The Large-scale 3D Geometric Dimension Measurement Method and Application Based on Computer Vision

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Abstract: With the foundation of computer vision theory, the author studies the 3D reconstruction technology based on stereoscopic vision. The early-stage 3D reconstruction technology has been limited by the theoretical research level. The modeling process should be realized by dedicated devices, such as visual coordinate measuring machines. Moreover, the camera movement is strictly limited. Under the unspecific environment, the common digital cameras are used to do 3D reconstruction for the unspecific model. This system is feasible and has simple operation. It can accurately recover the object position and geometrical shape that can't be provided by a 2D image detection method.

1. Introduction

80% of external information sensed by mankind is obtained by vision. Mankind gains, disposes and comprehends visual information through eyes and brains. Objects in surroundings can form an image on retina of eyes irradiated by visible light. They are transformed into nerve impulse signals through photoreceptor cells. Through the nerve fibers, they are introduced to cerebral cortex for disposal and comprehension. People use computers to realize the overall process of visual information processing, so as to form an emerging subject—computer vision.

2. The method of 3D reconstruction modeling research

Static 3D image reconstruction is used to recover stereoscopic information of scenes. Generally speaking, two or more than two pictures of different positions in the same scene are taken. According to relevant information provided by images, 3D reconstruction is conducted. For example, stereoscopic vision system diagram composed of two pinhole cameras(obtained from the author) is an example of the stereoscopic vision system formed by two pinhole cameras, showing a 3D object and its projection on two planes. The advantage of this method is that it is easy to gain and use the equipment.

2.1. Camera calibration

In order to gain the correspondence of points and points in 3D objects of the world coordinate system, as shown in Figure 2, geometric model of camera image must be constructed for calculating the position shape of objects and gaining its parameters. In most of conditions, these parameters must be obtained through the experiment and calculation. Such a solving process is called as camera calibration.

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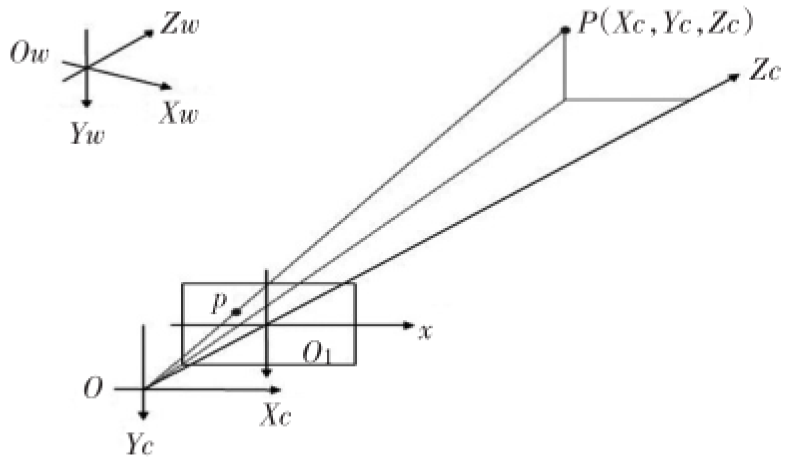


Figure 1 Schematic Diagram of the Correspondence in Each Coordinate System

2.2. Camera modeling

Camera calibration is divided into two steps. The first step is called as camera modeling. A group of parameters can be used to study physics of cameras and mathematical approach of optical behavior mode, as shown in Figure 2.

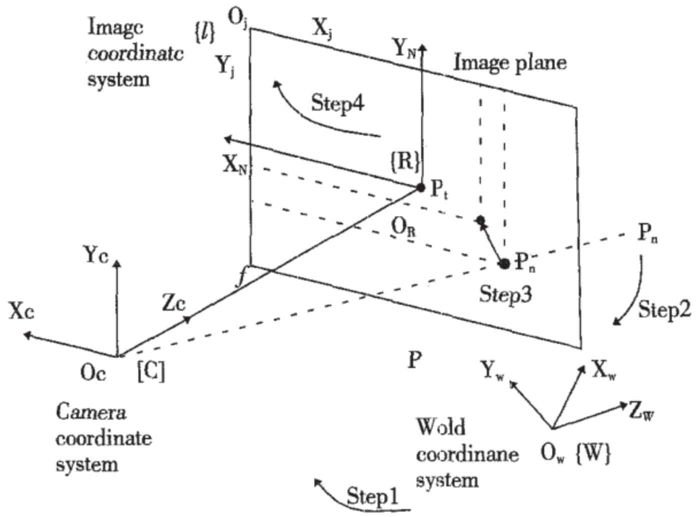


Figure 2 Projection Relationship between the 3D Target Point and Corresponding 2D Point on the Camera Image Plane

The basic formula of camera projection is:

$$s\begin{pmatrix}u\\v\\1\end{pmatrix}=A[R\ T]\begin{pmatrix}X_W\\Y_W\\Z_W\\1\end{pmatrix} \qquad (1)$$

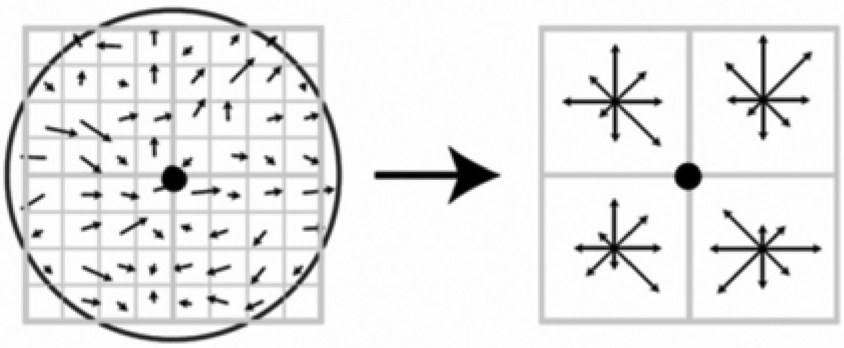
Among which, m=(u,u,l)T is the normalized coordinate of image points. M=(Xw, YW, Zw, 1)T is the normalized coordinate of the spatial point. R and T refer to rational and translation matrix from the camera coordinate system to the world coordinate system. They are called as external parameters. S is the scale factor. The matrix A is the internal parameter of cameras. Then, through 3D point Pw=(Xw, Yw, Zw) under the world coordinate system, the formula 1 can be used to obtain the pixel coordinate Pu=(u,v) of the corresponding 2D point on the image plane coordinate system.

Two types of parameters in the model must be considered. On the one hand, internal parameter group of geometric and optical property model in cameras is constructed to determine whether rays of light can be projected on the image plane through the lens. The another group includes external parameters, which measure the position and direction of cameras in the world coordinate system to provide measuring information in the coordinate system confirmed by users, instead of camera coordinate system.

2.3. SIFT feature point detection and stereo matching

Feature matching under the baseline condition aims to extract stable features for description, so as to realize the feature matching of two images with the large difference.

SIFT feature vector generating algorithm includes the following steps: (1) Scale space extremum detection key point position and scale. (2) Fitting function is used to accurately confirm the key point position and scale to remove low-contrast point. (3) The gradient direction distribution property refers to the assigned direction parameter of the key point. (4) SIFT feature vector is generated, as shown in Figure 3.



Gradient Direction in the Neighborhood   Feature Vector of the Key Point

Figure 3 Feature Vector of SIFT

After generating SIFT descriptor, Euclidean distance is used as the similarity measurement.

$$D(X,Y)\|X-Y\| = \sqrt{\sum_{i=1}^{d}(Xi-Yi)^2} \qquad (2)$$

2.4. 3D determination of coordinate and texture recovery

The same camera is used to take 3 pictures for the same object from different perspectives, ensuring that the same feature point is shown in three pictures. Next, three view images calculate 3-focus tensors, similar to basic geometric matrix of two views. It is only related to camera parameters. The camera matrix can be recovered by 3-focus tensors under the projective transformation of the 3D space. Meanwhile, basic matrix between images is determined. Figure 4 shows geometric correlation of 3 views projected by the straight line L.

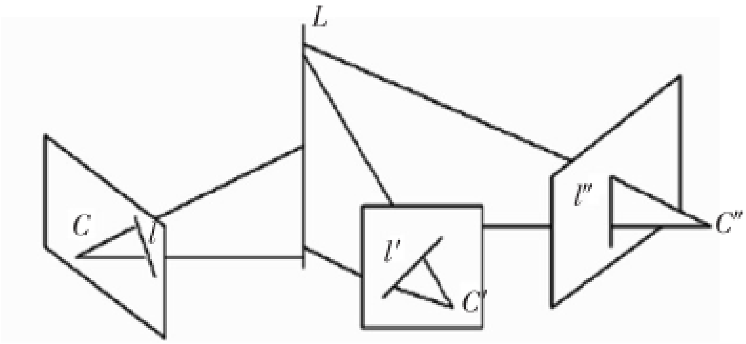


Figure 4 Geometric Correlation of Three Views

The specific process is stated as follows: (1) Two-view geometry is estimated from the sequence view. Next, matching set of two views is connected to calculate a group of corresponding feature points for three views. (2) 3-focus tensors are calculated for the 7 groups of nonsingular correspondence. (3) 3-focus tensors recover the basic matrix. (4) After confirming the matrix of two cameras, the third camera matrix is recovered under a projection matrix. (5) Feasibility error treatment is conducted. After obtaining 3D coordinate system, visualization on the object surface is conducted. Delaunay triangular section method is used in this thesis to reconstruct the 3D surface of objects. OpenGL is used to finish the texture mapping.

3. Global calibration of cameras

The target direction measurement method based on computer vision theory can flexibly conduct multi-point and non-contact measurement. The system structure is simple and has the strong universality. It is easy to operate, showing good practical value. Moreover, other traditional measurement methods can greatly supplement it. For the 3D geometric size measurement under the large-scale conditions, considering that it is impossible to cover the panorama of objects to be measured from a single scale, visual sensors often need to move several measurement positions. In each measurement position, visual sensors are based on the coordinate system of cameras to gain the global 3D morphology features of objects to be measured. However, only by unifying measurement results of each position can it realize the overall process of measurement and achieve the measurement of overall geometric size for objects. The process of constructing the unified measurement coordinate system and link each local coordinate system with the unified global coordinate system is the global calibration.

Global calibration actually is the process to solve and link the transfer matrix for each 2D coordinate system. Considering that freedom degree of matrix [R T] is 6, only 2 non-collinear global reference points are required to solve the coefficient of the matrix [R T]. In global calibration, visual sensors have the capacity to measure 2D coordinates under the global coordinate system. Under the circumstance, the calibrated reference points have the coplanar restraint. The calibration process is shown in Figure 5. The camera coordinate system of ith local camera is shown in Figure 5.

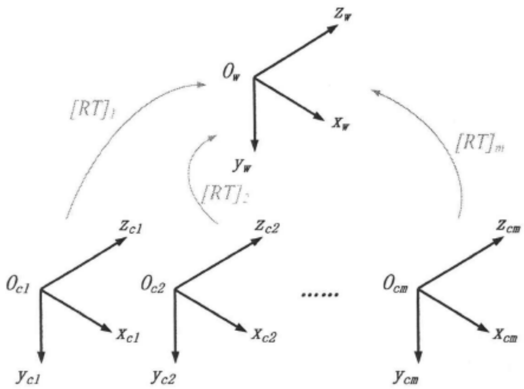


Figure 5 Global Calibration Process

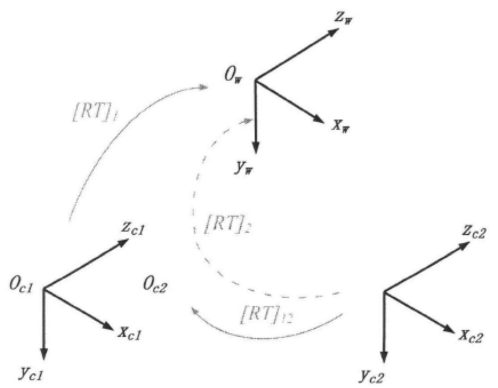


Figure 6 Parameter Passing Process in the Global calibration

Table 1 shows the property contrast to do stereo matching in the computer vision measurement. It is difficult to control light conditions under the large-scale conditions. We select the algorithm to do relevant matching for image areas, so as to avoid from negative effects of light changes on geometric dimension measurement results. Due to influences of noise, light changes, shield and perspective distortion, one point in the space is projected to the focal plane of two cameras. The property of feature points formed may be different. For a feature point in an image, there are several similar candidate points in another image, thus extra information or restraint is used as the auxiliary means to realize the accurate stereo matching.

Table 1 Contrast of Relevant Matching Algorithm Property

Algorthm types	Calculated amount	Light effect
SSD	Small	Strong
NSSD	Middle	Middle
CC	Small	Strong
NC'C	Middle	Middle
ZCC	Bigger	Weaker
ZNCC	Big	Weak

4. Conclusions

Computer vision is an important research direction in the computer field, while 3D reconstruction is a challenging research content in computer vision. Such a research is involved in computer graphics, virtual reality and data visualization. This thesis uses non-contact large-scale 3D geometric size measurement based on computer vision as the research content, conducts in-depth discussion and study for the large-scale 3D geometric size measurement direction based on computer vision from image acquisition, sensor modeling, image feature extract, sensor parameter calibration and 3D stereo matching and reconstruction, analyzes various factors affecting system accuracy by starting from principles of visual measurement system, and points out the approach to improve measurement accuracy. The phase equalization algorithm is used to do feature enhancement for focus images, so as to improve extractive accuracy of light bar center. The light bar restraint based on the polarline and structural light realizes the feature point machining of sub-pixel accuracy. These algorithms can significantly improve the image analysis accuracy, so as to reduce the influences of image analysis on system measurement accuracy. The large-scale 3D geometric size measurement system based on stereoscopic vision is constructed for field testing. When the measuring distance is 10m, absolute error of measurement does not exceed 6mm. The experimental results show that the system has good robustness to effectively guarantee measurement accuracy under the large-scale conditions.

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