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Sharp feature preserving MLS surface reconstruction based on local feature line approximations

Christopher Weber [a,*], Stefanie Hahmann [b], Hans Hagen [a], Georges-Pierre Bonneau [b]

[a] Technische Universität Kaiserslautern, AG Computergrafik und HCI, Postfach 3049, 67653 Kaiserslautern, Germany
[b] Université de Grenoble, INRIA-LJK, Innovallée, 655 avenue de l'Europe, F-38334 Saint Ismier Cedex, France

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ABSTRACT

Sharp features in manufactured and designed objects require particular attention when reconstructing surfaces from unorganized scan point sets using moving least squares (MLS) fitting. It is an inherent property of MLS fitting that sharp features are smoothed out. Instead of searching for appropriate new fitting functions our approach computes a modified local point neighborhood so that a standard MLS fitting can be applied enhanced by sharp features reconstruction.

We present a two-stage algorithm. In a pre-processing step sharp feature points are marked first. This algorithm is robust to noise since it is based on Gauss map clustering. In the main phase, the selected feature points are used to locally approximate the feature curve and to segment and enhance the local point neighborhood. The MLS projection thus leads to a piecewise smooth surface preserving all sharp features. The method is simple to implement and able to preserve line-type features as well as corner-type features during reconstruction.

1. Introduction

Point based surfaces have become a very popular and attractive mesh less surface representation over the last decade. They define a smooth surface using local moving least squares (MLS) approximations of the data.

Since the initial approach [2] based on Levin's [17,18] projection operator, many improvements in terms of efficiency [3,28], rendering [12], stability [11], studies on properties and limitations [3,4] and variants using implicit surfaces [28,16,21] or specialized to non uniform, low dense sampling [8] have been developed.

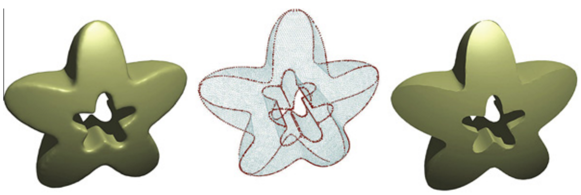

Fig. 1. Left: standard MLS surface. Middle: feature point detection in point cloud. Right: sharp feature preserving MLS.

The main strengths of MLS fitting include natural point denoising due to local least squares approximation, which can be seen as a local low pass filter. They generate smooth surfaces even in the presence of noise. It is thus assumed that the input data originates from a smooth surface.

Many scanned, manufactured or designed objects however exhibit sharp features. Sharp features are an important design element not only for mechanical parts. It is thus important to be capable to reconstruct those features not only for reverse engineering applications such as surface reconstruction, but also for quality control of a product, where the scanned object is compared to the CAD-prototype. Even though point based surfaces were initially developed as an efficient visualization tool for point sampled data, they are nowadays used in a wide range of applications [10].

* Corresponding author. Fax: +49 631 205 3270.
E-mail address: chweber@rhrk.uni-kl.de (C. Weber).

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However, the requirements on point based surfaces to handle uniform noise and to generate a smooth surface is in contradiction to sharp feature preservation. It is thus not surprising that for example Amenta and Kil [4] attest instabilities near sharp features.

Although visual smoothness is one of the most required properties of surfaces or shapes in general, for the mentioned applications in product design, reverse engineering or quality control it is however indispensable to preserve sharp features during reconstruction.

In this paper we address the problem of sharp feature preserving surface reconstruction from arbitrary point sets using moving least squares.

The output is a piecewise smooth point-based surface, meaning a refinable point cloud with normals. Feature points are first identified in the point cloud as part of a pre-processing using an adaptive Gauss-map clustering technique. Only neighborhoods containing some of the feature points are modified. Inside these neighborhoods, which are used by the projection operator, a local approximating feature curve is computed and serves to make a local decision in order to segment and enhance the point neighborhood. Applying standard MLS fitting [18] to the modified neighborhoods automatically generates piecewise smooth surfaces with sharp features since the points are projected to only one smooth surface part.

All advantages of standard MLS fitting (local smoothness, robustness to noise) are preserved and augmented with the ability to reconstruct sharp features.

Similar to RMLS [9] we identify individual neighborhoods within the regions of identified feature points, but we do not rely on computational expensive robust statistics. Instead we fit local curves through the identified feature points in order to slice the neighborhoods. Contributions and advantages of our technique in contrast to previous works [9,11,25,21] can be listed as follows:

- Sharp features are automatically reconstructed, no manual tagging [11,25] of feature lines is required.
- It is shown how local feature curve approximations can be used to partition the neighborhoods used for MLS projection.
- The method is much more simple to implement than statistical methods [9,6,7,21] where many parameters have to be fine-tuned.
- The quality of reconstructed sharp features is improved with respect to previous MLS methods, e.g. our local feature curve approximation and neighborhood modification reduces the appearance of jagged edges and produces smoother features.
- Feature point detection is a costly part here. MLS fitting with sharp features is then done in usual computation time. Performing the feature point detection in a precomputation has the advantage that MLS reconstructions with different smoothness parameters can be performed multiple times. Our method speeds up such a process significantly.

The rest of the paper will be composed as follows: In Section 2, we review related work in the field of MLS reconstruction. Section 3 sets basic notations of MLS fitting. Section 4 describes the pipeline from feature point extraction, neighborhood modification and sharp feature surface fitting. Section 5 presents experimental results. Final remarks and future work close the paper.

2. Related works

Moving least squares (MLS) surfaces are a very popular mesh less surface reconstruction tool [1,2]. In contrast to the common approach to generate a triangulated mesh, MLS approximate an unorganized dense, possibly noisy, set of points by an overall smooth point-based surface [18]. Many variants have been published [1,9,11,16,25] and several applications of point-based geometries can be found in [10]. Preservation of sharp features is not an inherent property of MLS fitting, any sharp feature will be smoothed and appears rounded after the fitting process.

So let us focus now only on MLS approaches with sharp feature reconstruction in this section.

As one of the first, Fleishman et al. [9] presented a MLS approach that could reproduce sharp features. The so-called robust moving least squares fitting approach is based on methods used in statistics to search for outliers in the point set. It assumes, that the surface consists of several smooth patches connected by sharp features. The idea is, that a sample point lying on another smooth patch will be identified as outlier during the statistical analysis. An iterative refitting procedure is necessary to add points successively to the used neighborhood until an outlier is detected. Several iterations are necessary. It reconstructs the smooth surface parts, which in the end are connected through a sharp feature. Although the resulting surface is of a good quality, the outlier search and the refitting of the smooth surface parts are quite tricky to implement. The method also has problems with jagged edges as pointed out in [6,7] and needs a quite dense sampling. Our approach is inspired by the partitioning of the local neighborhood to reconstruct sharp features, although the way how we achieve this is completely different.

Guennebaud and Gross [11] presented APSS, algebraic point set surfaces. They use moving least squares fitting of spheres instead of planes. This leads to a good stability in undersampled datasets. The sharp feature extraction itself is done manually by tagging of the point cloud, or automatic and based on a statistical analysis analogous to [9].

Öztireli et al. [21] use a kernel regression technique to reconstruct sharp features. They called it RIMLS, Robust Implicit MLS. Analogous to [9] they also use a statistics approach to find outliers belonging to different smooth patches on the surface. This technique has global parameters that can control the global visual sharpness of the reconstruction. However the resulting surface remains always C^2-continuous. So the reconstruction does not have a tangent plane discontinuous sharp feature, but only gives the visual effect of a sharp feature during rendering. Depending on the application, this can be seen either as an advantage or disadvantage.

An other interesting approach is the ERKPA by Reuter et al. [25]. ERKPA stands for Enriched Reproducing Kernel