摘 要

三维重建是计算机图形学研究的核心内容之一，它广泛应用于工业制造、产品设计、影视动画制作、虚拟现实等诸多领域。随着研究对象复杂程度日益提高，传统的正向三维建模方法在计算效率和交互自然性等方面遇到了巨大的挑战。基于图像、深度、视频等视觉信息对真实世界的物体进行三维重建，虽然大幅度提高了建模过程的自动化水平，但如何简化用户操作、降低建模难度、提高建模精度，同时获取完备的模型语义信息，使所建的模型数据能与科研和制造需求无缝对接，仍然是该领域的重点和难点问题。

基于上述研究背景，本学位论文主要研究基于图像的交互式建模与构建模型的完备语义信息。本研究有效的降低了建模门槛，提高了建模效率，能够自动提取、分析和优化模型的完备语义信息，从而得到“立即可用（readily usable）”的三维模型。本文研究重点是如何获取与优化的模型语义信息，该信息分为两个层次：高层语义信息，该信息包含模型部件的几何数据与运动参数；低层语义信息，该信息包括三维模型的网格拓扑结构。精准的模型几何数据是构建大规模虚拟数字场景的基础信息，完备的模型运动参数能够完成高质量的模型运动仿真与演化，高质量的模型网格拓扑结构能够加速模型仿真与传输的算法效率。总体来说，本文研究内容为获取与优化完备的三维模型信息，使重建的三维模型可直接应用于3D打印、虚拟现实、运动仿真等产业及研究领域。本学位论文主要贡献如下：

1. 提出了一种高效精准的基于多视角图像的“傻瓜式”交互式建模方法。针对三维建模过程复杂、对用户专业知识要求高、交互自然性差等问题，本文提出了在多视角照片上通过简单“三笔”直接绘制出模型草图的建模交互方式，极大的提高了建模的交互自然性，降低了建模的门槛。在此基础上，针对图像中模型部件间的遮挡和建模精度差等问题，本文通过模型的多视角图片得到的点云数据辅助引导用户绘制模型，并基于数据驱动探测模型部件间的几何约束关系，进一步优化模型部件的几何参数信息，最终得到与真实照片中完全匹配的精确三维模型。基于这些研究成果，本文研发了一个基于多视角图像的交互式三维建模系统，对于普通用户在三十分钟时间内，即可重建出“内燃机”、“机械臂”等具有工业级精度的复杂三维机械模型。
2. 提出一种基于视频序列的三维模型运动自动提取及优化方法。人工构建三维运动模型门槛高、工作量大，而基于视频自动获取模型的运动精度低，且无法获取具有复杂运动链的模型运动参数。针对这些问题，本文创新的提出了一种基于机械运动先验知识的模型运动链中运动关节类型搜索算法和基于视频序列的模型运动匹配优化算法。本文根据机械模型运动关节先验知识构建连接关节类型候选集，建立模型运动传递链，并建立三维模型剪影与图像边界匹配能量函数，通过模拟退火优化能量函数，依次优化出模型的关节类型和部件的运动参数，从而得到与视频序列中真实运动完全相匹配的模型运动信息。该方法很好的解决了复杂模型关节运动难于形式化描述与优化的难题，并且根据实验证明，通过3D打印得到的重建模型与原模型具有相同的运动结果。
3. 提出了一种基于部件运动优化的三维模型快速拆解与装箱方法。特别针对三维模型在熔融沉积三维打印时，打印时间长、耗费支撑材料多等问题，本文通过优化模型部件的运动参数，贪心地在空间耗费最大的关节处进行拆分，并计算出使模型部件组包围盒体积最小的部件参数，使模型在装箱时能够排列得更加紧凑，从而最小化三维打印时的最小包围盒体积。由于模型拆解和装箱均为动态优化中的NP-hard问题，本文采用层次化拆分策略和启发式装箱策略，有效的平衡了模型的最佳拆解次数与装箱空间利用率，并且很好地解决了传统装箱算法效率低等问题。
4. 提出了一种实时鲁棒的三维模型网格结构的并行半规则化方法。针对模型渲染速度慢，网格压缩率低等问题，通常采用半规则化的层次网格结构（Levels of Detail，LOD）多分辨率地表达复杂模型，而目前的半规则化方法算法效率低，无法满足实时要求。本文通过分层简化与建立并行独立集，有效的解决了网格简化算法无法并行的难题，从而使算法并行达到实时的效率。通过网格简化时对参数化的平滑和网格细分时高精度的采样，可以使简化后的粗糙模型网格细分为精确的半规则网格。

**关键字：** 三维重建，交互式建模，多视角建模，运动提取，运动优化，半规则三角网格化，模型拆解与装箱

Abstract

3D models reconstruction is one of the core contents of computer graphics research. It is widely used in industrial manufacturing, product design, film and television animation production, virtual reality and many other fields. With the increasing complexity of research objects, traditional forward 3D modeling methods have encountered enormous challenges in terms of computational efficiency and interactive naturalness. 3D models reconstruction of real-world objects based on visual information such as images, depth, and video, while greatly improving the automation level of the modeling process. However, how to simplify the user operation, reduce the difficulty of modeling, improve the modeling accuracy, and obtain complete model semantic information, so that the model data can be seamlessly connected with relevant research and manufacturing requirements, which is still a challenge in this field.

Based on the above related research, my dissertation mainly focus on image-based interactive modeling and the complete semantic information of construction models. Our study effectively reduces the modeling threshold, improves the modeling efficiency, and automatically extracts, analyzes and optimizes the complete semantic information of the model, thus obtaining a "readily usable" 3D model. The focus of this paper is how to obtain and optimize model semantic information. The information is divided into two levels: High-level information, which contains geometric data and motion parameters of the model components; Low-level information, including the mesh topology of the 3D model. Accurate model geometry data is the basic information for building large-scale virtual digital scenes. Complete model motion parameters enable high-quality model motion simulation and evolution. High-quality model mesh topology accelerates algorithmic efficiency in model simulation and transmission. In general, the research content of this paper is to obtain and optimize the complete 3D model information, so that the reconstructed 3D model can be directly applied to a wide range of industries and research fields such as 3D printing, virtual reality, and motion simulation. The main contributions of this dissertation are as follows:

1. An efficient and accurate "simple" interactive modeling method based on multi-view images is proposed. Aiming at the problems of complex 3D modeling process, high requirements for user's professional knowledge and poor natural interaction, this paper proposes a modeling interaction method for directly drawing out model sketches through simple “three strokes” on multi-view photos, which greatly improves the model. The interactive nature of modeling reduces the threshold for modeling. On this basis, for the problem of occlusion between the model parts and poor modeling accuracy in the image, the point cloud data obtained from the multi-view image of the model assists the user to draw the model. Based on the geometric constraint relationship between the data-driven detection model components, the geometric parameter information of the model components is optimized, and finally an accurate 3D model that exactly matches the real photo is obtained. Based on these research results, we developed an interactive 3D modeling system based on multi-view images. For common users, within 30 minutes, a complex 3D mechanical model with industrial precision such as “Poston-engine” and “Robot-arm” can be reconstructed.
2. A method for automatic motion extraction and optimization of 3D model based on video sequence is proposed. The artificially constructed 3D motion model has a high threshold and a large workload, while the motion automatic acquisition model based on motion has low motion accuracy and cannot acquire model motion parameters with complex motion chains. Aiming at these problems, this paper proposes a motion joint type search algorithm based on mechanical motion prior knowledge and a model motion matching optimization algorithm based on video sequence. In this paper, based on the prior knowledge of mechanical model joints, construct a joint set of joint types and establish a model motion transfer chain. And establish a 3D model silhouette and image boundary matching energy function. Through the simulated annealing optimization energy function, the joint type of the model and the motion parameters of the component are optimized in order to obtain the model motion information that completely matches the real motion in the video sequence. This method is a good solution to the difficulty of formal description and optimization of complex model joint motion. According to the experiment, the reconstruction model obtained by 3D printing has the same motion result as the video.
3. A fast disassembly and packing method for 3D models based on component motion optimization is proposed. For the 3D model, when the 3D printing is performed by fused deposition, the printing time is long and the supporting material is expensive. In this paper, by optimizing the motion parameters of the model components, we greedily split the joints where the space is most expensive. And calculate the component parameters that minimize the volume of the model component group bounding box, so that the model can be arranged more compactly when packing, thus minimizing the minimum bounding box volume in 3D printing. Since model disassembly and packing are both NP-hard problems in dynamic optimization, this paper adopts hierarchical splitting strategy and heuristic packing strategy to effectively balance the optimal number of disassembling and packing space utilization. And it solves the problem of low efficiency of traditional packing algorithm.
4. Parallel and robust semi-regular triangle remeshing is proposed. For the problem of slow rendering speed and low grid compression rate, the semi-regular hierarchical structure (Levels of Detail, LOD) is usually used to express complex models with multiple resolutions. The current semi-regular method algorithm is inefficient and cannot meet real-time requirements. In this paper, the layered simplification and the establishment of parallel independent sets effectively solve the problem that the mesh simplification algorithm can’t be paralleled, so that the algorithm can achieve real-time efficiency in parallel. The simplified rough model mesh can be subdivided into precise semi-regular meshes by parameterized smoothing and high-precision sampling during mesh simplification.

**Keywords:** 3D Reconstruction，Interactive Modeling，Multi-image Modeling，Motion extraction，Motion Optimization，Semi-regular Triangulation，3D Model Packing