A Fully Automatic Colorimetric Saliency Detection Approach for 3D Meshes

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***Abstract*—With the democratization of acquisition systems, 3D meshes have established themselves as the most optimal modality for representing, analyzing, transmitting, editing and printing 3D contents. All these processes have one thing in common: the human observers who visualize the 3D content downstream. To optimize these different processes, it would be judicious and relevant to take advantage of a characteristic present in all human visual systems, namely the sensitivity to visual saliency. In the literature, very little work has been carried out on predicting visual saliency on colored meshes, as opposed to uncolored meshes. Yet the colorimetric aspect of visual content (whether 2D or 3D, static or moving) plays a key role in directing the human visual attention. In this paper, we propose a new approach, requiring no intervention, parameterization or learning, for the detection of visual saliency of 3D colored meshes. The results demonstrate the relevance and the superiority of the proposed approach.**

***Index Terms*—3D Colored Meshes, Visual Saliency, Visual Attention, 3D content, Graphs**

I. Introduction

The future of photography [1], multimedia interactions [2], remote surveillance, navigation for people or machines, cultural heritage preservation [3] [4], etc. is being and will be realized using 3D models. These 3D models represented by 3D polygonal meshes, are used in several cutting-edges technologies and areas such as Virtual Reality [5], volume rendering [6], 3D printing [7], 3D face reconstruction [8] and 3D face recognition [9].

Due to the complexity of a target 3D mesh or a 3D scene, it's often useful to select the regions to be processed or analyzed in order to reduce execution time. This selection can be made according to the degree of saliency of these regions. Among the processings of 3D objects that can be guided by visual saliency, we can name: Automatic viewpoint selection [10], 3D printing [11], filtering for structure preservation [12], smoothing and denoising [17], simplification of 3D meshes [13], etc.

In the literature, very little work has been done on the visual saliency of colored 3D meshes (characterized by an RGB color in addition to the x,y,z coordinates associated with each mesh node), in contrast to the colorimetric saliency of 2D images [14]. In [15] Yu and *al.*, compute the visual saliency of a colored 3D mesh for geometric simplification purpose, using the average luminance differences of a node with respect to its neighborhood. The RGB colors of the nodes are converted to luminance in order to compute the average differences of intensities. Then the saliency map, obtained as a function of the degrees of intensity differences, is used to guide mesh simplification based on the squared error. However, as the luminance information is used, this does not fully exploit the color information at each vertex.

In one of our earlier works [16], we proposed a new approach to predict the visual saliency of colored meshes based on local adaptive patches. The latter acted as local descriptors of the colored mesh surface at each node, encoding the

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colorimetric configuration of its neighborhood on a tangent 2D patch. The degree of the monoscale saliency of a node was then computed as the weighted similarity between its local descriptor and the local descriptors of neighboring nodes. The multi-scale saliency was computed as the sum of the single-scale saliencies (considering successive larger neighborhoods) weighted by the entropy of the saliencies at that scale.

In [17], we proposed, for the first time in the literature, the concept of the global saliency of 3D meshes, making it possible to predict the saliency of a 3D object while taking into account both geometric and colorimetric information (similar to what the human visual system does). We also presented the first colored mesh database we built to test our approach [18] [17]. More recently, Ding et al. [19] have proposed an approach that estimates the color saliency of meshes based on 2D saliency approaches. 2D views of the target mesh whose saliency is to be assessed are taken, and a 2D saliency detection algorithm is used to generate saliency maps of the different views. These are then aggregated onto the target 3D mesh to obtain a 3D saliency map. The authors were able to validate their approach by constituting a panel of observers equipped with eye-trackers to detect and analyze the observers' eye movements on the built database in [18] [17]. Unfortunately, the eye-tracker results presented in [19] that can be used as ground truth are still not available to the community.

From these approaches in the literature, we can easily see that colored mesh saliency has been little studied. The few existing approaches each present a non-marginal flaw. For the approaches proposed in [15], [16] and [17], these require manual parameterization of the neighborhood radii to be taken into account. To cope with this manual parameter, these radii can be defined by a percentage of the length of the mesh bounding box diagonal. However, for some meshes whose shapes are not simple, non-accurate results can occur due to the non-representativeness of the bounding box diagonal [15]. On the other hand, the approach proposed in [19] suffers from the 2D view dependency aspect of estimating colorimetric saliency. As explained, 2D saliency measurement approaches that have been used ignore de facto the depth between color-bearing mesh nodes. Indeed, nodes of different colors, but located at different depths, are put on the same plane when the 2D view is generated. In this paper, we propose a new view-independent color saliency detection approach for colored 3D meshes. Our approach is fully automatic and requires no manual parameterization or learning phase. The rest of the paper is organized as follows. In section II, we will present the details of our new approach, the applied notations, the spherical neighborhoods formulations and the computation of single-scale and multi-scale colorimetric saliencies. In section III, details about the database considered to test our approach are presented and discussed. Finally, we conclude in section IV.

II. Colorimetric mesh saliency

A. Notations

In the following, we represent a 3D mesh $\mathcal{M}$ by a non oriented graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ where $\mathcal{V}$=$\{v_1, ..., v_n\}$ is the set of $\mathcal{N}$ vertices and $E \subset \mathcal{V} \times \mathcal{V}$ is the set of edges. The set of edges is deduced from the mesh faces that connect vertices. To each vertex v_i are associated its 3D coordinates $\mathbf{p}_i = (x_i, y_i, z_i)^T \in \mathbb{R}^3$ and its colors $\mathbf{c}_i = (r_i, g_i, b_i)^T \in \mathbb{R}^3$. The notation $v_i \sim v_j$ is also used to denote two adjacent vertices in $\mathcal{G}$ (i.e., $(v_i, v_j) \in E$).

B. Non-local neighborhood formulation

In order to design a colorimetric saliency detection approach that would judge a node to be salient if it stands out strongly from its neighborhood, we decide to consider the spherical neighborhood of the target node instead of its 1-ring neighborhood that is obviously more sensitive to the presence of noise. Hence, we propose a definition of non-local neighborhood around each vertex that depends on the mesh edge length and not on the diagonal bounding box length, as do competing approaches in the literature [16] [17] [15]. This makes our approach fully automatic without any need for ray hard-coding. For each node v_i of a mesh $\mathcal{M}$, two spherical neighborhoods are defined $\mathcal{S}_\varepsilon(v_i) = \{v_j | ||\mathbf{p}_j - \mathbf{p}_i||_2 <= \varepsilon\}$ where $\varepsilon \in \{\varepsilon_1 : \text{maxLengthEdges}, \varepsilon_2 : 3 \times \text{maxLengthEdges}\}$ where maxLengthEdges refers to the edge of maximal length and is defined as $\max_{(v_i,v_j)\in\mathcal{E}} \|\mathbf{p}_i - \mathbf{p}_j\|_2$. The vertices v_j contained into these spheres $\mathcal{S}_\varepsilon(v_i)$ will be considered as neighbors of v_i in each scale ε.

C. Single-scale Colorimetric Saliency computation

The proposed approach also differs from competing approaches in that it takes into account both the 3D locations of vertices and their colors for colorimetric visual saliency detection. This feature allows to take into account the intrinsic trimensionality of 3D meshes, which is naturally absent if we choose to use 2D views for saliency prediction. Once the spherical neighborhoods have been established, we define the single-scale colorimetric saliency using neighborhoods of radii ε_1 and ε_2 as follows:

$$\text{SsCSaliency}_{\varepsilon_1,\varepsilon_2}(v_i) = |\sum_{j=1}^{|S_{\varepsilon_1}|} \text{diffCIE}(v_i, \varepsilon_1) \times exp\left(\frac{-||\mathbf{p}_j - \mathbf{p}_i||_2}{2\varepsilon_1^2}\right) - \sum_{j=1}^{|S_{\varepsilon_2}|} \text{diffCIE}(v_i, \varepsilon_2) \times exp\left(\frac{-||\mathbf{p}_j - \mathbf{p}_i||_2}{2\varepsilon_2^2}\right)| \quad (1)$$

where diffCIE represents the weighted sum of color differences between L^*a^*b color components of v_i and the ones of its neighbors v_j using the ΔE^*_{00} (CIE 2000) formula :

$$\text{diffCIE}(v_i, \varepsilon) = \sum_{j=1}^{|S_{\varepsilon_1}|} \Delta E^*_{00}(\mathbf{c}_i, \mathbf{c}_j) \quad (2)$$

where $\mathbf{c}_i$ and $\mathbf{c}_j$ represent respectively the L^*a^*b color vectors of vertices v_i and v_j. More details about the ΔE^*_{00} formula can be found in [22].

D. Multi-Scale Saliency computation

To make our approach more precise for the detection of colorimetric saliency, we compute it at different scales. On fine scales, the saliency measurement will detect sharp, exiguous details, while on large scales, it will highlight large, prominent areas. Another advantage of the multi-scale aspect is the robustness to noise, thanks to its perceptibility on just a few scales only. Therefore we consider two more radii (ε_3 : $6 \times$ maxLengthEdge and ε_4 : $9 \times$ maxLengthEdge) and compute the single-scale colorimetric saliency using these new radii (ε_1, ε_2). The aggregation of these two single-scale saliency is done as follows to obtain the final multi-scale saliency measure:

$$\begin{aligned}&\mathrm{MsCSaliency}(v_i) = log(\mathrm{SsSaliency}_{\varepsilon1,\varepsilon2}(v_i)\\&\times(\mathbf{max}(\mathrm{SsSaliency}_{\varepsilon1,\varepsilon2}) - \overline{\mathrm{SsSaliency}_{\varepsilon1,\varepsilon2}})+\\&\mathrm{SsSaliency}_{\varepsilon3,\varepsilon4}(v_i)\times(\mathbf{max}(\mathrm{SsSaliency}_{\varepsilon3,\varepsilon4})\\&-\overline{\mathrm{SsSaliency}_{\varepsilon3,\varepsilon4}}))\end{aligned} \tag{3}$$

where **max** refers to maximum operator of a vector and $\overline{x}$ represents the mean operator of a vector.

III. Experimental results

Unlike non-colored 3D meshes, there is currently only one publicly available database for the scientific community to the various algorithms for processing and analyzing colored 3D meshes : The GREYC 3D Colored Mesh Database [17] [18]. It was created in the GREYC laboratory, using a NextEngine 3D laser scanner equipped with a turntable to acquire both the geometric and colorimetric properties of the object. 15 objects of different shapes and colors were acquired. To enrich the reference corpus, distortions such as Gaussian noise on 3D coordinates, simplification, Gaussian noise on RGB colors, smoothing on 3D coordinates and smoothing on RGB colors were applied leading to a total number of 425 colored meshes.

In order to test our approach, we selected two meshes from the GREYC Colored Mesh Database: 4arms.ply and RedHorse.ply. The former contains large, homogeneous color regions, while the latter exhibits rapid color variations. Figure 1 shows these reference meshes and the multi-scale colorimetric saliency maps computed by our approach. We can see that our approach enables to distinguish areas of high color variations by judging them to be highly salient (areas in red on the images in the second column of figure 1). On the other hand, areas of low color variation are judged to be of moderate or low prominence, such as the belly areas of the 4arms.ply and RedHorse.ply meshes (images (b) in the second column of figure 1).

Figure 2 shows the colorimetric saliency detection results on two 3D meshes from the GREYC Colored Mesh Database, compared with the results of the approach proposed in [17].

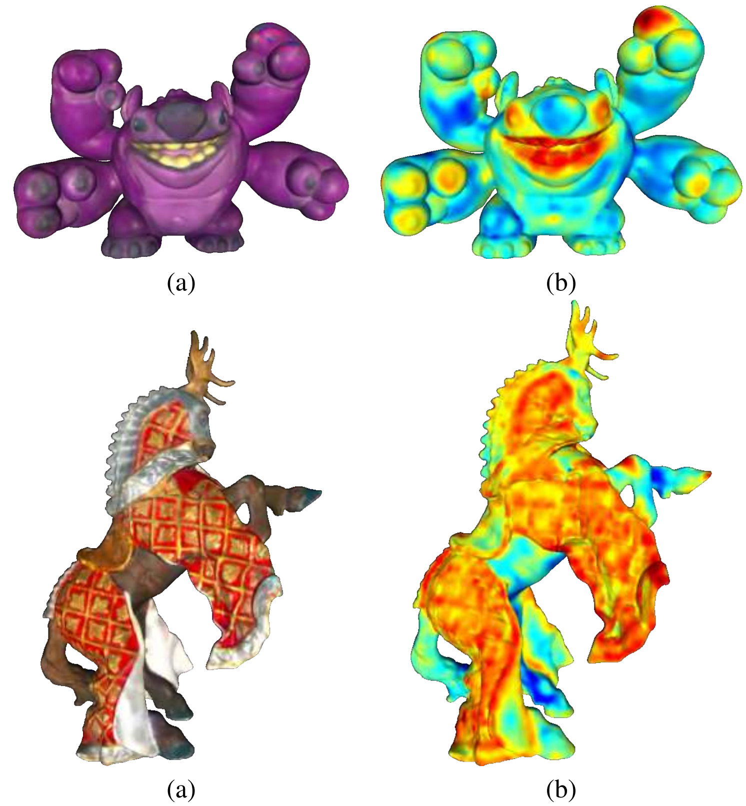
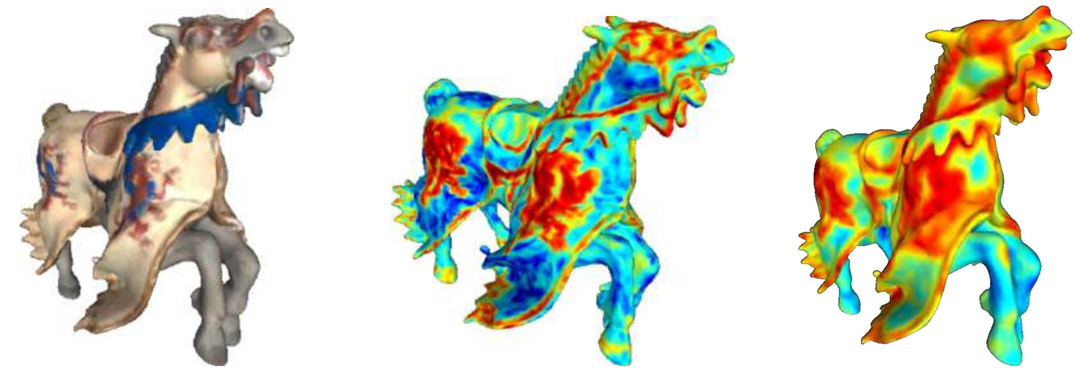


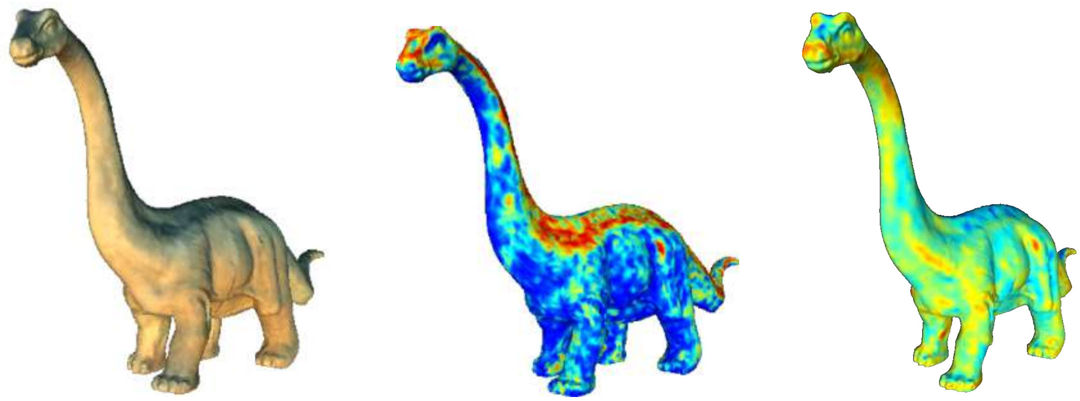
Fig. 1. Colorimetric saliency results on two different 3D meshes from the GREYC Colored 3D Meshes Database. Images (a) refer to reference 3D meshes. Images (b) refer to their colorimetric saliency maps. Warm colors represent high saliency values while cold colors refer to weak saliency degrees.

We can remark that the proposed approach (third column) enables better detection of the colorimetric saliency by rendering less saturated saliency regions (back of the dinosaur on image(b) in the second line) or blue areas signifying degrees of saliency equal or almost equal to 0 (case of the horse on image (b) in the frst line). On the new automatically-generated maps (third column of figure 2), we notice that the detected saliency is more diffuse, bringing out the salient areas with nuance and precision.

We also compared our approach with the most recent one in the literature [19]. We considered the same *Asterix* mesh from the GREYC 3D Colored Mesh Database (see figure 3(a)) and tested on it the proposed approach for visual saliency prediction (figure 3 (c)). In contrast to the saliency detected with the approach proposed in [19] shown in figure 3(b), we can easily notice that the yellow tip of the sword carried by the left hand of *Asterix* is judged to be very weakly salient, whereas it stands out strongly from its context. The proposed approach (figure 3(c)), on the other hand, judges it as a very prominent feature. On the other hand, the uniform part of *Asterix*'s red pant is judged moderately salient by our approach due to its uniformity, whereas the approach of [19] judges it to be very salient despite the absence of any gradient. Hence it appears that our predicted salient regions are more relevant to the human visual system in contrary to those resulting from



(a) Reference 3D mesh (b) Colorimetric Saliency map [17] (c) Ours



(a) Reference 3D mesh (b) Colorimemtric Saliency map [17] (c) Ours

Fig. 2. Comparison between the results of the proposed approach and those provided in [17].

the approach of [19].

IV. Conclusion

In this paper, we have proposed an automatic, view-independent approach for detecting the colorimetric saliency of colored 3D meshes. By taking into account the spatial location of vertices and their colors in the L*a*b a coordinate system, an efficient space to compute color distance, we were able to accurately distinguish salient regions on the surface of a colored 3D mesh. A comparison with reference approaches from the literature was presented, showing the contribution in accuracy of the proposed approach. Future work will quantify this contribution by integrating the proposed approach into applications such as simplification, smoothing or optimal viewpoint selection.

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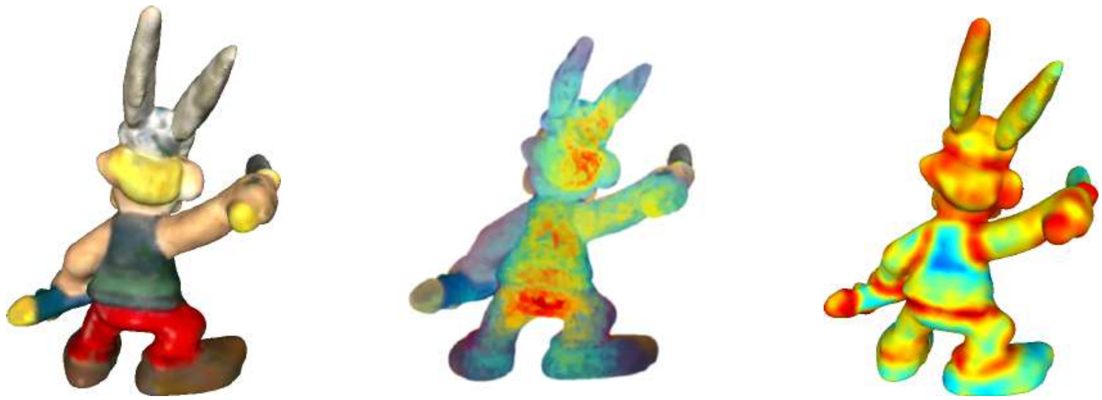

(a) Reference 3D mesh (b) Colorimetric saliency detected with [19] (c) Proposed

Fig. 3. Comparison between the results of the proposed approach and those provided in [19].

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