Sketch-Based 3D Shape Modeling from Sparse Point Clouds

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ABSTRACT

3D modeling based on point clouds is an efficient way to reconstruct and create detailed 3D content. However, the geometric procedure may lose accuracy due to high redundancy and the absence of an explicit structure. In this work, we propose a human-in-the-loop sketch-based point cloud reconstruction framework to leverage users’ cognitive abilities in geometry extraction. We present an interactive drawing interface for 3D model creation from point cloud data with the help of user sketches. We adopt an optimization method in which the user can continuously edit the contours extracted from the obtained 3D model and retrieve the model iteratively. Finally, we verify the proposed user interface for modeling from sparse point clouds.

Keywords: 3D modeling, point cloud, human-in-the-loop, sketch-based, user interface

1. INTRODUCTION

With the rapid development of 3D modeling technology, 3D models are currently used in various applications, such as in the medical industry, films, video games, and architectural designs. It is increasingly important to retrieve and reconstruct 3D models from sparse input. 3D data can be represented in different formats depending on the end use. Common formats include depth maps, point clouds, voxels, meshes, and volumetric grids. In particular, point clouds can preserve high-quality geometric information in 3D space without discretization. Therefore, it is a feasible representation for various real-world applications using point clouds, which can be easily obtained using 3D imaging sensors such as binocular cameras, depth cameras, and LiDAR laser scanning.

However, the acquired point clouds may be noisy or incomplete with sparse density or partially missing data due to the limitations of the data acquisition process. Therefore, it is challenging to reconstruct and acquire high-quality 3D content efficiently from point clouds. Figure 1 shows the modeling results of MeshLab’s automatic surface reconstruction approach. We observed that automatic processing is quite susceptible to the quality of point clouds. Previous work can reconstruct 3D models by recovering shapes from sketch inputs,\textsuperscript{1} but the geometric shapes extracted from point clouds are usually simple and regular, and it is difficult to generate accurate 3D contents from sparse point clouds. Automatic extraction approaches may require pre-processes to simplify data or fill in missing data, which will complicate the process. Because users may have excellent cognitive abilities in spatial recognition, we represent the extraction of object shapes from point clouds as a human-in-the-loop tracing process.

In this work, we propose an interactive drawing interface to construct 3D models from point clouds, especially sparse point clouds. Our main contributions include the following: (i) an interactive 3D object drawing interface to handle sparse point cloud data and (ii) an iterative optimization method based on model contours with sketch retrieval and model contour editing on public point cloud datasets.

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2. RELATED WORKS

Automatic shape modeling from point clouds has been explored extensively for various applications. PolyFit was proposed for reconstructing lightweight polygonal surfaces from point clouds. Topological priors were recently incorporated into point scans for reconstructing point cloud surfaces. The automatic modeling approaches show robust and satisfying reconstruction results for dense point clouds. However, these approaches may fail to provide a feasible solution for sparse point clouds, and we found that the human factor can greatly improve modeling results due to users’ spatial cognitive abilities.

Sketch-based user interface is an important research topic in computer graphics to improve automatic processes with human power, such as shape retrieval, motion retrieval, image generation and task guidance. For image-based shape editing, 3-sweep introduced an interactive technique based on extracting simple 3D shapes from a single image. Similarly, Gemketch can extend 3-sweep to extract 3D models of generalized rectangles and cylinders from single or multiple viewpoints. However, these approaches usually require strong assumptions or expertise on natural images. In this work, we use point cloud data as drawing background and allow users to sketch interactively in an iterative routine until satisfactory modeling is achieved.

3. SYSTEM OVERVIEW

Figure 2 shows the system overview of the proposed system. In the user interface, the user can adjust the angle to observe the spatial structure of the input sparse point cloud. After the observation, the user can determine any satisfactory angle and draw a sketch with reference to the sparse point cloud of the current angle. We overlay the sparse point cloud data with the retrieved 3D model with model alignment. If the user is not satisfied with the current model, the proposed interface allows the user to continue the retrieval based on the current model without redrawing. After the user confirms that the sketch modification is complete, the user can perform a re-retrieval in an interactive manner to obtain a new 3D model. By extracting the contours of the retrieved model (step 5), users can edit the contours and perform re-retrieval (step 6) in an interactive manner to continuously improve the overlap between the retrieved model and the initial point clouds.

3.1 Datasets

The dataset is constructed based on SHREC 2012. In our prototype design, our sparse point cloud database contained 100 point clouds, 20 for each of the 5 categories (teacup, chair, table, vase, and animal). In addition, we obtained 102 viewpoint matrices from the 102 uniformly distributed view directions, and used these matrices to capture contour images for each model. After these processes, we constructed a contour dataset of model data with 10,200 contour images. With the sketch input, the user can retrieve the most similar models from the dataset. We adopted OpenSSE to retrieve the 3D model by comparing the similarity between the current sketch and the model contours in the contour dataset.
3.2 Contour Extraction

The extraction of model contours is mainly implemented based on OpenCV. First, we store the 3D model data of a specific angle displayed in the current canvas window as an image. This image is then converted into a grayscale image. Then we perform a median filtering operation on the grayscale image. The filtered image is then converted into a binary map using a threshold function. Finally, we extract the contour lines of the current 3D model from this binary map. Once the contour lines are extracted, we draw the contour lines to a new image file with the same image size as the current canvas window size. This new image file of the model contour is finally displayed back to the user interface as an input sketch. After the above process, we complete the extraction of the current model contours to the interface, which gives the user a sketch of the model contours that can also be modified.

3.3 Model Alignment

In this research, we adopt point cloud alignment to integrate the input and retrieved result into a unified coordinate system with an iterative closest point (ICP) approach. First, we randomly select 2000 points in the sparse point cloud as control points to improve the computational efficiency and alignment accuracy of the ICP algorithm. We calculate the Euclidean distance of the corresponding points in the 3D model data, rotation matrix, and displacement vector using the control points and their corresponding points. We apply the computed rotation matrix and displacement vector to the 3D model data iteratively until the convergence condition is satisfied or the maximum number of iterations is achieved. Finally, the final aligned 3D model is displayed as the background of the proposed user interface.

3.4 User Interface

Figure 3(a) shows the proposed user interface. First, we provide the basic operations on point clouds and model files: importing point cloud data, exporting model files, and drawing or canceling function settings. The middle part is the canvas where the user can observe the point cloud and model and draw the sketch. We also provide “brush,” “eraser,” and “undo” functions that are commonly used in drawings. We provide specific functions, including retrieving 3D models, extracting 3D model contours, and ICP alignment of point clouds and models. In addition, we can show the spatial coordinates of the current viewpoint and control the display and hiding of the axis system, point cloud, and 3D model on the main canvas.
3.5 User Study

We evaluated the proposed system quantitatively and qualitatively in user study. We invited six participants (three male and three female graduate students) to use the proposed interactive interface to extract 3D models from sparse point clouds. We quantitatively evaluated the results to compare the overlapping similarities of the point clouds and the retrieved models. In the user study, we recorded the number of times the user retrieved the target, the number of sketch modifications, and the ICP error value in the model alignment.

We asked all participants to conduct the designated experiment twice with the following three tasks: (1) select sparse point cloud data to input into MeshLab for surface reconstruction; (2) use our proposed system without inputting sparse point cloud data (the user draws a sketch randomly according to his own imagination, and then performs a database search based on that sketch to eventually verify if the target 3D model can be retrieved); and (3) use our proposed system with the input of sparse point clouds. For the sparse point clouds, the users draw the sketch according to their recognition of the spatial structure of that point cloud. Note that the users do not have prior knowledge of the target models. Users can perform sketch retrieval interactively until they believe that the feasible target 3D model is achieved.

4. RESULTS

In this section, we present the modeling results using the proposed interface and the evaluation results from our user study to verify the effectiveness and user experience of our proposed interface.

4.1 Modeling Results

Our proposed system can support not only 3D modeling from point clouds but also sketch-based model retrieval without point clouds. Figure 4 shows that the user can input a sparse point cloud of a vase and retrieve the target model from only the top view. The proposed interface can involve the user’s spatial cognitive ability so that users can sketch the spatial structure of the point cloud data successfully.

Figure 5 shows that the user retrieves a model that does not match the target and then uses the ICP algorithm to align this model with the point cloud and extract the contour of the model. The user can modify and edit this contour to match the features of the point cloud and use the modified sketch for the next retrieval step. The method we provide allows the user to find the target model faster and more accurately, based on previous work. It is also more in accordance with the user’s habit of modifying and editing the previous sketch.

4.2 Evaluation Results

We collected and analyzed data from participants during the user study. As shown in Table 1, the average number of times they needed to draw was 1.67. The mean similarity of the sketch drawn by the user was 0.61. The mean value of ICP error was $5.37 \times 10^{-2}$. The ICP alignment results were relatively stable, and the point
5. CONCLUSION

We proposed a sketch-based human-in-the-loop interactive system to retrieve and reconstruct 3D models from sparse point clouds. We provided an iterative strategy to help users modify and improve the sketch. Benefiting from the freely observable point cloud data, users can draw sketches of structural contours in arbitrary viewpoints with a free proficiency level and imagination. We conducted a user study and found that the target 3D model can be acquired well by drawing sketch contours from sparse point clouds. We plan to expand the variety of
objects in the dataset with complex objects, such as the human body. Furthermore, we would like to explore the deep learning-based generative model for shape generation rather than model retrieval.

ACKNOWLEDGMENTS

We thank all the participants in our user study. This work was supported by JAIST Research Grants, and JSPS KAKENHI Grant 20K19845, Japan.

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