry, computer vision, graphics and geometric modeling, applied and focused to special properties of the problem(s) to solve, e.g. differential geometry, algorithm complexity, quality metrics...). **The methods used in the thesis have been appropriate and led to a successful solution.**

The „most important contribution" (p. 133), is the „high-quality curvature estimation... targeted for a high-quality data... results significantly improved over existing algorithms". The new method can be used after interactive geometry processing to achieve the highest possible curvature estimation. The Summary of Contributions (p. 19) enlists five published contributions in total, two curvature estimations [PVK16, PV18], curvature use in shading [PVK17] and shape characteristics [Pra+17], and alignment of two partially overlapping scans [PVK19]. The methods process mainly meshes, but there is a relevance for point clouds. These results meet both thesis objectives (shape characteristics, human head models application, p. 18). **The dissertation fulfills the given goal(s) in full extent.**

The work is done and written in a professional quality. The thesis satisfies conditions of a creative scientific work and there is observable both deep erudition and rich experimental experience of the author. However, there are observable some minor questionable formulations or maybe mistakes, e.g. page\line 8/6, 52/13 charactetistics>>characteristics; 18\13: area>>areas, 19\11: collegues>>colleagues, 23/15: [Kla>>[Kal, see p. 139, 23/17: space is a coordinate system, 25\12 used algorithms... are used, 30/6 interpolant>>interpolant error, in Table 3.1 radius r undefined, 34\9 two osculating circle>>circles, 42/9 „curvature of the triangle face“, 42\13 „... vectors... describe the area of the triangle“ 43/14 noise>>noisy, 51/11 „The size of vector should be compact with small dimensionality D“, 52/16 round sphere>>sphere, 62/4 radial neighbourhood undefined (here, or in p. 22/3), 63/20 consist>>consists, 63 in fig. 6.10 the pixel (4,4) should not be black, 64/9 store>>stores, 64\3 report>>thesis, 65/14 HF11>>Fou11, 65\1 „the more points the curve has“ >> sample points (the curve has an infinite number of points), 66/12 represent>>represents, 66\6 FPFH undefined, 70/11, 70/17 constant>>fixed, in p. 71 below formula 7.5, there is obviously missing a line of text, maybe more, 77\1 method>>data, 78 [Mel13]>>[Mel15] (Mel13 has one page only, Mel15 means the software), 86/20 Missing verb: „One for convex and one for concave areas“, 95/3 expect>>assume, 95\17 is is>>is, 110\11 curvature>>curvature software, 128\7 Missing verb: „In our tests.“, 129\10 data radius>>extent or bounding circle radius, 133/3 problem>>solution/research, 135 understing>>understanding,139/10 Methematics >>Mathematics. It would be desirable to complete pagination in refs [Bri07, BSD08, Gel05, HKM11, KZK17, Mel13, PC16, Rus08]. Ref. [Sko17] contains a string „download this paper“. The author of ref. [Unk(nown)] should be probably Sonja, present in the URL. Ref. [Wen95] contains a string „English“.

These remarks and a few evident typo errors (marked in the printed copy, see e.g. layout of pp. 55, 60, 80, 81) do not decrease the valuable contribution of the work. The written presentation could have been less noisy. The literature survey can be completed by patent or standard literature, e.g. 3D shape retrieval (MPEG-7), feature points for facial animation (MPEG-4). On the other hand, several subproblem formulations are of discovery quality, e.g. a new function for curvature mapping (p. 86), outperforming state-of-the-art algorithms (p. 90), automatic feature detection (p. 109), or fixing the incorrect registration (p. 121). The experiments are designed and carried out very carefully, to document the properties of novel ideas at work. The partial discussions covers precision, complexity, and limitations, as well. There is identified several promising research lines for future work. The author co-authored 3 referred papers in impacted journals, 5 ones at international conferences (WoS, Scopus) (and (how many?) software implementations), all but one related with the PhD topic. Publications of the author appeared in the years 2016-2019. Are there already some citations? The publications are comparable with PhD. projects from multiple universities in Central Europe.

Here we summarize the explicite final judgements: 1. The thesis topic is very relevant in current state-of-the-art rendering research. 2. There are original contributions, as summarized above. 3. The main achievements were properly published at international level. 4. The author is a well informed scientific researcher.

In the discussion, it would be desirable to discuss the following questions: 1. In p. 75\2, the function is not defined at the point [0,0]. How is this fixed? 2. Visual comparisons should be improved by difference images in chapter 7, pp. 82-83. What are the properties of the easiest and the hardest instances? Why there are different lower silhouettes in fig. 7.14? 3. In p. 123\13, what type is „dot product of this field“? 4. What is the final number of novel or modified algorithms/implementations?

Conclusion. The author of the doctoral thesis, **Ing. Martin PRANTL**, proved to have an ability to perform research and to achieve original scientific results. I do recommend the thesis for presentation with the aim of receiving the Degree of PhD. (philosophiae doctor).

Bratislava, June 17, 2019