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Weighted Graph-Based Assessment of Visual Quality in Triangular Mesh Models

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Abstract. This paper focuses on evaluating visual quality in triangular mesh models. We introduce a novel approach using weighted graphs to address this challenge, motivated by the increasing necessity for accurate quality assessment in fields such as computer graphics and 3D modeling. The methodology is initiated by generating saliency maps for each distorted mesh model. Then, we build a network representation where mesh vertices serve as nodes and mesh edges as graph edges. Vertex weights are determined based on saliency values, and a diverse set of topological properties are extracted and statistically measured to generate a signature vector. The quality score prediction is conducted through rigorous evaluation of three regression algorithms. Experiments cover four publicly available databases tailored for mesh model quality assessment, showcasing the superior performance of the proposed approach with significant correlations to subjective evaluations.

Keywords. *Weighted graph; quality assessment; triangular mesh; saliency.*

1 Introduction

The increasing use of 3D models in various fields has led to a demand for robust methods to assess their visual quality, especially considering the potential distortions introduced during processing [1, 2]. Objective methods have emerged as practical solutions to streamline the traditionally human-intensive process of assessing distortion levels. These methods, categorized as full reference [3, 4], reduced reference [6], and blind methods [7, 8, 9, 10], with blind methods gaining particular significance, aim to replicate human judgments without relying on reference models. 3D meshes, complex structures comprising vertices, edges, and faces, are crucial for shaping 3D models, and selecting an appropriate data structure for representing them is essential for effective quality assessment. Graphs, being versatile data structures, have shown promise in addressing various challenges in computer vision, including tasks like image segmentation [11, 12, 13], classification [14, 15] and denoising [16, 1]. However, relatively few studies have explored graph-based approaches to assess 3D mesh quality, with existing methods often separately learning geometric and perceptual attributes without integration into the weighted graph construction process [17, 18]. In this paper, we propose a novel approach to assess the visual quality of 3D meshes using a weighted graph constructed from geometric coordinates and mesh vertices' saliency values. We subsequently train the graph's characteristics using a

machine learning-based regression method to predict the quality score.

2 Proposed method

The proposed method aims to evaluate the visual quality of 3D meshes by leveraging geometric and perceptual features extracted from fundamental mesh components. Fig. 1 illustrates the process. Initially, saliency maps are computed for each mesh, utilizing mean curvature and

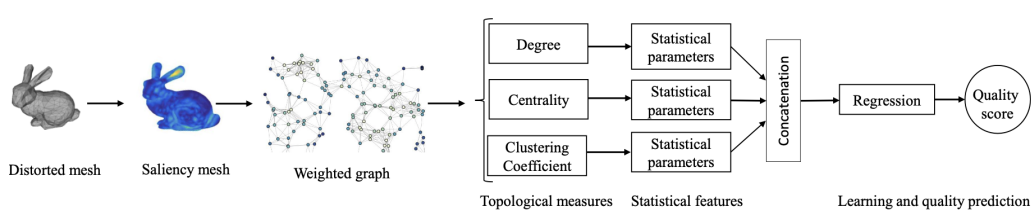


Figure 1: Scheme of the proposed method

Gaussian filters [19]. These maps are then used to calculate a weighted graph representation of the mesh, where vertices correspond to graph nodes and edges to graph edges. The graph is weighted based on a function considering Euclidean distance and saliency values. Local topological measures, including degree, degree centrality, and clustering coefficient, are derived for each mesh-weighted graph. Statistical parameters, estimated using the Gamma distribution, are obtained to represent the network structure.

$$p(x; \alpha, \beta) = \frac{\beta^{-\alpha} x^{\alpha-1}}{\Gamma(\alpha)} \exp\left(-\frac{x}{\beta}\right) \quad 0 < x < \infty \quad (1)$$

Where $\Gamma(\cdot)$ denotes the Gamma function.

The statistical measure vector SM is a concatenation of degree statistics SM_d , degree centrality statistics SM_{dc} and clustering coefficient statistics SM_{cc} of the mesh network. For example, SM_d is defined by:

$$SM = \{\hat{\alpha}_d, \hat{\beta}_d, \hat{\alpha}_{dc}, \hat{\beta}_{dc}, \hat{\alpha}_{cc}, \hat{\beta}_{cc}\} \quad (2)$$

where $\hat{\alpha}_d, \hat{\beta}_d, \hat{\alpha}_{dc}, \hat{\beta}_{dc}, \hat{\alpha}_{cc}, \hat{\beta}_{cc}$ are the estimated Gamma parameters of the probability density function of the mesh network, respectively. Finally, SM is input for regression algorithms to predict quality scores.

3 Experimental results

We perform a comparative analysis of three machine learning-based regression algorithms, Random Forest (RF), Support Vector Regression (SVR), and Generalized Regression Neural Network (GRNN), for forecasting mesh visual quality scores. We use a leave-one-out cross-validation (LOOCV) methodology, wherein a training regression model is constructed using all 3D objects in the repository, excluding one object and its distorted variants during each iteration. This omitted subset is the test set against which the established regression model is evaluated. This iterative procedure is repeated for every 3D object within the repository. Our evaluation is conducted on four datasets specifically curated for quality metrics assessment (LIRIS/EPFL General-Purpose database [20], LIRIS Masking database [21], UWB compression database [6], The IEETA simplification database [22]). These datasets comprise original and distorted meshes graded by human observers. Ensuring diversity in content and

distortion levels is imperative in dataset selection to reflect a comprehensive range of quality evaluation scenarios. We utilize The Pearson Linear Correlation Coefficient (PLCC) to assess the monotonicity of predictions relative to human observer scores. Additionally, the Spearman Rank-Order Correlation Coefficient (SRCC) measures the prediction accuracy concerning the ordinal ranks of the scores. First, we investigate the influence of saliency on quality score prediction by comparing weighted and unweighted graph-based techniques. Results, reported in Table 1, reveal notable performance advantages for weighted graphs across all mesh types and datasets. We observe significant disparities between regression techniques. The most effective strategy involves RF regression with weighted graphs. We also performed an extensive

Table 1: Performance with weighted and unweighted graphs on the four databases.

| Regression | Method | Masking | | General | | Compression | | Simplification | |
|------------|------------|---------|------|---------|------|-------------|------|----------------|------|
| | | SRCC | PLCC | SRCC | PLCC | SRCC | PLCC | SRCC | PLCC |
| GRNN | Unweighted | 70.6 | 63.2 | 63.8 | 61.4 | 64.5 | 60.0 | 59.4 | 65.5 |
| | Weighted | 82.8 | 81.2 | 83.8 | 80.1 | 82.0 | 79.0 | 78.3 | 80.4 |
| SVR | Unweighted | 74.2 | 62.4 | 63.9 | 65.0 | 63.1 | 61.4 | 62.2 | 67.8 |
| | Weighted | 87.6 | 86.3 | 89.4 | 82.5 | 87.2 | 82.6 | 80.9 | 83.1 |
| RF | Unweighted | 78.1 | 68.6 | 66.6 | 72.2 | 75.6 | 73.5 | 70.5 | 75.9 |
| | Weighted | 91.1 | 91.9 | 90.3 | 88.7 | 91.2 | 89.4 | 88.6 | 90.8 |

comparative analysis of the proposed method with alternative NR methods. Table 2 reports the results. It shows that the proposed method consistently outperforms many alternatives, with its scores often surpassing or closely approaching 92%. Notably, MVQ-GCN, NR-SVR, and NR-GRNN also demonstrate respectable prediction scores, with MVQ-GCN showing consistent performance across all databases.

Table 2: Performance of NR objective methods on the four databases.

| Type | Method | Masking | | General | | Compression | | Simplification | |
|------|-------------------|-------------|-------------|-------------|-------------|-------------|------|----------------|-------------|
| | | SRCC | PLCC | SRCC | PLCC | SRCC | PLCC | SRCC | PLCC |
| | NR-SVR [23] | 91.1 | 89.1 | 84.6 | 86.8 | 85.5 | 88.1 | 88.9 | 87.6 |
| | NR-GRNN [24] | 90.2 | 82.4 | 86.2 | 88.7 | 86.3 | 86.7 | 87.7 | 88.0 |
| | BMQA-GSES [17] | 91.3 | 84.1 | 87.9 | 90.5 | 87.3 | 87.4 | 89.1 | 89.6 |
| | MVQ-GCN [18] | 91.7 | 90.9 | 89.3 | 88.6 | 90.5 | 87.7 | 89.9 | 89.4 |
| | Our method | 91.1 | 91.9 | 90.3 | 88.7 | 91.2 | 89.4 | 88.6 | 90.8 |

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