The Application of Vision Principle in 3D Reconstruction

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Abstract. 3D reconstruction technology provides digital model of the actual product for the CAD/CAM system of the reverse engineering, which has practical significance for promoting the development of manufacturing automation. Meanwhile, the digital models through 3D reconstruction have the important applications in the fields of virtual reality, video conferencing, criminal investigation and cosmetic surgery. Especially the research for 3D reconstruction of freedom surface is an important research topic in the computer graphics. In this paper, the technology of 3D reconstruction based on stereo vision principle is presented, which can effectively realize reconstruction of 3D digital model of freedom surface. Firstly, the experimental system of stereo vision is established consisting of two CCD cameras in accordance with the principle of binocular stereo vision. Then, the calibration of stereo vision system is completed by selecting the BP neural network for simulating the mapping relation between the images in left and right imaging planes and 3D spatial objects after comparing the two calibration methods of genetic algorithm and BP neural network. Finally, the vision system is experimentally verified taking the face of plaster and human foot as examples, and very good results are achieved.

Introduction

The main task of the reverse engineering is turning the real parts into engineering model and concept[1], which is based on the existing advanced products and gets the model of geometric shapes by the 3D measurement and reconstruction. To combine reverse engineering with rapid prototyping manufacturing technology giving full play to their strengths, which can be a powerful tool for new product development, can realize reproduction, analysis and modification of existing advanced products, improve the quality of the development of new products effectively, can shorten product development cycle, and will reduce development costs. It has a positive role in promoting manufacturing for a developing country, and is also of great practical significance [2, 3].

The 3D reconstruction technology of the digital model generated by the physical model not only has important application in reverse engineering, but has a great advantage in the structure of the realistic digital model. The realistic model of human body and its related parts are widely used in such field that video conferences, virtual reality, forensic and cosmetic surgery, etc [4, 5].

Free-form surfaces widely exist in the industrial products and in real life, such as the surface of some parts that auto bodies, turbine blades, aircraft wings constituted by the free surface, surface of the human face and foot are free-form surfaces of highly smooth and shape complex. With the development of science and technology and the increase of consumer demand for personalized products, free three dimensional surface of the shapes used in the design has become more and more, such as personalized shoe. Freeform shape is complex and difficult to measure, therefore, the research and development of advanced 3D freeform surface form refactoring is objective requirements of the development of such field that reverse engineering technology, realistic face modeling, etc [6].

In the technology of free-form surface reconstruction, the way obtaining the most basic information through the shape of the surface measure has two classes, and they are contact
measurement and non-contact measurement [7]. Among them, the contactless measurement is getting coordinates location of the point by sensing probe recording surface and geometric surface contact. In practice, the most widely used non-contact measuring equipment is the coordinate measuring machine. And non-contact measurement is mainly based on the basic principle of optical, acoustic and magnetism disciplines, which will convert physical analog into three dimensional coordinates of a point on the surface through appropriate algorithms.

The measurement precision of coordinate measuring machine is high, but the measuring efficiency is low, which makes it being more applicable to conventional high-precision measurements of parts. Meanwhile, due to the contact pressure inevitably existing between the probe and the measured surface, it accordingly brings all sorts of malpractices [8]. And non-contact measurement can overcome the shortcomings of contact measurement, and can avoid surface damage and deformation for some soft, fragile objects in the measurement process. The non-contact measurement technology at home and abroad was carried out extensive and in-depth research, and gains a large amount of application in areas such as aviation, automobile, marine and mold.

The typical non-contact 3D measuring method have phase measuring method, laser triangulation, laser holographic method, time of flight method and stereo vision method. Among them, the stereo vision [9] is an important branch in the field of computer vision, and is also a kind of typical non-contact measuring method, which obtains two or more images of measured object by using imaging equipment from a different location, by use of triangulation, and by calculating the position error among the corresponding points of the image to obtain the 3D surface information. The vision measurement method with high efficiency, accuracy of fit, simple structure, low cost, is very suitable for manufacturing of online, non-contact inspection and quality control. In particular, measurement of moving objects, as the image is instantly, so stereo vision method is a kind of more efficient way.

This article first illustrates the basic principles of stereo vision, and puts forward construction scheme of the experimental system to meeting the requirement of the basic principle of stereo vision. The construction of the experimental system is completed on the basis of the comparison among plans, and adopts different methods for vision system calibration. Finally verifications and calculates are done in the visual system taking the plaster model of facial and body foot as examples. The 3D reconstruction experiment and calculation results show that the proposed 3D reconstruction technique can effectively achieve the digital model reconstruction of free-form surface.

Basic Principle of Stereo Vision

As shown in Fig. 1, the stereo vision system consists of double CCD cameras. In the system, \( o_i x_i y_i z_i \) and \( o_r x_r y_r z_r \) represent respectively left and right camera coordinate, \( o_i \) and \( o_r \) represent the optical center of the camera location, \( O_i X_i Y_i \) and \( O_r X_r Y_r \) are the camera's image plane coordinate, \( O_i \) and \( O_r \) are the point of intersection respectively about the optical axis \( z_i \) and \( z_r \) of the camera and with the respective image plane, and \( X_i, Y_i \) parallel to \( x_i, y_i \) respectively, and \( X_r, Y_r \) parallel to \( x_r, y_r \) respectively.

![Figure 1. The stereo vision system.](image)
For such a stereo vision system, when the surface point P of the space object is observed from right and left camera at the same time, assuming the system has been calibrated, and can determine that the point $p_l$ on the left camera image and the point $p_r$ of right camera image are formed by point P at the same location. It can be seen from the figure that because of the space point P is located in a straight line $o_l p_l$, at the same time, is also located in a straight line $o_r p_r$, so the point P is the intersection of two straight lines $o_l p_l$ and $o_r p_r$, which means that the 3D position of points P can only be determined by stereo vision system. This is the basic principle of stereo vision.

Establishment of Vision System

Stereo vision can understand and recognize the 3D information by sensing devices, which simulates the mechanism of human using a binocular cue to perceive around the scene. In practice, stereo vision uses triangulation method that generally needs two cameras on the same scene from different perspective, and then recovers 3D shape from two projection images of space objects.

In the binocular stereo vision system, different geometric structure arrangement between the two cameras will directly affect some experimental parameters such as the common vision of two cameras and the search area of the image matching.

Structure with Parallel Optical Axis. As the Fig. 2 shows, the focal length of the left and right camera and other inner parameters equal each other, and optical axis is perpendicular to the imaging plane of camera. The x axes of two cameras are overlap, and y axes are parallel to each other. Hence, the left camera will coincide with the right camera by translating along the x axis direction for a distance $b$. The intersection lines $pl$, $pr$, which are formed through the epilolar plane determined by space point $A$ and light heart $O_l$, $Or$ of left and right cameras and imaging plane $C_l$ and $Cr$, are the conjugate of polar, and they are collinear and respectively parallel to the axis $ul$ and $ur$.

![Figure 2. The structure with parallel optical axis.](image)

In the ideal structure form, the geometric relationships of the configuration of right and left camera are most simple. The polar line is of a good nature, which provides a very convenient condition for looking for matching relationship between the projection point $al$ and $ar$ in the imaging plane. However, in general, the optical axis can't be seen in the process of installing the cameras, so its position is difficult to reach this ideal state.

Structure with Intersecting Optical Axis. As the Fig. 3 shows, $zl$ axis and $zr$ axis angled around two cameras, which facilitate arrangement by using this type of structure. And the distance between the two camera and tilt direction of camera is able to be adjusted flexibly. It avoids the two situations, which is the structure too small or the image block exists. Considering the above circumstances, it should be adopted the structure of the optical intersecting axis to carry out the experimental system.
Choice of Calibration Method

The calibration of binocular stereo vision system is a bridge established between the 2D projected images coordinates of on the surface point of the object being measured and the 3D world coordinate, the basis of free curved surface 3D reconstruction, and also one of the difficulties of the application of stereo vision in the research field.

**Calibration Method Based on Genetic Algorithm.** Genetic algorithm [10] is an adaptive search algorithm referring to natural selection and genetic evolution mechanism for global optimization. It uses groups search technology that a new generation of groups appears by imposing the current group on a series of genetic manipulation such as selection, crossover and mutation, and gradually groups evolved to the state of including or nearing optimal solution.

This is a camera calibration method based on nonlinear mathematical models by using mathematical analysis to approximately express the nonlinear geometry mapping relationship between the 3D geometry of space surfaces point and the points corresponding in the left or right image of the image respectively. And the calibration of stereo vision system is to solve all internal and external parameters of mathematical model.

But the standard genetic algorithm for the high dimensional space optimization that the number of parameters is greater than ten might not meet the accuracy requirements. At the same time, the results show that the performance of genetic algorithm will be deteriorated sharply with increasing dimension of the search space. Therefore, the standard encoding in genetic algorithms should be improved.

Improved genetic algorithm can overcome the disadvantages of the standard genetic algorithm encoding in solving high dimensional space optimization. And it has a variable search interval adaptive adjustment ability of genetic algorithm, which not only can ensure that the variables have enough search range, as a variable interval size set provides a convenient, but ensure that the search step length is small enough to make calibration precision of camera meet engineering application of requirements. This method of coding with adaptive function provides a new way of computing performance for improved genetic algorithm to solve nonlinear, complex function optimization problem.

**Calibration Method Based on BP Neural Network.** The camera calibration method based on neural network do not need to establish mathematical model of the camera stereo vision system, instead of mapping the relationship between two-dimensional image coordinates and three dimensional coordinates of the world by using artificial neural network nonlinear fitting capability construction.

In stereo vision system, the ultimate goal of camera calibration is to build mapping relation between 2D images of the object point coordinates and the scene coordinates, which can directly calculate the corresponding 3D coordinates from 2D images coordinates of an object point at the right and left, and then to make the modeling process. Therefore, it has no need to calculate each
physical camera parameters in stereo vision system, and only to put the camera physical parameters into some intermediate parameters. Doing in this way not only can simplify the calculation process, but improve the camera calibration accuracy in some extent, which is called implicit calibration of the camera.

The basic principle of artificial neural network [11] is extremely similar to the camera implicit calibration process, which both get unknown data needed based on the system model established from the known system data model. Error back-propagation (Back Propagation, referred to as BP) neural network current widely used is one of the multilayer forward neural network learning algorithm. The mapping process which simulates object point 2D image coordinates to 3D world coordinates of the stereo vision system using BP neural network, does not need to set up a complex system model with regardless of lens distortion and effects of environmental factors, thus can reduce errors due to imperfection of mathematical model, which can improve the accuracy of 3D coordinates restoration.

In the process of the actual system calibration, due to the BP neural network method which no mathematical model is established, and the calibrated system can ensure recovery precision of 3D coordinates, so the neural network method are chosen more.

### 3D Reconstruction Results

In accordance with the principle of stereo vision, using two CCD cameras and intersecting axis structure, building the stereo vision system experiment equipment, and then processing collected images necessarily, the system is calibrated by selecting the method of BP neural networks. Finally, the corresponding solid models are obtained by testing and calculating the refactoring objects of the plaster face and human foot.

![Figure 4. the reconstruction model of plaster face.](image)

![Figure 5. the reconstruction model of human foot.](image)

### Summary

In this paper, the experiment system is build by adopting the structure of intersecting axis, according to the principle of stereo vision and on the basis of the comparison of system structure. By using BP neural network to simulate the mapping relationship between 2D image plane and 3D space, the implicit calibration of complex systems is achieved. Then, the 3D reconstruction is verified taking the plaster model face and human foot as examples. The results of experiment and calculation show that the 3D reconstruction technology can effectively realize reconstruction of digital model of free-form surface.
References


