Design of 3D Reconstruction System of Indoor Environment based on Virtual Reality Technology

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Abstract: The indoor 3d reconstruction system based on virtual reality technology was designed to solve the problem that traditional 3d reconstruction system is time-consuming and inaccurate. The hardware part of the system consists of a laser scanning device, a Micro Blaze microprocessor and the FSL bus. On the basis of hardware, the point cloud data collected in indoor environment is preprocessed, and the point cloud data after preprocessing is matched and fused. After the point cloud data is converted to the global coordinate system, the 3d image is preliminarily reconstructed by using the OpenGL 3d graphics function library. After the texture patch processing, the error of 3d reconstruction results is verified to complete the design of 3d reconstruction system. Compared with the traditional 3d reconstruction system, it is proved that the designed system can reduce the time consumption of 3d reconstruction and improve the accuracy of 3d reconstruction.

Keywords: Virtual reality technology; Indoor environment; Three-dimensional reconstruction; The system design

1. Introduction

With the continuous development of social productivity and science and technology, the demand for virtual reality technology in all walks of life is increasingly strong. Virtual reality technology USES a computer to generate a simulated environment in which the user is immersed. It is using the data in real life, through the electrical signals generated by computer technology, combined with a variety of output devices so as to make it into a can make people feel phenomena, these phenomena can be a real object in reality, it can also be invisible to the naked eye, we display [1] through the 3 d model. Virtual reality technology has been applied in film and television entertainment, education, design, medicine, military, aerospace and other fields, has a very broad application prospects.

Accurate 3d reconstruction of indoor environment plays a vital role in the fields of cultural relic protection, public service, emergency rescue and so on. Traditional indoor 3d reconstruction system usually adopts a single device such as a camera to obtain two-dimensional images of the actual indoor environment, and complete 3d reconstruction by extracting the features in the images [2]. However, in the process of collecting two-dimensional images, lighting conditions, camera geometric characteristics and other factors have a great impact on the subsequent two-dimensional image processing, resulting in poor accuracy of subsequent three-dimensional reconstruction. And the realization process of the traditional 3d reconstruction system is complex and the reconstruction efficiency is low. Therefore, this paper will design a 3d reconstruction system of indoor environment based on virtual reality technology, which is described in detail below.

2. Design of Hardware Module of 3D Reconstruction System of Indoor Environment based on Virtual Reality Technology

The 3d reconstruction system of indoor environment based on virtual reality technology designed in this paper is mainly divided into two parts: hardware and software. Since the traditional reconstruction system USES a single camera to collect two-dimensional images of the actual environment, which affects the reconstruction effect, this paper adopts a three-dimensional laser scanning unit to collect relevant data of the indoor environment, and upload the collected data to the software module for processing through the FSL bus.

3d laser scanning unit can realize non-contact measurement of indoor environment. In order to achieve high-precision indoor environment data collection, 3d laser scanning unit can be divided into vertical and horizontal scanning. Figure 1 shows the frame diagram of 3d laser scanning unit.

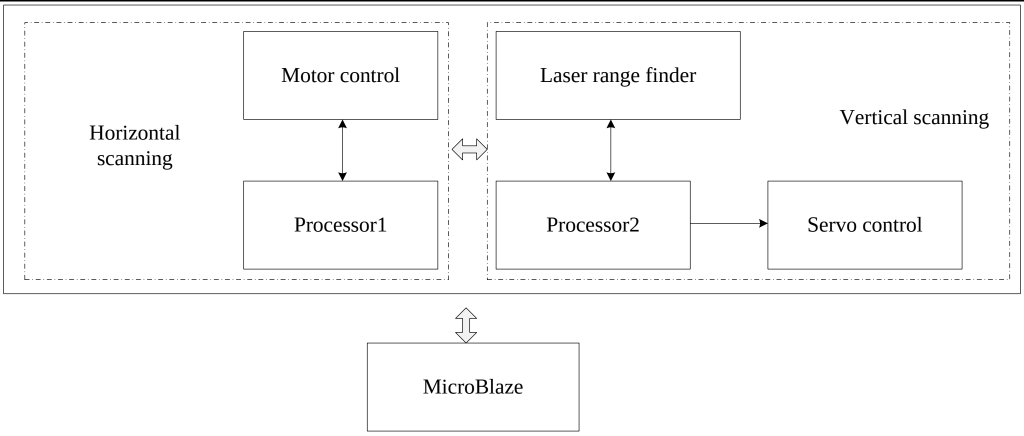

Figure 1. Frame diagram of 3d laser scanning unit

The main function of the vertical direction scanning module is to drive the laser ranging module to measure the distance through processor 2, control the motor and measure the Angle through the encoder, and finally transmit the distance and Angle information to the upper computer through the interface circuit for data fusion [3]. The motor controls the laser scanning in the horizontal direction, which drives the vertical direction scanning device, which adds a rotational degree of freedom in the horizontal direction. The horizontal data information is transmitted to the upper computer through the communication serial port of vertical scanning. The host computer selected a Micro Blaze soft core with a 32-bit microprocessor, and each FSL interface of the Micro Blaze could be directly connected using FSL. FSL bus is mainly responsible for the transmission of data within the range of each clock, so that data can be read and write in sequence. The FSL bus realizes the whole process through the communication between registers and memory. It takes one clock cycle for data to transfer register information to memory for output. Figure 2 describes the timing sequence of FSL main device data writing interface.

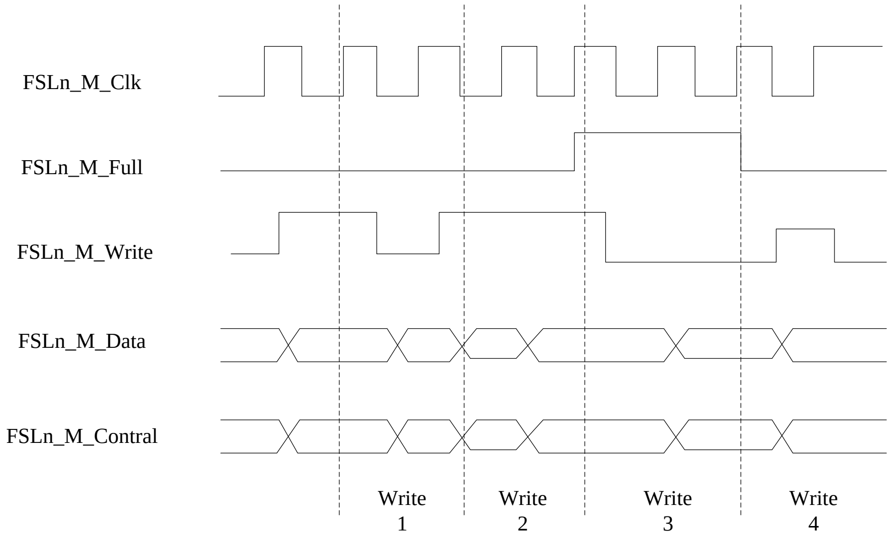

Figure 2. Sequence diagram of FSL bus write operation interface

As you can see from figure 2, the data write process is in the Write1 and Write2 fields. When entering the Write3 region, the FSL_M_Write signal is reduced because the storage is full and the data write is stopped. When data is read out, FSL_M_Full signal will gradually decrease and data will be written again [4]. The FSL bus injects the data collected by laser into the software part of the system. After the software part processes the data, the 3d reconstruction of indoor environment is realized.

3. Software Module Design of 3D Reconstruction System for Indoor Environment

On the basis of data collected by hardware, data are processed, and point cloud data are matched and fused by relevant algorithms. Finally, 3d reconstruction of indoor environment is achieved, and the design of 3d reconstruction system of indoor environment is completed.

3.1. Point cloud preprocessing

Due to some errors in the manual measurement and the characteristics of the laser measurement itself, the 3d point cloud obtained from the 3d laser scanning unit needs to be pre-processed, such as filtering, to meet the requirements of feature extraction of the point cloud data. In this paper, sparse outlier elimination algorithm based on statistical principle is adopted to process the collected data. Assuming that the point cloud contains n points, the entire point cloud is defined as set P, and each point element is denoted as $p_i(1 \le i \le n)$. The mean distance of k adjacent points of each point is calculated, that is, the sample individual, and denoted as:

$$dis_i = \frac{\sum_{j=1}^{k} d_{ij}}{k} (i \ne j) \quad (1)$$

In formula (1), d_{ij} is the distance between point I and point j [5]. The sample set can be obtained by repeatedly calculating the distance mean and traversing all the points in the point cloud, denoted as:

$$DIS = \{dis_1, dis_2, \ldots, dis_n\} \quad (2)$$

The mean value μ and standard deviation σ of the DIS of the above sample set are calculated according to formula (3).

$$\begin{cases} \mu = \dfrac{\sum_{i=1}^{n} dis_i}{n} \\ \sigma = \sqrt{\dfrac{1}{n-1}\sum_{i=1}^{n}(dis_i - \mu)^2} \end{cases} \quad (3)$$

The filtered point cluster is defined as P*, and the DIS of the entire sample set is retrospectively traversed, then there is $P^* = \{p_i \in P | dis_i \le \mu + \varpi \cdot \sigma, 1 \le i \le n\}$, where ϖ is the weighting factor, and the setting of the weighting factor depends on the number of adjacent points. In this paper, the weighting factor is set as 2.5. Due to laser scanning non-contact measurement, a single point cloud can reach hundreds of thousands or even millions of points. Although the more points, the higher the accuracy of the model obtained in the later stage will be, the large amount of data will greatly increase the processing time and the efficiency of 3d reconstruction [6]. The voxel mesh based descending sampling algorithm is used to divide the hole into several small cubes, namely voxel. The points represented by voxel are represented by the center of mass of the sub-point set contained in the effective voxel. Go through each point $p_i(1 \le i \le n)$ in the point cloud, obtain the smallest cuboid, and make all the faces of the cuboid perpendicular to the coordinate axis. Assuming that the side length of voxel is l, starting from the origin of the coordinate axis, the cuboid containing the entire point cloud is partitioned to fill the whole cuboid with voxel, and the index of the points contained in each voxel is obtained [7]. After traversing all non-empty voxel, the center of mass containing point sets in decent element is obtained, and finally the point cloud after falling sampling is obtained. After obtaining point cloud, data matching is required to obtain complete information of indoor environment and complete three-digit reconstruction.

3.2. Point cloud matching fusion

Point cloud data after down sampling need to be matched after point cloud segmentation. The false fixed-point cloud contains n points, and the whole point cloud is defined as set P. In order to achieve the goal of point cloud segmentation, it is necessary to first distinguish between different sub-point clouds. Here, $O_j = \{p_{j,m} \in P\}$ sub-point cloud is defined as $O_i = \{p_{i,m} \in P\}$.

$$\min \| p_{i,m} - p_{j,m} \|_2 \ge d_{th} \quad (4)$$

In formula (4), is the maximum distance threshold, that is, when the minimum distance between two word point sets is greater than the maximum distance threshold, the point cloud subset set is defined [8]. In order to speed up the point cloud matching algorithm, kd-tree is established to represent the entire input point cloud, and a list C containing sub-point cloud is created, which is denoted as $C = \{O_i, i = 1, 2, \cdots\}$, and a temporary set Q is used to store the temporary sub-point cloud. For any point $p_i \in P$, repeat the process. First add to the temporary set Q, and then search for any point $p_i \in Q$ with radius r, where r<dth. Search for another set of points p_i^k, traverse the entire set p_i^k, and add the unprocessed query points to the set Q. When all the points in set Q have been processed, add Q to list C and set it to an empty set. When all the points are traversed, the algorithm is terminated and the sub-point cluster C is obtained. After point cloud segmentation, it is matched and fused. The normal projection method is adopted to find the matching points. When a straight line is sent along the normal direction of the sampling points in the source point cloud data set, the intersection point between the line and the target point cloud data set is regarded as the matching point.

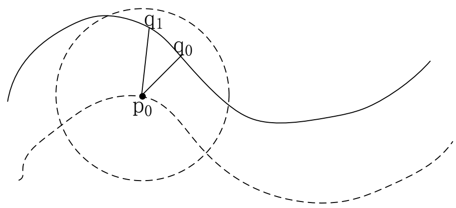

Figure 3. Normal projection

As shown in figure 3, if the sampling point is p0, the matching point obtained by Euclidean distance nearest method is q0, and the matching point q1 is obtained by normal projection method. According to the analysis of geometric knowledge, q1 is more accurate than q0. After obtaining the normal vector through the kd-tree established by the above operations, more accurate matching points are selected from the sampling points in the point cloud data after segmentation to complete the matching. In the actual 3d reconstruction, many frame point clouds need to be fused into the global coordinate system to form the global data cube shown in figure 4 [9].

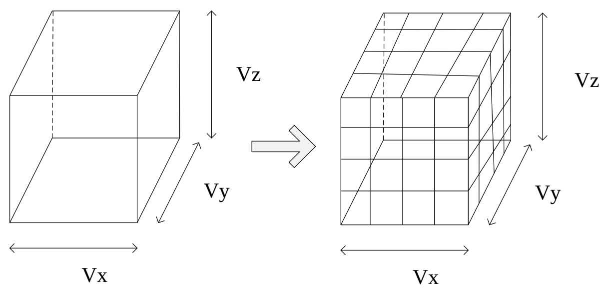

Figure 4. Global data cube

First, obtain the coordinate $V^g(x, y, z)$ of voxel in the global coordinate system, and then transform it from the global coordinate system to the origin cloud coordinate system to get V(x, y, z) according to the transformation matrix obtained by matching. The point cloud is fused to the global coordinate system through coordinate transformation, and the point cloud fusion is completed. 3d reconstruction of indoor environment is realized according to the point cloud data after fusion.

3.3. Realize 3d reconstruction of indoor environment

Marching Cubes algorithm is applied to segment fused 3d point cloud data into multiple individual elements in the way of triangular surface segmentation. Multiple segmentation makes the triangular surface approximate to the equivalent surface in the 3d point cloud data, and finally obtains the overall polygon mesh. Firstly, the corresponding index number is determined by the gray value of each corner point of voxel, and then the edge of voxel intersecting with the contour surface is found. By means of linear interpolation, the intersection coordinates of edge and contour surface of volume element are determined. The normal vector of each corner point of voxel is calculated by the central difference method, and the normal vector of each vertex of the triangular plane is calculated by the linear interpolation method again. Finally, the corresponding 3d reconstruction image is drawn by using each vertex coordinate and normal vector on the triangular plane. After using OpenGL 3d graphics function library to reconstruct the 3d image, the texture mapping of the 3d image is carried out. Since the texture information is not collected when the laser collects indoor environment related data, the texture information is obtained from the indoor environment color images [10]. Get the depth data of 30 frames per second, and store the current color image to the hard disk every 45 frames, and store the current camera position to a TXT format text file, used to calculate the texture coordinates. After the texture mapping is completed on the 3d reconstruction image, the error of 3d reconstruction is calculated. If the error meets the national standard of 3d reconstruction or the project requirement standard, the 3d reconstruction of indoor environment can be realized. Thus, the design of 3d reconstruction system of indoor environment based on virtual reality technology is completed.

4. Experiment

The kd-tree algorithm used in the 3d reconstruction system of indoor environment designed in this paper based on virtual reality technology can improve the matching speed and accuracy of high point cloud data. Therefore, this section designs a comparison experiment to verify the performance of the 3d reconstruction system designed in this paper by comparing it with the traditional 3d reconstruction system.

4.1. Experiment preparation

The experimental group is the 3d reconstruction system of indoor environment based on virtual reality technology designed in this paper, while the control group is the traditional 3d reconstruction system based on two-dimensional images. The development environment and experimental platform environment of the two systems are shown in table 1.

Table 1. System development and experimental platform environment

Project	Tools or parameters	Instructions
Operating system	64 - bit，Windows8.1	Microsoft's Windows operating system
Integrated development environment	Visual Studio 2017	Microsoft's visual integrated development loop habitat
Development of language	C++	Programming language
	PCL	Open source point cloud library across platforms
Third-party development library	OpenNI 1.5.4.0	Open source somatosensory development library
	OpenCV 2.4.3	Image processing development library
	CUDA Toolkit7.5	General parallel computing development tool
Auxiliary software	MeshLab	3D modeling software
	Matlab	Mathematical software
Hardware	Intel Corei7，3.6GHz CPU, NVIDIA graphics card, XBOX 360 KINECT motion-sensing device	System hardware

According to the space of indoor environment, the tripod is placed at fixed points. Laser scanning device and camera are placed on the tripod according to the requirements of the experimental group and the control group. Two systems, the experimental group and the control group, carried out 3d reconstruction of the indoor environment of 10 groups. Obstacles were placed in the indoor environment. The time consumption of 3d reconstruction of the indoor environment and the relative error of indoor obstacle size data of the two groups were counted.

4.2. Experimental results

The experimental comparison results are shown in table 2 and figure 5 respectively.

Table 2. Time consumption of 3d reconstruction of two groups of systems (s)

Group	Experimental Group	Control Group
1	10.41	15.80
2	13.92	14.71
3	12.28	15.99
4	10.84	16.47
5	11.43	13.68
6	11.80	14.13
7	12.60	14.84
8	13.22	16.43
9	13.65	15.37
10	12.33	13.65

Table 2 shows that 3d reconstruction of indoor environment in 10 groups takes less time in the experimental group than in the control group. The average time of the reconstruction system of the two groups was calculated. The average time of the experimental group was 12.248s, and that of the control group was 15.107s. Compared with the control group, the experimental group could save some time. Due to the small space size of experimental objects selected in this experiment, the difference in reconstruction time between the two groups of systems is small. Obstacles were placed in 10 groups of experimental environments, and the relative errors between the size of obstacles and the actual size after the reconstruction of the two groups of systems were recorded, as shown in figure 5.

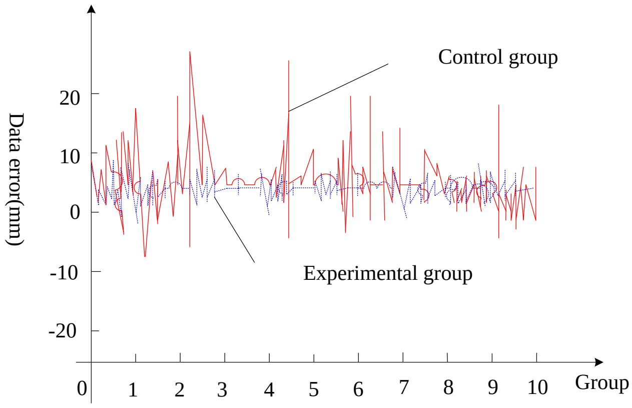

Figure 5. Error comparison

The analysis of figure 5 shows that the relative error of the experimental group is significantly smaller than that of the control group. The relative error fluctuation of the experimental group is small, while that of the control group is large, indicating that the accuracy of 3d reconstruction of the experimental group system is higher than that of the control group system, and that the experimental group system can better adapt to 3d reconstruction of different environments. To sum up, the 3d reconstruction system of indoor environment designed in this paper based on virtual reality technology can improve the efficiency and accuracy of 3d reconstruction, which is more advantageous than the traditional 3d reconstruction system.

5. Conclusion

Virtual reality technology has been widely used by virtue of its good performance such as interactivity and ideation. 3d reconstruction of indoor environment is helpful to grasp environmental information. When some operations are not suitable for implementation in the actual environment, repeated operations can be carried out in the environment of 3d reconstruction, which not only protects the actual environment but also saves economic cost. This paper designs a 3d reconstruction system of indoor environment based on virtual reality technology. By comparing with the traditional 3d reconstruction system, it is verified that the 3d reconstruction system designed in this paper has better reconstruction effect, can achieve more accurate 3d reconstruction, meets the requirements of 3d reconstruction, and has more advantages.

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