A Thesis for the Degree of Ph.D. in Engineering

Real-time 3D Reconstruction of Dynamic Scenes Using Moving Least Squares

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Graduate School of Science and Technology
Keio University

Siim Meerits

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Keio University

Thesis Abstract

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Registration Number	☒ "KOU" □ "OTSU" No. *Office use only	Name	Siim Meerits

Thesis Title

Real-time 3D Reconstruction of Dynamic Scenes Using Moving Least Squares

Thesis Summary

Three-dimensional (3D) reconstruction is an actively researched area of computer vision. The general objective in this field is to construct digital models of real objects and scenes. With the advent of RGB-D cameras and increase in graphics card processing power, the focus of reconstruction has recently shifted from static to dynamic content and from offline to online systems. In the current state-of-the-art works many difficulties remain: multi-camera scene capture requires use of bespoke hardware, fast motions and big topology changes cannot be correctly handled and large scenes cannot be reconstructed due to memory constraints or too computationally expensive reconstruction methods. This thesis addresses all of these issues and proposes novel methods as solutions.

To avoid capturing scenes using custom and expensive hardware this thesis proposes capturing scenes for reconstruction using low-cost consumer-grade RGB-D cameras. As a drawback, the consumer devices lack capability of synchronizing camera shutters. This issue is mitigated algorithmically by developing a novel depth frame interpolation method that allows generating new temporally consistent depth data. As a byproduct, this method can be used to generate synthetic slow-motion 3D reconstruction videos.

Two novel real-time 3D reconstruction methods, ZipperMLS and FusionMLS, that allow reconstructing both highly dynamic and very large scenes are proposed. Both are based on moving least squares (MLS) surface estimation technique and produce triangle meshes as output. The methods differ considerably in the way geometry is handled. ZipperMLS reconstruction method belongs to the explicit surface reconstruction methods family. Triangle meshes are directly generated from depth maps and then merged. To smooth surfaces a new projection operator is contributed for MLS that is suitable for direct meshing of depth maps. To merge meshes, the concept of mesh zippering from previous work is re-engineered to work as highly parallelizable algorithm suitable for execution on GPUs. FusionMLS reconstruction method belongs to the volumetric reconstruction methods family. It uses MLS to estimate signed distance function (SDF) at each voxel location and marching cubes method to generate triangle mesh of the scene. The main novelty of the method is packing surface estimation and mesh generation into a single process. That allows very low memory usage and fast reconstruction.

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The developed 3D reconstruction methods can be used in various applications. A diminished reality system is demonstrated as a practical example. Diminished reality is part of mixed reality research field and its purpose is to hide, i.e. diminish, user selected objects from captured scenes. Diminishing complex objects can be demonstrated as the proposed reconstruction methods are very general.

Presented 3D reconstruction and application implementations are completely GPU-based and work in real time. The results shown in this thesis, obtained with real data, demonstrate the effectiveness of the proposed methods and its advantages compared to state-of-the-art works.