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Multi-scale mesh saliency based on low-rank and sparse analysis in shape feature space

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ABSTRACT

This paper advocates a novel multi-scale mesh saliency method using the powerful low-rank and sparse analysis in shape feature space. The technical core of our approach is a new shape descriptor that embraces both local geometry information and global structure information in an integrated way. Our shape descriptor is organized in a layered and nested structure, enabling both multi-scale and multi-level functionalities. Upon devising our novel shape descriptor, the remaining challenge is to accurately capture sub-region (or sub-part) saliency from 3D geometric models. Towards this goal, we exploit our novel shape descriptor to define local-to-global shape context in a vertex-wise fashion and concatenate all the shape contexts to form a feature space, which encodes both local geometry feature and global structure feature. It then paves the way for us to employ the powerful low-rank and sparse analysis in the feature space, because the low-rank components emphasize much more on stronger patch/part similarities, and the sparse components correspond to their differences. By focusing on the sparse components, we develop a versatile, structure-sensitive saliency detection framework, which can distinguish local geometry saliency and global structure saliency in various 3D geometric models. Our extensive experiments have exhibited many attractive properties of our novel shape descriptor, including: being suitable for perception-driven analysis, being structure-sensitive, multi-scale, discriminative, and effectively capturing the intrinsic characteristic of the underlying geometry.

1. Introduction

Visual saliency is an important and fundamental research topic in psychology and neuroscience to investigate the mechanism of human visual systems, and is also an attractive topic in computer vision and computer graphics. Saliency together with its effective and accurate detection depends on the fact that meaningful shape context and its corresponding physical location in an object always attract people's attention. Saliency can also be treated as certain type of broadly-defined features (Gal and Cohen-Or, 2006). Although much excellent work has been carried out in signal processing and computer

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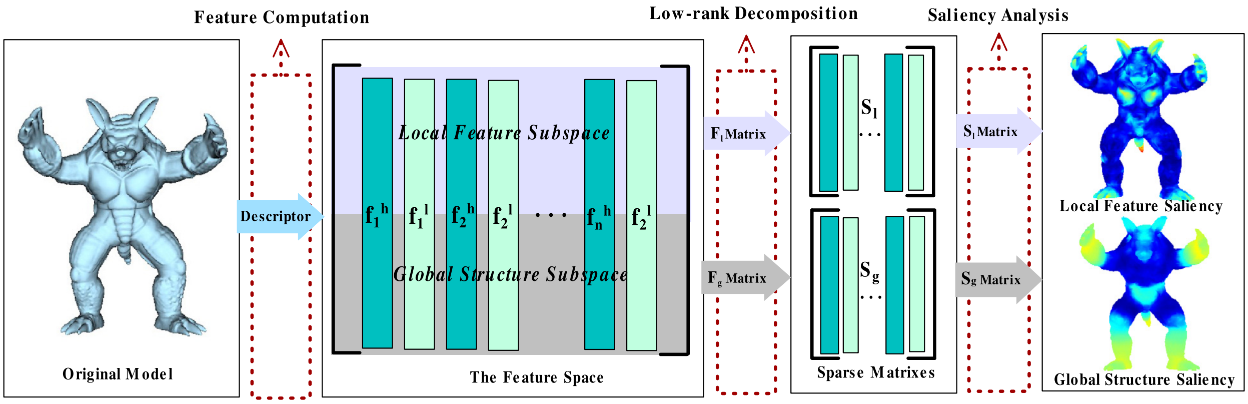

Fig. 1. The functional pipeline of our saliency detection. We first use the proposed structure-aware descriptor to construct a feature space, which consists of the local feature subspace and the global structure space. A local feature matrix and a global structure matrix are extracted from the corresponding subspace. Then, we explore the low-rank decomposition and sparse representation to decompose the matrices into low-rank parts and sparse parts. Finally, the local feature saliency and the global structure saliency are obtained by analyzing the corresponding sparse matrices.

vision, there is still a limited research attention paid to the utility of perception-inspired metrics for saliency definition and its effective detection in geometry processing of 3D surfaces.

Moreover, most of the existing approaches on 3D mesh saliency detect the saliency according to the local contrast (Gal and Cohen-Or, 2006; Kim and Varshney, 2006; Kim et al., 2010). Recently, the multi-scale computation (Lee et al., 2005; Shilane and Funkhouser, 2007; Leifman et al., 2010) and the global rarity (Wu et al., 2013) are proposed to detect the saliency in a larger region. Nonetheless, both of them consider only the local geometric features of the salient (i.e., distinctive) differences in different scale regions. On the other hand, the global structures, which depict global shapes, have not yet to be fully considered when detecting mesh saliency.

Our motivation in this paper is to empower 3D mesh saliency with novel techniques that also enable more meaningful applications in graphics and geometric computing. We observe that, only detecting the saliency of local features, whether in local scale or global scale, is not discriminative enough at present to express the perceptual importance of global structures, such as the limbs in certain animal models. Moreover, generic shape features in a global setting are also relevant to shape frequency. From the point view of shape frequency, a 3D shape can be decomposed into a shape spectrum that spans across high frequency information to low frequency information, which collectively forms the “shape-DNA” (Reuter et al., 2006; Bronstein et al., 2010). The high frequency information is more sensitive to the fine features with geometric details, and the low frequency information contributes more to the base shape, which is much more stable. The novel method to be presented in this paper has been built upon our strong belief that effectively and accurately recognizing the global importance of different frequency information will help us quantify the saliency of 3D models. Equally important, at the computational level, our work has also been strongly inspired by the successful application of low-rank and sparse analysis for image processing (Yan et al., 2010; Zhang and Li, 2012), we have found that the feature space spanned by the proposed shape descriptor can be decomposed into the low-rank part and the sparse part respectively, which means that we could also make use of the low-rank and sparse analysis for mesh saliency and its effective detection.

To handle the aforementioned problems, we propose a versatile saliency detection framework based on the low-rank and sparse analysis, as shown in Fig. 1. Towards this goal, we first propose a new structure-aware descriptor that integrates both multi-scale and multi-level information to capture the intrinsic characteristic of the underlying geometry. Then a low-rank and sparse modeling is explored in a feature space spanned by the shape descriptors to exhibit the sparse characteristic, which are further reformulated into different saliency, including local feature saliency and global structure saliency. The former captures the salient regions of local scope that is related to local features, and the later captures the salient structures from the global point of view, such as the limbs of animal models.

2. Background and related work

The concept of saliency originates from the area of computer vision, and in recent years we have seen many research progresses in saliency and its effective detection. The technical essence of saliency detection is to identify automatically the important sensory information that is pertinent to a human vision system. Also, the newly-proposed and promising method, namely low-rank and sparsity decomposition, is popular and powerful for saliency analysis.

Earlier research works on saliency analysis concentrate more on the saliency measurement in a local scale. From the point of view of fundamental geometric perception, the intuition of salient regions should be those that are distinctive from their immediate surroundings, as suggested by Koch and Ullman (1987). Such type of definition is so straightforward that it tends to ignore the object’s details mechanically. To address this problem, Einhüuser and König (2003) performed the detection process via the combinatorial use of color and texture information. Similarly, Ma and Zhang (2003) defined a perceived field to set up the unit, from which the contrast value based on color and intensity was calculated. Other feature